

# **NPR 7120.5, NASA Space Flight Program and Project Management Handbook**

February 2010

## Preface

NASA accomplishes its strategic goals through human and robotic missions, which are conducted through programs and projects. In 2006, NASA undertook a major reordering of the management structure for its program and project life cycles. The result was codified in NASA Procedural Requirements (NPR) 7120.5D, *NASA Space Flight Program and Project Management Requirements*, modified in NASA Interim Directive to NPR 7120.5 D, and will be further refined in NPR 7120.5E. With the establishment of significantly revised Agency policy and requirements for program and project management, a handbook to aid practitioners in the implementation and practice of policy was needed.

The Agency-level requirements in the policy documents provide the basis of practice across the Agency. However, the scope of NASA programs and projects—from research into new ways to extend our vision into space, to designing a new crew vehicle, or exploring the outer reaches of our solar system—is vast. This handbook takes a more detailed look at the principles of how to implement those high-level requirements.

The Office of Chief Engineer (OCE) chartered a team of experienced individuals from each of the Centers and Headquarters to capture perspectives from different sectors and directorates within NASA. They gathered information from experienced practitioners on how to meet the challenges that occur in managing programs and projects. This handbook captures their best practices of program and project management, providing the continuity of that expert knowledge base. Initially based on the requirements in NPR 7120.5D, this handbook will be updated to reflect ongoing changes in the program and project management policy requirements. In process are changes in baseline and replanning and joint confidence level policy and use of the term Unallocated Future Expenses (UFE), for example. In this handbook, the word “reserves” is used generically for resources not yet specifically allocated. The section on tailoring principles is current with the NID for 7120.5D. The guidance contained herein will help program and project managers with the “how to” of implementing NPR 7120.5 requirements. The guidance in this handbook is supplemented by NASA’s body of requirements, policy, and standards documents and practices specified in Center documentation.

The Office of Chief Engineer would like to thank the managers who gave interviews, review teams, and specifically the handbook development team for their time and effort in developing this handbook: Jim Greaves, GSFC; John Hrastar, GSFC (ret); John Hunter, JPL; Beth Keer, GSFC; Ken Jenks, JSC; G. Krishnan, HQ; Darryl Lakins, GSFC; Neil Martin, GSFC; Stephen Newton, MSFC; Ray Morris, JPL; Steve Robbins, MSFC; Mark Schmalz, JSC; Maria So, GSFC; Ann Tavormina, JPL; James Walters, JSC; Dinah Williams, MSFC; Mona Witkowski, JPL; Rod Zieger, JPL; and Chris Fleming, technical writer.



Mike Ryschkewitsch

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## Foreword

NASA Procedural Requirements (NPR) 7120.5, *NASA Space Flight Program and Project Management Requirements*, defines requirements that must be implemented while developing NASA human and robotic flight programs and projects. NPR 7120.5 defines “what” must be done to properly and successfully manage NASA programs and projects.

This companion handbook was developed to take further the implementation of policy requirements specifically of NPR 7120.5D. It captures best practices, processes, techniques, and lessons learned from successful program and project managers across the Agency on “how” to properly manage NASA programs and projects in accordance with NPR 7120.5D. While oriented to the practice of NPR 7120.5D requirements, the handbook is consistent with the NID for NPR 7120.5D and reflects NID policy in some places. It identifies characteristics and attributes of successful NASA program and project management. This handbook addresses NASA spaceflight programs and projects, both human and robotic. It addresses some of the fundamentals of successful program and project management, including roles/responsibilities, checks and balances, and reviews. This handbook is not a requirements document—there are no “shall” statements; instead, it provides guidelines and real-world examples of how previous NASA managers have successfully implemented NPR 7120.5 principles. This handbook will be updated to reflect ongoing changes in the program and project management policy requirements.

The successful practitioner will use different approaches in different phases of a program or project, as well as different approaches on different projects. Therefore, there is no single correct way to implement the NPR 7120.5 requirements.

This handbook is intended to be used by anyone who uses NPR 7120.5. This includes experienced practitioners, as well as those aspiring to program/project manager positions. All project practitioners, such as deputy project managers, observatory managers, instrument managers, resource managers, and systems engineers, will find this handbook useful.

### Applicable Documents

*NPD 1000.0, NASA Governance and Strategic Management Handbook*

*NPD 1000.3, The NASA Organization*

*NPD 1000.5, Policy for NASA Acquisitions*

*NPD 7120.4, NASA Engineering and Program/Project Management Policy*

*NPD 8700.1, NASA Policy for Safety and Mission Success*

*NPR 7120.5, NASA Space Flight Program and Project Management Requirements*

*NPR 7123.1, NASA Systems Engineering Processes and Requirements*

*NPR 8000.4, Agency Risk Management Procedural Requirements*

*NPR 8705.5, Probabilistic Risk Assessment (PRA) Procedures for NASA Programs and Projects*

*NASA/SP-2007-6105 Rev 1 NASA Systems Engineering Handbook*

*NASA-SP-2009-10-015-HQ, Standing Review Board Handbook*, which can be found at <http://www.nasa.gov/offices/pae/references/index.html>

*NASA Cost Estimating Handbook*, available at: [http://ceh.nasa.gov/ceh\\_2008/2008.htm](http://ceh.nasa.gov/ceh_2008/2008.htm)

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## Chapter 1 Introduction

### 1.1 Background

NPR 7120.5D Chapter 1, Section 1.1 is mainly background and descriptive material. See NASA Procedural Requirements (NPR) 7120.5, *NASA Space Flight Program and Project Management Handbook* for this information.

### 1.2 Overview of Management Processes

It is assumed that any program or project manager (PM) will bring some degree of technical expertise and management skills to the table. There are, however, other attributes that are required in a good PM. (NOTE: The acronym PM is used throughout this handbook. It signifies either program manager or project manager, based on the context.)

One of these is leadership. Leadership implies more than managerial skills, such as scheduling and budgeting. It includes the ability to lead a team by example toward the successful development of a mission despite the problems that any program/project will always encounter. A PM needs to look ahead to see the whole picture, anticipate potential problems, direct the project team (including the prime contractor) around obstacles, and provide the environment that enables the team to be successful. Project leadership communicates priorities to the team members through their own actions and where they spend their time. A can-do but realistic attitude is part of the leadership challenge. The PM's strong commitment to the success of the program/project, backed by a strong work ethic, communications, and respect for the team go a long way to providing the leadership necessary for a successful team. The institutional support that provides the needed resources and environment for the team to succeed is also an important component of this leadership.

There is one other thing we should discuss, and that is the difference between management and leadership. Management is figuring out how to get the job done. Leadership is deciding what needs to be done and inspiring the team to get where you want to go.

– Program Manager, JSC

Leadership is about being proactive. This means anticipating problems and taking action prior to experiencing issues to preclude, or at least minimize, impacts. A reactive PM will always be behind the curve and will never catch up. Being proactive means looking ahead and talking to all stakeholders. A proactive leader is always questioning the way things are done to make sure the program/project is on the right track. This questioning is not a distrust of the team, but should work as a sign that you expect and encourage everyone on the team to do the same. This proactive approach should not be limited to the PM. The PM should encourage everyone on the team to be proactive.

Timely decision making is necessary to keep program/project development moving. Ideally, everyone would like to have all the information possible before making a decision. This would go a long way to ensuring a correct decision in all cases. However, that is a luxury generally not available to a PM during the development cycle. Often, a decision must be made with minimal information. The ability to make good decisions with less than perfect information is a

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distinguishing characteristic of a good PM. Keep in mind that a wrong decision can be reversed if you find yourself on the wrong track. A nondecision, however, cannot be reversed and can have severe consequences.

You, as a project manager, are called on to make some key decisions, but you are also riding on the top of the 95 percent of the good decisions that were made by the people you delegated to. So it is a team activity and how you treat and manage those people ... makes the real difference.

– Human Research Facility Project Manager, JSC

Flight program/project development is an intense activity that requires a strong team. Although the PM does not have total control over the staffing process, s/he needs to ensure the team is properly staffed, especially with experienced people in key positions. Delegating proper authority to team members is critical to team self-confidence and to getting the work done. With proper leadership, the team will be confident in its decisions and willing to work hard to ensure a successful mission. In addition to experienced team members, it is necessary to include less experienced members and to mentor them in the teaming environment. This ensures proper experience is passed along to subsequent programs/projects.

The project manager should be skilled in technical project management, as well as having some knowledge of each of the technical domains and a depth of knowledge in one. This essential skill mix enables the PM to manage and make better decisions because s/he understands the concerns of the subsystem managers and technical staff.

Clearly, having a good system philosophy and well-transmitted expectations makes a big difference in how they do their jobs.

– Project Manager, JSC

Managing relationships with program/project stakeholders is critical to a successful development. Stakeholders include the scientists, program office, Center management, other NASA Centers, international partner institutions, Headquarters (HQ), other Government agencies, and personnel from the legislative and executive branches. Openness is the best approach to these relationships (as well as with review teams). Don't hide problems. Stakeholders understand problems are inevitable and are a normal part of the process. If you take proactive, assertive steps to solve problems you will get the stakeholders' support rather than their distrust. Part of this process is managing expectations. For example, if the program/project budget is cut, you need to be realistic and work with stakeholders to replan or develop a new baseline without promising all the original goals can be met. The main objective when working with stakeholders is to continually communicate with them—supplying information and receiving input—to maintain the support they provide and that you need.

PMs often work with major contractors and PMs are responsible for the end products delivered by these contractors. To be successful, the project team needs to work with the contractor, not just passively monitor the contract. If you have a strong, capable team, the contractor will respond with a similarly strong team. The ideal situation is when both Government and contractor teams feel like one integrated project team. This enables the teams to work together with confidence. If you see a contracting team issue, take early and proactive action to correct it, because despite problems, the program's or project's requirements still need to be met. For

example, if you ascertain there is an issue not being addressed by the contractor, don't wait for it to surface through routine reporting. Some problems that should be reported may never be, so take action when you see the situation. Waiting reduces your reaction time. Keep in good contact with your team members who work directly with the contractor and start questioning issues immediately.

Although almost no NASA PM has a legal background, the PM is still responsible for the sound legal foundation of the program/project during implementation. Thus, for issues including International Trafficking in Arms Regulations (ITAR), Export Administration Regulations (EAR), Sensitive but Unclassified (SBU) information, contract oversight issues, or similar issues, the PM should seek appropriate advice from legal staff, the Contracting Officer, Center Export Administrator, or other authorities. Export control issues, for example, can take a long time to resolve, so these need to be addressed at the very beginning of an international project. It is also critical to go through your Contracting Officer to make any changes to the contract. By law, changes—no matter how desirable—cannot be directed by anyone else on the project. See Handbook Section 4.1.B.e Program Interfaces with HQ and Other Organizations, for more information about export control and SBU information control.

Underpinning all these attributes and actions is the integrity and honesty of the PM. These two essential qualities are key to the successful application of all other leadership attributes and roles, including stakeholder interactions, team strength and morale, and contractor relationships. Even during difficult times, it is possible to proactively work problems, as long as you consistently stay within a sound legal and ethical framework.

I also believe in a set of core values. It is essential to lead by focusing on values you hold dear. [...] These values should be strong, well understood, and often repeated. They literally become who you are. When done right, they lead us in everything we do. These are the moral compass of the organization.

– KSC Center Director

### 1.3 Document Structure

The premise of this handbook (see Foreword) is to capture the approaches—the “how”—used by successful practitioners in the field of program and project management. It was not generated by a single group of experts trying to recall all their experiences in these fields. Instead, it incorporates input from more than 85 individuals across the Agency. These experts range from an Administrator down to lower level practitioners in program and project management.

The material in blue text boxes comes directly from interviews with these individuals or from similar sources, such as *ASK Magazine*. The individuals identified in the blue boxes may be present or former NASA employees. Much of the other handbook content also comes directly from these interviews.

The format of this handbook is closely tied to NPR 7120.5D—the chapters and sections are almost identical. This enables the reader to find the chapter in this handbook that addresses the corresponding requirement in NPR 7120.5D. Because some areas in NPR 7120.5D are definitional or descriptive (i.e., “how” is not applicable), the corresponding section in this handbook is labeled not applicable (N/A) to limit the handbook size.

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This handbook consists of five chapters. The first three chapters directly map to the first three chapters of NPR 7120.5D.

- **NPR 7120.5D Chapter 1** is an introduction; most sections are definitional or descriptive. NPR 7120.5D Section 1.2 provides good management principles and is expanded on in this companion handbook.
- **NPR 7120.5D Chapter 2** covers program/project life cycles. Some sections (e.g., Sections 2.2, 2.3) are definitional or descriptive. This handbook provides the “how” for NPR 7120.5D Sections 2.4, Program and Project Oversight and Approval and Section 2.5, Program and Project Reviews.
- **NPR 7120.5D Chapter 3** includes program/project roles and responsibilities. This handbook provides important content about handling dissenting opinions and utilizing the technical authority and covers all prescriptive elements of NPR 7120.5D Chapter 3.

Chapters 4 and 5 in this handbook vary slightly from the structure used in NPR 7120.5D, but are closely related to Chapter 4 of that document:

- **NPR 7120.5D Chapter 4** covers program and project requirements by phase. Chapter 4 in this handbook covers **program** requirements only.
- **Project** requirements from **NPR 7120.5D Chapter 4**, Sections 4.3 through 4.9, are separated out into **Chapter 5** of this handbook.

This handbook groups the six standard project phases (Pre-Phase A and phases A through E) into Formulation, Implementation, and Operations.

- Handbook Section 5.1 Project Formulation, covers Pre-Phase A through Phase B and corresponds to **NPR 7120.5D** Sections 4.3 through 4.5.
- Handbook Section 5.2 Project Implementation, covers Phases C and D and corresponds to **NPR 7120.5D** Sections 4.6 and 4.7.
- Handbook Section 5.3 Operations, covers Phases E and F and corresponds to **NPR 7120.5D** Sections 4.8 and 4.9.

The numbering system for sections in this document correspond with NPR 7120.5D, and then is further expanded using letters. The letters are supplied for navigation within this handbook and do not directly relate to section numbering in NPR 7120.5D.

### Instruments and Instrument Managers

Projects may also include science instrument development. Therefore, instrument managers (IMs) should also find the information in this handbook useful. Recently, NASA completed the *NASA Instrument Capability Study* (NICS), which was chartered to assess the state of science instrument development across the Agency. The NICS team developed recommendations to enhance the capability of science instrument development. The Agency Program Management Council (PMC) passed these recommendations along to the Headquarters Directorates via the Office of the Chief Engineer (OCE) for consideration. This handbook has instrument-specific sections that include relevant NICS recommendations. The NICS report is available at:

[http://oce.nasa.gov/OCE\\_LIB/pdf/1021184main\\_NICS\\_Final\\_Report.pdf](http://oce.nasa.gov/OCE_LIB/pdf/1021184main_NICS_Final_Report.pdf)

## Chapter 2 NASA Life Cycles for Space Flight Programs and Projects

### 2.1 Defining Programs and Projects

#### 2.1.A Project Categorization

Projects are assigned to one of three categories (Category 1, 2, or 3) depending on the project cost, use of nuclear sources, use for human space flight, importance to NASA, extent of international/interagency participation, the degree of uncertainty of new or untested technologies, and spacecraft/payload development risk classification. Category 1 projects receive the highest level of management attention and oversight. Categorization is defined in NPR 7120.5 Table 2.1, but may be modified based on recommendations by the Mission Directorate Associate Administrator (MDAA). The NASA Associate Administrator (AA) approves final project categorization.

Project categorization determines the project's Decision Authority (DA) and Governing Program Management Council (GPMC). The project manager works with the DA, Office of Program Analysis and Evaluation (PA&E), Independent Program Assessment Office (IPAO), Technical Authority (TA), and MDAA to determine if a Standing Review Board (SRB) is required and, if so, to identify the SRB chair and members and the Terms of Reference (ToR). Be aware that convening an SRB and developing ToRs can take up to several months.

#### 2.1.B Risk Classification

Payload projects are also assigned a risk classification depending on factors such as criticality to the Agency Strategic Plan, national significance, availability of alternative research opportunities, success criteria, magnitude of investment, and others. NPR 8705.4, *Risk Classification for NASA Payloads*, defines these classes as A through D. Class A has the highest priority, lowest risk, and places the most stringent requirements on the project in the areas of management controls, systems engineering processes, mission assurance requirements, and risk management processes. Class D is the lowest priority and highest risk with the simplest requirements.

JPL has a Category 3, risk class C/D mission that is approximately \$100 million. The project manager knew the project could not follow all Center standard requirements, practices, and principles to the letter and stay within budget. At the start of Phase A, the project manager and Center senior management, S&MA, and Chief Engineer agreed on deviations to the Center's requirements, practices, and principles that were acceptable risks for the project, and agreed in advance on what waivers would be acceptable at PDR.

– Member Project Support Office, JPL

### 2.2 Program Life Cycle

This section is not applicable for this handbook. See NPR 7120.5, Section 2.2.

## 2.3 Project Life Cycle

This Section is not applicable for this handbook. See NPR 7120.5, Section 2.3.

## 2.4 Program and Project Oversight and Approval

NASA's oversight approach for programs and projects is embodied in the Agency's governance model. This section describes the roles of management councils and Decision Authorities and introduces the concept of Key Decision Points (KDPs), which are the points at which approval is given or denied for a program or project to proceed to the next life-cycle phase.

### 2.4.A Management Councils

NPR 7120.5 incorporates the Agency governance model, which includes Program Management Councils (PMCs) at the Agency and mission directorate levels, and Center Management Councils (CMCs) at the Center level. Mission directorates are the Programmatic Authority.

PMCs review all NASA programs and projects and evaluate their technical, cost, and schedule performance; risk management; and content. The Agency PMC is the Governing PMC (GPMC) for all programs and for Category 1 projects. Mission directorate PMCs are the GPMCs for all Category 2 and 3 projects. GPMCs recommend approval or disapproval for programs or projects to enter the next life-cycle phase at KDPs. Mission directorate PMCs also provide recommendations to the Agency PMC for programs and projects within that directorate.

CMCs ensure that Center engineering and management practices are met by the program/project, evaluate whether Center resources match program/project requirements, and assess program/project risk. CMCs also evaluate performance to identify trends and provide technical guidance. The CMC provides its findings and recommendations about the technical and management viability of the program/project to the program/project managers and to the appropriate PMC. The policies and procedures that govern the interaction between program/projects and the CMC are defined at each Center by center management.

### 2.4.B Decision Authority and Key Decision Points

NPR 7120.5 introduces two concepts: Decision Authority (DA) and Key Decision Points (KDPs). The DA is the final authority and determines program/project readiness to progress to the next phase of the development life cycle. KDPs are the points at which the DA makes those decisions. Refer to NPR 7120.5 Sections 2.4.2 and 2.4.5 for detailed descriptions of DA and KDP.

PMs need to understand the process leading up to the KDP, what information the DA will require, and should include development time for the information required by the DA in their project planning. Note that allowances are made within a phase for the differences between human and robotic space flight programs and projects, but phases always end with a KDP.

### 2.4.C Gate Products

NPR 7120.5 also introduces requirements for the Gate Products presented at KDPs. See NPR 7120.5 Table 4-3, Project Gate Products Maturity Matrix, for a detailed list of the specific products presented at increasing degrees of maturity (KDP A through KDP F). These Gate

Products are the minimum requirements for all NASA projects and programs. Centers and/or programs may supplement this list with additional products for specific types of projects.

PMs need to identify in the project plan a responsible person and the resources required for each Gate Product. SRBs expect a status of Gate Products and may expect to see examples. The PM should plan to have all Gate Products available at all SRB reviews.

### 2.5 Program and Project Reviews

As required by NPR 7120.5 Section 2.5, programs and projects conduct internal reviews that prepare for and support the life-cycle review process. This is accomplished as part of the normal systems engineering work processes, as defined in NPR 7123.1, *NASA System Engineering Processes and Requirements*. These reviews are conducted at the element, subsystem, and lower levels in accordance with applicable Center and/or program requirements. Internal reviews are scheduled by the PM based on the needs of the project and are generally chaired either by the PM or by an independent chair (typically from the Center's mission assurance or engineering organization) on the PM's behalf. SRB members may participate, as mutually agreed between the program/project and the SRB, as observers in the program/project's internal review process. This may include attendance at specific subsystem, module, and other levels, and system-, mission-, or project-level reviews if held.

The SRB conducts independent life cycle reviews. The SRB is formed at the beginning of the program/project and most SRB members serve throughout the entire program/project life cycle. (The intent is to provide membership continuity within the SRB to increase the quality and efficiency of the review process by capitalizing on the corporate knowledge of the SRB on issues and progress from previous reviews and avoid reeducating SRB members at each milestone.) Membership is evaluated before each review to ensure the right technical and programmatic expertise is present for that review and is not unnecessarily duplicative. Participants are also evaluated for independence from the program or project. SRB mission-level reviews are conducted according to NPR 7120.5. The *NASA Standing Review Board Handbook* provides guidance for these reviews. The overall review process is shown in NPR 7120.5 Figure 2-5.

Project teams should embrace the external reviews. External reviews allow the project to think about all the tough questions they're going to be asked and give them time to plug the holes. Brainstorm possible questions with the team to make sure they are covered. Next, projects should determine what the decision points are and what decision trees should be used for addressing these points. The project manager should assign actions and revisit them prior to the review, using this as a preparation for the review.

— JPL Programs and Projects Manager

#### 2.5.A NPR 7120.5 Review Process

Programs/projects follow the same basic process across the Agency, but there are some differences in implementation and terminology across the Centers.

### **2.5.A.a Human Flight Centers Reviews**

For tightly coupled programs at the human flight Centers, internal reviews leading to a system level review (e.g., a PDR) are conducted over a period of several weeks or months and evaluate all parts of the program (including subsystems, elements, and projects). The baseline is considered frozen for these reviews. Internal reviews typically begin at a kickoff meeting with an overview of the project requirements or design.

In accordance with NPR 7123.1, a review package is provided against which the review team generates Review Item Discrepancies (RIDs). RIDs are typically limited to issues that clearly indicate a failure of the system to meet a requirement.

The RID process includes:

- Agreement that the discrepancy is valid.
- Development of a proposed plan for resolution. RIDs need to be diligently worked and tracked to closure. To close a RID, the discrepancy needs to be resolved and evidence or documented revisions need to be provided.
- All RIDs should be closed before conducting the next review in the life cycle. If there are open RIDs upon kickoff of the next review, they should be addressed in some way during the review.

Internal reviews leading to a system-level review conclude with a pre-board meeting and a review board meeting. During these meetings, dispositions are decided for all RIDs and issues or RIDs with significant cost or schedule impact are discussed. Any issues or RIDs that were disapproved by the review screening process may also be presented if the initiator insists. These pre-board and review board meetings typically last from several hours to more than a day. At the human flight Centers, Preliminary Design Review (PDR) (or Critical Design Review (CDR)) is used to refer to the activities from the time that the baseline is frozen through the review board meeting.

For most human flight projects, reviewers should have at least one week to review the data package, a week to discuss potential RIDs with the design team, and another week to combine similar RIDs and develop potential dispositions. An in-depth review of requirements and design materials requires many days unless the project is very small. Similarly, discussion to determine the project's RIDs also requires significant time. Pre-board and review board preparation may require a week, and larger projects will require longer than a week. To accomplish the requirements specified in NPR 7123.1, the PM should allow four weeks for small projects to eight weeks for large projects to accomplish the internal review cycle.

Upon completing the internal review process, results are presented to the SRB at the life-cycle review along with a current project programmatic status that includes cost, schedule, and risk status and future projections.

### **2.5.A.b Robotic Flight Centers Reviews**

At the robotic Centers, internal reviews are also conducted at the element level (e.g., Spacecraft PDR, Instrument PDR) and below (e.g., subsystem PDRs, peer reviews). Activities that lead up to the element-level reviews are consistent with those conducted by the review teams of the tightly coupled programs at the human flight Centers. (See Handbook Chapter 4 for program

type definitions.) At the robotic Centers, however, only the final presentation to the SRB is referred to as the PDR (or CDR, etc.). Requests for Action (RFAs) are assigned at the internal and SRB reviews and are tracked to closure. RFAs tend to be systems oriented, but are not precluded from being document based. The PM should allow at least four weeks for small projects and more for larger projects to accomplish the internal review cycle.

The concept of the Standing Review Board or an Independent Review Board is, theoretically, that people with experience who have encountered relevant problems before and solved them come in and look at your project with a fresh set of eyes. People on the project are in the middle of the forest and they see a lot of trees but they don't necessarily see the forest, and sometimes can miss some major items that an independent board can find.

– Science Directorate Chief Engineer

## 2.5.B Peer Reviews

Peer Reviews provide a means to get insight into the technical aspects of the project. That level of intimate knowledge is not necessarily possible at reviews with high-level boards, which do not have the expertise or time to dig into details that may cause problems during implementation. Peer reviews are conducted as discussions, and RFA or RID forms are not required. Findings and actions are recorded in a review report, usually written by the review team lead. This report documents the review purpose, objectives, participants, concerns, disposition of findings, and any assigned actions. Followup with the initiators who provided concerns ensures actions properly answer the reviewer's concern. There are no formal pass/fail criteria specified for a peer review. The review team determines the need for any follow-on reviews.

Peer Reviews that are really small and really informal are the most productive. There are no RFAs at Peer Reviews. Results are captured in notes. There is no confrontational aspect to the Peer Review process.

– Project Manager, JPL

Peer Reviews are defined with the agreement of the project, conducted by the line organizations, and characterized by tabletop discussions with Subject Matter Experts (SMEs). The Project Review Plan identifies the peer reviews the project intends to conduct and provides resources to implement the reviews. Peer reviews may be used throughout the project life cycle and at all levels, whenever it is determined that an in-depth critique will be beneficial to the project.

Sometimes a Subject Matter Expert would insist on doing the task perfectly, which was not practical for the project. Other options are almost always possible.

– Project Manager, ARC

## 2.5.C Purpose and Value of Reviews

Independent reviews are important; 95 to 98 percent of the value of any review occurs before the actual review. It forces systems engineering to occur. Peer reviews are the most valuable reviews. These reviews guarantee that a systematic approach is being followed. It is very important to articulate the design to another; it helps the engineer to understand the subtleties of the design.

– GSFC Deputy Center Director

While life-cycle reviews are important and necessary gates prior to KDPs, the PM should not lose sight of the main benefit reviews offer to the project. A review is a forcing function that requires the project to evaluate its progress. Many PMs have commented that much of the value of a review was in the project team's effort to prepare for the review. The PM needs to keep the focus of the review preparation a serious, critical internal assessment. For the project, the ultimate goal of the review is to uncover areas where there are shortfalls and to address these. I think the most significant benefit to the project from independent reviews is in the effort the projects themselves make in preparing for the review. They need to have the review to go through the critical thought process of, "How do I explain this to others?" "How do I explain my status?" "How do I explain my interfaces and what kind of problems I am having?" "How do I describe those, and how I am going to solve those [and] develop the resolution plans?"

– Science Directorate Chief Engineer

To ensure good external reviews, the PM should establish in the Project Plan how review teams will be selected. Because large review teams are unwieldy and ineffective, the goal is to provide adequate coverage with a small team. The review team needs to have the correct mix of specialty skills and experience; however, sometimes it is necessary to allocate a specific, limited number of people per group to keep the team size to a manageable number.

Big gate reviews are not the kind of reviews where design and implementation problems are found. These reviews are really more an evaluation of the team and whether they really know what they're doing. A problem like the Genesis anomaly won't be found at a review like this. It would be more likely to find this kind of flaw in a more detailed, informal peer review.

– WISE Project Manager, JPL

It is essential to fully understand the review team's drivers and concerns—and not to blindly follow their recommendations. Obtain a good understanding of what is driving the review team's perceptions, as well as the missteps and/or pitfalls they see as a result, so you can make improvements and avoid introducing additional error.

In accordance with NPR 7120.5, the SRB's role is to provide the convening authorities and the program/project with expert judgment concerning the adequacy of the program/project technical and programmatic approach, risk posture, and progress against the management baseline and the readiness against criteria in NPR 7120.5 and NPR 7123.1. The SRB does not have authority over program/project content. SRB review provides expert assessment of the technical and programmatic approach, risk posture, and progress against the program/project baseline. When appropriate, SRB members may offer recommendations to improve performance and/or reduce

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risk. SRB outputs are briefed to the program/project prior to being reported to the next higher level of management. Required independent programmatic assessments (Independent Cost Analyses (ICAs), Independent Cost Estimates (ICEs), and Independent Schedule Risk Assessments) are reconciled within the SRB and with the program/project prior to the PMC review.

## Chapter 3 Program and Project Management Roles and Responsibilities

Roles and responsibilities for key program/project officials are outlined in NPR 7120.5. Many roles and responsibilities within programs and projects can have profound impact on mission success.

### 3.1 Overview of Roles and Responsibilities

Roles are often affected by the type of program/project and the interrelationships within programs. There are four primary types of programs: tightly coupled programs, loosely coupled programs, uncoupled programs, and single-project programs. See Handbook Section 4.1 Program Formulation Phase for definitions of these programs.

The management approach to uncoupled and loosely coupled programs is similar. In both cases, the program has general responsibilities, but each project in one of those programs is capable of implementing a complete mission.

In tightly coupled programs (e.g., Constellation), no single project is capable of implementing the whole mission. All the component projects are required to complete the mission. In addition to program manager duties, for all the projects within the program, the program manager for a tightly coupled program also performs functions similar to those of a project manager. This includes team building, technical oversight, budgeting, scheduling, formulation, contracts, implementation, integration, and other necessary functions.

Single-project programs are very similar to projects and are run as projects, albeit at the higher level required for these large missions.

The program/project manager is accountable for execution of the program or project, and manages overall formulation and implementation. The project manager reports to the program manager and both are supported by one or more NASA Centers (with facilities and experts from line or functional organizations). Each is responsible and accountable for the safety, technical integrity, performance, and mission success of the program or project while also meeting programmatic (cost and schedule) commitments.

The approach is to ensure that the roles and responsibilities are clear and understood. Imagine if there were a problem and the project manager wasn't there. How would the team react? Would someone take care of the responsibility or wait until the project manager returned to deal with it? The project should be set up such that everyone knows the roles and responsibilities and it is clear who has responsibility even when the project manager isn't there.

– Galileo Project Manager, JPL

Program/project managers must take the time to understand their home institution and the Centers supporting the project. PMs need to understand that all institutions do not operate the same way. Different Centers have different constraints. For example, at MSFC, procurement support is a direct cost to projects, while at KSC it is indirect (and some other support may be direct). Therefore, where work is shared between Centers, be aware that each institution may operate differently when supporting the same project.

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Programs and projects are integral members of the institutional team where they reside and work (even if there is multi-Center project support) and, therefore, need to feel that connection. As PM, if you have a potential problem involving the institution, do not immediately complain to the parent program—work with Center management on solving the problem locally.

The project manager needs not only to be able to look “down” at their project, but also be able to look “up” at the environment the project is operating under. Environment is seldom static. Political and other environments can change ... and the project manager must be aware of potential changes and be prepared to react to them. The project manager must stay in communication with Center and Program management, but he/she can't depend solely on others to keep them advised on “environmental” changes.

– Project Manager, MSFC

Ideally, a Deputy Project Manager (DPM) should have attributes that complement (rather than duplicate) those of the PM. Day-to-day duties and responsibilities may vary from one project to another based on the individual strengths of the PM and DPM. Commonly, the DPM may be less experienced and is being mentored for more responsibility in later missions.

The program/project Lead Systems Engineer (LSE) is also a key member of the program/project leadership team. (This title may vary by program or Center, e.g., Mission Systems Engineer (MSE) at some Centers.) The LSE is part of the program/project leadership team and the independent technical authority reporting to the Agency Chief Engineer. This role ensures the existence of and adherence to sound system engineering processes and activities throughout the program/project life cycle. This person needs to be forward looking and see the big picture, i.e., both the forest and the trees in the project. S/he directs the technical development of the project and therefore must have some familiarity with all the subsystems. This role also implements the engineering technical authority process. Some programs with an LSE may also have a Program/Project Chief Engineer (PCE). If so, the PCE, not the LSE, implements the technical authority. See Handbook Section 3.4 Technical Authority for additional details.

Systems engineering is critical to the programs, and by that I mean: “How do you engineer a system?” not this requirements managements process stuff that is going on. You need someone with engineering judgment to look across disciplines, across systems, across programs/projects.

– Program Manager, JSC

The program/project manager is supported by the Mission Assurance Manager (MAM) or Chief Safety Officer (CSO), who ensures the existence of and adherence to robust safety and mission assurance processes and activities throughout all phases of a program/project. The MAM/CSO also performs independent program and project compliance verification audits and implements the Safety and Mission Assurance (SMA) technical authority process. While the MAM is part of program/project leadership team, s/he also has an independent reporting process to the Agency Chief Safety and Mission Assurance Officer. See Handbook Section 3.4 Technical Authority.

The program/project manager is also supported by Health and Medical Officers who ensure existence of and adherence to Agency standards for space flight crew health and occupational health and welfare of the NASA workforce. Center Health and Safety Officers and the Agency Chief Health and Safety Officer maintain awareness of institutional and project activities and/or

products that may impact institutional occupational health or flight crew health and safety; they also represent the health and medical technical authority. See Handbook Section 3.4 Technical Authority.

The program/project Business Manager is an equally critical position. The Business Manager needs to keep the PM apprised of the business status of the project on a regular basis, daily if necessary. Once the PCE has assessed the programmatic impacts of technical changes or decisions, s/he works with the Business Manager to convert that technical assessment into cost and schedule impacts to the project's integrated baseline.

Science missions in response to a NASA solicitation (Announcement of Opportunity (AO), NASA Research Announcement (NRA)) need to be led by a single Principal Investigator (PI) who has overall responsibility for the management and conduct of the investigation. The PI communicates directly with the Science Mission Directorate (SMD). PIs often appoint a PM to manage the project on a daily basis. This PM reports to and has a significant interaction with the PI.

The Project Scientist is a member of the project team; this individual works with the project manager and the scientists working on the project to ensure science needs are being met.

Another individual important to the success of the project is the Program Executive (PE). The PE coordinates all project activities at the program level except those dealing with the mission science. S/he ensures the project is initiated and executed according to approved processes and acts as the primary interface with the respective mission directorate and the program/project managers at the Center or other implementing organizations.

Because the majority of support for most projects is obtained via contract, the PM should establish a close relationship with the assigned Contracting Officer (CO). As for all members of the project team collocated or from other organizations, it is good practice to make the CO feel as much a member of the project as s/he is in his or her own organization (Procurement). See Handbook Section 5.2.C.f Contract Management.

Other key personnel are experienced schedulers who understand schedule logic, critical path analysis, network diagrams, and a resource-loaded schedule; and business experts who understand earned value analysis. Experienced personnel of these types are few and hard to find. Schedulers do not define task content and duration: they gather this information from the person or organization responsible for performing the task.

### **3.1.A Instrument-Specific Information**

The role of the instrument manager (IM) is similar to that of a PM. S/he is responsible for formulation and implementation of an instrument project per NPR 7120.5. The IM should work with the PM (or designee) to tailor the instrument development to NPR 7120.5. The NICS study recommended that IMs should be assigned full authority and responsibility to manage cost and schedule reserves (unallocated resources) and, accordingly, be held accountable.

### **3.2 Specific Roles and Responsibilities**

This section is not applicable for the Handbook. See NPR 7120.5 Section 3.2.

### 3.3 Differing and Dissenting Opinions

NASA teams must be able to have full and open discussion with all facts available to understand and assess issues. Diverse views should be fostered and respected in an environment of integrity and trust without suppression or retribution. This section provides recommendations and techniques for encouraging differing opinions. Section 3.3.B describes the process for handling the far more rare situations where an agreement cannot be reached, which triggers the formal process for Dissenting Opinions.

#### 3.3.A Encouraging Differing Opinions

It is up to the PM to encourage and guide the differing opinion process so that it stays balanced, beneficial, and does not degrade into less helpful forms, such as personality conflict or complaining. Healthy differing opinions are beneficial and should be encouraged to maintain and enhance project/program quality and success. Unresolved issues (e.g., programmatic, safety, engineering, acquisition, accounting) within a team should be quickly elevated to achieve resolution at the appropriate level.

Balance and judgment are required to ensure the program/project can make progress and not waste time revisiting issues for which there is no right or wrong answer, or for which a good and timely decision, rather than the best solution, is sufficient. However, there are times when new data becomes available or a new person enters the process. In these cases, it may be necessary to revisit a previously made decision. The PM needs to be able to manage this situation.

Team members need to be given authority to make decisions in their areas of responsibility. This balance and judgment begins with the PM. Team members should feel comfortable raising questions, but should also understand that ultimately, the PM is the decision maker. This philosophy can be conveyed at team retreats and in individual meetings with team members.

Failure to recognize and accept differing opinions early on can stifle free expression for the balance of the project. Trying to understand why an opinion is held helps opinions converge. Understanding often helps change your mind or the other person's view. One challenge handling differing opinions may be in discovering that one exists. Reserved team members may be difficult to engage. These individuals need to be encouraged to participate—as PM, it is your role to ensure all views are listened to and that no opinions are automatically dismissed or overruled.

I'm comfortable with listening to [differing] opinions, and sometimes it completely turns me around. By golly, they're right and I'm wrong. You just have to admit that sometimes. So my management style is to have different personalities [on my team] and to listen to [differing] opinions. Most often, when people have [differing] opinions, it could get to an abrasive situation, but I don't think it has to. For the most part, when people have [differing] opinions, they want to be heard, they want to be understood, and if you still make a decision that's in the other direction, well, at least you listened to them and they appreciate that.

– Mission Control Center ISS Project Manager, JSC

Some techniques that engage participants in communicating their opinions include:

- Assigning someone on the team to act as a devil’s advocate to develop an alternate concept or approach. This ensures the alternative is fully investigated and quieter individuals with an interest in the alternative are often encouraged to speak up on its behalf when they know they won’t be the only one arguing that side of the issue.
- Going around the table and giving everyone ample opportunity to speak. Specifically asking, “What do you think?” rather than asking individuals if they have anything to say can sometimes result in useful dialogue. Take this input seriously and, if appropriate, assign actions to follow up on the ideas and suggestions.
- Using blind votes or providing a method for anonymous suggestions.
- Engaging team members in both formal and informal settings to elicit their opinions. Sometimes team members may be more comfortable discussing an issue one-on-one rather than within the team meeting format.

If a group is polarized, the PM can summarize the issue and the basis for each side’s opinion. This alone may bring the group to consensus. If not, the PM should make a decision and state the reasons for it. Once a decision is made, it is a good idea to document it and the opinions for and against it.

Open discussion should be encouraged, but there always needs to be a final decision authority. It is impossible to take every piece of advice—the project would become bogged down and suffer from cost and schedule overruns—but it is imperative to listen to and acknowledge hearing the differing opinion. The PM has to participate in resolving, not just encourage team members to voice these opinions. The PM should always make it widely known that an unsatisfied dissent has a potential path of recourse.

### 3.3.B Process for Handling Dissenting Opinions

In any team environment, it is normal and expected that differences of opinion will arise. In assessing a decision, a team member has three choices: agree, disagree but be willing to fully support the decision, or disagree and raise a Dissenting Opinion. (Dissenting Opinion—a formal disagreement—is capitalized here to distinguish it from a difference of opinion.)

A Dissenting Opinion is expression of a view that a decision or action, in the dissenter’s judgment, should be changed for the good of NASA and is of sufficient importance that it warrants a timely review and decision by higher level management. It needs to be supportable and based on a sound rationale (not on unyielding opposition). The decision about whether the issue in question rises to the significance that warrants the use of the Dissenting Opinion process is the responsibility and personal decision of the dissenting individual.

NASA provides a recognized formal process for handling the identification, resolution, and documentation of Dissenting Opinions:

- **Identification** – A Dissenting Opinion has three distinct parts: 1) A substantive disagreement needs to exist; 2) the dissenting individual needs to judge that the issue’s level of importance warrants a specific review and decision by a higher level of management; and 3) the individual specifically requests that the dissent be recorded and resolved through the Dissenting Opinion process.
- **Resolution** – NASA Policy Directive (NPD) 1000.0 and NPR 7120.5 define the resolution process and the roles and responsibilities of the two parties in a Dissenting Opinion. The

resolution process is a shared/joint process that needs to involve both sides of the disagreement as the issue is elevated to higher levels of management.

- **Documentation** – Dissenting Opinions need to be fully documented and become part of the formal program/project records.

The key steps of the **Resolution** process are:

- Disagreeing parties need to jointly establish the facts agreed upon and their respective positions, rationale, and recommendations. This is documented in a memorandum and provided to the next higher level. Whenever possible, resolution should occur prior to implementation. However, the PM may proceed at risk in parallel with pursuit of resolution if s/he deems it in the best interest of the program/project. In such circumstances, the next higher level of Programmatic and Technical Authority is informed of the decision to proceed at-risk. However, nothing in the Dissenting Opinion process should be construed to abridge Safety and Mission Assurance's suspend-work powers documented in NPD 1000.3, *The NASA Organization*.
- The parties jointly present their case to the next higher level of the involved Authorities (e.g., the Programmatic and/or Technical Authority) and the resulting decision is documented. Required notifications are covered in NPR 7120.5.
- If the dissenter is not satisfied with the process or outcome, the dissenter may appeal to the next higher level of management. The dissenter has the right to take the issue upward through the organization, even to the NASA Administrator if necessary. The resolution path of a Dissenting Opinion depends on the parties involved.

One project manager noted that in a recent Flight Readiness Review, a dissenting opinion raised by one of the engineers resulted in a followup investigation after the Review. In the Review, the go-ahead was conditionally given with the stipulation that the issue must be resolved prior to flight. The engineer was thanked for bringing his concerns to management. This issue was resolved in a way that was satisfactory to management and the engineer and the flight was successful.

– Director of Launch Vehicle Processing, KSC

### 3.4 Technical Authority

It is essential to establish a management structure that promotes effective checks and balances between decision-making authorities. This ensures different points of view are vetted appropriately, and no decision is made in isolation.

The NASA Governance Model provides an organizational structure that emphasizes mission success by taking advantage of the different perspectives that organizational elements bring to issues. The organizational separation of mission directorates and their respective programs and projects (Programmatic Authorities) from Headquarters Mission Support Offices and Center organizations aligned with these offices (Institutional Authorities) is the cornerstone of this organizational structure and NASA's system of checks and balances (see Figure 3-1).

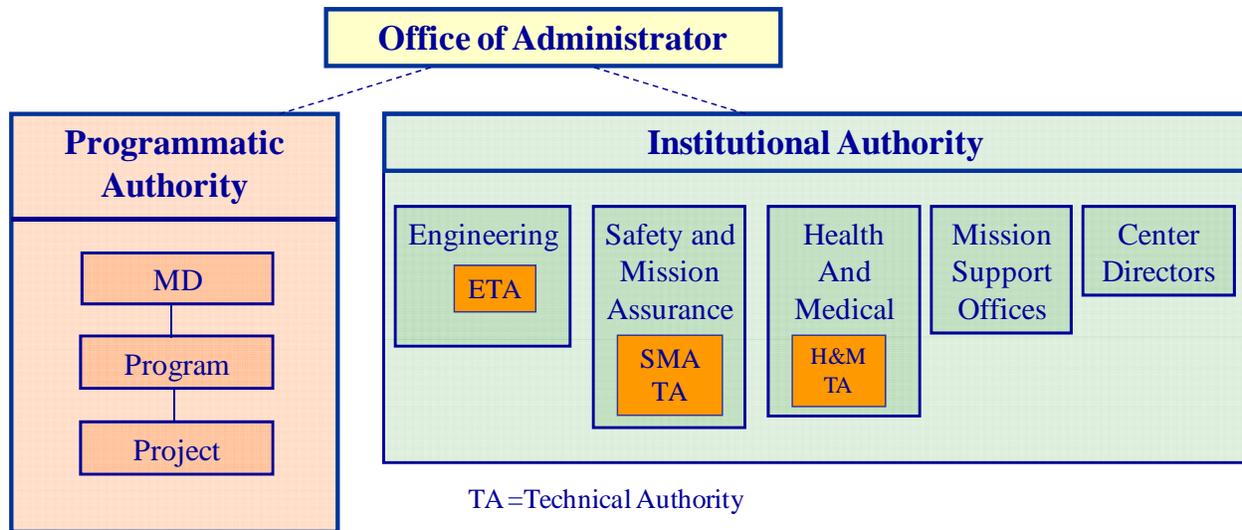


Figure 3-1: Separation of Programmatic and Institutional Authority

Programmatic Authority resides with the mission directorates and their respective programs and projects. The Institutional Authority encompasses all those organizations not in the Programmatic Authority. Engineering, Safety and Mission Assurance, and Health and Medical organizations are a unique segment of the Institutional Authority. They support programs and projects in two ways. They provide technical personnel and support and oversee the technical work of personnel who provide the technical expertise to accomplish the project's or program's mission. In addition, these organizations provide the Technical Authorities, who independently oversee programs and projects. These individuals have a formally delegated Technical Authority role traceable to the Administrator and are funded independent of programs and projects.. Only a limited number of individuals have formally delegated Technical Authority; however, many other individuals have authority within NASA. Some non-TA authority is formally delegated as part of a particular organizational position, some of it comes from experience, and some of it comes from discipline expertise. These authorities are not necessarily Technical Authorities in the context of NPD 1000.0.

Technical Authority came about as a result of the Columbia Accident Investigation Board report, at least the way we have implemented Technical Authority since the Shuttle accident. The basic high-level concept is to make sure that the process has a clear path for anyone involved to express a concern about the way things are going, if they believe there is a problem. The goal is to avoid the suppression of differences of opinion; to let them come out and be vetted and, after due consideration, either accepted or turned back. We want to make sure that all concerns are addressed. Some may not be valid, but you don't want a valid concern to go unaddressed and risk the chance that it will come back and bite you.

– Science Directorate Chief Engineer

### 3.4.A Technical Authority Process

The technical authority process provides programs and projects with unbiased, independent overview and support. Technical Authority is implemented according to the policies and

procedures in *NPD 1000.0*, *NASA Governance and Strategic Management Handbook* and NPR 7120.5. Technical Authority is implemented through the Centers and each Center has a TA implementation plan.

There are three different types of Technical Authorities:

- **Engineering Technical Authority (ETA)** is responsible for establishing the engineering design processes, specifications, and rules/best practices necessary to meet programmatic and mission performance requirements. Some Center TAs also need to follow Center practices or request formal waivers to these practices.
- **SMA Technical Authority** is responsible for establishing the SMA design processes, specifications, and rules/best practices necessary to meet programmatic and mission performance requirements. This is accomplished by starting with best practices and tailoring requirements to best suit the needs of each specific project. For example, Class A and human flight missions have much more rigid and stringent Safety and Mission Assurance Requirements than a Class D mission or a Technology Demonstration. Risk is also assessed as requirements are tailored to ensure that the appropriate balance between risk and requirements is achieved.
- **Health and Medical Technical Authority** is the NASA Chief Health and Medical Officer (CHMO). The Center Health and Medical TA is responsible for ensuring the program/project complies with health and medical requirements in the Center Health and Medical Authority (HMA) Implementation Plan, as well as with Agency-level requirements.

The key to the success of the Technical Authority is that this role is funded independently from the program/project, enabling the TA to be truly objective and independent.

Implementation of TA works well. It increases the value of the SMA perspective and the Engineering perspective. Keeps the programmatic in check. These are the three legs of a stool and they keep each other in check for the best chance for a successful mission. Institutional perspective is included since the processes are owned by the Center.

– GSFC Deputy Director

### 3.4.B Appointment and Responsibilities of Project Technical Authority Personnel

The requirements for appointment and approval of Technical Authorities are in NPR 7120.5. The program/project TA personnel need to have a good foundation in their areas of expertise, as well as an appreciation for project/program cost and schedule. A program/project TA also needs to be able to distinguish between urgent and important and respond accordingly. Center TA organizations need to ensure the personnel they appoint to these positions have these characteristics.

The responsibilities of individuals with delegated Technical Authority at the program/project level include:

- Being the single point of contact for Technical Authority matters.
- Serving as members of program or project control boards, change boards, and internal review boards.

- Working with the Center Management and other Technical Authority personnel, as necessary, to ensure direction provided to the program or project reflects the view of the Center or, where appropriate, the view of the NASA Technical Authority community.
- Ensuring that requests for tailoring (changes, waivers, or deviations) of Technical Authority requirements are submitted to and acted on by the appropriate level of Technical Authority.
- Providing the program or project with a view of matters based on his or her knowledge and experience and raising a Dissenting Opinion on a decision or action when appropriate.
- Serving as an effective part of the overall check and balance system. This includes conforming to the principle that serves as the foundation of NASA’s system of checks and balances, which states “an individual cannot grade his or her own work.” (NPD 1000.0)

### 3.4.C Project/Technical Authority Relationship

Program/project internal control boards, change boards, and review boards provide mechanism for control. The PM (or delegated representative) is responsible to chair these boards and resolve conflicts. PMs need to ensure that TAs are represented on the boards and provide independent assessments; however, decision authority resides with the board chair (subject to the Dissenting Opinion process).

The role of the ETA is not to become a policing organization but to support and be involved in the project’s engineering process development and technical trades. To reinforce that the ETA is not there to police the team, the PM should establish an open relationship with the ETA and foster a similar relationship between the ETA and the project/program team. This can be accomplished by ensuring the ETA has a role on the team that allows for open collaboration with team members.

Engineers also have a voice through their line organization. If there is a decision that is made on the project that an engineer does not agree with, the engineer can voice an opinion within the project as well as through the line organization. The line organization (Director of Engineering) has the right to raise issues through the Center Director as well as to the NASA Chief Engineer.  
– HST Project Manager, GSFC

The PM should meet regularly with Center TAs and delegated representatives to foster good communication and ensure issues are raised and resolved in a timely manner. The PM needs to clearly support the role of TA and effectively communicate and support the TA role to all project personnel. Personnel from NASA Center(s) need to be technically involved in and provide oversight of every NASA program/project.

### 3.5 Center Reimbursable Work

This Section is not applicable for the Handbook. See NPR 7120.5 Section 3.5.

### 3.6 Principles Related to Tailoring Requirements (formerly Waiver Approval Authority)

Early in a project, the PM makes decisions about the processes required to successfully accomplish the program/project. Not all projects/programs will fit 100 percent of the NPR

7120.5 structure or other requirements. For this reason, NPR 7120.5 provides a process for adjusting or seeking relief from prescribed requirements to accommodate the needs of a specific task or activity (program or project). This enables the PM to tailor processes to fit best with the type and size of the program/project effort. A process for tailoring requirements is described in NPR 7120.5, Section 3.6.

It is often easier to meet requirements than to fight the need for the requirement. Fight only if it is a global issue that will save on future work.

– Project Manager, MSFC

### 3.6.A Documentation

To manage the work, the PM needs to have a good understanding of the project's requirements and needs. Standard processes provide infrastructure. However, if a required process or prescribed requirement does not help the program/project, the PM is responsible for recommending appropriate tailoring in accordance with NPR 7120.5. Tailoring can be accomplished by submitting a waiver or deviation. The PM is also responsible for ensuring that the requirements relief process is available to, and functioning for, the implementing organization.

When developing the project organizational structure and establishing project processes, the PM produces an initial draft of the Project Plan (PP) and ensures the development of the Systems Engineering Management Plan (SEMP). These documents describe how project activities are to be conducted. The PM needs to address requirements in NPR 7120.5 and determine which help ensure a successful project. The PM should examine requirements that do not add value and do not create excessive risk if deleted or reduced in scope. The team should make conscious decisions regarding project needs and write down the planned approach and obtain appropriate approvals per NPR 7120.5. If the approach does not meet NPR 7120.5 requirements, a rationale supporting the planned approach needs to be documented in the PP. Similarly, any deviation from the requirements of NPR 7123.1 needs to be documented in the SEMP with the supporting rationale and the planned approach. It is important for the PM to work with the designated governing authority throughout the process to address any issues.

## Chapter 4 Program Guidance by Phase

This section provides an overview of the program manager's functions during the Formulation and Implementation phases of a program.

NPR 7120.5 defines a program as “a strategic investment by a mission directorate or Mission Support Office that has a defined architecture, and/or technical approach, requirements, funding level, and a management structure that initiates and directs one or more projects.” A program defines a strategic direction that the Agency has identified as needed to implement Agency goals and objectives.

Much of the information in this handbook's Chapter 4 is directly applicable to Chapter 5.

### 4.1 Program Formulation Phase

The principal activity of the program during Formulation is to perform planning and initiation.

#### 4.1.A Introduction

During Formulation, the program manager (PM) develops program level requirements, management organizational structure, multiyear cost estimates and planning, and funding allocation profiles, and obtains approvals for these program elements.

These PM functions are governed by the following key documents:

- NPD 1000.5 *Policy for NASA Acquisition*
- NPR7120.5 *NASA Space Flight Program and Project Management Requirements*
- NPR7123.1 *NASA Systems Engineering Processes and Requirements*
- NPR 9420.1, *Budget Formulation*
- NASA-SP-2009-10-015-HQ, *Standing Review Board Handbook*, which can be found at <http://www.nasa.gov/offices/pae/references/index.html>
- *NASA Cost Estimating Handbook*, available at: [http://ceh.nasa.gov/ceh\\_2008/2008.htm](http://ceh.nasa.gov/ceh_2008/2008.htm)

Figure 4-1 shows the interfaces, processes, and organizations of these relationships and how program managers work within the environment. Each interface varies in importance throughout the lifetime of the program. For example, there will be times when an external link requires a lot of the PM's attention. Other times, the project link will take up a majority of the PM's time. The program and the PM need to develop methods to monitor and respond to each of these entities. To be effective, the PM needs to be managing perceptions and expectations, brokering knowledge, and making sure the right people are involved. The most effective PMs make sure the right people are involved on the right problems.

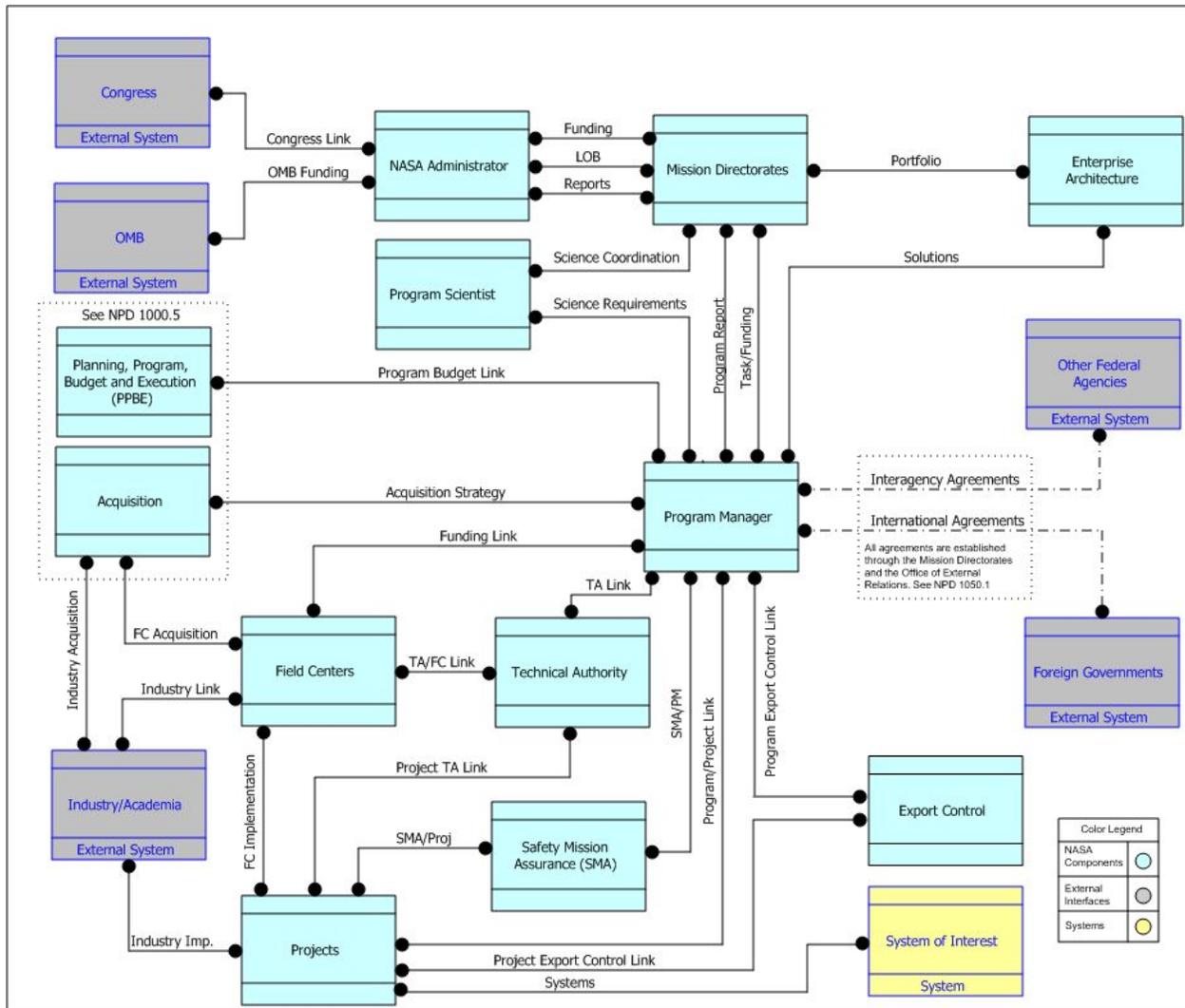


Figure 4-1: Program Manager Environment

Within NASA, programs are categorized into four groups: Loosely coupled projects programs, tightly coupled projects programs, uncoupled projects programs, and single-project programs.

- **Loosely coupled projects/programs**, such as Mars Exploration, are responsible for the management and leadership of projects for which there is organizational commonality but little programmatic and technical commonality.
- **Tightly coupled projects/programs**, such as Constellation, contain projects that have a high degree of organizational, programmatic, and technical commonality. No single project within a tightly coupled program is capable of implementing the complete mission. Such programs typically have greater integration functions at the program level, such as risk management, reserve management, and requirements management.
- **Uncoupled projects/programs**, such as Discovery, are implemented under a broad scientific theme and/or a common program implementation concept, such as providing frequent flight opportunities for cost-capped projects selected through Announcements of Opportunity

(AOs) or NASA Research Announcements (NRAs). Each project is independent of the other projects within the program.

- **Single-project programs** are considered synonymous to tightly coupled projects programs for the purposes of this handbook. In addition to duties as a program manager, a single-project program manager or the manager of a tightly coupled program needs to manage like a project manager, although at a much higher level.

Work on the shuttle (development) program was widely distributed. The program office was at Johnson Space Center; the engines, solid rockets, and tanks were developed at Marshall; and ground operations were at Kennedy, with major work done by contractors North American Aviation, Lockheed Martin, Morton Thiokol, and Rocketdyne, among others. Although Centers and contractors had primary responsibility for different elements of the shuttle system, those elements were tightly interrelated. For example, avionics and flight control systems were on the orbiter but directly affected the control of the main engines and solid rocket boosters, so success depended on a tremendous amount of coordination and integration. That meant multi-Center working groups meeting and communicating frequently, lots of travel, many meetings at Johnson with management and technical people, and daily communication at the program and project level. The frequent budget discussions were held at NASA Headquarters in Washington, DC.

– Jim Odom, *ASK Magazine*

Formulation and implementation of programs that consist of tightly coupled projects, or of a single project, are very similar to that of projects. Projects are described in greater detail in Handbook Chapter 5.

For tightly coupled and single-project programs, the program manager has a significant role and influence over the management and execution of the project(s). In the case of a tightly coupled program, major project decisions frequently require the approval of the program manager. Decisions to change elements, such as reduce scope or extend schedule, for one project may affect all other projects within that program. The project manager is required to provide frequent briefings and regular progress status to the program and certain project risks may be integrated into a list of top program risks. Any change in program requirements has a direct impact on certain project requirements. The program manager may hold some or even all of the reserves.

For loosely coupled or uncoupled projects, the program office may simply provide a management infrastructure and serve as a funding source. Program requirements are few and are general or high level. They are typically stable and have very little impact on day-to-day project management once the project requirements have been established. Most, if not all, reserves are maintained by the project.

### 4.1.B Program Planning and Initiation

Figure 4-2 shows the activities that the program manager accomplishes for program planning and initiation. The first activity is development of Level 1 Requirements. Level 1 Requirements are negotiated during Formulation Authorization Document (FAD) development. The FAD documents stakeholder requirements, expectations, and any constraints.

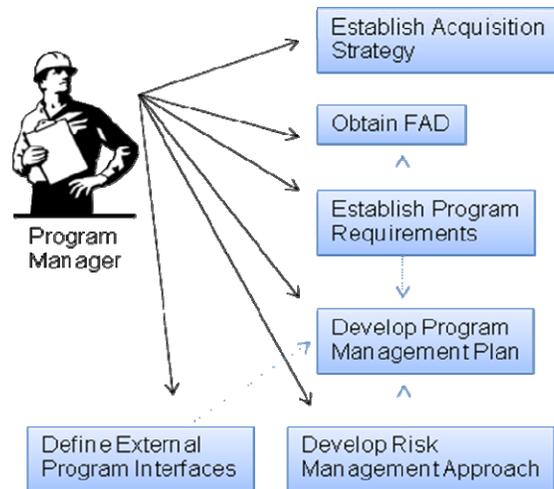


Figure 4-2: Program Initiation Activities

The next activities are acquisition strategy and Program Plan development. Acquisition strategy defines the acquisition approach for the program (see Handbook Section 4.1.B.a Program Acquisition Strategy). The Program Plan captures program requirements, organizational structure, risk management approach, and all activities (i.e., schedule and cost) to be accomplished (see Handbook Section 4.1.B.b Program Plan Development). Another important activity at this stage is for the PM to negotiate roles and responsibilities, including external-internal interfaces, between the program and projects.

#### 4.1.B.a Program Acquisition Strategy

Acquisition strategy is critical to program success. NPD 1000.5, *Policy for NASA Acquisition*, establishes a comprehensive acquisition strategies framework for NASA programs. The framework establishes the process for taking the program through strategic Agency planning, acquisition planning, procurement strategy development, and disposal. The framework enables NASA programs to consider the full spectrum of acquisition approaches—from commercial off-the-shelf buys to complete in-house design and build efforts when NASA has a unique capability and capacity or the need to maintain or develop such capability and capacity. Strategic acquisition is used to promote best-value approaches (taking into account the Agency as a whole), encourage innovation and efficiency, and take advantage of state-of-the-art solutions available within NASA and from industry, academia, other Federal agencies, and international partners. Acquisition planning should begin as soon as the need for a service or product is identified.

The initial Acquisition Strategy Planning (ASP) meeting for a program or project is an Agency-level meeting. It is designed to address strategic issues, such as the fit of this new program or project into the overall Agency portfolio, budget planning, resources, and best utilization of NASA’s internal capabilities. The ASP provides an early view of potential major acquisitions and changes in portfolio content. Mission directorate and top-level Center assignments are established. The output of the ASP ensures planned programs and projects are aligned with Agency strategy and may result in direction for the acquisition strategy.

When thinking about acquisition planning, the program manager should consider:

- Chains of responsibility in the management structure, given the limits of the candidate organizations. What organizational and contract structure will result in the strongest program/project team? How will the program be integrated across all elements with this acquisition strategy? How will risk be identified, integrated, and managed with this acquisition strategy?
- Drafting work breakdown and organizational breakdown structures to ensure all program elements and their relationships to one another have been considered.
- Common cost, schedule, and risk tools for the program and subordinate projects and other products that may be rolled up and/or integrated at the program level.
- What depth of penetration/insight/oversight NASA should expect to apply and what dilution of contractor responsibility would result.
- How firm the program operation/mission concepts and requirements are. As an initial step in the acquisition strategy process, is contractor support required to perform alternatives analysis (including technical, schedule, cost, and risk) to better refine program requirements? If so, may multiple contractors be utilized to conduct these trades and concepts, and, if so, are fixed price or Indefinite Delivery, Indefinite Quantity (IDIQ) contract vehicles the most beneficial for this support?
- The likely program reserve strategy (i.e., where the reserves are held and when they are to be distributed). Note: Per NPD 1000.5, programs are required to budget at the 70 percent Joint Confidence Level (JCL) for the program unless another JCL level has been authorized by the DA. This 70 percent JCL directive still allows the concept of margin (or Unallocated Future Expenses (UFE)). Programs are also required to fund projects at a minimum level that is equivalent to a confidence level of 50 percent or as approved by the DA. Programs have the flexibility to resolve problems within the program, but NPD 1000.5 establishes new language and provides a set of tools. The primary intent of the JCL is to force better project planning earlier in the life cycle and to support development of more accurate estimates.
- What some of the most important elements of candidate projects are that would drive incentives and contract structures.
- The skills required to successfully execute the effort and where are they located.
- Whether new or refurbished facilities valued over \$500,000 will be required. If so then the program and project planning need to comply with the congressionally mandated Construction of Facilities (CoF) Program. For additional information on the CoF program, see NPR 8820.2 *Facility Project Requirements*, NPD 8820.2 *Design and Construction of Facilities*, and NPD 7330.1 *Approval Authority for Facility Projects*.

The Acquisition Strategy Meeting (ASM) is a forum in which senior Agency management reviews major program acquisitions before authorizing budget expenditures. The ASM is chaired by the Administrator (or a designee) to review materials at the mission directorate/Mission Support Office level. The PM implements decisions that flow out of the ASM and recommends implementation plans for approval. Make/buy strategies are assessed during the ASM. A Procurement Strategy Meeting (PSM) leads to major procurements approach approval. The output from the ASP meeting, ASM, and PSM are the basis for the acquisition plan. The acquisition plan should address all technical, business, management, and other significant considerations necessary to support acquisition (make/buy) of items within the program. For major procurements that are subject to the Master Buy Plan (MBP) and that require NASA

Headquarters approval, a Procurement Strategy Meeting (PSM) is used instead of a written plan. See *Guide for Successful Headquarters Procurement Strategy Meetings* at: <http://prod.nais.nasa.gov/portals/pl/documents/PSMs.html>

When weighing obtaining products and systems via contract:

- PMs should expect contract changes. Some PMs are overly optimistic about stable requirements and the absence of contract changes. A plan with few or no assumed changes is not realistic. The PM should recognize that contract changes are a way of adjusting the agreement when necessary because the environment changes.
- There is a misconception that noncompetitive contracts are easier and quicker than competitive ones. This is seldom the case. There are cases where using noncompetitive contracts cost more due to requirements ambiguity, poor (or unfocused) contract oversight, and contract exploitation. The approval process (which usually includes NASA Headquarters approval) for a noncompetitive contract frequently takes longer to complete than the time required to award a competed contract.
- A contract is the formal business agreement between the Government and the contractor. Your contract counterpart may share your priority for making the best widget possible, but somewhere up the corporate ladder, the most important driver is profit.

#### 4.1.B.b Program Plan Development

The mission directorates conduct multiyear mission implementation planning activities within each theme managed by their Directorate to support achieving NASA's strategic goals.

- Directorates develop program and project plans through the Centers to articulate the commitments of each appropriate NASA organization and to ensure that the specified resources can be used to meet the identified priorities and plans.
- Agency priority and Agency oversight are assigned based on the level of risk.
- Appropriate measures include life-cycle schedule variance, life-cycle cost estimate variance, risks to mission, and technical scope.
- Details of program and project requirements, standards, and procedures are called out in the documents that govern program and project management within NASA.
- These policies and processes, governed by the PMC, guide program and project planning.

If program reserves are not sufficient to meet annual budget challenges or if a high-priority project requires unexpected budget augmentation, the PM (or mission directorate) may elect to cancel or reduce the scope of a lower priority project within that program.

Most of yesteryear's projects overran because of poor estimates and not because of mistakes. Getting better estimates may not lower cost but will improve NASA's business reputation. ... A better reputation is necessary in the present environment.

– Jerry Madden, *100+ Lessons Learned for Project Managers*, NASA LLIS

Although poor estimates are a culprit in cost overruns, they are not the only cause. Others include such things as poorly written requirements, incomplete requirements, and poorly written contracts. These all need to be addressed in the development of the Program Plan.

The history of human and robotic space flight is replete with examples of cost overruns due to a confluence of underfunding, misunderstood risk and complexities, overly aggressive schedules, and difficulties meeting ambitious technical requirements. Advanced concept study teams may optimistically underestimate cost to keep the program moving. An early, unreasonably optimistic estimate usually leads to funding problems later. If the risks identified can't be mitigated with the dollars available it will require additional planning and possibly a request for more funding. Congress, the Government Accountability Office (GAO), and the Office of Management and Budget (OMB) are placing more scrutiny on this process to reduce this result. Proper planning required during program formulation is often underfunded. There may be zeal and/or political pressure to get the program underway. Often the program contains challenges that have never been undertaken and effort is required to define the work and the cost of that work. The best thing a program manager can do is to establish a comprehensive risk management process and capture any risk that results from pressure to expedite the planning schedule.

During the development phase of a project, NASA should take on the cost risk because of the challenge associated with first-time developments. However, once the project is in the production and operations phases or if acquisition of continuing services is required, industry should assume some of the cost risk of performance. Award fee, incentive fee, and in some cases firm-fixed price (FFP) contracts should be used. Industry should earn the appropriate profit for the amount of cost risk assumed. Program/project and procurement offices should work together to develop workload projections for their requirements.

All acquisitions should start with a requirement definition that clearly identifies the Agency's desired outcome for a contract. Program/project managers and teams shall employ a zero-based approach to develop requirements and then must maintain the zero-based approach in program execution. A zero-based approach means that all requirements shall be thoroughly evaluated for direct applicability to the planned procurement and thereby "earn" their way into contracts. The zero-based approach includes reviewing the number and frequency of data deliverable requirements and reviews. Additionally, there may be a need to modify institutional standards and processes to obtain a requirement in a more cost effective manner. Programs and projects should develop a detailed plan for the correct number and type of data deliverables and insight on a planned contract prior to completion of the Request for Proposal documentation. Commonality of hardware, software, and data deliverables shall be part of the requirements development process.

– NASA Procurement Web site [[http://prod.nais.nasa.gov/cgi-bin/nais/nasa\\_ref.cgi](http://prod.nais.nasa.gov/cgi-bin/nais/nasa_ref.cgi)]

Program managers use a Work Breakdown Structure (WBS) to begin developing a technical baseline (see the NASA Standard WBS in NPR 7120.5, Appendix G and the *NASA Work Breakdown Structure (WBS) Handbook* at: <http://evm.nasa.gov/handbooks.html>). A WBS is used to define the total system; to display it as a product-oriented family tree composed of hardware, software, services, data, and facilities; and to relate these elements to each other and to the end product. Program offices should tailor a program WBS using guidance provided in *NASA Systems Engineering Handbook*, NASA/SP-2007-6105 Rev 1. The program WBS is developed initially to define the top three levels. As the program proceeds through development and is further defined, program managers should ensure that the WBS is extended to identify all high-

cost and high-risk elements while ensuring the contractor has complete flexibility to extend the WBS below the reporting requirement to reflect how work will be accomplished.

Once the program technical baseline has been developed using a good WBS, it is important to document major program components and how the program will be executed in a Program Plan. See NPR 7120.5, Appendix E for a Program Plan template and Handbook Appendix C: Sample Documents for a sample Program Plan. The Program Plan should document specific roles and responsibilities at the program and project level (for all supporting projects), and clearly document the roles and responsibilities of Center management for monitoring the projects.

Once the technical scope is defined, develop the schedule first before developing cost. It may seem more intuitive to develop cost before schedule, but that is backward. By resource loading the schedule, cost can be assigned to the right phases and resource analysts can determine the dollar amounts required per year. Once the technical content is defined, then schedule, then cost, these combined elements make up the integrated baseline.

NASA's budgeting practices are fully integrated with other planning and execution practices. This was manifested in a formalized policy to utilize the Planning, Programming, Budgeting, and Execution (PPBE) process as an Agency-wide methodology for aligning resources in a comprehensive, disciplined, top-down approach. This includes a separate breakout of budget dollars for CoF projects. PPBE goes beyond NASA's traditional Program Operating Plan (POP) budget approaches of the past and introduces an enhanced level of analysis to ensure resource alignment supports accomplishment of Agency strategic goals and objectives. However, the PPBE process has not yet been acknowledged at the lower levels of some Centers. The program manager needs to recognize this discrepancy. For more information, refer to NPR 9420.1 *Budget Formulation*, and the *NASA Cost Estimating Handbook*, available at: [http://ceh.nasa.gov/ceh\\_2008/2008.htm](http://ceh.nasa.gov/ceh_2008/2008.htm).

The Mission Directorate Associate Administrator (MDAA) determines the appropriate point at which to fully fund a program. Generally, program funding starts when a system concept and design have been selected, a program manager has been assigned, capability needs have been approved, and system-level development is ready to begin. Full funding for programs is based on the cost of the most likely system alternative.

See Section 5.2.C.d for information on recovering from budget impacts.

### **4.1.B.c Program Risk Management**

Effective risk management is somewhat an art and improves with experience. Managers need to be able to identify risks and add the mitigation costs to the program baseline. When risks are identified and the qualitative value assigned to the risk has been verified, the PM needs to take action in the timeframe associated with that risk (near-term risk versus far-term risk). The PM needs to balance the early commitment of reserves to mitigate serious risks with maintaining sufficient reserves to resolve problems that are encountered during hardware/software fabrication, integration, and testing (periods of peak spending), when schedule delays are most costly. For additional information, refer to *NPR 8000.4, Agency Risk Management Procedural Requirements*.

#### 4.1.B.d Program Requirements

Establishing a good set of program mission/operation concepts that are evolved into a useful set of program requirements is one of the most critical products for program success. Program managers should develop a concept of operations (ConOps) early in the program life cycle to capture the top-level stakeholders' expectations. The ConOps also enables the program to translate the stakeholders' requirements into technical requirements by articulating the system within its reference context from an operational or user perspective. This context establishes the system's logical and physical boundaries, which help establish operational scenarios and capabilities for its operators and users. Scenarios, use cases, capabilities, and associated performance attributes are vital to the concept of operations. The ConOps also helps create, analyze, and evaluate competing concepts for applying the system and its technologies. The *Systems Engineering Handbook* NASA/SP-2007-6105 Rev 1 provides guidance on the use of a ConOps to obtain stakeholder expectations.

- It is important to understand, define, and document top-level requirements that drive the execution and management of technical solutions. Understanding and defining these top-level requirements characterizes the architecture required for such activities as budgets, resource planning and monitoring, and risk mitigation.
- Interfaces need to be well defined in program and project plans. It is the program's responsibility to ensure interface definition is consistent and comprehensive at all levels. These interface definitions are implemented by the program systems engineering team.
- Although system requirements will not be fully defined and matured at the start of a program, there should still be a comprehensive system sensitivity analysis done on the selected configuration and technology base. This will help to identify and flag high-risk areas and interrelationships. An analysis of requirements maturity will support the qualitative assessment of the associated risks.
- Clear, realistic program objectives should be established before design start and maintained as a major program driver throughout the program. Operational goals should be given strong, even overriding, consideration in systems/hardware design. The combination of development and operational costs lead to a consideration of the life-cycle costs of the program.
- Many times engineers look at requirements differently than scientists (typically robotic programs), and there are differing views between project component personnel and those representing the total program/system (typically human flight programs). Consider a requirements forum early to allow people with different roles within the team to express what requirements mean to them, to see if everyone agrees with the interpretation expressed, and to get an appreciation of how a subsystem requirement affects the entire system.
- Get concept (with cost and schedule) done as soon as possible and get in front of the decision makers early. It isn't useful to refine the concept too much before asking for initial management buy in.

Make sure everyone knows what the requirements are and understands them. Much easier to say than do. On GRO, we stated quite clearly that the scientific instruments had to take 18g in a specific axis. Everyone understood the requirement, but until the mechanical test on EGRET, no one stood up and said it was impossible to meet it. The thermal specification for the momentum wheels required that they run 5 degrees colder than normal limits to make the spacecraft thermal engineers' life easier. No one stood up until after 9 months of failure in the test program to say that the grease used changes state if taken that cold, and would not recover when brought back to higher temperature. You have to have the right people look at requirements. A bunch of managers and salesmen nodding agreement to requirements should not make you feel safe.

– Jerry Madden, *100+ Lessons Learned for Project Managers*, NASA LLIS

A Requirements Verification Matrix (RVM) is a tool that helps to ensure that the program's scope, requirements, and deliverables remain as is when compared to the baseline. It traces the deliverables by establishing a thread for each requirement—from the program's initiation to the final implementation.

The RVM can be used during all phases of a program/project:

- Track all requirements and whether or not they are being met by the current process and design
- Track methodologies of verification, key facility needs, and closure
- Where requirement gaps are identified, this matrix can assist the program manager with any additional project assignments and/or make-buy decisions

The RVM should be created at the beginning of a program because it forms the basis of the project's scope and incorporates the specific requirements and deliverables that will be produced. The RVM is bidirectional. It tracks the requirement forward by examining the output of the deliverables and backward by looking at the program requirement that was specified for a particular feature of the deliverable. The RVM provides a necessary input to the program verification planning to help determine the types and number of integrated ground and/or flight tests and test facilities required by the program. Finally, the RVM is also used to verify that all requirements are met and to identify changes to the scope when they occur. The PM needs to ensure the NASA RVM is linked to contractors' and subcontractors' RVMs. Examples of the RVM can be found in NASA/SP-2007-6105 Rev 1 *Systems Engineering Handbook*, Appendix D.

#### **4.1.B.e Program Interfaces with HQ and Other Organizations**

Most NASA programs require establishing agreements with external entities. These entities include other Government agencies, foreign governments, and commercial entities both foreign and domestic. The agreements generally establish a set of legally enforceable promises between NASA and another party to the agreement, requiring commitment of NASA resources to accomplish the objectives of the agreement. Failure to meet agreements (e.g., launching some components of the International Space Station) has occasionally been the United States' fault. Program managers need to strive to meet these commitments. NPD 1050.1, *Authority to Enter into Space Act Agreements*, explains NASA's agreement practice and provides assistance to those involved in formation and execution of Space Act Agreements. Programs should seek early

support from their mission directorates as well as the Agency Office of External Relations for help with interagency and international agreements. The Science Mission Directorate has a list of current agreements at <http://nasascience.nasa.gov/about-us/science-strategy/interagency-agreements>.

A Non Disclosure Agreement (NDA) may be required prior to signing Memoranda of Understanding (MOU) to allow civil service (CS) employees to discuss technical issues with outsiders. If a project is located at JPL, a Technical Assistance Agreement (TAA) will be required to be negotiated and approved by the State Department to cover non-CS project members so that they can discuss technical details with the foreign partner or supplier. The TAA process is part of the Export Control program, which is discussed later. For some projects, multiple TAAs may be required depending on the size, makeup, and complexity of the project.

A TAA was required between JPL and the Indian Space Research Organization (ISRO) for the M3 Project. It took longer than anticipated to obtain the approved TAA and the project was almost cancelled as a result. Headquarters had a signed NDA with ISRO allowing CS employees to discuss technical issues. The Interface Control Document (ICD) was required to be signed prior to confirmation (KDP-C). In order to meet this deadline, the Discovery program office assembled a CS team that traveled with the project to ISRO and acted as intermediaries (voices for the project) thus allowing for a successful ICD meeting and resulting in the signed document.  
– Discovery and New Frontiers Program Mission Manager, MSFC

Export control is an overarching term that covers International Trafficking in Arms Regulation (ITAR) and Export Administration Regulation (EAR) requirements. ITAR is governed by the Department of State and is concerned with issues that could potentially affect national defense. Any satellite, satellite components, or hardware/software associated with the space shuttle is ITAR controlled. EAR is governed by the Department of Commerce and is concerned with information that might provide another country with a technological or competitive advantage currently held by the United States. The space station vehicle is EAR controlled; space station payloads are EAR controlled. Export control needs to be addressed in program and project plans, and in some cases, an Export Control Plan is required. SBU data includes personal protected information (e.g., Social Security numbers, medical information) and certain program or project design and programmatic data. Typically, each program and project will name a Designating Official for SBU; this official determines what data is classified as SBU.

Programs need to ensure policies and procedures are in place to protect any potentially sensitive data. For more information, see *NPR 1600.1, NASA Security Program Procedural Requirements* and *NPR 2190.1, NASA Export Control Program*. For programs that include foreign involvement, the export control plan is critical to identify the technologies and/or technical data that will be shared in the program and the participants who will receive that information. Once the Program Plan is approved (including the Technology Transfer Control Plan), the program then operates in accordance with these plans and any additional approvals (from the Center or Agency Export Control Administrator(s)) should be expedited, as the overall plan has already been approved by the designated authorities.

Creating an integrated baseline for an international mission isn't easy, although in general the foreign partners want to cooperate and do so very well. NASA has control over and can set

measurement indices only for the U.S. effort. Despite this added complexity, NASA portions of missions with international involvement still need to use all standard procedures, stringently define the mission, and establish metrics for the U.S. portion. It is a good idea to include plenty of schedule and cost margin for areas you cannot control, such as international products delivery.

Consider also that other nations' fiscal years, budgeting, and approval processes differ from NASA's. Learn from foreign counterparts how their system works to anticipate where it could impact NASA's project. NASA has negotiated with many international partners. To gain insight, talk to another PM who has worked with the partner, since foreign space agencies' approaches are quite different. Consider taking a course in international project management.

When dealing with international partners, a good strategy, if possible, is to arrive a day early for a meeting and meet with your counterpart to discuss all issues on the agenda for the group meeting. The goal is to arrive at an agreeable response (or a decision to table the issue for later discussion) and agree with your counterpart to be flexible on any new issues brought up at the meeting. This assures the larger group that you and your counterpart are of one mind and that the work is in good hands. Most international meetings are held in English. It is important to have adequate discussions so there are no misinterpretations about what is said.

– Jerry Madden, *100+ Lessons Learned for Project Managers*, NASA LLIS

### 4.1.C Program Technical Activities

The degree of technical involvement of the program with the projects depends on the type of program involved. For single-project and tightly coupled programs, technical planning and execution is the role of the program office. A program-level Systems Engineering Management Plan (SEMP) is developed similar to the ones developed by the projects in uncoupled or loosely coupled programs. This document defines all systems engineering activities. The program office may also need to initiate development of technologies that cut across multiple projects within the program. These technical activities can be initiated through a technology development plan. This plan describes how the program will assess its technology development requirements, including how the program will evaluate the feasibility, availability, readiness, cost, risk, and benefit of new technologies. For loosely coupled and uncoupled programs, much of the technical planning and execution is conducted at the project level; however, the program office generally provides a chief engineer or technical manager to oversee project technical activities.

#### 4.1.C.a Technology Assessment

Technology assessment identifies the major critical technological advancements required for a program/project. It is extremely important to define a technology assessment process at the beginning of the program/project and to perform this assessment at the earliest possible stage (concept development) and throughout the program.

*NASA Systems Engineering Handbook* SP-2007-6105 Rev 1 describes how to perform technology assessments. The process begins by determining technological maturity via NASA's Technology Readiness Level (TRL) scale. This process also guides determining the requirements needed to advance the level of maturity. Conducting technology assessments at various stages throughout a program/project is required to provide Key Decision Point (KDP) products necessary for transition between phases.

In some cases, the degree of technology insertion is schedule driven; a very aggressive program schedule may limit the amount of new technology considered, or only mature technologies may be candidates. In other cases, inability to achieve critical requirements (e.g., mass reduction) may drive a search for new technology to meet requirements.

At the beginning of a program, the PM should appoint a responsible individual to determine and evaluate technology needs and options. The PM should be aware of relevant developments and their level of maturity. The PM can be advocate and sponsor, when appropriate, and develop a transition plan. Also be aware of technologies developed through the Small Business Innovation Research (SBIR) program. Significant insight into technologies where investments have occurred can save time and resources if the program requires an alternative.

### 4.1.C.b Developing Descope Options

Descope simply means that the original program has been partly reduced in capability. Program descopes can include anything from removing an entire project to removing parts of projects (e.g., an instrument, reducing the capability of a system, shortening the operational life of the mission,). Descopes are most often caused by the program's inability to continue funding an item. They can also be caused by unavailability of a new technology that was expected but cannot be delivered on time.

Establishing baseline requirements as well as a floor or minimum acceptable program or project (a level below which the program or project should not go forward) is necessary. This method can be applied to any new program or project and the agreed-to minimum acceptable mission can be used to bound descope options. Descopes must not cut a project below the minimum success criteria needed to carry out the missions in the program. If a descope is invoked, it is necessary to take a systems view to ensure that all potential interactions are identified.

It is important to identify potential descopes early and to get sponsor buy in. It is also important to identify the risk associated with taking potential descopes. Many potential descopes are possible and beneficial when taken early in the program life cycle but may be much less useful or even increase overall program or project risk when taken late in the life cycle. When identifying a descope, the analysis should include a date by which each descope needs to be taken and the associated risks of taking the descope.

Although descopeing is sometimes necessary, it should be used as a last resort. Having a good plan and monitoring status, using tools such as the Integrated Master Schedule and Earned Value Management, are key to early problem identification. Early identification can possibly preclude the need to descope.

One program was forced to remove content that did not have a set of minimum or threshold requirements from the original scope of the program. To realign the program's scope, the PM assembled key stakeholders, including all levels of Technical Authority, and "put everything on the table." Every potential descope item was ranked in terms of risk versus benefit. Items that were essential or that the team did not want to eliminate were determined relatively quickly. For nonnegotiable items, the team didn't waste time debating; however, as part of the process, everything was questioned. After this process was concluded, the PM communicated the decisions and rationale to the entire team.

– Program Manager, GSFC

This example describes a thorough process for developing descope candidates. However, had a descope analysis been developed early in the program (proactively), the team would have had a descope list ready to be implemented if and when necessary. The last-minute reaction would have been avoided.

On another program, the team maintained a descope list with actions and the rationale behind the action as well as any resulting program risks and updated the list periodically. Exercising descopes early on was key to the program staying within its cost and schedule baseline.

Frequently, a descope occurs as a reaction to an unplanned budget cut or a continuing resolution; the budget challenge is met with resulting reductions in program scope. This type of scope change cannot be preplanned; it occurs as a result of various trades to achieve the optimum program content or scope that the new budget (and/or schedule) will allow.

### **4.1.D Conducting KDP Readiness Activities**

As a NASA program enters and moves through the life cycle, it reaches Key Decision Points (KDPs)—the process through which approval is granted prior to proceeding with the next phase of the program. KDPs are placed at specific program maturity assessment points between the program/project phases. KDP criteria are outlined in NPR 7120.5.

KDPs provide a structured approach for determining whether or not a program or project is sufficiently ready to proceed into the next phase. For programs, the Agency Associate Administrator is the decision authority responsible for authorizing entry into the next life-cycle phase, consistent with phase-specific entrance criteria and statutory requirements. Progress through the life cycle depends on obtaining sufficient knowledge to continue to the next stage of development. Program managers need to explain and appropriately tailor, within their acquisition strategy, the program's life-cycle phases and placement of KDPs to meet the program's needs. PMs also need to plan for the fact that all parts of the program are not at the same stage of development. For example, the instrument development may be well ahead of the spacecraft development.

It is important for the PM to be fully aware of and have a credible plan to deal with any issues raised by events such as internal reviews, Standing Review Boards, or latest cost or schedule estimates prior to going forward to a KDP Review chaired by the program Decision Authority. There should be no surprises for the PM at this meeting.

#### **4.1.D.a Program Life-Cycle Formulation Reviews**

For all program types, Formulation requires multiple program reviews for the formal Key Decision Point required to allow the program to proceed from the Formulation to the Implementation Phase. (The program life cycle differs in NPR 7120.5E.) See NPR 7120.5, Tables 4-1 and 4-2 for the products and product maturity required to support KDP I (and KDP 0, if required). Typically, there is no incentive to move a program into implementation until its first project is ready for implementation. Biennial program reviews ensure that the program continues to contribute to Agency and mission directorate goals and objectives within funding constraints. A summary of the required gate products for the program Implementation phase is available in NPR 7120.5. The program life cycle has two different implementation paths, depending on program type. Each implementation path has different types of major reviews. All programs are

required to undergo two technical reviews (Systems Requirements Review and Systems Definition Review).

1. Reviews are for the reviewed and not the reviewer. The review is a failure if the reviewed learn nothing from it.
2. The amount of reviews and reports is proportional to management's understanding (i.e., the less management knows or understands the activities, the more it requires reviews and reports). It is necessary in this type of environment to make sure the data is presented so that the average person, slightly familiar with activities, can understand it. Keeping the data simple and clear never insults anyone's intelligence.

– Jerry Madden, *100+ Lessons Learned for Project Managers*, NASA LLIS

Regardless of the format or formality of the review, the PM should require the same amount of preparation for the review so that all necessary understanding and information is conveyed to the reviewing authority. Informal reviews require planning and preparation discipline to ensure that all aspects of the program are understood by the program management team and that the cost, schedule, and technical and risk statuses can be accurately and completely communicated.

For more detail on reviews, refer to NPR 7120.5, Section 2.5A, Review Process.

## 4.2 Programs Implementation Phase

Program implementation begins with the successful completion of KDP I or II as specified in NPR 7120.5. The Decision Authority will always be the Agency PMC for Programs. The primary focus of the program during Implementation is to execute the Program Plan in a cost-effective manner.

This section discusses uncoupled and loosely coupled programs. These require Program Status Review (PSRs)/Program Implementation Reviews (PIRs) to assess the program's performance and authorize continuation at a biennial KDP. Single-project programs and tightly coupled programs are very similar to projects in Implementation (see Handbook Section 5.2 Project Implementation).

### 4.2.A Introduction

For all programs during implementation, the primary program activity is to ensure all projects are following the program plan. Single-project programs and tightly coupled programs have the characteristics of very large projects. They are run using all project requirements in NPR 7120.5. Loosely coupled and uncoupled programs oversee the implementation of the projects in the program, helping with funding, assisting MDAA in such activities as selecting projects, performing systems engineering between projects, ensuring technology insertion at appropriate points of the program. The projects in these types of programs are generally independent of one another. (See Handbook Section 4.1 Program Formulation Phase for definitions of the four different types of programs.)

## 4.2.B Team Development

Regardless of the type of program, team development is very important within a program—the team concept is important to accomplishing the overall goals of the program.

Funding will always be finite and possibilities will always be infinite, leaving NASA program managers with the challenge of implementing programs by finding the right balance between technical considerations, cost, and schedule among the elements and/or projects. To accomplish this, the program manager needs to have project managers that s/he can trust and that trust him or her. One successful PM states that his best skill as a PM is his ability to judge raw talent. As a result, he is willing to give new people the chance to reach their potential. He also selects team members who are not afraid to push back when things don't make sense.

Balance the team with people that complement one another's strengths and weaknesses. Program managers have the added challenge of dealing with multiple cultures (NASA Centers, as well as contractors), geographic distance, issues of competing resources, and complexity of the systems and projects.

It is the PM's responsibility to maintain the balance for all aspects of the program portfolio, from elements to projects. The PM relies on the project teams, which may need to make sacrifices for the good of the overall program. Negotiations and compromise are key aspects to the success of the program. The PM needs to be able to break down barriers that get in the way of open and honest communication among the program team, as well as between the projects or subsystems. (See Handbook Section 5.1.B How to Establish and Manage a Project Team for detailed information about establishing a team.)

I was faced with two contractors on an instrument team who were not communicating well. I knew that if they did not stop fighting the instrument would not be delivered on time, there would be more cost overruns on the project, and future projects in the program would be impacted. After unsuccessful attempts of trying to get the PMs of the two organizations to talk, I determined it was time for creative measures. I held an impromptu off-site meeting and invited them to come in my car. As I drove from the plant, I told them we were going to do a team-building activity. I drove about three blocks and then pulled into a strip mall. They immediately saw the elephant and the sign "Elephant Rides." They both started complaining that they were not going to ride the elephant. I paid the fee and the three of us mounted (boarded?) the elephant. Afterwards, I found that there was nothing like having three grown men (two in suits) holding onto each other for dear life to take down barriers to communication.

– Instrument Systems Manager, GSFC

## 4.2.C Perform Technical Activities

Program implementation occurs with selection of the projects that execute the Program Plan, as discussed in Handbook Section 4.1 Program Formulation Phase. The PM utilizes systems engineering to support the selection process for projects. Clearly defined program requirements help the program and project to adhere to the technical, cost, and schedule commitments during implementation.

Documentation of the requirements at the program and project levels enabled both the program manager and the project manager to hold the XTE project under the baselined dedicated spacecraft cost. This enabled the next new start of the Mid-EX Program to proceed on schedule despite other areas within the program that had technology challenges. XTE returned \$12 million by holding to the original science requirements and resisting “requirements creep.”

– Explorer Program Manager, GSFC

#### 4.2.C.a Systems Engineering

In a single-project program, the program systems engineering (SE) effort ensures that the interfaces between the elements and/or subsystems are well defined and that the systems as defined will operate as planned. The SE effort also verifies compliance to the requirements using a verification matrix throughout the environmental testing of the subsystems and overall system. Single-project programs are typically Category 1, meaning high dollar and high visibility. For example, JWST used a combination of SE, risk management, and reserve management to retire the risk of ten critical technologies prior to reaching PDR. The risk reduction was successfully completed—all ten technologies were independently determined to be at TRL 6 prior to PDR. Systems engineering in single-project programs is essentially the same as it is for any project.

Loosely coupled and uncoupled programs have less interdependence between the projects within the program than do single-project or tightly coupled programs. Systems engineering takes place on each project, with little between the projects due to the minimal levels of dependence between the projects themselves. However, there are times where SE trades need to be made between the projects of a loosely coupled or uncoupled program. These could include, for example, which technology to fly on which mission in the program. The program manager, therefore, needs a strong systems engineering effort to support these trades.

Tightly coupled programs have a strong need for program systems engineering because of the interdependence of the projects to accomplish a mission. There are interfaces and performance specifications, as well as derived requirements that are affected by the other projects. SE efforts are critical to the success of the program. If one project falters, it can have devastating effect on the other projects. New technologies are generally part of the tightly coupled program designs. This compounds the risk, because the failure is not isolated to one project and the impacts are also intertwined. In the case of tightly coupled programs such as the Constellation Program, there is a very large Systems Engineering and Integration (SE&I) organization within the program office. During program implementation, the focus of this organization shifts from requirements development and allocation to system design.

Some of the functions of an SE organization for a tightly coupled program include, but are not limited to:

- Ensuring appropriate end-to-end mission analysis is defined and performed to confirm that the integrated design can perform the mission.
- Providing a strong program integration office staffed by experienced integrators to support boards and panels that oversee proposed configuration changes, integrate and evaluate program risks, and similar activities.
- Providing experienced people to work key issues.
- Ensuring that operability and life-cycle costs get folded into the integrated design.

A tightly coupled SE organization also contains a strong test and verification component that develops test objectives (ground support and flight hardware and software) from the bottom up and ensures that the program has a comprehensive approach for integrated (total system) verification and validation.

#### **4.2.C.b Decision Making at the Program Level**

It is important to make program decisions using all information that is available at the time that the decision needs to be made, but timely decisions often need to be made without complete information. These decisions, regardless of incomplete information, cannot be random and pure chance. They need to be well thought out. Program managers need to evaluate the risk of making a decision, as well as the risk of not making the decision.

The difference between a program manager and a project manager is that a project manager will make a decision pretty quickly to keep the team moving forward where a program manager wants to keep his options open until they absolutely have to make a decision.

– Orbiter Project Manager, JSC

In the decision to fund a parallel path for a high-risk item on one project, the program manager also needs to consider the impact that the decision will have on other projects. A decision to fund a parallel path for a high-risk circuit board, for example, may divert available funds from another activity that may affect a future mission. In other words, the program manager has to consider the risk and impact to the entire program portfolio.

It is also important to revisit decisions as information becomes available to ensure that the decision remains the best answer. There are times when decisions will need to be reversed or the program may decide to move on and live with the consequences of the decision.

In a tightly coupled program or a single-project program, decisions are complex because of the inherent interdependencies between the projects or elements. Schedule becomes a critical factor because completing an element too early or too late can also have impacts to the program. If an element completes early, for example, its technical development team might have to be disbanded, or the program might have to pay for a costly team waiting for the rest of the program to catch up.

The Decision Analysis Process described in NPR 7123.1 is used to help evaluate technical issues, alternatives, and their uncertainties to support decision making. Only selected decisions are subjected to a formal process. One of the important tasks for the PM early in the program is to establish programmatic guidelines to determine which technical issues are subject to a formal analysis/evaluation process. Decisions about medium- or high-risk activities, program termination, major changes in program scope, or key personnel changes are good candidates for formal decision analysis.

A formal Decision Analysis Process can assist the PM in reevaluating decisions when more information is available, informing new members of the program staff about the decision history of the program, and defending key decisions at milestone reviews. A history of important decisions also can help guide future programs and projects. Programs are often not good at documenting the history of decisions and need to improve this process.

Often, decisions only show up in meeting minutes. For small programs, maintaining a file that contains all meeting minutes may suffice. A more extensive approach is to capture the detailed decision information (i.e., decision package) in a central repository. That decision package would include the genesis of the decision, augmenting information, and the assumptions that were considered for the decision. The decision package may also include the alternatives that are considered, the rationale, and the resulting actions from the decision. Examples of results from a decision include change in a requirement, a new requirement, or a new component added to the system of interest. This decision package can be retained in a repository such as a spreadsheet or a database.

### **4.2.D Program Control**

Many program control activities in loosely coupled and uncoupled programs involve monitoring the projects in the program and supporting the MDAA in such activities as updating the Program Commitment Agreement (PCA), selecting the new projects in the program, and approving Formulation Authorization Documents (FADs) and project plans. Examples of support for projects include cross-cutting technology, dealings with international partners, and the annual funding process. Single-project programs and tightly coupled programs are essentially run as very large projects, and the program control is the same as project control except at a higher level. (See Handbook Section 5.2 Project Implementation.)

#### **4.2.D.a Oversight**

It is important for the program manager to have oversight of both the technical and programmatic activities of the project. The program manager needs this information to be able to make decisions about the overall program portfolio.

The PM has the approval authority for annual project budget submissions as well as the responsibility to prepare the project budget submissions. Implementation of Earned Value Management (EVM) guidelines and/or an EVM system provides data that can give indications of overall health of the projects. The program uses this data to make decisions at the program level that might include holding additional reserve, applying reserve in other areas than previously applied, implementing descopes, making changes to the start times for new projects, and cancelling a project or work. The PM and the program staff need to be thoroughly familiar with EVM guidelines and use. This should include taking NASA training in EVM.

The program also requires insight into project technology development activities. The program may be responsible for cross-cutting technologies from a strategic perspective that will apply to a later mission. The program needs to have open communication and oversight of the development progress to make decisions for future projects. The PM may decide to push the implementation of a new technology to a later mission if the development is not progressing as planned. This is the type of decision that the PM may need to make from a strategic perspective but that a project might not understand at the project level. The PM needs to communicate this.

### **4.2.E KDP Readiness Activities**

The KDP I review is the gateway that begins Implementation. For each Program KDP conducted after KDP I, the program products are required to be reviewed for necessary updates. This

provides an opportunity to incorporate lessons learned into the documentation, as well as to evaluate the effectiveness of the program and to identify additional risks or areas of risk as the program matures. The products should be updated to reflect the level of maturity at a given point.

The program products include, but are not limited to:

- Program Commitment Agreement, as appropriate
- Program Formulation Authorization Document
- Program Plan
- Interagency & International Agreements
- Traceability of Program Requirements to the Agency Strategic Plan

The program products need to be kept current to ensure that the program supports the Agency's overall strategic objectives and is on track for implementing projects within the program. The program documents are a source for the basis of project planning. These documents need to be consistent and current to support the Decision Authority at each KDP. It is important for the documents to reflect how the work is actually being implemented rather than how it was initially planned.

Internal reviews are conducted within the projects that make up a program. These internal reviews are used to establish the baseline. The baseline for each project within a program contributes to the overall baseline of the program.

As the program matures, the control plans also mature and are baselined by KDP II. The control plans need to be sufficiently mature and baselined to support implementation of the first project within the program. Program Control Plans are an integral part of the Program Plan; however, they may be stand-alone plans that are summarized and referenced in the Program Plan. The Program Control Plans are listed in NPR 7120.5, Table 4-2. Sometimes it may be useful to work to preliminary or draft plans prior to the formal baselining to keep things moving early in the program.

PDRs and CDRs in the past have been fairly large activities. These are necessary functions. Whether they are overdone or not is in the eyes of the beholder. The sequence of reviews I think has served NASA well. How you manage reviews to be the right size and cover the appropriate content has always been a debate. But the idea of a series of reviews is fine. You need to move the program along and get everyone together and make sure everyone is at the appropriate place in their activities. It gives a way to look across systems and organizations to see how things are coming together.

– Program Manager, JSC

## Chapter 5.0 Project Guidance by Phase

This section provides an overview of the project manager's functions during the Formulation and Implementation phases.

NPR 7120.5 defines a project as “a specific investment identified in a *Program Plan* having defined requirements, a life-cycle cost, a beginning, and an end. A project also has a management structure and may have interfaces to other projects, agencies, and international partners. A project yields new or revised products that directly address NASA's strategic needs.”

Much of the information in this handbook's Chapter 4 is directly applicable to Chapter 5.

### 5.1 Project Formulation

This section corresponds to NPR 7120.5, Sections 4.3, 4.4, and 4.5.

NASA places significant emphasis on project formulation because adequate preparation of project concepts and plans is vital to success. Most project expenditures occur during the Implementation and Operations Phases, are based upon the planning performed (or ignored) during the Formulation Phase, and will likely determine the overall project success or failure.

During Formulation, the project, among other things:

- Establishes performance metrics
- Explores the full range of implementation options
- Defines an affordable project concept to meet requirements specified in the Program Plan
- Develops needed technologies
- Develops and documents the Project Plan

Formulation is an iterative set of activities rather than discrete linear steps. System Engineering plays a major role during Formulation, exercising an iterative set of activities as described in NPR 7123.1, *NASA Systems Engineering Processes and Requirements*. See Handbook Section 5.1.C Technical Planning and Execution for more about Systems Engineering.

#### 5.1.A Introduction

Project formulation begins in Pre-Phase A. A viable project is able to trace its goals and objectives to those of a mission directorate and/or a specific Program Plan, as well as to the Agency Strategic Plan. Once these goals and objectives are defined, a study project team is established to develop preliminary mission concepts. This team begins the technical and planning activities that will continue throughout the project life cycle.

Even though a viable project has traceability to the goals and objectives of a Program Plan, the project concept may not come from an objective analysis of that plan. It often comes as a unique scientific idea from a person or team. As this idea is developed and gains acceptance by the community, it is then related to the NASA goals and objectives of a particular program. At this point, the idea begins the process of transformation into a space-flight project in the earliest stage of the project cycle (i.e., Pre-Phase A).

It's important to get a clear understanding, with the project team as to what the objectives are and to ensure that everyone on the team is on the same page. ... Lastly, ensure that you continually manage the project objectives, such that you always take your team back to the common, agreed-to objectives. Understanding and agreeing on objectives determines your priorities.

– Orbiting Carbon Observatory (OCO) Project Manager, JPL

Once the objectives are understood, the team should address the preliminary mission concept. This is simply the general idea of how the mission could be implemented. The early part of this mission concept phase needs to be creative. Now is the time to come up with creative ideas and put them on the table. Early in formulation there is an opportunity to learn what drives the design. There can be an advantage to having people with diverse experiences in this phase of the project, because these people will not be committed to a single way of doing business. Later in the life cycle, you will need people with the talent to implement the project. This is often the reason that those who staff the early phases of a project are not the ones to carry it into implementation; different skill sets are sometimes needed. The individuals that work the Formulation phase of a project need to understand and be comfortable with the uncertainties that come along with undefined requirements.

However, because you are making decisions that impact the project later, you need both flexibility and consistency. This means you want a balance of people who think creatively about what needs to be done and others who are good at doing things in a controlled, standard way.

Mission directorate/program managers/line managers need to allow PMs the time and resources to perform adequate Formulation planning. If too many poor decisions are made during Formulation (which will become apparent later in the project life cycle), the PM's options to deliver a successful product become limited.

Two major Formulation activities are:

- **Technical Planning and Execution** – developing a Systems Engineering Management Plan (SEMP) and executing this SEM and various technical management processes to achieve a preliminary design; and
- **Project Control and Execution** – projecting all work, materials, and facilities in a logical order into a project schedule that is developed and matured. This includes defining resources required to support the schedule activities (along with parametric estimating) to establish a cost baseline, and utilizing management tools to measure and ensure successful project performance. The project cost estimate and schedule will mature from draft in Pre-Phase A, to preliminary in Phase A, to baseline in Phase B. For more information on cost and schedule development, refer to Handbook Sections 5.1.D.i Life-Cycle Cost Estimates and 5.1.D.d Integrated Master Schedule.

### 5.1.A.a Pre-Phase A

A mission directorate, working through a program office, typically provides a small amount of discretionary resources for concept studies (i.e., Pre-Phase A). Concept studies involve design reference mission analysis, feasibility studies, technology needs analysis, and alternatives analysis. This iterative design process continues as concepts mature. Parametric cost estimates are used to develop Life-cycle Costs (LCC) for each concept.

One of the earliest activities is defining program and project objectives. It is important to not only define these objectives, but to understand how they fit into the overall NASA program objectives and how to communicate them to the project team. This is a continual process. It often requires bringing the team back to the original objectives later in the project when the team may get sidetracked or be tempted by requirements creep. The idea is to ensure that the team keeps the big picture or end state in mind. Focusing on objectives helps prioritize issues as they arise. One technique is to split objectives into primary and secondary. The project team needs to be prepared to sacrifice secondary objectives but not primary objectives. It is important to identify primary and secondary objectives early in the project to understand what can be cut as the project evolves and inevitable problems appear.

Learn the basics of the project. If you're going to fly a scientific mission, the least you've got to do is to go out and learn about the science that is going to be done. Get a couple of books. Don't try to get too-detailed an understanding, because you'll never be able to catch up if you aren't already knowledgeable in the subject. Read so you understand the nomenclature and get a grasp of the basic principles. ... When I first started in this business, I was a mathematician and was working on telemetry data. I didn't know anything about telemetry, so I went to Radio Shack and got a simple book on telemetry. When an engineer came in and started spouting off about this stuff, he couldn't believe that I knew what he was talking about.

– Jerry Madden, *ASK Magazine*

This phase culminates in KDP A. A number of products are due by KDP A, including Headquarters and Program Products, Project Technical and Planning, Cost and Schedule Products, and KDP Readiness Products. These are summarized in NPR 7120.5, Table 4-3, Project Gate Products Maturity Matrix.

### 5.1.A.b Phase A

During Phase A, the team performs activities to fully develop a baseline mission concept and to begin or assume responsibility for the development of needed technologies. This work, along with interactions from stakeholders, helps establish a mission concept and the program requirements for the project. See Handbook Section 5.1.C.d Developing Project Objectives, Concepts, and Requirements for additional information.

The project team begins to form during this phase. Selecting the project team is one of the most important activities the PM performs. Management processes, team dynamics and communication plans, and programmatic processes develop and mature. The team's work effort in Phase A focuses on analyzing mission requirements and establishing mission architecture. Activities become formal, and emphasis shifts toward optimality rather than feasibility. The effort addresses proposed concepts in greater detail and considers many alternatives. The team solidifies goals and objectives and identifies minimum or threshold objectives. The project also further develops the operations concept, system requirements, and top-level system architecture. Conceptual designs are developed to provide additional engineering detail, more than was possible in previous studies. The team also identifies technical risks in more detail and focuses on identifying and preparing for technology development activities.

A good example of cooperation in concept development between the implementers of a project and the stakeholder, in this case the Project Scientist, was shown on COBE.

Nobel Laureate, Dr. John Mather, talking about Cosmic Background Explorer (COBE) said, “I met with the engineers all day, every day. We would just talk: How can you do this? How hard is that? How well do you have to do this?” Regarding interactions between scientists and engineers, he continued, “We come from different cultures and have different ways of thinking. Engineers are trained to make something that really works. The scientist says, ‘I know I can’t do this or that, but I want to find a way around all the things that can’t happen.’ That’s why I spent so much time with engineers. They knew what could be done, and I knew what we wanted to do. They’d say, ‘You can’t do that,’ and I’d say, ‘If we change our request a little bit, could we do that?’ That’s how the project evolves. ... A scientist has to work with the engineering team to find a way around the impossible. It’s fundamentally a science-engineering job.”

– Dr. John Mather, *ASK Magazine*

Concept development can involve not only the technical design of an instrument but the means of implementing the project, including the mission operations concept. The steps taken to change the mission concept, such as for the Geostationary Operational Environmental Satellite (GOES) project as described below, has the effect of reducing risk—in this case by making the spare spacecraft readily available as a backup.

When I joined the project, the customer [NOAA] had a problem. NOAA requirements necessitated having two GOES spacecraft flying at all times. While they did have two at the time, the issue was replacement. If they waited for deterioration of a spacecraft on orbit, it was almost too late. For this reason, NOAA wanted the ability to call up a replacement spacecraft for flight within 180 days if necessary. NOAA’s request was not economically feasible. The project would encounter an enormous cost of having a launch vehicle “reserved” for use at any time. There was also the problem of storing the spacecraft on the ground and a long wait might require extra testing before flight (e.g., an extra thermal vacuum test).

I proposed that NOAA launch the next spacecraft in the sequence when it became available instead of storing it, and to keep it as a spare on orbit. This had a number of advantages:

1. A successful launch and checkout would have already been accomplished if at any point the spare is required.
2. It eliminated any special precautions required for storing the spare.
3. Launch schedule could be optimized to fit with the launch vehicle manifest.

– GOES Program Manager, GSFC

Also in Phase A, the team starts to bring focus on allocating functions to particular items of software, personnel, and other aspects. The team develops a draft project Work Breakdown Structure (WBS), and matures make-buy decisions. The team also develops a preliminary integrated master schedule that shows the critical path through the project and the timing of critical resources, such as facilities, and the need dates for major procurement deliverables. The team also iterates on system and subsystem trade-offs in an effort to determine the most cost-effective design. Given a number of concepts, trade studies should precede—rather than

follow—system design solutions. Major products in Phase A include an accepted system and end items functional baseline. During Phase A, the team will also identify major risks, and produce various project management plans, which are all summarized in the Project Plan, to prepare for managing the project’s downstream processes, such as verification and operations, and required support infrastructure. This phase culminates in KDP B.

### **5.1.A.c Phase B**

During Phase B, the team performs activities to establish an initial project baseline. This includes a formal flow down of project-level performance requirements to a complete set of system and subsystem design specifications for both flight and ground elements. The technical requirements need to be sufficiently detailed to establish firm schedules and cost estimates for the project.

In this phase, the effort shifts to establishing a functionally complete preliminary design solution (i.e., a technical baseline) that meets mission goals and objectives. To support the technical baseline, the team develops a Work Breakdown Structure (WBS) and uses the WBS to develop its Integrated Master Schedule (IMS). The IMS enables the team to develop its integrated budget (including the CoF budget) and leads to developing a Performance Measurement Baseline (PMB).

In practice, the activities described for each phase are not exclusively carried out in that phase; timing depends on the particular schedule requirements of the project and the contracts in place. For example, to meet the project launch date, some long-lead procurements, or subsystem or developmental testing may occur in Phase B.

The effort and fidelity dedicated to each preceding phase will affect the quality of every phase that follows. The later in the project life cycle changes are introduced to the project baseline, the more costly they become.

This phase culminates in KDP C and the beginning of project Implementation. (See Handbook Section 5.2 Project Implementation for additional details.)

### **5.1.A.d Announcement of Opportunity Missions**

Some mission directorates have chosen to establish projects that use a one- or two-step AO process to initiate projects. NASA issues AOs as vehicles to initiate missions that will meet particular scientific goals. In a one-step AO process, scientists submit proposals to NASA that are either rejected or selected for implementation. In a two-step selection process, two or more projects are selected during Step 1; these selected teams mature the mission concept during a funded Phase A study. Following this study, the teams report on their findings by providing NASA with a Concept Study Report. This report has additional detail about the project’s science concepts, cost, schedule, technical performance, project implementation strategies, safety and mission assurance strategies, and management approach. NASA evaluates the information and down-selects one or more projects to proceed with further formulation. These projects are often referred to as competed or AO-driven.

The selection process is driven by Agency objectives, decadal surveys from the scientific community outside the Agency, and project maturity. Proposals deemed mature and ready for implementation are generally highly rated by the proposal evaluation team. Describing how the project will embrace NPR 7120.5 is a required portion of the proposal.

A proposal that follows the AO outline and instructions is easier to evaluate and score. Teams should craft their proposals according to the AO instructions and write clear, substantive, fact-based paragraphs, which are more likely to score well. To ensure the proposal meets all requirements of the AO, many teams use a detailed AO Compliance Matrix that lists every requirement and where in the proposal these items need to be addressed. Teams with a strong Compliance Matrix will score higher in the evaluation process, since they have ensured the proposal responds to the AO requirements in the expected locations, making it easy for reviewers to find and give credit for the information.

From the point of view of the selected AO-driven project, the proposing teams are doing formal project formulation (e.g., putting together a detailed WBS, schedules, cost estimates, and implementation plan) during the funded Phase A concept study and/or preparation of the Step 2 Concept Study Report. The down-select process is, in effect, KDP B, and, following selection, the process follows the normal life cycle.

### 5.1.B How to Establish and Manage a Project Team

The final project development team is not necessarily in existence in Pre-Phase A. However, it does need to come together in Phase A or at latest in early Phase B. Many decisions are made in Pre-Phase A and Phase A that the development team will have to live with throughout the remaining life cycle. Establishing and managing a project team is similar to establishing and managing a program team.

Many experienced managers feel that the single most important job of the PM is selecting and managing the project team. Key support personnel need to keep the PM continually informed about programmatic, contract, and technical issues. In addition, the PM needs to select people whose opinions and experience they respect, and who are willing to speak up when they see issues. It is important to balance the strengths and offset the weaknesses of the management team. Diversity in backgrounds and skills is a must. Chemistry of the management team can be critical when making decisions. The personality of a project team is molded to a great degree by the personality of the PM. The PM defines team norms or the environment that s/he expects the team to operate within and should seek agreement from all team members that they will operate within these team norms.

Prelaunch, Spitzer had a management team face-to-face get-together on a monthly basis. This meant a lot of travel to get the JPL management team, the contractor management team, and the science management team together because they were not colocated. To mitigate the costs across the project, the trips rotated between the sites so no one team always had to travel. The benefit was to build *esprit de corps* and good teaming relationships within a well-managed team.

– Spitzer Project Manager, JPL

Team chemistry is the environment in which the team interacts with one another and those outside of the team. Attributes such as trust, respect, flexibility, and ability to work with others contribute to successful team chemistry. When interviewing a prospective project team member, in addition to the typical questions that relate to experience and skills, briefly describe the project and its major challenges, and ask the interviewee if s/he can buy in or accept the project

approach. The PM may also ask each person about their expectations of the job, followed by stating what the PM's expectations are from project team members.

In an organization like NASA, you find very few people who are poor performers, but you often find people who are in the wrong job. What we have to do as supervisors, leaders, and managers is find the right job for the person. When you do that, they usually excel.

– Chris Scolese, *ASK Magazine*

When determining skills and finding key team members, attributes that the project manager should look for are:

- Integrity (people you trust and others trust)
- Being a team player
- Technical competence

Other important attributes include:

- Ability to communicate and articulate up, down, and across the organization
- Passion and being self-starting
- Previous hands-on management experience
- Ability to articulate to the PM what risks the PM needs to mitigate or accept
- Flexibility

Team members need to be willing to see the big picture and their role in the success of the team as a whole.

You can't accomplish a project unless people are willing on various parts of the team to ... suffer a little bit for the greater good. I'll just give you an example: if a structures guy is going to make sure he has enough of the spacecraft mass to make sure his structure is never going to break, if he doesn't mind making somebody else work harder to get their weight down so he can look good, you never are going to have a successful project. If anybody is hoarding all the reserve, you'll never get there. So you have to have team-oriented people.

– NASA Administrator

Team members also need to have the ability to build relationships with all of the project team members, as well as with peers between projects and within the engineering support organizations. Team members need to know to whom to talk, and to ensure they communicate with those key people frequently. The team should also be staffed with a good mix and balance of people who will think creatively about what needs to be done and others who are good at doing things in a controlled, standard way. Every member of a project team has a critical role that needs to be performed. See Handbook Section 3.1 Overview of Roles and Responsibilities, for additional information about team members.

A manager who is his own systems engineer or financial manager is one who will probably try to do open heart surgery on himself. ... The project manager who is the smartest man on his project has done a lousy job of recruitment.

– Jerry Madden, *100+ Lessons Learned for Project Managers, NASA LLIS*

In AO-competed projects, a troika of the project manager, the principal investigator (PI), and the systems engineer (SE), all with strong personalities, often works best. They each need to think about all aspects of the project, but the PI focuses on what the project is trying to do, the lead SE focuses on how the project will do this, and the PM focuses on doing this within the cost and schedule. They all need to be concerned about each of these areas, but it is a question of the weight and expertise they apply to each.

For AO-competed projects, the PI is the organizational leader and is responsible for overall scientific integrity and mission success. The PM works for the PI and is responsible for programmatic and hardware/software elements that support the project, as delegated by the PI. The science team reports directly to the PI. In early Formulation, the PI organizes the team or consortium that will develop the mission concept, propose it, and, if selected, implement the mission. The PI chooses the management approach best suited to the mission design, skills and expertise of the team members and the available resources.

Once the key positions have been identified and filled, and work packages have been developed from the work breakdown structure, the PM has a good idea of the skills required from the other key project team members. The PM needs to work with the Center to determine the technical skills needed and then to staff the lead positions.

### 5.1.B.a Managing the Team

Team building is one of the PM's primary responsibilities. The PM needs to train the entire project team to think, act, and relate in an integrated fashion (team chemistry)—this mindset takes significant effort. A kickoff retreat to establish roles, responsibilities, communication strategy, and team norms is recommended. One PM stated in a team kickoff meeting, “We will have lively, healthy, respectable debates—be tough on issues, but easy on people.” The PM should discuss the shared vision of the project.

If you want to build a ship, don't drum up men to go to the forest to gather wood, saw it, and nail the planks together. Instead, teach them the desire for the sea.

– Antoine de Saint-Exupéry, from article in the *Harvard Business Review*

The PM also needs to stress the importance of keeping agreements and commitments—if a commitment cannot be met, it should be renegotiated instead of simply broken. Roles and responsibilities should be presented with as much specificity as possible. These should be matched to the scope of the project and to the skills of the project management team. This definition of roles and responsibilities should be documented and revisited twice per year. Roles will change through the course of the project development. The PM needs to make sure everyone knows their job and ensure they are doing it. Periodic retreats are recommended for the entire team. (Some very large projects have too many members to include every member in a retreat. In those cases, the PM should invite as many team members as possible.)

Make a point to personally welcome each new team member, even if a large number of team members join the project at the same time. Again, for very large projects this is not always possible. In those cases, the PM should have periodic meetings for small groups of new team members, or have the Deputy PM conduct individual meetings with new members. This welcoming meeting will reinforce many of the points made at the retreats, but also serves to

establish a rapport with the individual and give them an opportunity to discuss issues or ask questions that as new members they may not feel comfortable discussing in the open forum of the team retreat. The PM should describe the specific tasks to be performed by the team member and the skills that are expected or required, with a discussion of training needs and individual training plans.

Your integrity as a manager needs to always be impeccable. You need to always be as fair as possible and as honest as possible. To the extent possible, never send anyone else to deliver bad news.

I never put a person in a job that I felt they were fully qualified to perform, for fear that they would become bored. I wanted them qualified enough to not get overwhelmed, yet lacking enough that they would always feel challenged and stretched.

– Ames Deputy Center Director

The PM should discover the personal objectives of team members. These personal objectives might include career advancement, obtaining skills in new technologies, or working with intelligent people on a challenging project. Knowing about each team member's personal objectives can assist the PM in making mutually beneficial task assignments.

PMs usually have an inner circle of people, including the people holding the key positions described previously, who are most trusted and most often consulted. While this is natural and necessary, it is important to guard against isolating yourself to the point where you are only hearing what you want to hear. Also, be aware that team member office location can speak volumes in terms of perception.

It is best for all team members to be colocated in one work area and for all personnel to be dedicated to one project only. Where a full-time discipline is not required, the individual filling the position should be flexible and capable of other duties that comprise a full-time position. If possible, colocate even the part-time team members. This way, their help is more likely to be available when needed. Project team members generally enjoy challenges and don't mind taking on various or new roles or tasks.

Key attributes for a PM are:

- Ability to work with people
- Leadership ability
- Ability and desire to listen and understand (and be perceived as one who will listen)
- Ability to motivate the team
- Tenacity in the pursuit of project success
- Previous hands-on management experience with a smaller project or subproject
- Demonstrated integrity and trust. If either is lost, so is the ability to lead.

Other rules of thumb for team management are to:

- Drive as much accountability and responsibility (and provide associated resources) as low in the organization as possible. This trains and motivates team members to take responsibility and solve problems when they can, freeing management to handle issues that can't be solved by the rest of the team. This is important for several reasons. The PM's time is limited, and any decisions that can be appropriately delegated should be. Also, those most familiar with

the problem usually have the greatest expertise and knowledge creating the best solution, and they will feel more ownership if given commensurate responsibility and accountability for their part of the project.

- Establish a clear set of norms and guidelines for how the team works and operates.
- Make sure everybody has a stake in the project. Everyone has to feel ownership, responsibility, and accountability. The PM needs to find a way to establish this. When successful, the result is that team members and stakeholders rise to the next level in commitment and productivity.
- Make sure team members get visibility with the highest level of management possible.
- Foster peer-to-peer verbal communication (versus relying too heavily on e-mail, which is often seen as lobbing actions over the fence). Colocation helps.
- Mentor project team members.

It is important to recognize when somebody does a good job. This should be done right away. Don't wait for a special awards day. Reinforcement helps team building—whether it is a pat on the back, a note, handing them a check, or just saying thank you. Personal expressions of appreciation can be more important than more formal and tangible rewards. It is very important to show that kind of positive reinforcement because the team and individuals will build on that positive approach. People need (and value) recognition.

Likewise, poor performance cannot be ignored. A story from the early days of NASA is an interesting case in point:

We have a guy in the factory, and he says, "I know I messed up." He confesses that he made a mistake, recognizing he may be fired. You would like to make a case that this is not acceptable, but do you fire him? That sends a very dangerous message to the other guys. Integrity is not valued. See what I'm saying? You don't want them to mess up, but you also want them to come forward. You want [them] to be honest. I learned this from von Braun. We had this guy who didn't hook up some wires like he should have, and he confessed to that. I remember how von Braun bought him a bottle of booze. He did that to reward him for being honest—and he helped him to drink it too! Think about it, do you really want to punish the person for doing the right thing by coming forward? Why dampen his spirit? That makes him less motivated to succeed. We are talking about integrity and honesty.

– Alex McCool, *ASK Magazine*

The above example of accepting mistakes and recognizing honesty is very important. On the other hand, if someone is slacking and everyone knows it, and management fails to act, it can have a very negative effect on morale.

Over the years, NASA has had many quality teams on programs and projects. However, there is always the need for improvement and for training in the program/project manager area. Many good training opportunities are available through the NASA Academy of Program/Project and Engineering Leadership (APPEL) program.

Running meetings well is a key skill for the PM and the rest of the team leadership. Some good meeting management points to keep in mind include:

- Start and end meetings on time. Not ending on time is what gives meetings a bad reputation

- Have a specific purpose and agenda and tailor the attendance accordingly
- If one topic starts to derail the meeting, set up a special meeting for it or discuss with the relevant parties offline
- Be clear when decisions are made and make sure that they are communicated to the rest of the team
- Be clear when issuing actions. Actions should be formally written, tracked, and closed.

A working meeting has about six people attending. Meetings larger than this are for information transfer. ... A person's time is very important. You must be careful as a manager that you realize the value of other people's time (i.e., work you hand out and meetings should be necessary). You must, where possible, shield your staff from unnecessary work (i.e., some requests should be ignored or a refusal sent to the requester).

– Jerry Madden/GSFC, *100+ Lessons Learned for Project Managers*, NASA LLIS

### 5.1.B.b Partnerships

The early phases of the project are also the time potential partnerships are identified. These could be with other NASA Centers at which projects that contribute to the program are located. Other Centers with the expertise for particular instruments can be considered as the builders of that instrument for the mission. Other partnerships go beyond the Agency to include partnerships with other Government agencies (NOAA, DOE), and/or partnerships with other countries. All these partnerships need to be considered very early because of the long-lead issues involved. These include cost. The contribution of an element of the mission by a foreign partner could mean the difference between being able to afford the mission and not doing it at all. The long lead time is also needed to establish the appropriate agreements on how the mission work will be shared between the project teams and to promulgate the formal international agreements. Early planning needs to take place for export control (ITAR and EAR) issues. How will the designs and hardware be handled to comply with export control restrictions? The partnerships will not necessarily be promulgated in Pre-Phase A, but, because of long lead time and cost implications, need to be started then. See Handbook Section 4.1.B.e Program Interfaces with HQ and Other Organizations for more information about export control.

### 5.1.C Technical Planning and Execution

Flight project formulation is accomplished through establishing well-defined project phases and associated processes, products, and control gates. Specific technical activities need to be performed and judged successful by one or more reviews and approving authorities to proceed to the next life-cycle phase. The activities to be performed and the entrance/exit criteria for major technical reviews are documented in NPR 7123.1, *NASA Systems Engineering Processes and Requirements*, SP-2007-6105 Rev 1 *NASA Systems Engineering Handbook*, and NPR 7120.5, *NASA Space Flight Program and Project Management Requirements*.

Systems engineering (SE) is one of the most important technical efforts of a project and thus deserves particular emphasis. It encompasses the flight segment (spacecraft and instruments), ground segment, launch vehicle interface, and end-to-end data system. The systems engineer of a project is the technical owner of the system under development and provides a focal point for the SE effort throughout all project phases.

### 5.1.C.a Systems Engineering Processes

NPR 7123.1 states: “Systems engineering is a logical systems approach performed by multidisciplinary teams to engineer and integrate NASA’s systems to ensure NASA products meet customers’ needs.” This document should drive the project’s technical development. NPR 7123.1 defines 17 systems engineering processes (NPR 7123.1, Figure 3-1, SE Engine), which are divided into three groups used to guide the development process:

- System Design Processes (four processes)
- Product Realization Processes (five processes)
- Technical Management Processes (eight processes)

These common technical processes are referred to as the “SE engine” because they drive the development.

Compliance with requirements included in NPR 7123.1 is mandatory, so the PM and the systems engineer should become familiar with it. A good reference for day-to-day systems engineering is NASA/SP-2007-6105 Rev 1 *NASA Systems Engineering Handbook*.

Systems engineering processes are used repeatedly throughout the project life cycle. The major systems engineering efforts include but are not limited to:

- System definition studies
- Performance analysis studies of the system and requirements flow down
- System architecture
- Review and signoff responsibility for system and subsystem specifications
- System overview for Implementation Phase contracts
- Oversight of system design
- Project coordination of in-house technical support manpower
- System status reviews to the project manager and deputy project manager
- Advice to the project manager on risk assessment, design margins, adequacy of test plans, procedures, and test results
- Participation in all major project design and flight readiness reviews

During early definition stages of a project, the systems engineering effort is a main contributor to the formulation of a Work Breakdown Structure (WBS); the WBS is used to organize the composite technical disciplines necessary to carry out the project management tasks. In addition, the team generates preliminary milestone schedules that indicate the major system performance specification completion dates and management reviews for Formulation activities.

The Formulation Phase trade studies involve formulating design requirements and the implementation approaches best suited to meet the imposed mission requirements. See NPR 7123.1 and NASA/SP-2007-6105 for more information about implementing trade studies.

To develop and maintain system requirements, first get a good Systems Manager or Chief Systems Engineer for the project. This person then builds a team of systems engineers from the organization, developing the project from both Government and industry. This group develops and manages the technical aspects of the project, making appropriate recommendations to the project manager.

– GOES Project Manager, GSFC

Given that a major product of Systems Engineering is a definitive set of performance requirements, then the most important product of Systems Integration is the planned demonstration that each performance requirement has been met.

– Solid Rocket Booster Project Manager, MSFC

### 5.1.C.b Developing a Systems Engineering Management Plan

The Systems Engineering Management Plan (SEMP) is the technical planning document for systems engineering within the project. It describes the technical approach to be used in the system development and serves as the primary plan for implementation of systems engineering and integration. It serves as a bridge between the Project Plan and other planning documents. Development of a project SEMF is mandatory and needs to comply with NPR 7123.1, *NASA Systems Engineering Processes and Requirements*. NPR 7123.1, Appendix D contains an outline and description of the required contents. NASA/SP2007-6105, *NASA Systems Engineering Handbook* provides additional guidance and examples of project SEMFs.

The SEMF focuses on the project team and should clearly define roles, responsibilities, and authorities of key organizations, teams, and groups. It should also define long-duration (standing) boards, panels, and working groups. It should define the integration between the project office, engineering, safety and mission assurance, contractors, and other key participants. It should detail which areas are staffed by the managing Center, partner Centers, other Agencies, and contractors. The SEMF should detail project roles, interfaces, the system being developed, key challenges and risks, key milestones and associated requirements, and how the system will be integrated, verified, and turned over to the customer or the next higher level in the system hierarchy.

The SEMF should be developed early and updated at least once during each life-cycle phase. A good rule of thumb is to update the document after each milestone review. It is important to understand that SEMF development and maintenance doesn't end at PDR. Instead, the SEMF focuses more detail on upcoming phases of the life cycle, with each version providing more clarity and detail.

### 5.1.C.c Supporting Program Requirements Development

The project manager supports, as requested, the mission directorate and program manager with generating program requirements and formal requirements documentation. The project manager needs to help the program establish a clear set of mission/operation concepts first, and then derive top-level requirements that complement those mission concepts.

It is important to understand, define, and document top-level requirements that drive the execution and management of technical solutions. Understanding and defining these driving requirements is important during the early design and planning processes when negotiating scope, performing architectural trade studies, allocating resources, and identifying risk mitigation measures. One of the greatest risks that a project faces comes from ill-defined requirements. Deviations are usually associated with unrealistic requirements. It is better to change the original requirement than to submit waivers and deviations to those requirements later in the life cycle.

Taking the time early to properly plan the project is paramount to the success of the project. Poor planning equals poor results. One example occurred when Constellation program formation

lagged behind the start of the Orion and Ares projects by almost a year. Because Orion was going through the prime contractor selection process almost simultaneously with Constellation program planning, a major contract modification was needed to address the additional layer of requirements provided by the program. Since program requirements are at such a high level, the trade space can be fairly significant at the project level.

The project needs to insist on well-written requirements from the program. A good requirement defines a functional or performance characteristic that can be verified. Good requirements do not dictate a design solution. The project team has to resist the temptation to provide a more robust design solution than is required to satisfy mission objectives. Some design margin is warranted, but addition of significant capability beyond the requirements should be traded against cost, schedule, and mission value, and needs to be approved by project stakeholders before being added to the mission baseline. The project also has a responsibility to push back on program requirements that are unrealistic or unreasonable within the project schedule and/or budget.

### 5.1.C.d Developing Project Objectives, Concepts, and Requirements

The most common negative finding made by independent review teams is that a project did not place sufficient effort and importance on understanding and developing project requirements.

A project usually begins with a problem that needs to be solved and a proposed solution. As the objective is expanded and alternate solutions are evaluated, preliminary requirements for a design solution emerge, become better understood, and are refined until a requirements baseline is established. The baseline is then validated by a Mission Concept Review or System Requirements Review.

When the Administrator named me as the project manager, he gave me several key guidelines for the project. Working with the Center Director at my Center and other members of his management team, we roughed out a project concept (including organizational structure). These ideas were taken back to the Administrator, who made minor corrections and gave verbal agreement to proceed with project planning. Soon afterwards, the Center Director called a meeting with all of his direct reports and other key managers. He asked for a commitment that each person felt the project could be successfully executed and that they would support it. The consensus was that the job would be difficult, but the value was worth the effort and commitment required. Almost everyone was uncomfortable, which I thought was a good indication that they felt ownership and responsibility for the outcome.

– Ares Project Manager, MSFC

Brainstorm with partners and science investigators to identify a number of mission concepts and possibilities. Put everything on the table at first and then perform trade studies to pare down the list to form the final concept. Sometimes parallel developments and studies are necessary for risk mitigation (e.g., challenging technical concepts). Don't allow the project to become prematurely blinded by or enamored with the initial concept, because changes may be necessary as the project progresses. Many missions look very different as they progress from Phase A to Phase B. Be aware that changes are allowed and don't hesitate to make the necessary changes as more is learned about the mission requirements. Changes to the external environment (e.g., budget reductions) can also drive changes to the baseline (e.g., cost and schedule).

Another way to develop mission concepts is to bring the ideas of various contractors on board. One Advanced Development Project (ADP) first identified a number of concepts themselves and in partnership with a branch at the Center. After they started this, they got contractors on board to help develop these concepts. Once they were on board, they held technical interface meetings in which they put everything on the table and started formal trade studies. This is the start of the process. The more formal trade studies come in Phase A after the requirements are better defined. The contracts were Indefinite Delivery, Indefinite Quantity (IDIQ) contracts and were started early in the project, well before the prime contractor was chosen. This turned out well for the project as development proceeded.

– Project Manager, LaRC

Operational concepts (ConOps) help project planners bridge the gap between product scope and formal requirements. They are written in simple, conversational language and detail how a product will be designed, manufactured, and verified; integrated into a launch vehicle; and used during the flight mission, including all functions the item will perform. This story may be initially developed in a room with a white board, allowing planners to draw simple diagrams of the concepts they envision. It is easy to get all project team members and stakeholders involved in such discussions (and this format leads to more discussion and less debate) and in reviewing draft operational concepts. The operational concept development process allows for easy identification of product interfaces and visualization of off-nominal scenarios, which will lead to the generation of a more complete set of formal system requirements. The mission operations concept is a very important part of the mission concept. The mission operations concept documents how spacecraft and ground system are going to operate together to perform the mission.

The operations concept technically should precede the systems-level requirements document, because until you understand how it's going to operate, it's really hard to identify the requirements you need to levy on the build of the system.

– Science Directorate Chief Engineer

Once the mission concepts have been developed, the next step is to create the baseline requirements necessary to achieve that mission. When developing requirements, the PM should proactively challenge the requirements and assess what the drivers for those requirements are. They should be assessed against alternative design configurations. Requirements also need to be verifiable, so care needs to be taken to understand how requirements will be verified. As a baseline, one should strive to achieve verification via testing. Verification by analysis, inspection, or demonstration, however, are valid methods when appropriate. A detailed discussion of these topics is available in NASA/SP-2007-6105 Rev 1 *NASA Systems Engineering Handbook*.

In reference to the orbiting maneuvering vehicle: The program/project manager at the time essentially gave up all technical credibility and caved in to every desire that Headquarters had at the time—without thinking about what requirements needed to change. So, they changed all requirements at the whim of whatever Headquarters directed, such that if the project really had been built, it would have had very little utility.

– NASA Associate Administrator

The requirements should be written to satisfy the baseline mission (i.e., the mission solution designed to meet, within the allocated schedule and budget, all the project objectives). A subset of these requirements is the minimum mission requirements. These are such that if they are not met, the minimal project objectives cannot be met and therefore the mission is not worth developing. Such requirements represent the lowest acceptable level for a performance requirement. Requirements that can be stated in values of a range of minimally acceptable to project goals may be identified as Key Performance Parameters (KPPs) with a status provided at each major design review. The desired design solution should meet all objectives; however, if some are the cause of cost or schedule growth, or if budget or schedule cuts result in scope reductions, having predefined minimal acceptable requirements will allow the project manager to make rapid and higher quality responses to such reductions. Descope decisions are always made at a higher level than the project manager. The PM can only recommend descopes. See Handbook Section 5.1.C.h Descopes.

Projects need to devote the appropriate resources at the beginning to establish a sound and reliable cost and schedule baseline. PMs need to resist temptation to provide cost and schedule estimates that are overly optimistic just for the purpose of winning the project or with the expectation of being granted additional cost and schedule after the project is approved. Adequate reserves and technical margins are critical. PMs should seek advice from trusted individuals to gain assurance of the adequacy of project reserves. There also needs to be a good baseline change process in place at the start of a project. Changes will occur—therefore planning for change and having an established change process in place early in the project life cycle is essential.

The key to minimizing cost growth and operational constraints is large design and operational margins. (Budget constraints prevent this on many projects.) With minimum margins, every change becomes a performance issue, at the expense of cost, safety, and reliability. With adequate margins, changes can be made cost effectively. Even though incorporation of adequate margins results in a greater initial program budget, fidelity is higher and total program cost growth will be less. Trade studies of each requirement are required to determine the cost, performance, safety, reliability, and operational sensitivities as an aid when establishing margins, and as a basis for future changes. PMs are challenged to justify the initial cost and schedule required for design margins as required risk mitigation against future technical performance requirements.

Project cost, schedule, and technical quality are sometimes referred to as triple constraints. To improve any one of the three, the other two suffer (i.e., to reduce cost, scope or quality has to be reduced; to reduce schedule, cost needs to be increased if quality is held constant; to increase scope or quality, it is likely that both cost and schedule will increase). When asked to prioritize between the three, some PMs will say that all are top priority, but in reality, decisions are made

considering one as a higher priority than the others. When reconciling technical quality/scope versus cost and schedule in the development of the integrated baseline, some PMs might say that whenever there is a choice, technical quality should be preserved over cost and schedule (“In the future, they may not remember if the project overran, but they will certainly remember if it didn’t work!”). However, on many flight projects, the launch date is fixed and schedule drives everything. Other projects are cost capped, and objectives may have to be reduced to stay within the cost constraint. Risk is sometimes referred to as the fourth constraint and also needs to be considered in relationship to the other three constraints.

Try to get as much funding as possible. Analyze requirements and what will be required to meet them. Take time to identify risk and sound mitigation plans. Develop a sound basis for funding requests. No matter how much funding you receive, it will never be enough to cover all the “unknown unknowns.”

– Chandra Program Manager, MSFC

By KDP B, the technical baseline should evolve from a detailed analysis of functional and performance requirements to a set of system requirements that are defined and form the basis for the proposed design concept. The system requirements should include mission success criteria and any sponsor-imposed constraints. Most teams do not spend enough time and effort on this activity. Teams should devote significant effort to developing interface requirements and long-range requirements (operational requirements; flight and ground support equipment; and requirements for enabling products including test support, training products, production products, and deployment and disposal products). A comprehensive set of requirements that takes the entire project life cycle into consideration will eliminate many future design changes and cost and schedule overruns.

The team should thoroughly define design and production requirements before the project’s Preliminary Design Review (PDR). If the acquisition strategy calls for competing contractors to submit preliminary designs or design concepts for evaluation, with only the best design being awarded a contract, an extended PDR should be considered to thoroughly define requirements before committing to design margins, facilities, and tooling. In either case, PDR products should include comprehensive system and element requirements documentation, interface documentation, and technology validation.

By PDR and Key Decision Point (KDP) C, or after KDP C when all PDR issues have been resolved, all major risks and interfaces should have been identified and all system and driving subsystem requirements documented and placed under configuration management. The exact timing for this varies by Center. This makes up the technical baseline and contains the total scope of all products to be developed, including all interfaces and enabling products that comprise the total system as defined by the project. Everything in the PDR technical baseline should be captured in the project’s Work Breakdown Structure (WBS). The integrated baseline represents all components represented by the PDR technical baseline, as well as the work required to manage, integrate, test, and operate those products (i.e., the total project system). Note that in some programs, the operations phase may be identified as a separate project. The integrated baseline is the basis for the Integrated Master Schedule, the project budget, and Life-cycle Cost (LCC) estimate.

### 5.1.C.e Identifying Early Project Risk Drivers and Establishing a Risk Management Process

To identify project risks and to evaluate the risk likelihood and consequence (subjective determination, usually on a scale of 1 to 5) and the timeframe by which the mitigation needs to be achieved, the entire technical and programmatic team should engage in regular (monthly or more frequently) risk analysis sessions (see NPR 8000.4, *Agency Risk Management Procedural Requirements*). In dedicated risk meetings, the project team will prioritize project risks and the PM assigns team members to risk mitigation analysis and recommendation. The PM, with support from the project team, determines which risks will be mitigated (committing project resources for that purpose) and those that will be watched or accepted. This is an ongoing process and is an effective tool for successful project management. Typically, project reserves are committed later in the project life cycle; however, risk mitigation efforts will likely result in earlier use of project reserves, with the goal of resolving potential problems early and reducing total project costs. The PM should identify risks and quantify the estimated cost of the risk and the likelihood of the risk occurring. Through integrated risk analysis, a budget contingency should be developed for risks. This contingency is part of the cost baseline and is separate from the management reserves for unknowns. Risks known at the beginning of the project should have mitigations in the baseline budget.

Effective risk management is almost an art, and all those engaged in the process need to continually look for opportunities to improve. Risk mitigation is optimal when it minimizes impact to the project schedule, budget, and technical success. Committing project funds and actively tracking risks and mitigation efforts is an essential part of effective risk management. Too many times formal risk mitigation ends with general discussion about a risk chart, but does not result in an assigned action or follow up.

At the start of the project, I had the choice of spreading the limited amount of money I had among all of the players or looking at and mitigating the greatest risks on the project. I responded by putting the bulk of the money into trying to identify the key risks in the development of the instruments and mitigating these to the best extent we could. I wanted to enter the development phase with the least amount of technical, schedule, and cost risk as possible.

– Donald Margolies, *Ask Magazine*

See Handbook Section 5.2 Project Implementation for additional information about Risk Management.

### 5.1.C.f Technology Development

Assessment of new technology that might be used on the project is started in this early phase. The introduction of new technology very much depends on the program or project involved, and/or the stage that the program or project is in.

The project manager of a very successful NASA high-technology project believes that an important aspect of NASA project management is "...to keep one foot in the future for the good of the Agency." He feels that pushing the envelope is the responsibility of NASA program and project management.

Of course, this has to be balanced to meet the commitments of the Agency. Often for breakthrough science, new technology will need to be developed just to make the mission possible. In other operational programs, introduction of new technology is resisted until it has been proven on other programs. At this early stage, the team should assess the risk of introducing new technology or consider an Advanced Development Project or precursor mission to bring the technology to the appropriate Technical Readiness Level (TRL) for the mission. (For a definition of each TRL, see *NPR 7120.8, NASA Research and Technology Program and Project Management Requirements*, Appendix J.) It is good practice to achieve TRL 6 by PDR (see Phase B). Some projects, depending on the development schedule, may require demonstration of TRL 6 well before PDR. The project needs to have a backup plan in place in case the new technology development is not successful.

When a project is considering new technology infusion, the team should focus only on technology with a high potential for significant payoff and provide experienced leadership for the focused technology development. It is often assumed that new technology will result in lower costs and/or higher reliability. Although this is the desired outcome, many times proven, well-characterized existing technology may be a better choice than yet-to-be-applied technology.

**Q:** Would you still recommend in-house work on groundbreaking technology?

**A:** I would, but not unconditionally. In-house teams face hazards as well. University labs can do certain things better than we can. It's harder for us to bring in the radical thinking of graduate students. Thinking about small prototype equipment is a good thing to do at a university lab. We did that with COBE, in fact. They built a prototype for the FIRAS instrument at MIT and told me that I had designed it wrong, the focusing wasn't working. That was correct, and we fixed it as quickly and as easily in our labs here. When you're hunting over a wide range of territory with lots of ideas to try out, it's hard for an engineering team to shift into that mode."

– Dr. John Mather, *Ask Magazine*

The cost and schedule for advancing through the technology readiness levels is also uncertain. The PM should recognize this and have additional budget and schedule margin available in these areas. It is also in the PM's best interest to promote alternative funding sources for the technology needed by the project.

For projects with a high degree of technology development, the PM needs to balance the uncertainties of technology development and the need to meet schedule milestones. Many researchers interested in a technology may not be used to the rigorous milestones of a project schedule. The PM should create an environment on the project that recognizes the value of both technology advancement and meeting the project schedule.

### 5.1.C.g Safety Review Package

The PM is responsible for developing the required safety package for the hardware being delivered. The content of the package, as well as the review and approval process, is different depending on what requirements and instructions the customer invokes. All programs and projects need to focus on ground safety aspects, such as hazardous material handling (e.g., fuel, oxidizers, lubricants, batteries), pyrotechnics, Electromagnetic Interference (EMI) limits,

radiation, grounding, and launch abort/range safety that represent a hazard to the hardware handlers as they process the hardware for flight and early launch phase.

While programs providing hardware/software for human flight missions also need to address these same ground safety issues, they also need to document the in-flight safety risks to the crew. These mission risk assessments can and do frequently drive the design process to minimize either the likelihood or severity of risk to the crew. Frequently, increased safety is traded off for decreased hardware or system performance as part of the design/safety review process. Something as fundamental as the use of hydrazine for attitude control or ammonia for cooling can have a profound effect on the level of safety controls required for human flight vehicles, especially during Extra Vehicular Activities (EVAs). That is why it is so important to include the Safety and Mission Assurance (SMA) representative (sometimes referred to as the project Chief Safety Officer) at the very earliest stages of project formulation. During preliminary design (formulation), all hazards are identified. A detailed discussion of the hazard identification process and a listing of the specific hazards identified within the project preliminary design are the major components of a formulation safety review package. As part of the Implementation Phase, controls for these hazards are identified, designed, and verified. See more on safety and mission assurance in Handbook Section 5.2.B.b Product Integration and Verification.

### 5.1.C.h Descopes

It is important to identify meaningful descopes early in the project life cycle, to document them, and to obtain buy in from the program and for science projects, the Principal Investigator. Documentation of the project's descope plans should include a detailed description of the potential descope, the effect of the descope on the project's success criteria, the cost and schedule savings resulting from the descope, and key decision dates by when the descope needs to be exercised to realize the cost and/or schedule savings.

One PM stated that they negotiated descopes early and included them in the Project Plan. They discussed the descope list at SRB reviews. The PM believes this was fundamental in building adequate scope margin into the project plan. For additional information refer to the descope discussion contained in Section 5.1.C.d Developing Project Objectives, Concepts, and Requirements.

Descopes should be taken as early as possible in the project (i.e., during Formulation, if possible) for the descope to have the highest possible value. See handbook Section 4.1.C.b Developing Descope Options for additional information.

The project should maintain a descope list and keep records on descopes taken and continue to solicit descopes to add to this list. Exercising descopes early on was key to the project staying within the latest rebaseline plan.

– JWST Project Manager, GSFC

It is important for the PM to monitor the political environment to know if there are other reasons one or more potential descopes should or should not be exercised. One PM was aware that there was increasing Congressional sentiment to reduce the Mars requirements from his program, with lunar capability as the final program objective. When asked to submit a descope strategy to support an impending budget cut, the PM and his team evaluated the cost savings of eliminating

all Mars requirements from the project. This strategy was well received and implemented in other parts of the program.

### 5.1.C.i Orbital Debris

It is United States and NASA policy to limit orbital debris generation, consistent with mission requirements and cost effectiveness. To limit future debris, NASA requires each program and project to conduct a formal assessment of the potential to generate orbital debris during deployment, mission operations, and after the mission has been terminated. Limiting orbital debris includes limiting the generation of debris while on orbit, depleting onboard energy sources after completion of the mission, limiting orbital lifetime after mission completion (or maneuvering to a disposal orbit), and limiting the human casualty risk from space system components surviving reentry as a result of post-mission disposal.

Two key documents are required: an Orbital Debris Assessment Report and an End of Mission Plan. NPR 8715.6, *NASA Procedural Requirements for Limiting Orbital Debris* and *NASA-STD 8719.14 Process for Limiting Orbital Debris* provide the required content, format, and timing for these documents. They also provide specific requirements and assessment methods to ensure compliance. Further supporting information can be found in NASA-HDBK 8719.14, *Handbook for Limiting Orbital Debris*.

PMs are encouraged to contact the NASA Orbital Debris Program Office at Johnson Space Center (JSC). JSC is the lead Center for orbital debris research. JSC maintains software assessment tools for predicting the reentry survivability of satellite and launch vehicle upper stage components. These predictions are required to determine the risk to humans on the ground. This risk, based on the predicted total debris casualty area, orbit inclination, and year of reentry, should be less than 1 in 10,000 per reentry. Exceeding this limit could trigger a requirement for a controlled reentry, which could significantly increase overall mission cost and complexity.

### 5.1.D Project Planning and Control

A typical project office comprises technical and project planning/control components. These two disciplines are equally critical to the success of the project, and although they perform very different functions, they need to work closely together. Early formulation activities include defining project architecture and a preliminary Work Breakdown Structure (WBS). The WBS is developed jointly by these groups and forms the basis for make/buy decisions (which drive project contract activity), structured cost collection and monitoring, and risk analysis and management. As the WBS matures, Project Planning and Control (PP&C) personnel (working with their technical counterparts) expand the WBS into work activities that can be linked into a project schedule and resource loaded to form a Performance Measurement Baseline (PMB).

#### 5.1.D.a Acquisition Strategy

Acquisition planning should begin as soon as the need for a service or product is identified. The acquisition plan needs to address all technical, business, management, and other significant considerations necessary to support the acquisition. For major acquisitions subject to the Master Buy Plan (MBP) and that require NASA Headquarters approval, a Procurement Strategy Meeting (PSM) is used instead of a written plan. A *Guide for Successful Headquarters*

*Procurement Strategy Meetings* is available at <http://prod.nais.nasa.gov/portals/pl/documents/PSMs.html> . An Acquisition or Procurement Strategy Meeting is a prerequisite for Key Decision Point B, which when passed, formally authorizes the project to move to the next phase.

Planning required to support a project acquisition strategy should include:

- Which parts of the system will be made in-house or obtained from other Centers, Government organizations, or contractors (Make/Buy decisions).
- Chains of responsibility in the management structure, given the limits of the candidate organizations. What organizational and contract structure will result in the strongest project team (i.e., how the project will interface with in-house “suppliers”)? What type of contract should be used (Fixed Price, Cost Plus, Indefinite Delivery/Indefinite Quantity, or Time and Materials) that appropriately balances risk between NASA and the contractors.
- A draft WBS to ensure that all project elements and their interrelationships have been considered, including enabling products, such as crew trainers and transportation equipment.
- The depth of insight or oversight NASA should expect to apply. With what dilution of contractor responsibility?
- How firm the project’s concepts and requirements are. Is contractor support required to perform alternatives analysis (including technical, schedule, cost, and risk) to better refine program requirements as an initial step in the acquisition strategy process? If so, multiple contractors may be utilized to conduct these trades, and fixed price or Indefinite Delivery, Indefinite Quantity (IDIQ) contract vehicles may be the most beneficial.
- The likely project reserve strategy (e.g., all held at the project level, some distribution to subprojects).
- The most important elements that would drive incentives and contract structures.

See Handbook Section 4.1.B.a Program Acquisition Strategy for additional information.

The Project Planning and Control organization works with the project technical organization and with procurement personnel to determine the optimum amount and frequency of contractor data to be supplied to the Government. Data requirements are documented in contracts in the form of Data Requirement Lists (DRLs) and Data Requirements Documents (DRDs). This data is expensive for the contractor to produce, and therefore it is critical that it not be excessive, yet sufficient to monitor technical, cost, and schedule performance.

#### **5.1.D.b Integrated Baseline**

The integrated baseline refers to the technical performance and content, technology application, schedule milestones, and budget, which are documented in the approved Program or Project Plan. Developing an integrated baseline and a solid plan is key to the success of any project. It is important to expend the required Formulation planning effort to develop a Project Plan that is as comprehensive as possible.

The PM works with the core project team and discipline experts to determine the necessary functions for the Work Breakdown Structure (WBS) and then costs out the WBS. The WBS structure and cost should be reviewed by an independent group and reconciled with the project results. Early cost and schedule numbers are subject to change as the project proceeds, but the project cost and schedule should be baselined by the Preliminary Design Review.

One of the biggest problems in Formulation is cost and schedule. The project is so busy working the technical side they don't have time to do the proper planning for cost and schedule. Once the project has the technical scope defined, they should develop the schedule before developing the cost (based on the resources required to implement the schedule). Once the technical is defined, then the schedule, then cost, the project now has an integrated baseline.

– Senior Analyst, Independent Program Assessment Office

The PM works with the discipline experts and schedulers to develop the Integrated Master Schedule (IMS) and to maintain adequate margins and/or contingency. Schedule margins need to be risk based. Margins depend on a number of variables, from technical issues to the number of partners on the team. Many Centers have design guideline documents that dictate the margins for various phases of the project.

Early stage Formulation planning means starting on a draft integrated cost, schedule, and technical baseline. This baseline will mature until, by the end of Phase B, the cost and schedule integrated baseline has captured all elements of the technical baseline, including reserves consistent with the project risk. It is important to take a systems approach to the overall process. Each planning activity has the potential to be a check on other activities. Even in this early phase of the project, the scheduling activity needs to relate to costing and technical activities. Risk identification is also a key part of each of these areas. Mitigation of identified risks, along with reserves, is included in the project baseline to cover risks not yet identified. The integrated baseline includes the Life-Cycle Cost (LCC), assessment of technology needs, infrastructure requirements, WBS, and a resource-loaded IMS for in-house and prime contractor deliverables. Using the NASA standard WBS (see NPR 7120.5, Appendix G) provides a structure that assists with consistency and provides a systematic approach to these activities.

Unfortunately, on some projects both the cost and schedule are created and locked down before the technical scope is understood. This is backward and can lead to buy in. Buy in, in this context, is an overly optimistic estimate of cost and schedule used to try to ensure project initiation and funding. This type of buy in could ultimately lead to either cancellation, because of insufficient resources, or the need for NASA to add resources to complete the project. The latter case will drain program resources and preclude or delay follow-on missions. This premature lockdown of cost and schedule prior to understanding the technical scope can also be imposed top-down by the program on the project. Neither is helpful.

The WBS, Integrated Master Schedule, and associated budget (including estimates and reserves) all need to be integrated to allow the team to perform integrated performance management for effective project management.

#### **5.1.D.c Work Breakdown Structure and Dictionary**

Integrated performance management begins with a product-oriented Work Breakdown Structure (WBS) that accurately reflects all project work to be accomplished including level of effort activities such as management, systems engineering, and integration. The WBS provides the framework for organizing all technical, schedule, and budget planning. NASA's requirement for technical and financial WBS structures to be consistent will also enhance a project team's ability to successfully correlate cost, schedule, and technical plans into an integrated baseline.

In addition to the WBS, NPR 7120.5 also requires development of a companion document, the WBS Dictionary. This document contains, at a minimum, each element's title, element identification number, content description, date and revision identifier, and an indicator to reflect whether or not the element is an active charge code that can receive actual costs. A critical purpose for this companion document is to provide clarity about exactly what work content is included in each WBS element. Making sure content is clear prevents confusion during planning and execution and also mitigates the risk of work not getting completed.

### WBS Preparation Checklist:

- A strong WBS is a product-oriented, hierarchical division of hardware, software, services, and/or data required to produce the project's end products.
- Make the WBS logical, sensible, and easy to understand—it should be clear from each element description what work is to be done (via element name and through WBS dictionary descriptions). Define all interfaces. Align subdivision of work with the system architecture (e.g., system, subsystem).
- WBS elements must correlate with the following items. They need to correlate because the WBS is the link between all these elements. These need to refer back to the WBS for consistency to be maintained.
  - Project specification tree
  - NASA system engineering requirements
  - Functional design criteria
  - Technical scope of work
  - Manufacturing, engineering, and construction engineering requirements
  - Configuration management requirements
  - NASA internal reporting level requirements
  - Integrated Master Schedule
  - Project risks
- Ensure element nomenclature is logical and consistent with NASA Structure Management (NSM) system implemented by the Integrated Enterprise Management Program (IEMP). This will ensure project work is charged to the proper elements in the accounting system.
- Include all required work including level of effort activities such as management, systems engineering, and integration.
- Clearly identify all end products or deliverables
- Summarize work at each level
- Ensure modifications or changes involving new product elements have been appropriately integrated

As WBS elements are identified, each element, including element interfaces, must be fully described so that there is no confusion about what the element contains and does not contain. This communication and understanding is vital to resolving future questions concerning responsibility and scope. Because of this, it is imperative that all project stakeholders play a role in defining and agreeing to the top-level WBS before detailed planning begins. For more information, refer to the *NASA WBS Handbook*, available at: <http://evm.nasa.gov/handbooks.html>.

### 5.1.D.d Integrated Master Schedule

Accurate time-phasing of planned work is accomplished through an Integrated Master Schedule (IMS). The IMS provides the program/project manager a single integrated source of schedule data that accurately reflects how the planned work is to be implemented. At the core of the IMS is a logic network dataset that must be maintained in an automated schedule management tool and consist of tasks/milestones, task durations, interdependencies, project constraints, subcontract data, and an assigned data coding structure for in-house and/or contracted efforts.

Task time-phasing provided by the IMS is critical to successful implementation of performance management, including development of a project Performance Measurement Baseline (PMB). Identifying and incorporating the necessary resources required to accomplish the planned work within the IMS will help to ensure accurate time-phasing and schedule validity. Applying the appropriate unit and labor rates to each resource in the IMS provides a cost performance measurement baseline against which actual project performance is measured. For a prime contractor, all you get is a total dollar amount for a block of work, not the detailed labor rates. This can still be integrated into the IMS.

Project scheduling is an important function because it drives future work through the integrated baseline. There is often not enough analysis of schedule variability early in the Formulation phase. It is even more anecdotal than costing, for which there are viable models. For these reasons, it needs to be taken seriously. Schedulers need to have a technical background or at least understand the technical principles just as the project manager needs to understand the basic science behind the project. Ideally, the project schedule team is composed of civil servants fully integrated into the project team and working in the same location. Many projects will have prime contractors with their own scheduling functions. The schedules between the project and the prime contractor need to be appropriately linked. This process should be led by the NASA project. It is important to build trust within the elements of the project and to build open communication and accurate schedule activity reporting.

The Lunar Reconnaissance Orbiter (LRO) Project Manager, who was part of the team from the earliest concept of LRO, worked very hard to develop trust with all the subsystem leads on the project. An experienced scheduler was provided to the leads to help them establish a credible schedule that would also roll up to the integrated project schedule. At first, the leads were hesitant to accept the help, but the PM established trust by sticking to the working agreements established up front. Despite the initial hesitation, the element leads worked with the scheduler provided by the project and found the benefits to outweigh any of their initial concerns. Using one integrated schedule enabled communication to occur between the leads that may not have happened as early as it did had the leads maintained their own schedules. The PM established the trust with the leads to allow them to work their schedule challenges whenever possible without interference. The schedule issues were able to be worked at the lowest level and were escalated when necessary.

– LRO Project Manager, GSFC

The PM needs to ensure schedule requirements are included in the contract solicitation and that the solicitation explicitly defines the logic network schedule requirements. Requirements should include the establishment, management, and control of baseline master schedule and derivative

schedules. These provide the framework for time phasing and coordination of all project efforts into a master plan. The master plan enables the PM to measure accomplishments within program/project commitments and to achieve a truly integrated management control system. In addition, the Agency has created a *Schedule Management Handbook* (SMH), available at <http://evm.nasa.gov/handbooks.html>. The SMH provides recommended methods and best practices for project schedule development and maintenance.

In Phase A, the project continues to refine schedules with network logic based on technical input (subject matter experts and/or key team members) and historical data—identifying key milestones and durations. They refine resource-loaded schedules that address all WBS elements early in Phase B.

The IMS should be developed from the bottom up through several schedule workshops that include all parts of the project. Schedulers should work with each control account manager, then resolve any disconnects that occur during schedule integration. Through this process, the scheduler not only determines the time required to complete a task, but also the resources associated with that task. There should be a detailed schedule for everything and it needs to show the interfaces at the subsystem levels and below. Every subsystem does not need to mature at the same time. Put effort into high-risk areas first and defer low-risk areas, but don't ignore them.

On one project, I went to visit my contractor, and I met with their scheduler and project manager. We went into their war room, and there were schedules all over the wall. They were wonderful, as detailed as can be, and so I had to ask: "Who developed the schedule?" The scheduler said, "I did." And so I asked another question, "Did the people doing the work have input?" He said, "No." The next day I notified the contractor that I wanted the project manager and his scheduler removed from the project, and I told him to start building schedules that were representative of what work really needed to be done. As a project manager, there are certain things you can dictate: The end date, maybe certain review period dates; but in terms of what else has to be done, you've got to ask the people who are doing the job. Schedulers need to talk to the people who are doing the work. They need to find out what work has to be done and how long it's going to take. Even if you do it that way, your schedules can still be fallible, but at least you have something that everybody has bought into because they helped to develop it.

– ACE Project Manager, GSFC

As work is accomplished and progress is measured and reported within the IMS, actual costs for accomplishing that work are also captured from NASA's Core Financial System and used for comparison to planned cost. The prime contractor cost data comes via the monthly 533 report. There is always a time lag associated with this, although it should be minimized.

The 533 report provides project management with data necessary to assess contractor performance and for obtaining vital accounting information. The NASA policy for this reporting is in one paragraph of *NPD 9501.1, NASA Contractor Financial Management Reporting System*. The instructions and guidance for implementing that policy are found in *NPR 9501.2, NASA Contractor Financial Management Reporting*.

Resource loading serves two key project management purposes:

- It provides an accurate basis in the development of the performance measurement baseline.

- It also provides the PM with visibility into workforce projections regarding over- or underallocation of resources within the schedule. This information can alert the PM early if, due to a resource shortage, a task cannot be completed in the time scheduled.

The PM should review the project schedule carefully and frequently (possibly weekly at team meetings). Place equal diligence on approved risk mitigation efforts and any other drivers that may have a direct and major impact on schedule. Recovering lost schedule is very difficult, if not impossible. If the project is behind schedule at the end of the Formulation Phase, it is improbable that the project will recover and finish on schedule.

The whole Mars Exploration Program premise was to take the Mars Pathfinder entry-descent-landing system, make the minimum necessary modifications in that detailed design, and fly a rover that's designed to fit. That lasted about three months as a paradigm. It's June 2000 and the launch date is June 2003. Projects need four years: one to do preliminary design, another to do detailed design, another to do fabrication and assembly, and the fourth year to test and launch. Three years is not enough. Even before we started seeing these changes, we got a call from Dan Goldin's office saying, "Why aren't you doing two?" We said, "No one asked. We don't know that we can't, and it might help us." It turned out that it did. We couldn't have launched any had we only done one. When you're building an assembly line of aircraft, you typically build one and put it through its paces to qualify that system design. Would you do that same lengthy test program for the tenth aircraft you build? No. You put it through an acceptance test program to certify that it matches the first one. With two rover vehicles, we put one through the set of qualifications for its cruise and entry-descent-landing phases and the other one, in parallel, through the surface phase qualification, and split the acceptance testing. That knocked a couple of months off our schedule, which allowed us to launch on time.

– Rob Manning, *ASK Magazine*

### 5.1.D.e Earned Value Management

Earned Value Management (EVM) is a management technique that relates resource planning to schedules and to the technical cost and schedule requirements. All work is planned, budgeted, and scheduled in time-phased planned value increments constituting a cost and schedule measurement baseline. Simply put, EVM is sound project management. It adds the third dimension to planned versus actual performance measurement by also determining what work has been accomplished or earned for the money spent and the timeframe allotted. It is a widely used industry best practice and is required on most large Government contracts. (The first EVM reports are usually required 30 to 60 days after contract award.) (See *NFS 1834, NASA FAR Supplement*.) NASA has moved to broaden its application of performance management to encompass not only larger contracted efforts, but also significant project efforts implemented by in-house civil service and associated support contractor personnel.

EVM is an awesome tool because it gives you a mechanism to talk about how you are doing schedule-wise, and how you are doing cost-wise, in an intelligent, structured manner. It is a mechanism that can allow intelligent discussions between you and others in the field.

– NASA Associate Administrator

EVM has limitations, like any other tool. Once the project settles down, then EVM is very useful. Project scope changes over time are expected and are documented using a formal change management process.

There are three major objectives of an earned value system:

- To encourage projects to use effective internal cost and schedule management control systems
- To impose discipline, accountability, and monitoring of in-house products, using best practices of cost and schedule management
- To enable the Government and its contractors to rely on timely data produced by those systems for determining product-oriented contract status

NASA policy requires the use of Earned Value Management Systems (EVMS) on major projects and large contracts. (See NPR 7120.5 for specific thresholds.) Recognized as an industry best practice, EVM is one of the project's most effective tools to measure and forecast project performance. By integrating the cost, schedule, and technical plans into a single Performance Measurement Baseline (PMB), EVM guidelines ensure orderly planning and controlling of all project activities based on a mutual work breakdown structure.

Several resources are available to help project managers understand, interpret, and implement EVMS and the resulting data. Each Center and mission directorate has a member appointed to the NASA Earned Value Working Group (EVMWG) who is available to help project teams when EVM issues arise during the Formulation and Implementation phases of projects and contracts. In addition, the NASA EVM website at <http://evm.nasa.gov/> provides EVM Work Breakdown Structure, Schedule Management, and Integrated Baseline Review handbooks and other resources to support implementation of EVM.

Successful implementation of the PMB is substantiated through an Integrated Baseline Review (IBR). The IBR ensures that all stakeholders have confidence in the cost, schedule, and technical baseline and that major project risks have been identified. In-house projects hold IBRs consistent with the NASA and Center EVM systems. Federal Acquisition Regulations (FAR) requires an IBR on contracts within 180 days of award. Many programs and projects require an IBR within 90 days of contract award, but this is not enough time for contractors to have adequately planned their work into a realistic baseline and a good WBS. Unless the project is forced by program or mission directorate policy, sufficient time (up to 180 days) should be allowed for one or more contractor financial reports—Contract Performance Report (CPR) and the 533M—to be analyzed by the Government prior to the IBR.

Make sure you understand the requirements. Many times engineers look at requirements differently than scientists. Consider a “requirements forum” early to allow different people to express what various requirements mean to them and see if everyone agrees with the interpretation expressed. Achieving agreement on requirements and scope of work ... between the prime contractor and the Government is a requirement of a successful Integrated Baseline Review.

– Chandra Program Manager, MSFC

The PM conducts the Integrated Baseline Review (IBR) on both in-house and contracted projects with the support of the Center EVM Focal Point (EVMFP). The IBR is a continual part of the project management process for both NASA in-house and contractor projects. The IBR should determine if the project and the contractor have a good, realistic schedule, the proper personnel skill mix, and fabrication and test facilities; identified major risks; defined realistic performance measurements or EVM metrics; and accounted for all of the statements of work. Any issues that NASA may have as a result of the IBR may result in a required contract change, or may be carried as a Government risk without a contract change. An IBR also needs to be conducted within six months following exercise of significant contract options or a major contract modification. IBR process guidance is provided in the *NASA IBR Toolkit* at <http://evm.nasa.gov/handbooks.html>.

### 5.1.D.f Reserves

One of the more difficult tasks in the formulation phase is building a level of cost and schedule reserves that is adequate to successfully complete the mission but not so overstated as to jeopardize the chances of being given the go-ahead for implementation.

Some Centers provide guidance on the expenditure of cost and schedule reserves that should be anticipated as a function of time over the course of a typical project life cycle. There may even be internal Center schedule margin and budget reserve requirements that need to be met going into KDP C (when commitments are made as to what is to be built for what cost over what time period). Deviations from the specified margins are possible, but require the concurrence of Center management before approval is given to proceed to KDP C.

Once the project is in Implementation, the expenditure of the cost and schedule reserves is tracked and reported at regularly scheduled Center reviews. Deviations from the guidelines trigger a requirement for either an explanation about why the deviation is acceptable or for the initiation of activities to mitigate the trend.

Schedule reserves, in particular, may vary over the lifetime of the project. Budget reserve guidelines may also vary over the project life cycle. The PM should clearly understand the Center's guidelines for the project s/he is managing. See Handbook Section 5.2.C.b Cost Reserves Management for more on reserves management during implementation.

On one failed project, money and schedule were “thrown at” the project late in the life cycle, but critical decisions that contributed to the project failure were made early, due to the lack of reserves (or reserve options) that could not be undone. For example, an early decision was made not to have uplink capability (estimated cost of \$3 million). This was carried as a project risk but was never mitigated and could have possibly saved the mission if it had existed.

– Project Failure Review Board Chairman, MSFC

### 5.1.D.g Baseline CADRe

Cost Analysis Data Requirement (CADRe) is part of an overall Agency focus on performing best practices in cost estimating. CADRe is used for both internal project and independent cost estimating. Teams use the CADRe process to document programmatic, technical, and life-cycle cost information for Category I and Category II Flight Systems and Ground Support Projects.

Typical projects will make five CADRe submissions across the project life cycle. Two CADRe reports are due during the Formulation Phase with updates occurring during Phase C and later. See NPR7120.5, Table 4-3 Project Gate Products Maturity Matrix. The NASA PM is responsible for the CADRe. The PM may develop the CADRe system within the Project Office or use CADRe as a DRD on contract(s). Additional information is available at <http://ceh.nasa.gov/downloadfiles/CADRe.html>.

#### 5.1.D.h Work Agreements

Every NASA Center has unique policies and processes that projects need to use to secure organizational agreements for acquiring in-house personnel required to support project formulation activities. During Pre-Phase A, agreements need to be established early to ensure that the project obtains the support personnel required to conduct concept and trade studies and early planning activities. Agreements can be made for a finite period (possibly with the option or understanding of extensions). It is generally understood that support may not continue if the Pre-Phase A results do not result in a decision to proceed into Phase A and formal project formulation. However, if the decision is made to proceed to Phase A, work agreements need to be made at the end of Pre-Phase A (and during each successive life-cycle phase) to secure matrixed and/or dedicated personnel.

In addition to internal Center agreements for in-house support personnel, agreements may be required for support from other NASA Centers. These agreements are made through formal documents, such as Memoranda of Agreement (MOA) or Memoranda of Understanding (MOU). Because of the differences between Centers' internal practices, the PM needs to allow ample time to complete these agreements. If the project structure includes collaboration between NASA and another Government Agency or a private institute or research facility, these agreements, with clearly defined interfaces and deliverables, also need to be established as early as possible during project formulation.

#### 5.1.D.i Life-Cycle Cost Estimates

Confidence in the adequacy of the initial project budget is essential. Accurately estimating the costs of tasks that have never been done is difficult, and a PM should not cut short the time and effort needed to provide cost estimators the information they require. Resist pressure to discount or reduce the estimated cost or project reserves required to get the project approved.

You have to understand ... what is meant by prioritization. You have to be able to do it, because we live in a world of finite resources; you have so much time, you have so much money, and so many people, and so many skills to accomplish what it is that you'd like to accomplish, or as close to it as you can get it. You do not have infinite quantities of any of those things.

– NASA Administrator

To create a viable cost estimate for a project or program, you need to know and understand the mission objectives. A science mission PI might request a particular amount of funding s/he believes necessary to achieve all the goals s/he has in mind. This level of funding might not be available; a lesser amount might be all that is funded for that mission. The project team needs to be involved because a science PI might need help in developing these estimates. Although the

original mission goals may have been very ambitious, with smart decision making and good teamwork, it may still be possible to achieve good science within the funding provided. For a small number of missions, for example those of national importance, it might be necessary to strive to meet the ambitious parameters of the mission and request additional funding rather than to reduce the mission goals to fit into a restrictive costing profile.

One helpful strategy is to seek out an experienced PM who has managed a similar project to review as much of your approach as possible. Another approach is to spend time with personnel responsible for individual components of your project and ask them questions, such as how much time and effort will the component require (best and worst cases) and what are the potential risks (likelihood and consequence). It is critical that the proposed design be understood in sufficient depth before commitment is made at KDP C. Driving requirements, risks, and necessary mitigation actions need to be identified. Cost estimates should be made using bottom-up grass roots estimates, parametric models and comparisons with analogous systems. Differences in resulting estimates at the subsystem level need to be understood and reconciled. Invite the lead system engineer, project scheduler, and risk management lead to participate in these discussions. Perhaps most important is the involvement of the cost estimators available to the project. Using well-tested models will provide the most reliable cost projections.

As a project manager, you must understand the job that you are being asked to do. It will be the subtleties that haunt you. On one project, I was unsuccessful as a PM. I did not understand the job I was managing—software. The requirements were not defined and it was initially being designed to be everything to everyone. I was a hardware guy. ...Identify the biggest challenge to ultimate success and put top-quality people on those areas.

– GSFC Deputy Center Director

The cost and schedule personnel need to be using the same WBS (NASA Standard) as the technical people. A bottom-up (i.e., from the lowest level WBS elements) analysis is one way to approach this. Based on the apparent risk of the element, an appropriate margin is added to that element. These elements are then rolled up and an overall contingency value is added. It is important to begin using the WBS dictionary to help document the assumptions that are going into the cost estimate. During this stage of the life cycle, the cost estimates will be rough order of magnitude. Documenting the basis of estimate will be invaluable in the latter phases.

The focus should be on:

- Clarity of the objectives
- Thoroughness in the state of the technical and management plan
- Complexity of technology needs
- Evolution of the risks in the technical/cost/schedule
- Contingency reserve allowances in schedule and cost

It is sometimes noted in hindsight that a large factor in overruns turns out to be the unfounded assumptions that were made in the early phases of the project. Experienced PMs know to be cautious about giving out precise cost estimates early in the project life cycle. They recognize the conceptual nature of programmatic requirements and design characteristics. There are competing interests here. Project managers for AO competed missions, for example, do have to provide these cost estimates for the Step 1 and Step 2 proposals. The PM needs to consider all these

issues in providing these estimates. Also, wise PMs are not afraid to ask hard questions concerning project assumptions in all areas. They know the estimates for cost/schedule/risks/reserves are no better than the assumptions and understanding that lie behind them. The best you can do is to document the assumptions that go into the estimate and the basis for the estimate, including heritage assumptions, reuse of equipment/software, labor rates, and schedule assumptions.

No matter how well this is done, the Congressional budget process may affect it. Projects and programs funding levels may change from one year to the next based on changes that come out of this process. There is often no way to predict the changes. See Handbook Section 5.2.C.d Implementing Project Cost and Schedule Control Activities for additional discussion about funding levels.

The project started out with a lot of scope. We partitioned the requirements and ended up with 60 percent more content than we had budgeted for. We then did a priority assessment and used it to determine which things to get done first. Then when the budget cuts came we could tell the customer what wasn't going to get done.

– Human Research Facility Project Manager, JSC

One way to help ensure technical, cost, and schedule remain in synch during development is to assign large margins for each. The PM needs to understand the risks associated with the development areas, as well as the potential optimism of other areas (e.g., heritage). Even heritage-based concepts will have unforeseen costs based on obsolete parts or design changes. The PM needs to balance risks (both known and unknown) with cost, schedule, and technical reserve in a way that will not overly constrain the project as it progresses through the life cycle. If new technology is included in the initial concept, the cost estimates need to ensure the funding profile will support the requirements to get the technology to the appropriate readiness level.

Getting good cost data at the early stages is also tied up in how well the team defines the technical parts of the project. One operational program that depends on developing new instruments to observe the Earth uses competitive contracts in early Formulation with two or three contractors. These contractors, motivated by the future program contract for the operational spacecraft, come up with the concepts, do the early trade studies, and provide the cost estimates for the instruments. The competition brings out the cost issues and provides a good cost basis for the instruments. This is done well before any cost commitments are made for the program.

Project management principles are the same on project components as for the total project. Each piece has cost, schedule, and technical constraints, all wrapped in risk. ... Risk management is closely coupled to budget management. If you are spending money and not “buying down risk,” something is wrong.

– MSFC Deputy Center Director

Cost estimating organizations perform parametric cost estimates based on such factors as history, complexity, and mass. These estimates can be very helpful, but the assumptions used for cost models need to be selected carefully. It takes a lot of discussion between the technical team and the estimating group analysts to determine these factors. This is especially true if the mission is

the first of its type. Early LCCs are usually developed using a parametric cost-estimating approach, under which the total project cost is determined and then time-phased over a typical schedule duration.

While working an Independent Cost Estimate for a DoD milestone review, the review team recognized the radar system was using a COTS minicomputer (VAX). Everyone assumed the computer would just be there; no one gave it a second thought. We asked about the VAX and when it would be replaced. We found out that when the computer was replaced, the project would have to rehost new software. This would be on the order of every four years, which made this a LCC issue worth millions of dollars. After finding this out, the project changed its approach on how to deploy the computers. The issue was decided on LCC.

– Senior Analyst, Independent Program Assessment Office

A different approach than the parametric top-down approach is one coming from the bottom up. Once the technical scope is defined, the project develops the schedule before developing the cost. By resource-loading this schedule, the cost can be determined by fiscal or calendar years. LCCs developed later in project formulation using this approach are typically higher fidelity than earlier parametric estimates. This cost information is phased by fiscal year and is included in formal budget submittals and in the Project Plan. A true integrated baseline can only be achieved by assessing the time and resources required to complete each task included in the technical baseline and by using a schedule logic network to arrange each task in its proper sequence.

One experienced PM uses the standard methodologies to develop cost estimates but then assumes it will increase by 3 to 5 percent over a one-year period beyond inflation. However, on one project over a 6-month period, even that estimate plus the increased allowance was overwhelmed by an almost exponential increase in the price of steel. Increased fuel costs also contributed to the rise, because steel for the project had to be transported to several locations for processing before it arrived on site. Thus, even when estimating cost every 3 to 6 months, it is important to perform some checking in the interim. These status checks don't need to be full estimates, but spotting an early increase can alert you to trouble spots or possible impact.

First get the requirements, conduct trade studies, select designs, and then do an initial cost estimate, then look at the requirements more carefully because there is inevitably not enough money. An example on the facility project was that the initial cost estimate included dip galvanization on the gantry steel components. Since the facility was being built in a dry climate, White Sands, that wasn't really required, which reduced the cost of the gantry by close to a million dollars. A decision also was made to not enclose the gantry. It is important to really understand the requirements.

– Deputy Project Manager, Orion Launch Abort Flight Test, DFRC

For additional resources about cost estimating and analysis, the *NASA Cost Estimating Handbook and Parametric Estimating Handbook* is available at <http://cost.jsc.nasa.gov/>.

Initial budgets should be developed with a verification program based mostly on testing. Sufficient testing yields a high degree of confidence. Early in the life cycle, develop contingency plans in case tight budgets and schedules threaten mission success. Identify areas where you can

replace tests by analysis and simulation without adding significant risk. Also look for areas where performance could be reduced without violating baseline mission requirements. These options should be protected well into Phase C, when most development issues surface.

Eliminating some tests might introduce unacceptable risk. These tests should be preserved at the cost of removing technical content. Sometimes testing is eliminated early because it is so expensive. Later it is often put back, at a great expense, after a lot of agonizing over its need. Avoid this pitfall through early planning and team buy in.

In Pre-Phase A and Phase A, task agreements need to be developed based on historical estimates or expert opinion. During Phase B, data derived from the WBS and resource-loaded schedule can be used as a basis for project budget and Center personnel requests. Interface work is frequently ignored or underestimated to the detriment of the project. The greater the number of interfaces and NASA Centers or other organizations involved in the project, the significantly greater the resources required.

### **5.1.D.j Developing a Project Plan**

The Project Plan is prepared by the PM with the support of the project team. It defines the project's objectives, technical and management approach, environment within which the project operates, and commitments of the project to the program. Since the Project Plan documents agreements between the NASA program office, the PM, and in the case of AO-driven projects, the PI and the implementing Center(s), it is important for all pieces of these agreements to be worked out first. In particular, the program requirements need to be clearly stated and agreed to by all parties to properly establish the scope of the project.

The baseline Project Plan is required at the time of project approval and is used by the governing PMC in the review process to determine if the project is fulfilling its agreements. The Project Plan is updated and approved during the project life cycle if warranted by changes in the stated commitments or program requirements on the project. The MDAA may be added to the signature list for the plan at his/her discretion.

Larger and more complex projects may find it necessary or desirable to write separate control plans to convey project approaches and strategies. In these cases, the Project Plan summarizes the key elements of such separate plans. In smaller projects, separate and detailed control plans may not be needed to document project approaches, and the Project Plan itself serves as the single source for such information. NPR 7120.5, Appendix F provides further descriptions of Project Control Plans.

The Project Plan supports the cost, schedule, and delivery agreement and provides implementation approach detail. The specific documentation products developed by the project are also listed in this plan. The plan for managing project risks is documented in the Project Plan, and it addresses the severity and likelihood of risks associated with schedule, budget, environment, safety, technical aspects, people, and configuration management, as appropriate.

The implementation approach (e.g., in-house, contracted, partnership with other Centers) needs to be established and agreed to by the program office and all participating entities. It is essential to define clear roles and responsibilities for each of the participating entities. It is also important to establish and document how entities will work together, especially how decisions are made (e.g., jointly, unilaterally after requesting input). Part of the implementation approach is

establishing the level of schedule and budget margins, where these will be held, and the process for using them.

Good communication is the key to developing and achieving all of these agreements. It is very important for the PM to have frequent communication with the program office and partners, including those at other Centers, personnel at universities, and contractors. Face-to-face meetings early in the project help ensure the PM and stakeholders develop an open working relationship. It is also important to put effort into maintaining these relationships by continuing with regular communications and periodic face-to-face meetings.

NPR 7120.5, Appendix F contains a project plan template and a description of the major topics covered in the plan. Some required topics may be covered by a stand-alone plan (for example, Configuration Management Plan) and cited by reference in the Project Plan. See Handbook Appendix C for a sample Project Plan.

Communication is key to getting the plans and issues implemented. There are external sponsors and customers that need to be informed. Having a communications strategy or plan for how you communicate the risks on the project to all those who need to know is important.

– Project Manager, JPL

A communication plan is an important start, but clearly communicating according to the plan is the primary objective.

### Processes and Tailoring

Part of the technical planning process is planning the life-cycle phases and processes that will be used for the project. Standard processes reduce risk. However, each project is unique and it may sometimes be necessary to tailor the approach for an individual project.

NPR 7120.5 describes the project life cycle and processes. NPR 7123.1 describes the systems engineering process. Each Center's internal requirements and procedures need to be aligned with these processes. If a project deviates from these processes, there is the risk of missing an important step, which in turn might require project rework. To provide appropriate visibility into departures from the idealized process and to manage associated risk, PMs need to understand tailoring and waivers. Tailoring is the process used to adjust or seek relief from a prescribed requirement, thereby accommodating the needs of a specific task or activity. Not all programs/projects will fit 100 percent of the NPR 7120.5 structure or other requirements. For this reason, NPR 7120.5 provides a process for adjusting or seeking relief from prescribed requirements to accommodate the needs of a specific task or activity, program or project. This enables the PM to tailor processes to fit best with the type and size of the program/project effort. A process for tailoring requirements is described in NPR 7120.5, Section 3.6. The tailoring process results in the generation of deviations and waivers depending on the timing of the request. A waiver is a documented authorization releasing a program/project from meeting a requirement after the requirement is put under configuration control at the level the requirement will be implemented. Tailoring the project management process with an approved waiver can provide the project a path to meet the intent of requirements, while informing the PM of the potential risks. The PM should discuss tailoring with the program office prior to taking any particular path.

### 5.1.D.k Project Reporting and Management Briefings

NPR 7120.5, Tables 4-3 and 4-4 list the products and product maturity level required for Formulation Phase KDP reviews before the project-governing PMC. In addition to these required meetings, a significant amount of a PM's time is spent providing written and oral status and briefing presentations to the Program Manager, Center management, and other stakeholders. A PM needs to be constantly aware of the technical, cost, schedule, and risk health of the project. If a problem occurs, the PM should not wait to inform the Center and program management. An open, honest relationship builds trust between the PM and management, and the stakeholders may be able to offer solutions and options.

A project manager depends on people with integrity to report honestly.

– Project Manager, JSC

### 5.1.E Conducting Formulation KDP Readiness Activities

NPR 7120.5, Table 4-3 Project Gate Products Maturity Matrix, supplies a list of the required products to support each KDP. Assuming all technical and programmatic products contain the appropriate level of detail, final approval to proceed depends on recommendations contained in the “KDP Readiness Products” section of the table.

Prior to presenting formal recommendations to the proper Decision Authority, projects need to conduct internal reviews and status reports with local management in accordance with Center policies where the project resides. The subtleties of expectations between partnering organizations (i.e., Centers, Agencies, countries) will begin to surface at initial milestones and should be addressed as soon as they arise to minimize potential issues later.

#### 5.1.E.a Reviews

During the Formulation Phase, the project must plan for and execute the technical life-cycle reviews, as required in NPR 7120.5, Figure 2-4. See also Handbook Section 2.5 Program and Project Reviews for more details about reviews.

Based on their size, complexity, and cost, not all projects will conduct all reviews; however, during the Formulation Phase most will conduct:

- Mission Concept Review
- System Requirements Review
- Either a System or Mission Definition Review
- Preliminary Design Review

The review products and exit criteria for technical reviews, such as a System Requirements Review (SRR) or Preliminary Design Review (PDR), are detailed in NPR 7123.1. The purpose of these reviews is to ensure sufficient technical progress has been completed before allowing the project to proceed to the next phase in the project life cycle. The success of these reviews supports Key Decision Points (KDPs), where permission for a project to formally move to the next phase is granted (or denied) by the appropriate Decision Authority.

Although the overall purpose and result of a technical review is the same for all NASA projects, there are some differences in review approach between robotic and human flight projects. For

robotic projects, the technical baseline is characterized by a detailed presentation to the review team and the quality of the content is evaluated by the review team. If a review team member has a concern, s/he generates a Request for Action (RFA). Robotic presentations cover the project cost and schedule status, as well as technical quality. The presentation is generally brief and for the purpose of introducing independent reviewers to a high-level view of the project. The technical design is evaluated by reviewing existing drawings and documents (e.g., thermal analysis, manufacturing plans, component and interface requirements and detailed drawings). In human flight, Centers identify any discrepancy with requirements via a Review Item Discrepancy (RID), and the validity of the discrepancy and the estimated correction cost and schedule impacts are either accepted or rejected by the review board chair. See handbook Section 2.5 for more on the review process.

Each Center has unique processes for staffing and conducting technical reviews. Process documentation may exist in the form of Center work instructions, handbooks, or documented best practices. A senior PM leading another project may be the best source of information for someone new to the project management processes at a particular NASA Center.

LCROSS follows a somewhat different review process because Center management wanted to reduce the size of their reviews (there were 150 people at the PDR for a \$79M project). LCROSS holds Design Audits prior to the major reviews. ... These are small groups (fewer than 20 people) of technical people, like a peer review. LCROSS allowed the program office to attend and stated that, at the PDR and CDR, the project would only report-out a summary of the audits. This requires trust on the part of the stakeholders and was only partially successful because they still wanted complete presentations at the big reviews.

– LCROSS Project Manager, ARC

### **5.1.E.b Project Life-cycle Cost Estimate Reconciliation with Independent Cost Estimates**

Independent review boards such as the SRB may develop an independent Life-cycle Cost (LCC) estimate, utilizing support from the Independent Program Assessment Office (IPAO). The independent team reviews the estimate with program/project personnel to ensure both parties agree on the ground rules, but not necessarily the totals. For example, reconciliation may occur based on what Technology Readiness Level (TRL) the assessment team has determined the project is at compared with the project team's TRL assessment. Any major issues and/or significant differences in costs estimates between the project and the independent review team that cannot be resolved are discussed when the independent review team presents its findings to the appropriate Decision Authority. Some Centers maintain their own internal cost/schedule estimating organization.

### **5.1.F Instrument-Specific Information**

The instrument manager should be assigned full authority and responsibility to manage cost and schedule reserves for the instrument and, accordingly, be held accountable. See Handbook Section 3.1 Overview of Roles and Responsibilities for additional information.

### **5.1.F.a Staffing**

The NASA Instrument Capability Study (NICS) found instrument managers (IMs) often face unique challenges associated with building a technologically advanced science instrument that meets requirements and remains within technical, budget, and schedule constraints. IMs, like PMs, have to manage budget, schedule, and risks, as well as oversee configuration management activities. And while IMs typically have instrument systems engineers to support them, to do their job successfully IMs require additional resources/people (i.e., project staff) with the appropriate level of expertise in these areas. The NICS team recommended that instruments have a dedicated level of support staff (configuration management, schedule management, risk management, budget management) for instrument developments over \$10 million.

### **5.1.F.b Requirements**

Systems engineering is a critical discipline when developing science instruments. NASA has well-defined processes and procedures in place to facilitate good requirements formulation to ensure the final product meets the intended goals and objectives. However, the NICS team found there were significant problems with implementation of the requirements management process. Specific issues were identified with requirements formulation/definition, requirements review, and requirements management.

To address these issues, the NICS team made the following recommendations:

- NASA instrument team leadership should take requirements formulation/management training prior to requirements development. This will provide instrument teams with a better understanding of how to formulate and manage requirements.
- Instrument teams should conduct Peer Reviews of requirements (for each instrument subsystem) in preparation for instrument SRR. This is viewed as necessary because instrument SRRs occur much earlier than mission SRRs, which often leads to requirements changes as well as traceability issues.
- Draft mission Level 1 and 2 technical requirements should be controlled and provided to IMs prior to instrument SRR. Additionally, IMs should be notified of any changes to the draft requirements so that impact assessments can be performed. Providing the instruments with top-level requirements early in formulation enables a thorough requirements development and management process.

### **5.1.F.c Costing and Scheduling Activities**

In Phase A, the instrument team is required to develop a preliminary integrated schedule and life-cycle cost estimate. IMs should ensure sufficient schedule and budget reserves are included in the instrument schedule/budget. NICS found the rule of thumb of 25 percent cost reserve and 1 month per year of schedule reserve may not be sufficient for instrument developments. The NICS team recommended that, for instruments greater than \$10 million, IMs consider carrying larger cost and schedule reserves to account for the fact that most instrument development projects are highly complex single builds.

### **5.1.F.d Instrument Budget/Schedule Peer Review**

To increase confidence in budget and schedule credibility going into Confirmation Review, the NICS team recommends that instruments hold a peer review prior to PDR for instruments greater

than \$10 million. The review objective is to assess budget and schedule baseline credibility and increase emphasis on cost and schedule assessment at PDR.

## 5.2 Project Implementation

The Implementation phases include execution of approved plans for development of the project. This handbook section corresponds to NPR 7120.5, Sections 4.6 and 4.7.

### 5.2.A Introduction

Project implementation commences after the Formulation phase, when the Decision Authority approves the project for full implementation. It includes all the activities of Phases C, D, E, and F. (This Handbook covers phases E and F in Section 5.3.) This includes final design, fabrication, integration, verification, validation, and, ultimately, launch and operations. This is the time of peak activity in terms of workforce, dollars, and schedule. It requires intensive decision making, replanning for workarounds when things go awry, contractor monitoring, and generally ensuring that technical quality, cost, and schedule all remain on track.

#### 5.2.A.a Phase C

During Phase C, the project team performs both the technical and project control activities leading to the design of the flight and ground system. These activities focus on preparation for the Critical Design Review (CDR) and the System Integration Review (SIR). This phase culminates in KDP D. The final design and fabrication have been completed and it is time to start the assembly phase.

#### 5.2.A.b Phase D

During Phase D, the project team performs the technical and control activities leading to system assembly, integration, test, and launch of the mission. These focus on preparing for the Flight Readiness Review (FRR). By the end of Phase D, the project is ready to transition to launch and then operations. This phase culminates in KDP E.

Too many of our project managers—all they want to work on is the technical side. Like it or not, project management is about one-third, one-third, one-third for cost, technical, and schedule.

– Deputy Director of Engineering, JSC

### 5.2.B Performing Technical Activities

During the Implementation phases, the PM and the systems engineer work together to perform the technical activities of the project following the plan laid out in the project's Systems Engineering Management Plan (SEMP). See Handbook Section 5.1.C.b Developing a Systems Engineering Management Plan. NPR 7123.1 describes the seventeen common technical processes for systems engineering, organized into three groups: System Design Processes, Technical Management Processes, and Product Realization Processes. These processes and the systems engineering engine are detailed in a project's SEM. The PM has overall control of the

project, including the technical and resource areas. The systems engineer manages most of the technical processes for the PM.

### **5.2.B.a Technical Management Processes**

The technical processes described in NPR 7123.1 are implemented to accomplish the technical work of producing the product. They are implemented by the lead systems engineer under the direction of the PM. These include, for example, requirements management and risk management.

#### **Project Teams in Implementation**

The PM negotiates agreements with Center management and other organizations to supply personnel for the project. This is often done using a matrix organization between the project and the engineering organization that supplies the discipline engineers. These agreements may include Memoranda of Understanding (MOU), internal agreements, or contracts.

The project consisted of two elements. I held daily telecons (typically about 30 minutes in length) with my prime contractor counterpart and other members of one element team, as well as frequent tag-ups with key members of the other element team. This daily status and assessment is especially critical for projects that are schedule driven.

– External Tank Project Manager, MSFC

The project needs to integrate technical information from all engineering disciplines, including specialty engineering disciplines such as safety, reliability, human factors, logistics, maintainability, quality, operability, and supportability. This is often best accomplished by early formation of an Integrated Product Team (IPT) for selected products in the Product Breakdown Structure (PBS).

It is very common for some project members, or even the PM, to change at this phase of the project. Some personnel who were involved in early phases of the project, such as concept and advanced technology development personnel and project cost estimation personnel, are much less involved in later phases. New team members with more experience in project development are brought on board for the Implementation phase. These will include people experienced in manufacturing, quality, and testing, particularly for in-house activities. There are many who believe instead, that continuity of the project from Formulation to Implementation is important because of the early commitments. In this case, the recommendation would be to make any key management changes early (i.e., Phase A). The staffing approach is determined by the Center.

Operations personnel who will be key players in Phase E should be included in design and planning discussions. Depending on the nature of the project, these may include launch control center, mission control, Deep Space Network, real-time data repository, and science operations personnel; real-time engineering support; and astronauts.

#### **Requirements Management**

As the systems engineer and the technical teams are defining and refining the technical requirements from the set of stakeholder expectations (during Formulation), the PM needs to keep track of the nontechnical implications of those requirements. Sometimes requirements that

appear reasonable from a technical perspective can be unworkable in terms of resources, schedule, or political concerns. These requirements must be discussed with stakeholders so a doable set of requirements is defined.

Project management participation in the Technical Requirements Management process is a key element in cost and schedule control. As a change to the project requirements baseline is identified, either as an internal proposal from the technical team or as a change request from a stakeholder, the PM must guard against requirements creep and unacceptable changes in cost and schedule. In evaluating potential changes to project requirements, it is important to separate desires from hard requirements. For a requirement to be changed or added in the Implementation phase, a formal change request needs to be evaluated (impacts to cost, schedule, and technical baseline, as well as risk impacts) by a Configuration Change Board (CCB) or the equivalent.

The PM must also manage requirements such as delivery timetables, collaboration between organizations, training, and customer support. In general, nontechnical requirements include anything other than hardware, software, or documentation.

### Risk Management

In addition to technical, cost, and schedule management, risk management is one of the most important areas of project management. Risk management is the focal point of managing a project and can drive the other three areas. In the context of mission execution, risk is the potential for performance shortfalls with respect to achieving explicitly established and stated performance requirements.

Performance shortfalls may be related to any one or more of the following mission execution domains:

- Safety
- Technical
- Cost
- Schedule

A shortfall in institutional support for a mission may mean that the project needs to be reduced in scope or cancelled altogether—a risk to the project’s continued existence. These lack-of-support risks can come from many levels, including lack of support from a contractor or another NASA organization or lack of adequate funding support. Methods for mitigating these risks include managing communications with stakeholder organizations and periodically reassessing, forecasting, and validating the institutional support they provide to the project.

A known risk can be analyzed, quantified, and managed. Unknown risks can be managed only by maintaining sufficient project reserves. The PM needs to ensure that there is a strategy for involving the project team in continually identifying risks and managing them to closure.

Risk management is as much about not taking action to mitigate risks as it is about taking action. The key is the “management” part. Risk management is not about eliminating all risks wherever possible, as that will not fit in a cost and schedule box. If anything, a Class D project has more responsibility to pay attention to risk, because the answer won’t always be “mitigate it.” There are tough trades. Managing risks can be seen as taking opportunities.

– LCROSS Project Manager, ARC

By the implementation phases, the PM and systems engineer should have a fully operational Risk Management Plan per *NPR 8000.4, Agency Risk Management Procedural Requirements*. This includes control of cost and schedule risks, as well as safety and technical risks.

Each organizational unit oversees the risk management processes of unit(s) at the next lower level and manages risks identified at its own level. So, a program oversees project-level risk management processes as well as manages program risks. Similarly, each project oversees subproject-level risk management processes and manages its own project risks. These program and project risk management systems tie into Center risk management systems.

Risks can be elevated from one level to another, and some risks can reside in multiple risk management systems at the same time. For example, in a program consisting of a booster project and a capsule project, a schedule risk on the booster project may reside in the booster project's risk management system. If that risk exceeds a predefined threshold, it could be elevated so that it also resides in the overall program's risk management system.

NPP [NPOESS Preparatory Project] did a good job handling risks. They recognized they had interfaces with DoD and others, which could cause problems, so they set up options in the contract to give themselves more time for late delivery. They saw the risks and allowed large blocks of time for deliveries.

– Independent Program Assessment Office (IPAO) Reviewer

Every member of the project should be encouraged to identify new risks. Project personnel commonly worry about identifying risks because they perceive management or team members will shoot the messenger who brings up a potential problem. The PM can take several steps to encourage active risk identification and open risk status discussion. One technique is to ask each person who identifies a new risk, "Who, other than you, would be the best person or organization to evaluate this risk?" Using this technique, the PM can avoid assigning the responsibility for solving the potential problem to the person who identified the risk, can engage both that person and other team members in creating the solution to the problem, can obtain independent evaluation of the risk, and can help project team members become better acquainted with the technical expertise of other team members.

To encourage communication about risks, the PM should discuss risks openly and often with project personnel. Risks and risk mitigation should be the focus of risk management meetings rather than being covered in normal status meetings. In the management-by-walking-around strategy, the PM can periodically visit each subsystem to discuss their risks. This makes everyone more aware of risks and encourages communication within the project. Communication on risks also means using the 5x5 risk management matrix described in *NPR 8000.4, Agency Risk Management Procedural Requirements*. This is a normal part of the project reporting.

New technology has its own risks and may require unique risk mitigation techniques. If the project has a performance floor and the team is also trying to push a new technology, consider parallel development paths where one part of the team focuses on the new technology and another part of the team focuses on a standard technology approach to the same problem. This can be more expensive up front, but for a risky technology development it is a way to mitigate development risk.

Approaches that help PMs control project risks include, but are not limited to:

- A robust risk management system that allows risks to bubble up from the bottom. There should be a way to classify risks so the PM can act on them.
- Liens against reserves that are added as threats develop against the project:
  - Hard liens, where the decision has been made to fund the lien
  - Soft liens or threats, where no decision has yet been made to fund the lien. These need to be watched closely and assessed regularly.
- Giving attention to developing a good ranking of risk and impact to achieve the correct balance. Most reserve decisions are based on risk, not on the availability of reserves. There are rarely enough resources to deal with all the identified risks.
- Separating desires from hard requirements to minimize the risk of requirements creep.
- Constantly asking “Why did this make it to the top risks list?”
- Elevating a risk to a Technical Authority issue through the line organization by the person identifying the risk, if a risk is not treated appropriately by a project.
- Visiting each subsystem to discuss their risks. This makes everyone more aware of risks and increases communication within the project.
- Breaking out risk as a separate area of project management, in addition to technical, cost, and schedule management. Risk management is really the focal point of managing a project and can drive the other three areas.
- Risk management closely coupled to budget management. If you are spending money but not buying down risk, something is wrong.

### Configuration Management

Configuration Management (CM) is a management discipline applied over the product’s life cycle to provide visibility into and to control changes to performance, functional, and physical characteristics. CM ensures the configuration of a product is known and reflected in product information, that any product change is beneficial and is effected without adverse consequences, and that changes are managed.

When the PM identifies a particular product as a configuration item (CI), the CM process can plan for its storage, identify it uniquely, control its configuration (including the arrangement of its parts), and provide configuration accounting, configuration traceability, and configuration verification and configuration audits. This concept applies to documents, source code, data, and physical objects. CM ensures that a CI will only change with an approved change request and that every approved change request will result in changes to only the affected CIs.

General Sam Phillips instilled Management and Configuration Management control processes into the Apollo Program. These processes brought needed discipline to the program and were the key to its success.

1. Interface Control Documents (ICD) were signed at the Headquarters level—this forced all Centers to work together.
2. Well-documented design and interface data created by this formal CM process was essential.
3. NASA essentially adopted Air Force documentation for CM processes.

– NASA Program Manager

During the Implementation phases, the PM spends a relatively large proportion of time interacting with the CM system, including change request evaluations and participating in control board activities. The PM also receives the results of configuration audits.

Typical CIs include:

- Plans
- Requirements documents
- Design (or the end product design specifications)
- Drawings
- Models and simulations
- Interface documentation including the Interface Requirements Document (IRD), Interface Control Document/Drawing (ICD), Interface Definition Document (IDD), and Interface Control Plan (ICP)
- Problem reports
- Life-cycle phase success criteria
- Ground support equipment
- Flight hardware including mission critical hardware
- Flight software including mission critical software

CM reduces technical risks by ensuring correct product configurations, distinguishes among product versions, ensures consistency between the product and information about the product, and avoids the embarrassment of stakeholder dissatisfaction and complaint. Inadequate configuration management is a common source of project risk.

*NASA-STD-0005, NASA Configuration Management (CM) Standard* provides a consistent and systematic method for configuration management of products delivered to or produced by the Agency under configuration control. The project's CM system needs to comply with this standard.

A NASA standard CM system is used to:

- Identify the configuration of a product at various points
- Systematically control changes to the configuration of the product
- Maintain the integrity and traceability of the configuration of the product throughout its life
- Preserve the records of the product configuration throughout its life cycle, properly dispositioning the records

### Decisions

It is important to make timely decisions and to communicate with the team that is working hard on the project. On LRO, we have to make decisions quickly because of schedule constraints. Decisions and the context of those decisions are written up and sent out to the team. Also, having the right people involved in the decision is key. We also will “double-back” on any decision that is made if we determine that we would find out in flight that it was the wrong decision. Again, it's key to have the right people involved for each decision. I always explain to the team why we make certain decisions.

– LRO Project Manager, GSFC

Decision making is a regular activity throughout project development. It is critical to keeping the project moving ahead. Thus, a PM needs to know when to make a decision. Some decisions are made from a technical perspective and some from a programmatic perspective. Ideally, you would like to have or be able to wait for perfect information before making a decision. Gathering perfect information takes time, and meanwhile, costs are increasing or other critical decisions pile up behind the decision yet to be made. In reality, it is often necessary to make a decision with less than perfect information, and you need to be prepared to know when that is and be able to lead the team in recognizing such situations. In design and development phases, a wrong decision made in a timely manner is better than a nondecision. You can quickly correct a wrong decision, but you cannot correct a nondecision. Preparing the team for a possible misstep is also an essential part of the decision-making process. Decision makers should strive for consensus if reasonable and possible, but need to not be afraid to make decisions as necessary. (See Decision Analysis in NPR 7123.1.)

Part of the decision process is anticipating difficulties. A PM should always be thinking about what could go wrong in the future (i.e., unintended consequences of the decision). Understand and commit to what it is you are trying to do, but be aware that problems, often subtle ones, plague all projects. Plan for success, but expect and prepare for failure.

Galileo was a dual-spin spacecraft with the problem of how to pass signals across the interface between the two parts of the spacecraft. The traditional method was slip rings with brush contacts. At the time, Division 34 at JPL had a new design: roll rings with a “frictionless” band between them. I chaired a meeting to decide which way to go. The people at the meeting were unanimous for the roll rings, except for one reliability guy. He had a gut feeling that not enough was known about the roll rings. I made the decision to go with the roll rings. Six months later during the life testing they found that they were shedding all kinds of metal debris. I made the decision right away to go back to the slip ring design with the brush contacts. I felt reversing the initial decision in a timely manner rather than dragging it out was the right thing to do.

– Galileo Project Manager, JPL

The Galileo PM had two management rules for working with his team: Do what I tell you, and don’t let me do anything stupid—and he ensured his team understood that the second rule always took priority over the first.

I’m in charge at whatever level from group supervisor to NASA Administrator; I am in charge and I am responsible for this entity, this group, this project, whatever it is. But I grade myself on the quality of the decisions that go out the front door, not on who has the best idea, and I try over and over again to encourage people who think we are not on the right track to please speak up, be willing to have the argument. And I promised people over and over again, because you need to promise them, that I will not shoot the messenger; you know you can tell me bad news and you won’t suffer for it. ... I also try to tell them that the right to have and the obligation to express a dissenting opinion does not imply agreement. ... You can legitimately be in a situation where it’s more important to have data at the 80-percent confidence level now than it is to have it at the 98-percent confidence level two years later, because a lot of money depends on making decisions now.

– NASA Administrator

### Design

In Phase C, the lead engineer for each discipline (spacecraft subsystem or instrument) is responsible to ensure that:

- The design will meet the specification and interface requirements
- Standard and/or qualified parts are used as much as practical
- Detailed specifications and software specifications are compatible with the mission specifications established earlier (i.e., margins and error budgets are considered)
- Proper consideration is given to reliability, safety, usability, maintainability, and good design practices for space flight hardware and ground support equipment

The lead discipline engineer reviews the design with the project's system engineer and obtains concurrence. The design may be breadboard and functionally tested to verify the design, depending on the complexity and state-of-the-art considerations.

Between the Preliminary and Critical Design Reviews (CDR), engineering model fabrication and test and any associated design changes are incorporated into the effort.

Typical functions performed during this phase include:

- Fabrication of engineering model system and subsystem
- Preparing detailed functional and environmental test plans and procedures
- Preparing an integration plan and procedures
- Designing, fabricating, and checking out all ground support equipment
- Establishing and documenting programs for controlling weight, mass properties, and power budgets
- Establishing and documenting an error budget for each discipline, as well as for the overall flight segment
- Establishing and documenting a command and data-handling budget
- Establishing and documenting a command and telemetry signal margin budget (including bit error rates)
- Preparing a safety program that is in concert with the appropriate launch vehicle
- System and subsystem detailed design drawings
- Assembly and component specifications
- Procurement packages

At the conclusion of the design effort, a CDR is held. This occurs in Phase C. The results of the design effort, especially any testing of breadboard and engineering model hardware, are reported. At the conclusion of CDR, designs are frozen and are then controlled by the project's formal Configuration Control Board (CCB). Phase C culminates in KDP D.

### Fabrication

Fabrication follows the Phase C design process. During fabrication, all parts previously specified and designed are built and made ready for system integration.

Typical fabrication activities are defined in the Contract Deliverable Requirements List (CDRL) and include:

- Fabrication of system and subsystem flight or protoflight units with delivery dates
- Detailed functional and environmental test plans and procedures

- Detailed integration plan and procedures
- Technical aspects of shipping requirements and equipment
- Operations and training manuals
- Contamination Control Plans
- Operating plans and procedures pertaining to cryogenics and hazardous materials
- Plans for activities of launch site checkouts and test
- Plans for controlling weight, mass properties, power budgets, and error budgets
- Thermal Control Program Plan
- Quality assurance plans

Although implemented only at this point in the process, many of these plans will have been developed much earlier in the life cycle.

### **Documenting/Resolving Development Issues**

Problems always arise when developing complex systems. For critical hardware, software, and documentation, problems are tracked to ensure each one is resolved with the appropriate level of engineering and management attention. Various issue-tracking systems are used across NASA and contractors to track problems and manage knowledge related to problems. Problem Reporting and Corrective Action (PRACA) system users range from PMs making launch decisions to shop floor technicians who are often the first to discover a problem.

Programs and projects often use their Center's PRACA system for the main PRACA, but contractors, subcontractors, and other Centers often have different PRACA systems. One challenge of having multiple PRACA systems in various parts of the program/project is that problem reports generated in one PRACA system are not visible in the other systems. PRACA systems often have incompatible data formats that inhibit data transportability. These issues need to be worked out to avoid confusion when identifying problems and to avoid failing to learn from the experience of others.

There are numerous practices at each Center for handling changes and discrepancies during development, including engineering change orders, material review boards, and fracture control boards. The PM needs to be familiar with these, just as s/he is with the CCB. The PM should maintain a project log with a prioritized list of issues the project needs to address. Any tracking system used should include impacts on cost and schedule from correcting issues that arise.

### **5.2.B.b Product Integration and Verification**

In NPR 7120.5, Phase D is defined as the System Assembly, Integration and Test and Launch phase. This phase is sometimes known as the Assembly, Integration and Test (AIT) phase, or Integration and Test (I&T) phase.

Phase D begins after a successful System Integration Review (SIR) and KDP D. During this phase, the product is integrated and verified. These steps go hand-in-hand. Starting at the lowest level, the pieces are integrated and then verified. Testing is the verification. When appropriate, verification can also be done by analysis, inspection, and demonstration. This proceeds through higher and higher levels of integration and testing until the final system-level product has been integrated, verified, and validated.

Product verification is the process to determine if the product was built correctly (i.e., according to specifications). This means verifying each requirement generated earlier in the design phase. The gold standard for verification is test. Universally, PMs advocate testing the system at each level of integration. Using a tool, such as the RVM tool described in Section 4.1.B.d Program Requirements, is a helpful way to ensure all requirements have been verified.

Product verification also includes software verification. For many projects this is done through the NASA Independent Verification and Validation (IV&V) Facility in Fairmont, West Virginia.

The verification program consists of a series of functional demonstrations, analytical investigations, inspections, and tests that simulate the stress environments the product (e.g., payload, spacecraft) will undergo during its mission and during pre-and post-mission handling. Support from the various stakeholders is used to assess specific mission performance versus requirements of the payload.

The verification program should comply with appropriate Center verification requirements and begin at the component level of assembly, continue through the integration of components into subsystems, and proceed until the final product is complete. The PM needs to take into account that each Center has its own approach to verification and plan for the differences. Finally, the product mission performance should be demonstrated by end-to-end testing that simulates the entire chain of mission commands, orbital operations, and responses.

Verification documentation includes:

- **Product Specification:** stipulates the requirements for hardware and software developed for a particular project.
- **Verification Plan:** outlines the program for conducting activities required by the product specification. For each activity, the Verification Plan defines, as applicable, the configuration of the item, objectives, facilities, safety considerations, contamination control, phase and profiles, functional operations, and reporting requirements.
- **Verification Procedures:** describe details of each activity, such as the instrumentation to be used, detailed facility control sequences, test items functions, tests and test requirement limits profiles, quality control checkpoints, and data collection and reporting techniques.
- **Verification Reports:** describe the results of the verification process.

### Test Beds, Bench Systems, Simulators, and Trainers

Test beds, bench systems, and simulators are essential design and testing elements in the Implementation Phase and beyond. Budgets for test beds and simulators often get cut early to make up for budget overruns, but these elements generally prove to be effective cost-savers over the project lifetime. When on orbit, the higher fidelity the testbed, the better the team's ability to perform troubleshooting. For best results, the team should plan to use spare flight hardware, if possible, as the test bed and to maintain it throughout flight. The team then can use the test beds to check software uploads and for troubleshooting. This can resolve many issues before they ever reach the on-orbit craft.

The bench system should be made flight quality as soon as possible within the project schedule. The closer the bench system is to flight quality, the more likely the project will be able to re-create on-orbit anomalies. This speeds issue resolution and gives the team a place to work out any bugs before attempting a change to the spacecraft.

At one ADP on Orion, they are building their own test beds at the Center. They will then make them available to other Orion teams. The NASA Engineering Safety Center (NESC) wants to use one, as does the contractor. This project will provide hardware to the contractor for them to use in their test beds and they will test contractor hardware at the Center. This cooperative process works for all involved.

– Project Manager, LaRC

Flight crew training begins at least two years prior to flight. Getting all necessary training accomplished requires training hardware to be available two years prior to flight. Be aware that the crew's training schedule is normally overbooked during the final months prior to flight.

Project managers need to pay attention to training facility fidelity. The flight crew will always want flightlike capabilities; the PM needs the best available facility for a cost the program/project can afford. High-fidelity training facilities are generally high cost, and the PM needs to balance high-fidelity training capability against the total cost to the project. A lower fidelity training capability is commonly developed to meet the minimum needs for training.

### Integration and Test

Systems integration and testing (I&T) starts after the various system components are fabricated. Components are integrated into boxes, which then are tested. These are integrated into subsystems, which are again tested. This continues up the line until the major parts of the system, such as the space segment and ground system, are integrated and tested. The testing, which includes verification and validation, is done incrementally at each level. Trades may be performed during Phase B or Phase C to determine the most effective test bed design, which may test several levels of a subsystem or several subsystems at one time. The top-level verification and validation efforts include the space segment and the ground system.

Integration and Test (I&T) Checklist:

- Just before I&T starts, go over what will happen and create a storyboard or schedule of actions. Make sure developers/designers meet with the I&T team. Testing team members can add to the body of knowledge.
- Double check that all the support services and equipment are ready. Check readiness early, well before the equipment is needed, so there are no surprises.
- Calibrate the test equipment close to the time it will be used so that the calibration test period doesn't expire.
- Try to build hold points into the schedule (e.g., before breaking thermal vacuum). Allow time to uncover anything that needs to be done in that configuration or in that environment.
- "Test-as-you-fly/fly-as-you-test" is applicable. When it is not possible to test at the system level, combine analysis with testing at lower levels.
- The reserves budget should be ample just before integration, verification, and validation because at this stage, a problem can cause major schedule or cost overruns.
- You cannot supervise these efforts from a desk in an office. Have team members/Government representatives on the floor during the process. This surveillance needs to be done by experienced people. The contractor also should have a floor boss. Running these processes without one can cause substantial delays.

- Scheduling time in test beds is critical. These resources will be in high demand. You need to provide professional scheduling to utilize the test beds most effectively.

Again, it is the unknown unknowns that you have to worry about. Recall an added requirement in the early Shuttle days. We were planning to install payloads in the OPF. However, DoD came up with a requirement to install payloads on the pad. This caused us problems and additional operations that we had not planned for. We were forced into an area where we had no knowledge or experience. However, we did get it done with lots of effort. ... Sometimes speed is needed over efficiency.

– Shuttle Program Manager, JSC

### **Integration, Verification, and Validation of the Space Segment**

Systems integration and test is the process of assembling and functionally testing individual instruments and spacecraft subsystems into a total, operating, self-compatible space segment system. The logical sequence for integrating spacecraft components and instruments and the functional testing of an integrated system is accomplished with test plans and procedures performed in a manual or automated manner. Ground support equipment utilized in the verification process is a fundamental element of a successful program and needs to not be overlooked.

It is imperative for the test articles to permit analysis of test data to determine the mechanical and thermal performance of the integrated system. The electrical system is functionally tested to determine the compatibility of all operating subsystems. System performance is analyzed through the data derived from the system telemetry data stream. This ensures that data interpretation is accomplished in the same fashion as expected in flight operations. Therefore, these data ensure successful evaluation of the total system compatibility.

The same functional testing process then continues into launch and space simulation environments. The team performs systems testing through all simulated environments and analyzes the data obtained. In some cases, interfacing hardware may already be on orbit, such as payloads being mounted to the ISS. High-fidelity simulators built by the project may be required to ensure compatibility on orbit or to conduct appropriate environmental testing.

Subsystem- and system-level testing includes the full range of environmental conditions the space segment will see in orbit. Various test facilities, such as vibration tables and vacuum chambers, are employed for this testing. One of the PM's challenges is to schedule these facilities to match the project schedule. More often than not there will be conflicts with other projects. This will necessitate workarounds between the projects so all can eventually complete project testing.

### **Integration, Verification, and Validation of the Ground System**

As the preparation for flight mission operations progresses, the ground segment operating elements conduct individual and cooperative tests, simulations, analyses, and assessments to validate technical capabilities, support commitments, and operating policies and procedures. These activities are intended to evaluate the ground system and to identify problem areas and required changes. The results are continually fed back into the system for consideration and

action. The objective is to enter actual flight operations with the necessary certified capability and full understanding and evaluation of constraints.

Major test phases, each with a set of objectives, timeframe for execution, and association with other test phases, include:

- System Tests
- Network Compatibility Test
- Mission Compatibility Test
- End-to-end Testing
- Mission Simulations

A test team of knowledgeable representatives from each ground system element meets at periodic intervals to define, schedule, and perform ground system testing; evaluate and document the various test definitions, results, concerns, and needs; provide technical assistance; and exchange concepts. Test team activities should begin just prior to the end-to-end test phase and will continue until launch, with activities and meetings increasing as launch approaches.

A test event schedule details in chronological order each scheduled or anticipated test. The schedule defines test dates, times, test method, participants, and responsibilities. It provides a working tool for test team members and is a historical record of the progression of events.

If I had to make a choice, I would cut that time at the integrated level to make sure that each individual subsystem really worked well. Because if you get into integrated testing with subsystems that haven't been shown to work well, the integrated system doesn't work but you can't find it. It could be anywhere, and the whole marching army comes to a halt because of one guy.

– NASA Administrator

### System-Level Testing

System-level tests begin after the element testing. They use certified or conditionally certified segments of the system to enlarge upon the scope of technical certification and to introduce the expected time dynamics of the mission. System tests are typically cooperative or joint exercises between operating elements and include the appropriate interfaces.

System testing is performed in accordance with ground system and spacecraft development schedules, beginning months or years before launch, depending on if the mission is human flight or robotic. Preparation for this testing prepares personnel for upcoming tests and helps to avoid minor, time-consuming problems during more important, time-sensitive tests. Recorded data or simulator sources usually supply the method for preliminary testing.

**Mission Compatibility Test:** Mission compatibility testing is designed to ensure complete compatibility between the mission operations center software and the spacecraft when performing all command and telemetry functions. Commensurate with software development and system deliveries, it involves several command and telemetry tests with the spacecraft.

Mission compatibility testing usually begins months or years before launch (this varies depending on whether the mission is human flight or robotic), yet is subject to development schedules. It ends upon final verification of the as-built launch hardware and software systems.

During this test, actual command loads, operational sequences, and timelines are played against the actual operating spacecraft as interfaced with the network support system. Ensure ample access to the spacecraft at planned intervals to complete this testing.

**End-to-End Testing:** End-to-end testing is defined as the evaluation and subsequent approval of each system function (space and ground) and capability working between various interfaces (prime and backup methods). A result of end-to-end testing is an assessment of final mission readiness status.

Every time we added a new command capability, we insisted on testing end-to-end even if the pieces had been tested individually or simulated.

– Mission Control Center ISS Project Manager, JSC

End-to-end testing is usually accomplished well before launch. For robotic missions, it may be launch minus six months. For human flight missions it is much earlier. Plan to do these tests on an ongoing basis as capabilities come online. This provides time to correct problems. Tests performed during this phase are loading tests, interface tests, and production processing tests. These tests emphasize data processing and interface functions and resemble mission time dynamics in amounts of data and sequencing of events. Simulator and spacecraft data sets are utilized to complete this testing phase and achieve full confidence in the ground systems. During the final phases of testing, a complete end-to-end data test is accomplished using a data set validated by the project. These tests should involve the interaction of all space segment and ground system support elements. These tests should include access by the flight operations team to the spacecraft and spacecraft data sets, and participation in the evaluation and approval cycle.

**Mission Simulations:** These simulations are the final exercises and are intended to show flight readiness from a ground operations/ground system point of view. Simulations are defined and executed as needed to familiarize operations personnel with operation events, evaluate operating procedures, and assess overall operational readiness. Launch, day-in-the-life, and contingency operations simulations, and other special events (e.g., planned orbit maneuvers), are planned and executed as needed to obtain full confidence in personnel and procedures.

My biggest suggestion is to never assume you have something understood fully or nailed down, because as soon as you do, something will come up and bite you. We recently had a problem with mating Shuttle pyro cans. It turned out there was debris that we had never seen before that caused just enough of an interference to inhibit the mating. You should always keep your processes as simple as possible.

– KSC Launch Vehicle Processing Manager

### Test Versus Analysis

Testing is the gold standard for verification and for validation. However, testing is not always possible, and balancing between test and analysis is often left to the engineers and approved by the PM. The test operations team provides some input on test versus analysis when their assessment is that the test for some objective is so simple it makes more sense to just do the test rather than to go through an elaborate analysis. Sometimes the balance is trickier. For example, with moments of inertia it is a tradeoff between a complex test setup that cannot be performed

until late in the schedule and a complicated model with many inputs and resulting uncertainties. Sometimes it is a question of fidelity. In the case of the moments of inertia, one group made the decision to verify it with a test, at least for the first flight. They also planned to run the model and compare the results so that after the first flight it might be possible to do only analysis for future flights.

### Safety and Mission Assurance

Safety and mission assurance (SMA) encompasses a number of activities including quality assurance (QA) and system safety.

**Quality Assurance:** The project develops a quality assurance program intended to ensure quality that is built into product development from the beginning. It can't be added later. QA ensures there is oversight of the hardware and software that go into the product. This program covers support to design and design reviews, documents change control, identification and traceability, procurement quality requirements, fabrication control, process control, nonconformance control, inspection and test planning, configuration verification and control system, metrology, stamp control system, statistical planning and analysis, software assurance, training, and certification for manufacturing.

Program/project managers are responsible for the quality of their assigned products and services. In earlier phases, the project manager delegates some of this responsibility to a Safety and Mission Assurance (SMA) Lead or Chief Safety Officer and prepares a Letter of Delegation (LOD), as described in *NPR 8735.2 Measurement of Government Quality Assurance Functions for NASA Contracts*. In the Implementation phases, the SMA Lead coordinates and integrates quality assurance functions performed by NASA and contractors. The SMA Lead ensures that the delegated quality assurance functions are performed in accordance with the LOD or support contract. The SMA Lead continually evaluates the quality assurance process based on contractor performance and other changing risk factors.

**System Safety:** The project and contractor prepare a System Safety Plan. The plan describes the safety program requirements and implementation procedures used to ensure identification and control of hazards to personnel and equipment during fabrication, test, ground activities, launch, orbital operations, and landing. Early in the design phase and continuing until launch, the project develops analyses that identify the hazards associated with the mission hardware, support equipment, and related software. Ground operations as they affect the payload and flight operations should be analyzed. All hazards affecting either personnel or hardware should be identified as system requirements and each requirement verified during the appropriate level of flight hardware and software testing.

Engineering and safety are closely linked in a discipline as demanding as space flight. Every engineering decision has flight safety consequences, so our engineering and safety teams must be staffed with competent engineers and space system managers to ensure we are applying an effective, risk-based approach to the design. Routine, open, and honest communications among the project management, engineering, and safety is a must.

– Stephen Cook, *ASK Magazine*

In addition to quality assurance and system safety, other functions under SMA include:

- **Parts Control:** Under the parts control program, only parts with acceptable, demonstrated performance and reliability will be used. Wherever possible, only standard parts are used.
- **Materials and Processes Control:** The project and contractor implement a comprehensive materials and processes program beginning with the design stage of the hardware. This program helps ensure the safety and success of the mission by the proper selection and treatment of the materials of construction. Selection of materials and processes should be based upon past performance, available data, or current tests.
- **Contamination Control:** Each project is required to define and implement a contamination control program applicable to its mission. The program is defined in a Contamination Control Plan that describes the specific contamination allowance for the spacecraft/instrument and methods for controlling contamination.
- **Software Assurance:** Flight software and firmware, ground data systems software, and key parameter software all require an assurance program that includes verification and validation, quality assurance, configuration management, and nonconformance reporting and corrective action. Science and data analysis software are excluded from this formal requirement. Use of the NASA independent software verification and validation facility should be considered.
- **Reliability Program:** The project and contractor plan and implement a reliability program that interacts with assurance programs for design, parts, materials, testing, and other project activities.

The project should establish design criteria and standardize the control design practices to ensure that the design is capable of:

- Functioning properly during the required mission lifetime
- Minimizing or eliminating potential sources of human-induced failures
- Permitting ease of assembly, test, fault isolation, repair, servicing, and maintenance without compromising safety, reliability, quality, and performance
- Allowing for access requirements that might arise during assembly, test, and prelaunch checkout
- Utilizing such analytical techniques as Design Tradeoff Analyses, Failure Modes Effect and Criticality Analyses (FMECA), Parts Stress Analyses, Probabilistic Risk Assessment (PRA), and Worst Case Analyses

### 5.2.B.c Product Validation

Product validation is the determination whether or not the right product was built. The verification process compares the product to the specifications to see if it meets them. Validation, however, compares the product to the stakeholder's expectation to make sure those are met (i.e., that the right product was built). If the requirements and succeeding specifications were not correctly based on the stakeholder's needs, the product could be verified but it still won't meet the stakeholder's needs and can't be validated. Therefore, the validation process starts at the beginning of the development by validating the requirements with the stakeholder and continues throughout the life-cycle process. The final validation takes place on acceptance and usually consists of some type of end-to-end test in which the proper operation of the system is demonstrated (i.e., that the right product was in fact built).

Validation, like verification, is addressed through inspection, analysis, demonstration, and test. However, the intent for validation is completely different from verification as indicated above.

While they can be done concurrently, the focus needs to be on intent to ensure both are completed successfully.

### 5.2.C Project Control

Project control includes the processes used throughout the Implementation phase to perform cost and schedule planning and management. Project control is just as critical as technical management to project success.

Project control processes are established in the Formulation phase and used during Implementation to monitor and control the project. Problems will necessitate replanning, and the resulting workarounds need cost and schedule to be redone. The configuration management process is used to evaluate proposed changes to the integrated baseline and maintains a record of approved changes.

The PM should recognize that risk management is an integral part of project control. See Section 5.2.B.a Technical Management Processes for more about risk management. Solutions may require changing schedules and/or spending money to fix problems and/or mitigate risk.

Because it is such a frequently asked question, the PM should know the current project schedule and budget status and be aware of the status of major risks.

It is OK for a project to have (and report) a problem. The Center is in place to try to help with problems where possible. If a PM conceals a problem until the last minute, no amount of resources can float a flooded ship. Some projects tend to be overly optimistic and feel that a problem is not that bad until it has gotten really out of hand. ... Basically, PMs should just be honest—bad news doesn't get any better with time. Likewise, Center managers have a responsibility to not fly off the handle at the hint of a bad news story.

– MSFC Deputy Center Director

#### 5.2.C.a Management Planning

##### Planning and Costing

Although some costing and replanning is required in Implementation, most planning is done during Formulation. See Handbook Section 5.1.D Project Planning and Control for additional information about planning and costing.

##### Planning and Scheduling

Planning and scheduling are normally associated with Formulation. The basic planning starts there and needs to be done early in the project's life cycle to result in a successful project. However, no project will be able to follow the original plan without some changes that are brought on by changing circumstances. Therefore, the project needs to retain the ability to replan and reschedule throughout the Implementation phase.

Peak workforce and spending occur midway through the Implementation phase. Schedule delays are very costly during this time. The integrated master schedule should be updated frequently, and any observed risks should have planned mitigations in place. Planning for test facilities to support verification should also be updated with workarounds in place as required. Planning

should also be diligent for supplies, materials, support equipment, and infrastructure needs for all tasks on the project critical path or near-critical path.

...as painful as it is, late is better than wrong.

– NASA Administrator

During planning, there are a number of useful optimization techniques, including:

- Prioritizing by applying resources to the most difficult tasks first. Schedule and cost are always robust early in the project, so take advantage of retiring difficult tasks as early as possible.
- Knowing where the risks will or are likely to occur, so you know where to apply funded schedule contingency. The project manager should allocate funds in the correct years to account for this. I&T is a period when problems often cause delays because things go wrong and have to be fixed. Thus, extra time needs to be built into the schedule during I&T.
- Having a good, detailed, integrated schedule that is updated monthly is very important. Take milestone metrics very seriously. The schedule can be altered quickly as problems arise to plan for workarounds.

I have the scheduler keep the schedule in front of the team constantly. The scheduler presents weekly at the team meetings. I, as PM, am joined at the hip with the resource manager and scheduler, so I get updates immediately. I use the weekly meeting to bring the rest of the team up to date.

– Project Manager, LaRC

### 5.2.C.b Cost Reserves Management

Cost reserves management is one of the most important functions of project management. It starts early in the Formulation stage when the cost estimates are done. It continues in Implementation, where the PM has to manage reserves and replan if and when the funding profile changes. Planning for a recovery from a budget cut is often a reality the PM needs to address.

#### Program and Project Reserves

Projects are required to carry a certain level of reserves from year to year (budget and schedule reserves are shown graphically in Figure 5-1). NASA requirements necessitate most appropriated funds to be obligated and costed by the end of the fiscal year and represent a cost phasing challenge for project managers in carrying project reserves from one fiscal year to another. Without a reserve, projects would have almost no way of addressing problems. Projects may also use the option to remove technical content or scope to deal with a budget problem, unless that would take the project below the minimum mission requirements. In descope conditions that take a project below the baseline performance floor, more funding would need to be provided by the program, or the project would be subject to a cancellation review.

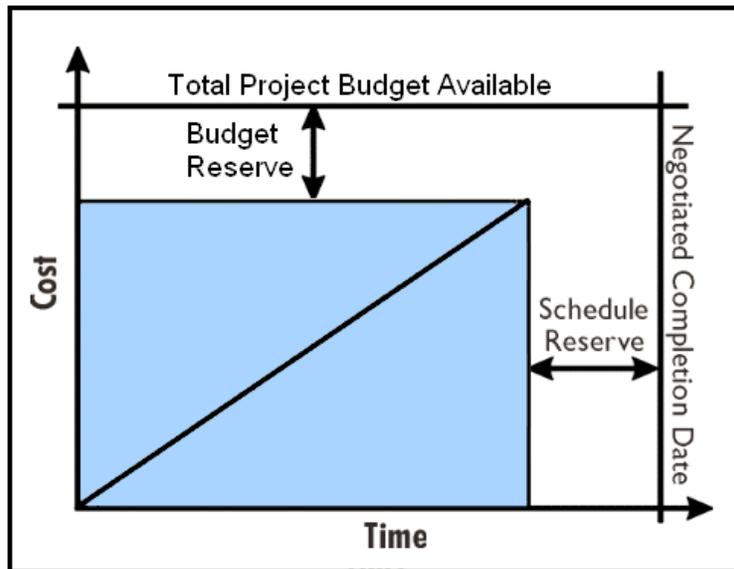


Figure 5-1: Budget Reserves and Schedule Reserves

NPR 7120.5D encourages project managers to identify reserves in the Formulation Phase consistent with project risk. The baseline life-cycle cost estimate from Phase B includes reserves, along with the level of confidence estimate provided by the reserves based on a cost-risk analysis. During the Implementation phase, the PM needs to manage the reserves that were established in previous phases.

When negotiating contracts at the beginning of a project, consider using some of the cost and schedule reserve to better ensure a solid baseline. After that (from “day two”), if you get a hit in schedule (or cost for that matter), behave as if you don’t have any reserve. Do your workarounds with this in mind. The reason is that eventually you will get to a situation where you can’t recover with any workaround and will have to use reserve.

– Project Manager. LaRC

One approach to managing reserves is described in NASA Lessons Learned Information System (LLIS), *Number 1780: How to Plan and Manage Project Reserves*.

### Managing Funding Reserves

Funding reserve should be based on two factors: known risks with contingency plans and unknown risks. The PM has several choices for managing funding reserves. One option is to allocate the reserve to specific subsystems and subprojects. Another choice is to hold the entire reserve at the project level and use it if subsystems get into trouble. A third choice is to embed the reserves in the project estimates, based on risk quantification.

Instead of maintaining explicit project reserves alongside the other budget and schedule items, some projects manage these reserves by building risks into budget and schedule items with cost and duration expanded. These implicit reserves may seem to have the same effect as explicit reserves, but their use imposes several new risks: a risk that future projects that use parametric

data from the “implicit reserve” project will have incorrect estimates and a risk of overpricing the project for the program budget.

The PM can make reserve numbers available within the project so all project team members know what reserves are, or the PM can keep reserve numbers quiet. This can be combined with management options to encourage openness but still provide control. For example, a PM on a recent successful science mission allowed science instrument teams to have insight into how much reserve he had allocated for each instrument, but reserve was held at the project level. This openness allowed everyone to see the situation but also provided oversight and control.

Reserves will necessarily decrease as the project moves through the life cycle. The usual measure of reserves is based on a percentage of “cost to go” on the project. Ideally, reserves reach zero at the successful completion of the development project. Reserves for the operations phase are separate from development reserves.

During Phase C, if the latest Phase C through phase D Estimate at Completion (EAC) exceeds the KDP C-approved integrated baseline cost for Phases C through D by 15 percent or more, the project manager is required to provide immediate written notice and a recovery plan to the program manager and the MDAA. Since the integrated baseline cost contains project reserves, an EAC exceeding the integrated baseline cost presumes that these reserves will be exhausted. The program manager may decide to spend program reserves, or the program manager may seek additional funding for the project. If reserves or funding are not available or it is not thought prudent to apply these, the project could face a cancellation review. The outcome of that review could be cancellation of the project. If it is not cancelled, the review will at least trigger replanning.

As new project risks are identified, funding reserves can be used in two ways. The PM can spend money from the reserves immediately on risk mitigation activities, or s/he could add a lien against project reserves to cover the cost of contingency activities.

There are several different ways I tried to handle risks. I had a favorite method for cost and schedule risks. I would program in extra operations on things that I thought could be difficult and the extra operations wouldn't even necessarily be in the area of difficulty. For example, if I thought that I needed two cryo-cycles on a cryo-cooler for a sensor, I would put in four into the baseline. That way of parking cost and schedule reserve would compensate me for risky areas that I could use almost anywhere in the program.

– NASA Administrator

### **5.2.C.c Schedule Reserves Management**

For most projects, the project manager can maintain a schedule reserve by scheduling activities, managing the project's critical path, and reviewing this information on a regular basis.

#### **Managing Schedule Reserves**

If a project activity takes longer than was originally estimated, the schedule reserve is decreased. If the duration of an unexpected activity exceeds the available schedule reserve, the project has run out of time. However, when the project needs exceed these planned (budgeted) schedule

reserves for any reason (e.g., very long delay in a delivery), then the project faces a problem with dollar reserves, since additional schedule needs to be funded from dollar reserves.

During Phase C, the project manager is required to provide immediate written notice and a recovery plan to the program manager and the MDAA if a Phase C or D milestone listed on the project life-cycle chart is estimated to be delayed in excess of six months from the date scheduled in the KDP C-approved integrated baseline. This requires at least an immediate update to the Project Plan per direction received from the program manager.

The program manager needs to decide a course of action. This will depend on the project's impact on the program. The decision also depends on whether the project is in a tightly coupled program or an uncoupled program.

As new project risks are identified, schedule reserves can be used in two ways. The project manager can spend time against the schedule reserves immediately on risk mitigation activities, or s/he could add a lien against project schedule reserves to cover the time required for contingency activities. This is analogous to the use of funding reserves.

The project manager can sometimes spend money from the funding reserves to accelerate some tasks along the critical path, effectively buying more schedule reserve. However, experience shows that this technique doesn't always work. There's a risk that the money will be spent with no acceleration in schedule and a risk that accelerating your carefully planned activities will introduce defects into products that are critical to the success of the project. There is also the risk that you'll spend the money, buy yourself some schedule relief, and then the due date slips because of completely unrelated factors, effectively wasting the money.

### 5.2.C.d Implementing Project Cost and Schedule Control Activities

By the Implementation phase, most planning is already completed. Replanning is continually required to contend with the inevitable changes that occur in complex engineering efforts.

The PM can use a variety of tools for project control, including Earned Value Management and schedule risk analysis. A PM's job of project control is often as much diplomacy as it is command and control. This includes engaging with the project staff and the other parts of the team (e.g., engineering, contractors) to make sure everyone understands the cost and schedule issues. This is where leadership is important.

In my career, I've worked for a lot of really good managers, and of course Gene Kranz was one of the best. One of the things I really admired about Gene ... is that if things didn't work out quite right in a project or in a thing that you were doing, Gene would often say, "Well, maybe I didn't explain as clearly as I should have what it was I needed you to do."

– Mission Control Center ISS Project Manager, JSC

The PM sets the schedule and engages stakeholders in dialogue about their needs and expectations, but it's the Deputy, among his/her other duties, who repeatedly calls for status information or nags delinquent team members about overdue action items. This good cop/bad cop scenario can help the PM maintain cordial relationships with the team while still providing a steady positive pressure on cost and schedule. Using this method requires the PM and the DPM to work very well together, and it also requires allowing the DPM opportunities to be the good

cop and to praise and give accolades to team members. If there isn't a balance, the DPM can be seen as actually in charge or the DPM may become ignored over time, as s/he becomes associated with only negative input.

Regarding the monthly reports from the contractor ... it is important for the project financial people, technical people, and schedule people to sit down together monthly to analyze these reports together to cross-check their correctness.

– GOES Program Manager, GSFC

Balancing cost, schedule, and technical activities requires an infrastructure that enables the project to collect and maintain the necessary information. Making good decisions regarding the project requires the PM to assimilate the various key pieces of information and provide direction to the team. Adjustments need to be made as the project progresses and the PM must have a diverse set of skilled personnel with which to discuss the implications of key decisions.

### Managing Funding Profile Changes

The PM is responsible for developing a strategy to implement the project within a defined cost and schedule and to get this strategy agreed to during the Formulation stage. Planning includes estimating the amount of resources required in each year to accomplish the goals set for the planning time period. This includes the personnel and skill sets needed to accomplish the tasks.

If projects are planned properly, a cost profile that ramps up fairly quickly in the early part of the project is typical. This type of cost profile is highest during Phase C and Phase D, when the design and fabrication effort is at its peak (see Figure 5-2).

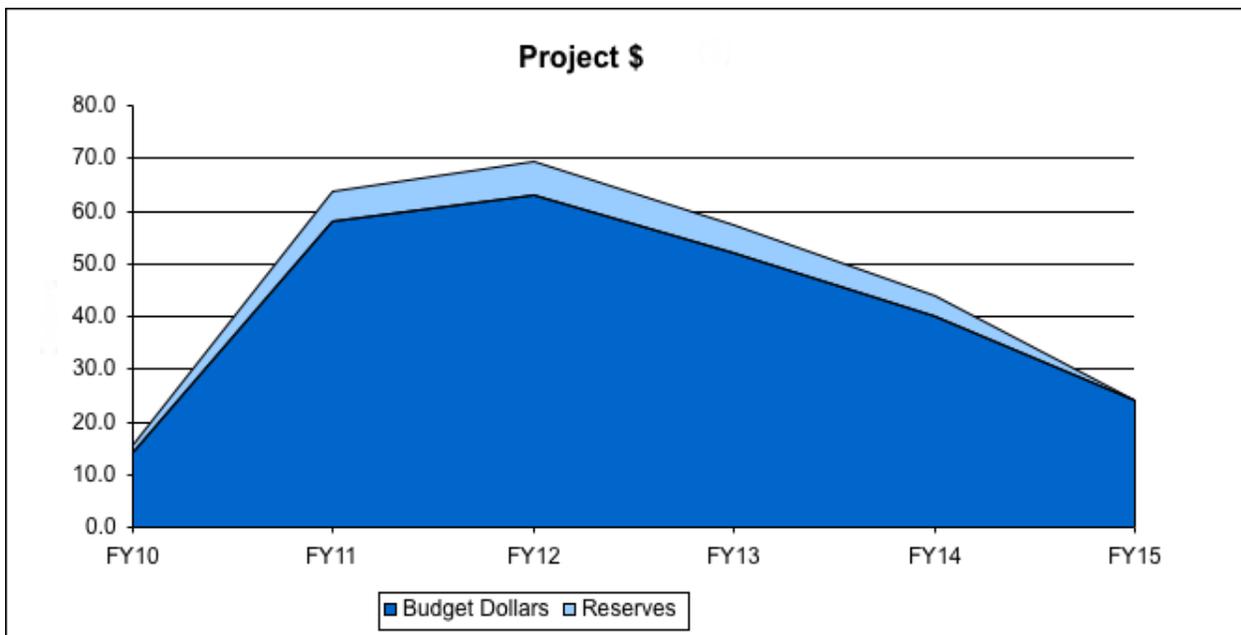


Figure 5-2: Typical Funding Profile

However, several issues commonly arise during project planning that hinder a project manager’s ability to implement a project according to an ideal project template. Experience is crucial to developing a strategy that addresses the issues associated with project cost and schedule implementation.

**Staffing:** Inability to acquire needed staffing/expertise in a timely manner. Often, the necessary skills are not obtained early enough, and the cost associated with obtaining these skills does not meet projections. This may cause a buildup of reserves early in the project (see Figure 5-3).

**Budget Resolutions:** Unexpected funding changes for any reason. One example is the delay in funding because of a Continuing Resolution. A project on the upward slope of this curve may be held to the previous year’s funding limit. This will require replanning for the delay and potentially add to the total project cost. If reserves are available, the project should be able to develop a plan to execute key elements during a Continuing Resolution. The project should expect this common type of perturbation and proactively plan for it.

**Schedule Slips:** Unexpected delays, technical issues, or cost issues often affect the ability of the project to maintain the planned schedule. Changes to the plan should be addressed as soon as the issues are identified, and the PM should lead the team to the appropriate solution while balancing technical, cost, and schedule issues.

**Lack of early funding:** Although reasonable in Figure 5-2 above, there is often a problem getting sufficient finding early in the project. The project manager needs to proactively address this issue in the same way the Continuing Resolution issue would be addressed.

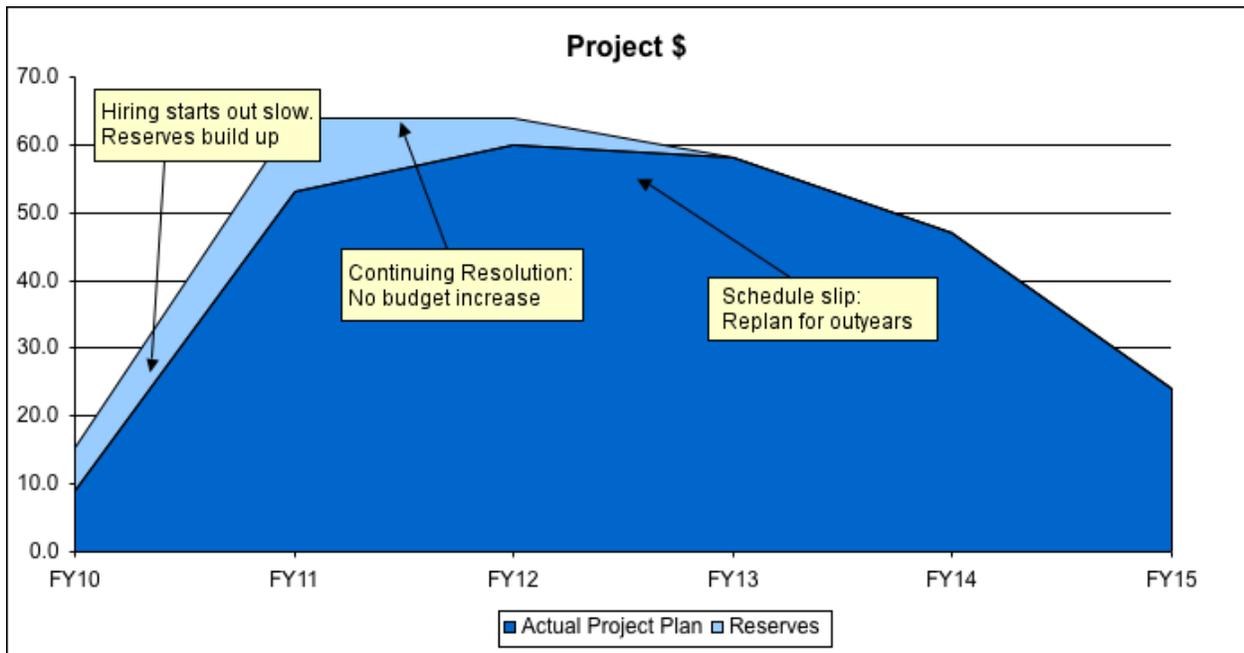


Figure 5-3: Impacted Funding Profile

## Recovering from Budget Cuts

Factors outside the project can result in budget cuts during any fiscal year of the project. Such cuts can be the result of changes in Agency policy, Congressional cuts, or overruns by other projects in the program that necessitate moving funding from one project to another. The PM needs to assess the consequences and determine how the project can recover. There is no single answer or approach that can be applied for all budget cut cases. All cases are unique. Reviewing past situations and understanding the approach may be useful when deciding how to proceed; some previous cases are provided below. It is also a wise practice to seek out other PMs who have dealt with similar budgetary cuts for advice and insight.

If there are changes to the baseline that are outside the project manager's control, s/he should seek a new agreement between the project and the program so the project manager is not held accountable for things outside his or her control.

Budget cuts often ultimately result in cost and/or schedule increases: commonly, the project will generally lose two dollars for every one dollar cut and/or experience a schedule delay on the order of 1.5 percent for every 1 percent of budget cut. This is generally true regardless of when the cut occurs, although the absolute dollar impact will be higher during periods of peak funding. A cut early in the project will have a larger downstream inflationary impact and may well affect the PM's ability to attract and retain a highly qualified team. Although more unlikely, a cut late in the project, when much of the work is done, will likely have a significant impact on morale (people will already be thinking about their next job and will be tempted to move on just when you really need them). Typically, a project will try to keep the core team together through risk mitigation or other activities. Obviously, these activities will do no harm, but they also may be unnecessary.

In addition to these straightforward impacts, the PM should anticipate that most, if not all, contractors will take advantage of any such change in funding to get well. This alone could produce a two-for-one or greater total cost impact, since it creates an undefined contractual situation that needs to be negotiated in an environment where the Government has little or no leverage.

All of the above assumes a mission with launch readiness date (LRDs) that can move to the right because a launch opportunity will still be available once the mission is ready. This is often not the case with today's very crowded Expendable Launch Vehicle (ELV) manifest. A delay of a couple months in the LRD could easily result in losing the launch slot, forcing an actual launch delay of many months. This is in addition to the launch delay penalties that would kick in. These launch delay penalties are a result of breaking the agreement with the launch vehicle supplier. For planetary missions, a month slip out of the scheduled launch window could force years of delay. Earth science missions are not immune to this complication. There may be restricted launch intervals due to solar illumination effects during ascent or time-of-year restrictions. The time-of-year restrictions may be because the Earth science mission needs to be operational during certain seasons. These difficulties are not limited to ELV launches and the ELV manifest. The same issues apply for human flight missions when a particular initial launch date is declared.

WISE was impacted by budget cuts and threats of cancellation. Budgets were cut by 50 percent halfway through the fiscal year as the project was getting ready for the mission confirmation review. This happened two years in a row. Lesson learned: you have to figure out a way to do *something*. You have to get creative to find a way to continue to produce. There is less money available for the year, but what can still be accomplished and which tasks does it make sense to proceed with? Being nimble and adaptable in the face of the programmatic disruptions was the key.

– WISE Project Manager, JPL

There are usually only three viable options in the face of a significant budget cut: slip the launch, descope the mission, or both. The gain from the descope option diminishes quickly as the mission gets into Phases C or D. LRD slips are almost unavoidable when facing a significant budget cut in Phases B, C, or D. Resist the temptation to cut into reserves since it is inevitable that the reserves will eventually be needed. They were built into the budget with that anticipation, and previous development experience has shown that they will be needed to accomplish the mission. Also, be wary of cutting back on Phase E operations, as this is ultimately self-defeating since the ultimate point of a science mission is data gathering and processing. NASA does not typically turn off healthy missions that are still taking useful science data.

Numerous examples exist of the nonlinear impact of budget cuts. One example is from a robotic mission that had a planetary launch window every two years; a slight slip in the LRD actually meant a 2-year slip in the mission. In another example from the Shuttle program, development funding of one of the Shuttle's systems was reduced from \$10 million to \$5 million early in the program. There was little impact on the ultimate development cost, but the operational cost increased by \$2.5 million for each year of the 30-year operational life.

Software programs are being developed to answer the question, "If I receive a budget cut in phase X and constraints Y and Z apply, how do I ascertain the budget payback needed to complete the mission?" One of these programs is the Q-TIPS (Quantitative Techniques for Incorporating Phase and Schedule) program developed at MSFC. One example is: You are given a budget cut in Phase A with the constraint that the launch date needs to stay fixed, but you are allowed to adjust content of the program (i.e., descope). The program result might show a 1.5 percent total project cost growth for every 1 percent the schedule was compressed (i.e., to maintain the current LRD). Although this type of software program might provide useful information, the present state of the art for deciding impact still needs to be done on a case-by-case basis.

### **5.2.C.e Providing Oversight/Insight with Contractors and Others**

Insight and oversight are both used in the project management process. Insight refers to the understanding of what is going on; according to one dictionary definition, "penetrating mental vision." Oversight, on the other hand, refers to a more active participation in the process; according to one dictionary definition, "supervision; watchful care." The PM needs to be able to determine where one or the other needs to be used in the development process, both with contractors and in-house. Insight is a surveillance strategy that relies on NASA understanding, validating, and monitoring the contractor's management systems and performance metrics.

Oversight is a surveillance process that implies a more active supervision of a contractor's processes and decision making. Oversight is often used in problem areas.

On-site representatives—NASA and Defense Contract Management Agency (DCMA) personnel at contractors' facilities—can be important to mission success. Representatives can learn a lot just by attending meetings and listening. Having a reliable person on site to report back to the larger team helps build confidence in a job being performed away from the majority of the team. Project leads should also spend time at contractor facilities. This should be scheduled not as just one- or two-day meetings, but as extended stays such as a week, so that leads can build good communications and rapport with their contractor counterparts. The PM should also spend a lot of time at the contractor facility to get a feel for what motivates the contractor. Motivation may not be driven merely by profit motive. For example, one PM spent time at the contractor's facility and found they were concerned about receiving certain award fee scores on tasks. Once he learned this, the PM was able to tailor his approach to the contractor so that both parties could benefit. Information such as this can help the PM push in some areas and pull back in others, but only a good working relationship with the contractor provides this sort of insight.

You also can pick up other information during an extended stay, such as the makeup of the contractor team. Are they pulling their best people off to work another project? This information is important in dealing with the contractor. In addition to talking to the contractor's management, talk casually to the people on the floor to find out what's really going on.

Part of providing oversight both to the Government project team and contractors is to choose good people and allow them to do their jobs.

If you have good people, don't muck with it—allow people to do their jobs. People must be able to push back on things that don't make sense. The PM needs to listen to experienced people or fully explain why another path is being chosen. An example involved a PM wanting to have special tests performed on an apogee kick motor. The motor expert tried to explain why the test was not necessary. The PM ultimately dictated that the test be performed. The expert performed the test exactly as dictated with no useful results. If the PM had explained what was required from the test, rather than dictating how the test be run, a different conversation would have taken place and valuable time and flight hardware would not have been wasted.

– GSFC Deputy Director

The PM needs to provide oversight and coaching to his or her own team, also. This means providing a lot of feedback. Although you do want to let people do their own jobs, there is always an element of oversight responsibility. Asking questions about the decision process and engaging the team member helps both understand and reconcile a decision—even if one party isn't satisfied, at least the team member was heard. A common question to ask your team members is “What led you to this decision?”

Step in where you see people not working together. I had an example where the contractor mission operations team and the Government mission operations team were not dealing with one another. The contractor team didn't want the help, but they couldn't do the job, either. I stepped in with a two-day team-building exercise. My basic position was "I don't care what is in the contract. What do we have to do to get the job done?" They worked at it for two days and reasonable people figured out how to do the work. Then they changed the contract to account for the new way of doing business.

– GOES Program Manager, GSFC

You need to learn who you can push, when you can push them, and also when you can't. Know your people. Take time to learn what is happening in their personal lives and take those things into account. Don't react negatively right away when you are being pressed for change you don't think is possible. Take it in, think about it, and talk to the people proposing it.

### **5.2.C.f Contract Management**

Most projects will have a major part of the project work done on contract, most often with a major aerospace company. The acquisition process results in a contract between the Government (NASA) and the contractor. This contract is managed by the project. The Contracting Officer (CO), the Procurement Manager, or someone who works for the Procurement Manager is the Government's certified spokesperson for the contract. The CO is the only Government person allowed to direct the contractor, and that direction is done within the stipulations of the contract. The Contracting Officer's Technical Representative (COTR) is the member of the project team who provides technical expertise and aids the CO in providing contract direction.

It is important for the project manager to make sure all employees working on the project are informed they are not allowed to give direction to the contractor. Direction given, even casually, will obligate the Government and impact the work specified on the contract.

#### **Contracting Officer's Technical Representative**

A Contracting Officer's Technical Representative (COTR) is appointed for each contract to monitor the contractor's technical, cost, and schedule performance. Technical monitoring means being aware, in a timely manner, of what the contractor and subcontractors are doing and not doing in all aspects of their work on the contract. On all large contracts, it is common practice to have one or more Government plant representatives (project and/or DCMA employees) on full-time duty at the contractor's plant. The representatives should keep in touch with the progress of the work and represent the project to the contractor and report on all significant events or lack thereof to the PM. The plant representatives and their accommodations at the contractor's plant are specified in the RFP and negotiated in the final contract. The COTR may be the PM, the DPM or a project team member just below the Project Manager.

#### **Contractual Documents and Control**

A Work Breakdown Structure (WBS) is included in the RFP package for the contract. A detailed WBS is one of a PM's fundamental tools. During negotiations, a contract WBS is generated to the appropriate level to support the needs of the project to monitor, direct, and control the contractor. The contractor WBS is subordinate to the project WBS and needs to identify the

individual responsible for the work and a basic milestone schedule. Development of a detailed WBS by the contractor and NASA, along with the specific need dates for each specific work package in a master schedule, is a powerful tool for developing full understanding of what the total job really is. Developing the WBS often exposes elements that need to be done or scheduled differently to meet the orderly flow of the total job. Tracking all work package elements should be performed by a hierarchical tracking system. The contractor and the project team need to be diligent in using the tracking system and taking corrective action once problems develop, so that they will eliminate or minimize schedule impacts. A detailed WBS is also fundamental input into the Earned Value Management (EVM) system that projects are expected to implement.

### **Contract Reviews and Meetings**

The contract should specify the full range of reporting, its content, and the schedule for all reports. Major meetings and reviews also should be specified along with the planned locations.

Effective project management depends on constant and open communication between the PM, the Center technical and business staff, and the contractor(s). The format for this communication is less important than its timeliness.

Periodic visits to the contractor's plant by both technical and resources personnel are greatly encouraged to fully evaluate status and progress on the contract and to assess the confidence and ability of the individuals performing the work to accomplish their responsibilities consistent with the contractual requirements.

The PM has an extensive range of management tools available to quantitatively measure a contractor's progress. The daily/weekly technical, schedule, and cost interchange between the project staff and the contractor should ensure that all problems surface quickly and are effectively dispositioned. The monthly formal EVM and/or business submission also serve as a valuable tool to highlight technical areas that are not being accomplished in an effective manner. The PM needs to understand these tools to become totally comfortable with utilizing them in the day-to-day management of the project. Formal monthly reviews should be conducted with the contractor staff to assess progress and highlight areas that need special attention. Periodic reviews with Center management should also be conducted. The contractor should be involved in all aspects of the planning, preparation, and conduct of these reviews.

Award fee contracts, a type of cost-plus contract, provide an excellent means of measuring contractor performance. Establishing a small number of technical and business milestones that need to be accomplished to maintain the project technical schedule and cost performance provides an opportunity for the PM to quantitatively monitor progress. The contractor understands the importance of meeting milestones. The PM should provide formal feedback to the contractor at least once during the award fee evaluation period to ensure the project and contractor teams mutually understand project status.

### **5.2.C.g Integrated Logistics Support**

Integrated Logistics Support (ILS) major elements include inventory management and control, storage, warehousing, packing and crating, and transportation for mission-critical space flight hardware, flight spares, and electrical and mechanical ground support equipment. The PM needs to ensure these essential activities are planned early and accomplished on schedule throughout the project. Transportation can be as stressful as some launch environments and needs to be

considered in the design process. ILS activities begin in the design and development phase of a project and continue through verification, validation, and pre- and post-launch activities.

Major ILS elements for a project at minimum life-cycle cost are:

- **Transportation:** All necessary actions, resources, and methods required to ensure the proper and safe movement of project systems, material, flight hardware, documentation (including drawings and photographs), and support equipment.
- **Supply Support:** All actions necessary to provide expendable and recoverable material such as spares, parts, and equipment to ensure a system meets operational objectives.
- **Design Interface:** The interaction and relationship of logistics engineers/specialists with the design engineers in the systems engineering process to ensure logistics supportability requirements influence project definition and design so as to reduce life-cycle costs.
- **Support Equipment:** All mechanical and electrical ground support equipment and flight hardware required for the development, production, and operations of systems.
- **Technical Data:** Obtaining, verifying, and maintaining the recorded scientific, engineering, and technical information necessary to define, produce, test, evaluate, modify, deliver, support, and operate a system or system element.
- **Maintenance:** The process of planning, establishing, and executing repair and servicing concepts and requirements to ensure the sustained operation of project systems.

## 5.2.D Conduct KDP Readiness Activities

Phase C includes the CDR and SIR. Phase D includes the System Acceptance Review (SAR), Operational Readiness Review (ORR), and Flight Readiness Review (FRR). These life-cycle reviews give the Decision Authority insight into the development status of the system as it matures from design through integration, acceptance by the customer, operational readiness, and readiness for final deployment or flight.

### 5.2.D.a Life-Cycle Reviews

The project should plan to archive data at each life cycle or KDP review. This provides a continuous project record and, in the event of termination or at project end, reduces the burden on the project team as team members are released to other projects.

I desire tough review board members who really know their areas of expertise. I want people who work hard at reviews, ask a lot of questions, and write a lot of RFAs (Requests for Action). Reviews allow the project to tap high-quality people with a lot of experience. In a sense it's free labor. These are good people to glean information from. Many look at reviews as a burden. I do not. We answer every RFA. There are no rejects or RFAs tagged as advisory. Every RFA is worked to the point where the initiator concurs with the closure.

– WISE Project Manager, JPL

### Critical Design Review

The purpose of the Critical Design Review (CDR) is to demonstrate that the maturity of the design is appropriate to support proceeding with full scale fabrication, assembly, integration, and test. It also demonstrates that the technical effort is on track to complete the flight and ground

system development and mission operations to meet mission performance requirements within the identified cost and schedule constraints. CDR is supposed to occur when the drawings are 90 percent complete, but that criterion is rarely the sole determining factor for timing the CDR. For robotics projects, the Project CDR is scheduled when the system design and subsystem interfaces are mature enough to proceed with detailed subsystem CDRs. The detailed drawings are then reviewed at the lower level CDRs and associated manufacturing reviews.

In preparation for CDR, the project team needs to have completed the PDR and all associated action items. The technical team, project manager, and review chair need to develop and agree upon a preliminary CDR agenda, success criteria, and terms of reference as called for in NPR 7120.5. The technical team needs to develop and publish the CDR technical work products listed in NPR 7123.1, following the guidance of *NASA/SP-2007-6105 Rev 1 NASA Systems Engineering Handbook*. The PM needs to prepare evidence to show progress against management plans, budget, and schedule, as well as risk assessment. NASA Earned Value Management (EVM) is the standard tool for large projects to show that evidence for technical, cost, and schedule parameters. See Handbook Section 5.1.D.e Earned Value Management for additional information about EVM.

Because the design is approximately 90 percent mature at CDR, this a good time to examine improvements and inventions created by the project to disclose new technology and identifying opportunities for patents.

The results of CDR are used to inform the Program Manager for the decisions made at KDP D. In addition, CDR results are used as part of the CMC findings and recommendations, PM recommendations, and SRB report presented to the mission directorate PMC. At the discretion of the NASA MDAA, these review results may also be reported to the Agency PMC. They automatically go to the Agency PMC if it is a Category 1 project.

### **System Integration Review**

A System Integration Review (SIR) ensures the system is ready to be integrated. Segments, components, and subsystems are reviewed to ensure they are available and ready to be integrated into the system. Integration facilities, support personnel, and integration plans and procedures also are reviewed to evaluate if they are ready for integration. The SIR is conducted at the end of the final design phase (Phase C) and before the systems assembly, integration, and test phase (Phase D) begins.

In preparation for the SIR, the project team needs to complete the CDR and all associated action items. The technical team, project manager, and review chair need to develop and agree on a preliminary SIR agenda, success criteria, and terms of reference. The technical team needs to develop and publish the SIR technical work products listed in NPR 7123.1, following the guidance of *NASA/SP-2007-6105 Rev 1, Table 6.7- 11*. The project manager needs to ensure the quality control organization is ready to support the integration effort and must ensure adequate training in integration and safety procedures for support and integration personnel. The project manager needs to ensure that verification and validation plans, integration plans, and test plans are ready for review. (See Handbook Section 5.2.B for additional information about verification and validation.) The results of the SIR are used to inform the program manager for decisions made at KDP D.

### System Acceptance Review

The System Acceptance Review (SAR) verifies the completeness of the system and assesses compliance with stakeholder expectations. The SAR examines the system, documentation, and test data and analyses that support verification. The SAR also ensures that the system has sufficient technical maturity to authorize shipment to the designated operational facility or launch site.

For robotics flight projects where the customer is often an integrated part of the project team, this review is unnecessary and is not included in the NASA life-cycle model, per NPR 7120.5.

In preparation for the SAR, the project team needs to develop the documentation and information described as entrance criteria in NPR 7123.1, following the guidance of *NASA/SP-2007-6105 Rev 1, NASA Systems Engineering Handbook*, Table 6.7-13. The PM needs to ensure that appropriate attention and resources are focused on developing the documentation and information in those documents, so that the project will be ready for the review.

The results of the SAR are used to inform the program manager for decisions made at KDP E. Upon successful completion of the SAR, the system is accepted by the appropriate stakeholder, and authorization is given to ship the hardware to the launch site or operational facility, and to install software and hardware for operational use.

### Operations Readiness Review

The Operations Readiness Review (ORR) examines the actual system characteristics and the procedures used in the system's operation to ensure that it is ready for operation. The ORR ensures that all support (flight and ground) hardware, software, personnel, procedures, and user documentation accurately reflect the deployed state of the system.

For human space flight Programs, the ORR involves the assessment of the flight crew and ground operations readiness to conduct flight operations. This review establishes the baseline for operations of the flight vehicle. The review also includes an assessment of the ground operations communications and data equipment readiness for use. Completion of the required training, the Flight Rules and Flight Data File are also assessed. The results of the review are to establish readiness to perform the flight mission or plan. This review normally precedes the Flight Readiness Review conducted to assess all aspects of the space vehicle, ground teams, and items associated with Launch Commit Criteria. The Launch Commit Criteria establishes the functional criteria for all systems to be ready for launch.

In preparation for the ORR, the project team needs to develop the documentation and information described as entrance criteria in NPR 7123.1, following the guidance of *NASA/SP-2007-6105 Rev 1 NASA Systems Engineering Handbook*, Table 6.7-14. The PM needs to ensure appropriate attention and resources are focused on developing the documentation and information in those documents, so that the project will be ready for the review. The results of the ORR are used to inform the program manager for the decisions made at the FRR and KDP E.

### Flight Readiness Review

The Flight Readiness Review (FRR) examines tests, demonstrations, analyses, and audits that determine the system's readiness for a safe and successful flight or launch and for subsequent

flight operations. It also ensures that all flight and ground hardware, software, personnel, and procedures are operationally ready.

In preparation for the FRR, the project team needs to complete the ORR and all associated action items. The project team needs to also develop the documentation and information described as entrance criteria in NPR 7123.1, following the guidance of *NASA/SP-2007-6105, NASA Systems Engineering Handbook*, Table 6.7-15. The PM needs to help the project team prioritize the closeout work leading to the FRR. If necessary, the PM should reassign resources within the project (or seek external help) to ensure all critical items are completed. The result of the FRR is a signed Certification of Flight Readiness (CoFR). The CoFR is used to inform the governing authority for decisions made at KDP E.

### 5.2.E Instrument-Specific Information

Due to their complexity and one-of-a-kind nature, science instruments require special attention to project planning and control. Instrument managers need to be involved in a very timely manner in project-level decisions that impact instrument development. The instrument manager should be afforded the opportunity to discuss any impacts prior to implementing changes to baselines.

During the early implementation phase, the project is developing appropriate test beds for testing flight hardware. Science instrument managers should pay special attention to these. An important aspect of the test beds is to involve the operations and science teams early. Test beds not only provide test articles for qualification and acceptance, but also provide a learning tool for handling and processing instrument data, as well as providing experience on instrument-unique behaviors and idiosyncrasies.

## 5.3 Operations

### 5.3.A Introduction

The principal job of the project during operations, i.e., once the project is launched and the spacecraft clears the tower, is to execute the mission and to analyze and archive the data and any returned samples. This section corresponds to NPR 7120.5, Sections 4.8 and 4.9.

A successful operation phase depends on all the preparations made in previous phases. Extensive mission simulations, for example, will include not only the development team, but also the operations team. These system-level tests are discussed in Section 5.2.B.b Product Integration and Verification. Operations and handling anomalies are covered in Sections 5.3.B Perform Technical Activities.

### Planning for Robotic Space Flight

The process for conducting operations of robotic missions varies from Center to Center. For example, at JPL, the same team that carried out mission implementation during the earlier life cycles usually remains largely in place during phase E operations. At GSFC, separate operations organizations take over routine operations for most missions once they have been checked out on-orbit by the implementing organization. A formal acceptance review is held, at which time (if the review is successful and all the requirements are met) responsibility for operations is handed over to the operations organization and the original project team is disbanded. Individuals within

the operations organization are assigned responsibility for the different missions. These individuals manage the project during the operations phase. The operations phase is where all of the preparation and training performed in Phase D is utilized in Phase E.

Operations people need to be retrained every time the game changes. For example, operating an orbiter is different than operating a lander or rover; deep space missions with large round-trip flight times versus Earth orbiters with instantaneous commanding. Projects working with a contractor are different than in-house projects. One Lockheed Martin project to the next could be expected to be similar, but a project with Lockheed Martin would be different than a project with Ball Aerospace. With any contract relationship, there are two teams that really need to be one.

– MRO Project Manager, JPL

### Planning for Human Space Flight

For human space flight, the number and complexity of activities prior to launch constitute major activities that affect readiness for launch. These activities include developing training facilities, training procedures and checklists for flight crew members and ground crew members, Flight Rules, and logistics requirements necessary to support the flight crew. In addition, the necessary health and medical support required to keep the crew healthy in microgravity or reduced gravity environments need to be considered. The operations phase is where all of this preparation and training come together to execute the mission.

Human space flight has some unique challenges for a project manager. Several recent programs have been criticized based on the operations costs for the program. In the earlier phases of a program, it is difficult to estimate cost of operations accurately. Program and project managers need to understand the cost drivers for operations.

Cost of operations depends on many factors; however, some of the main factors affecting operations costs include:

- Training time required to prepare the flight crew and ground crew
- The number of shifts planned for operations
- The number of subsystem support teams necessary to support the flight vehicle(s)
- The number of critical systems, such as power, thermal rejection, attitude control, command and control, and life support
- The decision-making process during flight operations and the number of personnel required to support critical decisions
- The amount of hardware processing, integration, and sustaining engineering being performed
- Vehicle production, sustaining engineering, logistics, ground processing, and design center support

During early phases of the project, incorporating the operations team into the design process will address several of the challenges. Operations team members help address spacecraft functionality by providing valuable knowledge, including which functions should be controlled by the ground team versus those controlled by the flight crew. They can also help identify processing requirements that may be difficult to work around. For example, access points for lifting and handling, tests, repairs, inspections, and component replacement need to be designed into systems from the beginning.

Flight crew support requirements have significant effect on operations cost and schedules. PMs should use *NPR 8705.2, Human-Rating Requirements for Space Systems* and Human Interface Standards (versions vary by program) to become familiar with human space flight issues. Significant human space flight design issues include radiation shielding and monitoring, potable water capabilities, food preparation, and waste handling. Weeks prior to launch, access to crew members is restricted to prevent biological pathogens from infecting the crew. Postflight, the crew needs a program for readapting to a 1-g environment. These requirements and standards constrain design and operations solutions.

### 5.3.B Perform Technical Activities

#### 5.3.B.a Execute the Mission

##### Robotic Missions

For robotic missions, an Operations Plan is developed prior to launch. This document details the operations organization, processes, and procedures to be followed by the operations team, the software tools that support them, and the interfaces between the teams. The PM needs to ensure this documentation has been prepared and that the operations team has been trained in the processes, procedures, and interfaces prior to the start of Phase E. The PM must also ensure procedures are followed during operations. It is likely that some procedures will change during execution of the mission, but such changes need to be controlled and documented. Since personnel turnover may occur during Phase E, this is essential to ensuring that current, accurate training information is available to new personnel. Ideally, when turnover occurs, the PM should ensure there is personnel overlap, so the new team member can go through the process first as an observer and then with an experienced person acting as his or her copilot.

The best way to train the initial operators is to involve them in the development and testing phases. The PM should consider assigning personnel to these tasks while the project is still in Phases C and D. Use this as a consideration for selecting personnel to staff the flight team.

It is important to keep the spacecraft simple by keeping the mechanism and deployable count low. It is also important to do realistic testing that involves the operations personnel.

– Spitzer Project Manager, JPL

Another essential ingredient for successful execution of the mission is the Mission Plan, which documents the planned spacecraft activities during the mission. Included in the Mission Plan are the operations scenarios and timelines of mission critical events that drive flight and ground system requirements and guide system testing. Some missions have a very clear objective and a straightforward, well-defined plan. Other missions have a higher level plan, but the details evolve as the mission is executed. The Mission Plan and the planned spacecraft activities within it are used to plan operations workforce levels, so it is important for the PM to be directly in line with configuration control of this document. A change to this plan can affect the Phase E budget and/or the project risk posture, but it can also affect the ability of the project to meet its objectives.

A necessary part of any good plan is contingency planning. It is important for the flight team to identify both potential problems and contingency plans to mitigate or ease the impact. While it is not realistic to expect to have a predesigned contingency plan for every possibility, the process of developing some contingency plans prepares the flight team for dealing with problems when they occur. If contingency planning is at least partially integrated with the design phase, it can also help in developing better, more reliable designs.

Odyssey developed several contingency plans in support of Phoenix landing, but no one planned on the MRO UHF radio resetting and being unable to provide support. The result was that Odyssey had to provide all of the relay support instead of sharing it with MRO.

– Odyssey Mission Manager, JPL

### Human Space Flight Missions

After launch and into mission operations, the PM for development turns over mission responsibility to the JSC Missions Operations Directorate (MOD) and the Flight Crew Operations Directorate (FCOD). The MOD and FCOD will implement mission operations under the management guidance of a mission management team.

The Mission Operations Plan includes establishing the capability to monitor the operations of the spacecraft and to address the needs of the flight crew. The operations of the spacecraft include monitoring the health of the subsystems and providing spares and maintenance necessary to maintain the spacecraft. This requires significant logistics planning to establish how many spares are required on board and when additional spares should be delivered to the spacecraft. Changes to this plan are especially important for human flight missions using the same vehicle (e.g., Orion) for multiple missions. Any changes need to ensure the risk posture, for example, is appropriate for the reused vehicle.

Flight crew training is a major element of mission success. Automatically controlled hardware is run by ground operations personnel, much like it would be for a robotic mission. Operator-controlled hardware requires flight crew training. It is essential to identify early in the project which flight hardware functions are operator-controlled and which are automatically controlled.

Flight crew training requires a variety of training facilities and equipment to simulate the operation. The training environment should be as close to the flight operation as possible. Cost associated with developing and operating training facilities are high. For this reason, each training facility develops requirements to support the minimal acceptable fidelity for flight crew training. The costs increase according to the fidelity required. If a simulation of zero-gravity is required, the cost can be prohibitive if the project has not planned for this requirement in advance. The project or program manager should involve the flight crew and operations team early in the project to help drive out the requirements for training facilities and ensure adequate costs have been included in the budget.

The flight crew training team develops a training plan to establish the amount of training each crewmember is required to accomplish. The training plan includes the delivery schedule for the training hardware, the facilities required to accomplish the training, and the schedule for developing flight crew procedures. Training can start as soon as the equipment, procedures, and facilities are ready. Because flight crew responsibilities vary, custom training procedures must be designed for each crew member. Training for a backup crew is also implemented, so crew

members can be changed if needed. Each crew member has only a certain amount of time per week devoted to training. Most flight crew members will tell you that during the last few weeks before the flight, everyone wants to get in more training. However, it is important in the last few weeks prior to a mission for the crew to take time to rest. The project manager needs to ensure that the flight crew is adequately trained, but also that they are well rested just prior to launch day.

Human space flight program operations teams also need to be trained. Human flight missions use Flight Rules to govern operations team responses to expected or anomalous events. Flight Rules determine the boundaries for operation of the spacecraft, the flight crew, and the operations personnel and are a key way to ensure the mission safety. Flight Rules need to be complete and fully understood prior to the mission, and operations personnel and crew members need to follow them during execution of the mission.

In addition to the Flight Rules, human missions prepare a Flight Data File, which includes procedures and checklists used by the flight crew. The Flight Data File helps coordinate flight crew and operations personnel by providing necessary reference material that can be identified during communications between the flight and ground teams. The Flight Data File must be complete because the crew follows only the procedures and checklists contained within it.

There is limited time available to perform tasks on orbit and these tasks have competing priorities. Each flight time increment can only accommodate a finite number of tasks. Due to adaptation to microgravity, early in the flight there is usually a crew time factor used (e.g., 1.5) when allocating time for tasks during the adaptation period. In addition to time for mission tasks, time is allocated for crew exercise, sleep, planning, meals, and private medical conferences with the flight medical officer. All of these other activities associated with maintaining the flight crew limit the time available for flight tasks. The PM must be aware of this resource and ensure proper management of crew time during operations.

### **Human Space Flight Logistics**

Human space flight requires a logistics capability to meet the needs of the flight crew. A program/project needs to be able to establish guidelines for different logistical requirements and track the on-board quantities and usage rates for food, water, oxygen, and waste, including carbon dioxide. Current law does not allow for dumping waste on orbit. Excess water can be dumped. Usually the program/project determines, for example, the amount of water that will be stored on orbit, the amount of planned water usage, and the amount of water that will be delivered at a particular time. If the water delivery launch is delayed, then the program/project must determine how long the water can last if none can be delivered as planned. Changes to water usage need to be managed by the program/project.

This same concept applies to food, oxygen, and waste products. Currently, technology is available to recycle much of the water; however, spacecraft design mass increases when water recycling capability is added. Equipment for delivering oxygen and removing carbon dioxide also needs to be included in the vehicle design and the efficiency of these systems drives the need for logistics to support these functions.

Also included in the logistics for the flight crew are clothing, personal hygiene, and medical and first aid capability. Developing a strategy for providing these capabilities is conducted during the earlier phases of a program/project, but greatly affects the logistics requirements for operations.

Handling of waste materials, used clothing, and a variety of scientific chemicals makes on-orbit waste removal a significant challenge. Waste is normally segregated based on type. Commonly, there is wet and dry trash, biohazardous material, chemical waste, and possibly radioisotope waste. These types of waste need to be handled differently, mainly due to safety concerns. Not only can waste become a hazard on orbit, but when returned to the ground, it can create hazards for the ground crew handling the waste. Use of cargo vehicles, such as the Russian Progress, provides the ability to burn up waste from the International Space Station as the vehicle enters the Earth's atmosphere. Early decisions about how waste will be discarded affect the logistic requirements during operations.

Analysis of these trades and decisions in the early phases of the program/project is key to minimizing the logistics requirements for human space flight.

In addition to the logistics required to maintain a human crew, human space flight also utilizes reusable flight vehicles. Each reused element needs to have a plan for logistics and refurbishment. This planning needs to be conducted during the early phases of the design. The plan begins with the number of flight units planned for delivery. Many times, cost dictates the number of units built, usually including an engineering development model, a flight unit, and a backup unit. Flight units exceeding this are justified through logistics planning.

The number of spare parts needed to maintain a reusable spacecraft is also a challenge to determine. Analysis of mean time between failures and limited-life items can help determine the number of parts needed. However, the logistics analysis needs to include plans for obsolete parts and lead times for acquiring the needed parts. It also is important to understand the mass and volume of spares that need to be delivered to orbit. During logistics planning, the team should determine where the refurbishment or repair will occur. Understanding the assembly level for refurbishment and/or repair is also critical. The project team should include in the logistics planning the assembly level accessible on orbit and the difficulty of the repair. Commonly, the repair level is defined as an Orbital Replacement Unit (ORU), and the design of the unit is such that it can be effectively repaired or replaced on orbit. On orbit checkout is accomplished to verify the success of the repair after completion.

Many times the repair or replacement is planned based on the life-cycle requirements for a particular item. In these cases, the replacement unit is launched on a predetermined schedule and the on-orbit unit is returned to the ground for refurbishment. These planned refurbishments require an entire ground support system to accomplish.

Refurbishment planned for ground operations requires facilities, test equipment, trained personnel, proper storage, and transportation. Logistics planning needs to include all of these elements. For each item to be refurbished, a plan for where, by whom, and the duration of each activity is included. The ground logistics team needs to track and maintain the status of all the required items. The team ensures that parts are procured and available when needed. The transportation requirements to and from the refurbishment location must be met and each item needs to be tested and reverified prior to being made available for installation in the vehicle or launched to the awaiting spacecraft. A dedicated team of professionals is required to maintain the capability to keep a reusable spacecraft in operation.

### 5.3.B.b Managing Changes Due to Anomalies

Prior to flight, the team should prepare an anomaly response plan that identifies (at least at a conceptual level) an anomaly response team. This team usually consists of the experts in each of the flight system subsystem areas. The most important thing a PM can do when there is an anomaly is to let the technical experts analyze the data and develop theories about the cause. The PM must give those people the time they need to do their work. Each anomaly is unique and will be solved in its own time.

Prior to flight, the design and operations teams should work together to brainstorm every conceivable potential anomaly and for each case, develop operational responses (such as in-flight maintenance or repair procedures, or alternate mission profile to capture maximum mission success criteria). This contingency planning is one way to prepare the operations team for dealing with the unexpected during the mission.

During flight, it is valuable to have development team members support operations—having the designer and developer available when anomalies occur is extremely helpful. Also, it is critical to document and feed lessons learned through dissecting flight anomalies into future designs.

Operators must have readily available, detailed, as-flown design drawings and verification test data. In one case, the operating temperature of an avionics box was exceeding the upper limit of the normal operating temperature. Verification test data revealed the box had successfully operated at a much higher temperature, and based on that data, the decision was made to continue flight operations with the box operating at the above-normal temperature.

In case of a failure:

- Determine how much time is available before a decision is required
- Make a timeline of events and include everything that is known
- Give all team members all known facts and check every theory against them
- Have multiple teams: some should investigate timeline replanning, others should work on hardware/software repair or workarounds
- Make sure any deviation from the norm is explained—remember, the wrong conclusion is prologue to the next failure
- Do not arrive at a conclusion too rapidly
- Know when to stop trying to force-fit a scenario

On a NOAA launch some years ago, as we prepared for launch, there were issues that needed to be resolved. During launch countdowns, I typically keep five or six channels open so I can hear what is going on across the board. Having participated in almost sixty launches has taught me that when everything is going well, the net is really quiet. When things aren't going well, people are talking constantly. In this particular case, there was chatter all over the place. As the countdown continued, it only got worse. It got down to about ten minutes, and I just had a gut instinct that we needed to stop the launch and assess where we were. So I did. We fixed our problems and launched the next night without any issues. It's tough, but as a manager you have to hold out against "launch fever." I have a motto I follow, which I've adopted from the wine industry: "No launch before its time."

– Bill Townsend, *ASK Magazine*

Having experienced personnel on the flight team can make it easier to come up with creative options in response to an anomaly. These people often have experience in more than one area, so they can be flexible in anomalies. It is also important for the PM to assign some of the flight team to look at mission impacts and options and to deal with these issues in parallel with the group looking into the specific anomaly and its resolution.

For human space flight there are specific protocols for communication between the ground team personnel and the flight crew. This is to avoid conflicting communications with the flight crew. Anomalies are resolved through direction provided by the Mission Management Team (MMT) and provided to Problem Resolution Teams (PRT). The MMT establishes a problem resolution team and assigns the necessary personnel to lead and support the PRT, based on the type of problem identified. The PRT normally has a limited time period for providing a recommendation with options to the MMT. The MMT approves the action to be taken prior to directing the ground operations team to perform the action. Problems that do not require action during the flight are collected and reviewed as in-flight anomalies. Resolution of all in-flight anomalies is conducted postflight and action may be taken to avoid the problem on future flights. Since the usual systems design for human space flight includes a reusable vehicle for ascent and descent of the flight crew, there are mandatory activities to assess any damage that may have occurred to the vehicle during flight. Typical assessments include thermal protection system inspections, micrometeoroid debris hit assessments, and assessment based on in-flight anomalies.

### **5.3.B.c Keeping Ground Data Systems Current**

The architecture of the ground data system determines the ease with which system changes can be made. The basic ground system consists of a receiving station, the routing systems, the data collection and distribution system, and a command system. Also included in ground data systems is a voice communication system that enables operations personnel to actively communicate with one another, and a video distribution system that allows the team to view various mission activities. In the past, ground data systems were centralized and made up of terminals that ran off the ground system mainframe. Current ground systems are more distributed. Function criticality determines the security, access, and training required to operate the system.

The longer the mission duration, the greater the likelihood that changes affecting the project will happen. The PM should assign a team member to monitor emerging technology and developments in Information Technology (IT) to evaluate if updates should be incorporated in the project ground data system. Other changes may be mandated by Center and/or Agency policy.

### **5.3.B.d Managing Analysis, Archiving, and Curating**

Once a mission is successfully launched and arrives at its destination or at the desired orbit, the task of collecting, analyzing, managing, archiving, and curating the scientific data begins. This is a critical task, as this is where the project discoveries take place. Great care must be taken to establish a system and process to adequately handle the volume of data. Many missions collect and return scientific data faster and in far greater quantity than can be quickly analyzed by scientists. Many times, analysis continues far beyond the mission duration, placing great importance on successful data archiving. PMs should establish a Data Management Team and data management strategy early, to ensure all data to be captured is recorded and archived in a

manner that will enable scientists to access it as soon as possible during the flight as well as for many years into the future.

While most scientists who work on space missions are eager to begin data analysis as soon as data becomes available to them, many scientists also work on many projects at once and may be overcommitted at any given time. Because of this, the project scientist or PI might need to ensure all team scientists are performing their assigned analysis roles within a reasonable timeframe. Regularly scheduled project science team meetings to discuss analysis results can help ensure science team members stay current with their analysis. The PM may be able to aid the project scientist or PI in getting this done.

For most robotic missions, the returning stream of data can easily outpace the ability of the science team to analyze it. It is important for the PM to ensure that there are routine, repetitive processes in place to turn the raw data stream into science data products that can be analyzed and archived. With a routine process and a steady data stream, it is important to set up a schedule for regularly archiving the low-level science data products. The PM should also establish a nominal schedule for higher level data products creation. The PM can use this schedule to keep the scientists on track. The PM should foster the expectation within the science team that these archive schedules will be met.

For both human flight and robotic missions, curating involves securing, storing, controlling access to, and distributing returned samples. The project manager ensures curating processes are defined, in place, and tested with personnel trained prior to sample return. Areas that require attention include making sure agreements with the curating facility have been negotiated, that members of the science team have been granted permission to access to the samples (when appropriate), that science teams are authorized to bring special equipment needed to analyze the sample (if necessary), and/or that authorization for distribution of sample material and any special handling/approvals has been obtained.

### 5.3.C Project Control

#### 5.3.C.a Preparation of Final CADRe

Typical projects will make five Cost Analysis Data Requirement (CADRe) submissions across the project life cycle, with the final two submissions due in Phase E. CADRe 4 (complete CADRe), covering the as-built or as-deployed configuration, is due 90 days after launch. CADRe 5 (Part C only—projected and actual life-cycle project costs) is due during the last year of the planned project life. The PM is responsible for CADRe and may develop CADRe within the Project Office or as a document on contract(s). Because CADRe collects Full Cost information, it is likely the project will have to perform final integration of a contractor-prepared CADRe to include all Full Cost information.

For additional resources on cost estimating and analysis, the *NASA Cost Estimating Handbook and Parametric Estimating Handbook* is available at <http://cost.jsc.nasa.gov/> and information about CADRe is available at <http://ceh.nasa.gov/downloadfiles/CADRe.html>.

### 5.3.C.b Planning an Extended Mission

The PM should work with the program office and program executive well before the end of the primary mission to determine interest in an extended mission. Planning for an extended mission cannot start too early. It is important to develop the scope and get approval for funding before making commitments. Depending on the planning required, some funds during the prime mission may need to be negotiated to smoothly transition into an extended mission. The PM needs to be aware of these schedule constraints to both minimize the impact to ongoing operations and to ensure proper planning for the extended mission.

For human space flight it is normal to plan additional mission day extensions based on the amount of consumable reserves held prior to launch. The reserves are preplanned and mission extension days can be used if the reserves are available. Reserves are also used in case a weather-related criterion creates an unsafe condition for landing. These preplanned reserves allow for landing to occur at later times or other locations than the original plan.

### 5.3.D Conduct KDP Readiness Activities

#### 5.3.D.a Preparing for Life-cycle Reviews

Life-cycle reviews conducted during the Mission Operations phase of robotic missions are: Post Launch Assessment Review (PLAR), Critical Events Readiness Review (CERR), and Decommissioning Review (DR). The PLAR is typically conducted approximately 30 days after Launch. The CERR is conducted approximately 30 to 60 days prior to a critical event, and the DR is conducted prior to decommissioning the mission and ceasing operations. It should be noted that according to the SRB Handbook, SRB participation in these post-launch reviews is minimal. They are typically non-voting members.

Demand tough reviewers and then evaluate their performance and contribution to the project. If they don't leave you better off after the review than before, do not invite them back.

– WISE Project Manager, JPL

#### Specific Guidance for the PLAR

The PLAR occurs so soon after launch for robotic missions that the preparation is typically simultaneous with checkout/commissioning—activities that are assessed at the review. The PM needs to keep the team focused on performing the planned spacecraft activities during the post-launch checkout. It is important for the team to document changes to the planned activities when these will affect PLAR success criteria. The PM needs to also ensure the team is assessing spacecraft, payload, and operations system performance against expectations (for both nominal and any anomalous conditions encountered thus far). If there are any significant deviations, the PM needs to ensure the project assesses the impact of these on the project budget and the ability to meet mission objectives/Level 1 requirements.

For human space flight missions, the PLAR is normally conducted by an MMT and is not considered a life-cycle review. For human missions, the MMT meets daily or as appropriate to continually monitor and evaluate the mission conduct. The MMT makes decisions about any

corrective or preventive action to be taken during the mission. These decisions take into consideration correction of the immediate problem and also evaluate the impact to future flights and missions.

### **Specific Guidance for CERR**

For robotic missions, the PM needs to ensure project focus is on preparation for the critical event. The preparation schedule should be laid out well in advance to avoid conflicts between preparation activities and ongoing spacecraft operations. The scope of preparation needs to include defining, designing, developing, and testing the spacecraft activities and training operations personnel for their role during the critical activity. Preparation also needs to include identification and development of appropriate contingencies in the event of anomalies that could threaten successful completion of the critical event. The CERR should be scheduled with sufficient time for redesign, rebuild, retest, and retraining following the review (based on recommendations from the board) prior to the critical event.

Critical events for human space flight are identified as those items that require a sequence of events to occur within a defined time period. The best example of a critical event for human space flight is an Extravehicular Activity (EVA), when a crewmember using a space suit is required to operate outside the space vehicle to perform installation or maintenance. The amount of oxygen and power available in the space suit is limited, so all activities need to occur within a set timeframe. Prior to these events, the Mission Management Team performs a review of readiness to conduct these operations. For human space flight, communications with the crew are normally available and are used to evaluate contingencies and direct appropriate actions. There are specific Flight Rules for operations during an EVA. Other critical events experienced during human space flight are vehicle docking and undocking, debris avoidance maneuvers, and orbital boost maneuvers. During human flight missions, the most critical times are normally launch pad to orbit, time of ascent, and the descent flight profile. These events put the most stress on the vehicle systems and monitoring vehicle performance is critical.

### **Specific Guidance for Decommissioning Review**

The PM needs to ensure mission designs and analyses relating to the end of mission have been completed. If it is a science mission, the reason(s) for ending the mission before the useful end of science data collection need to be clearly understood and agreement reached by all stakeholders. The PM needs to ensure this dialogue occurs and an agreement is reached prior to the Decommissioning Review (DR). For missions involving reentry into the Earth's atmosphere, negotiation and coordination with external agencies is required. The PM needs to ensure all required agencies have participated in the appropriate decommissioning/disposal planning and that they are in agreement with the plans prior to the DR.

### **5.3.D.b Planning and Preparation for Decommissioning and Disposal**

NPR 7120.5 identifies a phase for spacecraft disposal and retirement and requires projects to consider and plan for this event. In the past, most projects did not plan for these activities during initial planning. Now *NPR 8715.6, NASA Procedural Requirements for Limiting Orbital Debris*, requires projects to write an End of Mission Plan by project CDR, and so it needs to be considered early in project planning. Planning for this phase should be considered during requirements development in Pre-Phase A and in Phase A.

This activity is also required for human flight. The Agency is in the process of decommissioning the Space Shuttle. The International Space Station (ISS) has a disposal plan and systems for deorbiting. The Constellation program also has requirements for decommissioning.

Aspects to consider include:

- Any flight assets left in space and their potential to adversely affect future activities, including orbit debris considerations
- Whether or not a controlled reentry is required
- Designing and planning for reentry
- Ground equipment and other assets
- Completion of archival of all mission data
- Contract closeout
- Personnel reassignment and the end of the existence of the project as an entity

The project manager needs to ensure there are plans for all of these items.

### **Flight Assets Left in Space**

For deep space missions, the primary end of life consideration is planetary protection (to avoid contaminating a place where future exploration may happen). The Planetary Protection Plan developed before launch should be followed and any analyses updated as the mission proceeds (especially if there have been changes during the mission execution to assumptions made in the original analyses) to ensure noncontamination requirements can be met; if not, a new plan needs to be submitted. Another requirement for deep space missions is to avoid radio frequency interference with future missions. This is usually resolved by simply turning off the transmitter at the end of the mission.

For earth-orbiting missions, there are several steps required to plan for the end of the mission. The first is an analysis of the threat of adverse affect on future activities. This analysis needs to include the probability of reentry and/or interference with other orbiting assets (collision, contamination, or radio frequency interference). Once this probability has been assessed, then a plan of action to eliminate (or at least minimize) the effects need to be developed and approved.

In the case of a decision to control the reentry of the space asset (rather than just letting the orbit decay, resulting in an uncontrolled reentry) additional plans and actions are required.

The Agency requires teams to develop an Orbital Debris Assessment Report; the initial version is due prior to PDR and the final version prior to launch. In addition, an End of Mission Plan is required, with the initial draft due before CDR and the final version due 30 days before end of mission maneuvers. Extensive guidance for developing each of these documents is provided in NASA Technical Standard 8719.14 *Process for Limiting Orbital Debris*.

### **Ground Equipment and Other Assets**

Spare flight hardware needs to be properly disposed of at the end of a project. Ideally, the program office or the Center has a plan in place to facilitate use of excess flight hardware components by future projects. The PM should work with the Center and/or program office to facilitate this.

Ground system equipment reuse within the program and/or Center may also be facilitated by this same organization. If not, other projects may be interested in acquiring the equipment. The PM

needs to know what organizations exist within the program and Center to facilitate transfer of ground system assets to other projects and to use these resources as possible.

Excess property can and should be covered under normal contract performance requirements. PMs should guard against storing a large amount of excess property that is costly to maintain and represents more work for final contract closeout (and possibly additional scope change costs). Instead, the PM should analyze the excess property as the project progresses and dispose of it when it is no longer useful.

### **5.3.D.c Implementing Decommissioning/Disposal**

Upon mission completion, it is necessary to decommission and close out the project. This includes disposing of the spacecraft, archiving and distributing the final science data products, and transferring any property to excess or other projects.

The closeout phase of the project typically involves the project manager and minimal staff, as the project staff leaves the project per the decommissioning plan. However, the project manager should ensure that sufficient personnel with the right skills remain on the project to execute the decommissioning plan. This includes having resources in place to keep personnel past their planned roll off date to ensure the work is completed and team members don't leave prematurely because they are uncertain about their next assignment.

For earth orbiting spacecraft, the spacecraft disposal is conducted in accordance with the Orbital Debris Requirements established prelaunch. This may include either deorbiting the vehicle and allowing it to burn up in the Earth's atmosphere or maneuvering it into an orbit that does not interfere with other Earth Orbiting spacecraft or the International Space Station (ISS). Maneuvering the spacecraft to a higher altitude may also be done, to allow the orbit to decay over a predetermined period of time and enable a controlled reentry at a later date.

For planetary spacecraft, spacecraft disposal is conducted in accordance with the Planetary Contamination and Control Requirements established prelaunch. This may also involve intentionally destroying the spacecraft, as was the case with the Galileo and Magellan spacecraft.

Decommissioning the spacecraft and ending the mission is a necessary process. Projects should also consider documenting lessons learned in a final report so that future projects can benefit from their experiences. This should be completed soon after the end of development and updated at the end of mission.

Planning for reentry of spacecraft that cannot be left in space needs to start early in the design phase. When the time comes for reentry, the decommissioning review is held and the process for reentry is implemented.

As an example, the processes the Compton Gamma Ray Observatory (CGRO) performed prior to reentry included:

- Analysis of the size and spread of the debris field.
- Assessment of probability of loss of life/property damage that would occur for an uncontrolled reentry.
- Selection of a reentry location based on this information.
- Providing plans and hazard warning notifications for air and sea traffic in the reentry area.

- Developing contingency plans (in the event that debris fell outside of the planned debris field). These plans included the NASA Headquarters Office of External Relations and the State Department, because the plans involved rapid deployment of personnel into any location under the orbital track of the spacecraft, which included foreign countries.
- Analysis and coordination to avoid collisions with other space-borne assets during the reentry trajectory.
- Training the operations team for reentry activities. This training included team internal processes, interfaces and processes involving external agencies, and exercise of contingency plans.
- Finally, coordination with numerous organizations internal and external to the project. These included: The project's science team, the managing Center's management and legal department, Headquarters, Public Affairs, the Coast Guard and FAA for debris avoidance zones, NORAD for orbit determination, and JSC for space-borne collision avoidance.

The project manager needs to know the extent of potential external organization involvement with the disposition of flight assets and to ensure that contacts are established and plans started early enough to achieve an orderly end to the mission.

#### **5.3.D.d Contract Closeout**

Contract closeout language in the Federal Acquisition Regulations has been consistent for many years, and all contracts have closeout clauses. It is impossible to price into a contract at award such details as the specific costs, plans, and procedures for disposal of all contract property, because the dynamics will have changed by the time the actual closeout occurs. Also, for a long-term contract, if closeout costs are part of the contract value, then a fee is paid on that contract value, even though it may exist for more than 20 years (in the case of long operational contracts) before being exercised. Although contract change orders are expensive, they can be much cheaper as an instrument that is exercised when disposal requirements are well defined, than to carry costs of outdated plans for years. Serious contract closeout planning can be started about 18 months prior to actual project end for an ongoing operations contract/project that does not have a finite end. In a long-term contract, excess property should be disposed of when it is no longer needed rather than paying long-term storage costs and waiting until the end of the contract to locate and dispose of the property.

#### **Personnel Reassignment and the End of the Project as an Entity**

Project managers need to plan for the end of a project. The project staff remaining to deal with closeout and similar issues is very small. Don't expect to be able to retain key players for such tasks—they will likely be in demand and will move on to other projects as soon as your project starts to ramp down. One way to help mitigate this is to overplan the need for closeout staff, so that you can fully fund those personnel you do retain past the nominal closeout date.

The PM also needs to ensure there is a contact point for the project, even after it has ceased to exist. This may be someone within the program office. The PM (and key staff members) should also expect to be asked questions about the project for quite a while, even years after it has ceased to exist.

### **Final Mission Report**

A final mission report includes mission results and an assessment of how completely the mission objectives were achieved. Final mission report preparation requires input from personnel with discipline expertise and knowledge about and/or history with the project in key areas, including management, science, flight system, mission operations, mission planning, mission design, safety and mission assurance, and business. The PM needs to ensure these experienced personnel are still available to help compile the final report. For projects with contractors, support for the final mission report should be included as a deliverable in the contract to ensure adequate support.

Ideally, information for the report (achievement against mission objectives; scientific results; flight system design and actual performance; operations plans and actual performance; anomalies, responses, and resolution; cost and schedule plans; and actuals) is collected throughout the mission. The final report should also include important lessons for future projects. These are often less formal than lessons learned submitted to the Agency database and are often at the working level. The report should also include business plans (not just actuals). The final mission cost and schedule are important, but comparing actuals to plans at various points during mission execution can provide valuable insight. The PM should ensure final report information is collected periodically during the mission and is stored in an easily retrievable format and location.

## Appendix A: Glossary

**Acceptable Risk.** The risk that is understood and agreed to by the program/project, governing PMC, Mission Directorate, and other customer(s) such that no further specific mitigating action is required. (Some mitigating actions might have already occurred.)

**Acquisition.** The process for obtaining the systems, research, services, construction, and supplies that NASA needs to fulfill its missions. Acquisition—which may include procurement (contracting for products and services)—begins with an idea or proposal that aligns with the NASA Strategic Plan and fulfills an identified need, and ends with the completion of the program or project or the final disposition of the product or service.

**Acquisition Strategy Meeting.** A forum where senior Agency management reviews major acquisitions in programs, projects, or activities before authorizing budget expenditures. The ASM is held at the Mission Directorate/Mission Support Office level, implementing the decisions that flow out of the ASP meeting and recommending implementation plans for approval.

**Acquisition Strategy Planning Meeting.** A forum that provides an early view of potential major acquisitions so that senior leaders can consider issues such as the appropriate application of new Agency and Administration initiatives, current portfolio risk and implications to the future portfolio, high-level make-or-buy strategy, and the placement of development or operations work in-house versus out-of-house. It also provides the strategic framework for addressing challenges associated with fully utilizing NASA Centers' capabilities, including workforce and infrastructure, and shaping the Agency over time.

**Agency Program Management Council.** The senior management group, chaired by the NASA Associate Administrator or designee, responsible for reviewing formulation performance, recommending approval, and overseeing implementation of programs and Category 1 projects according to Agency commitments, priorities, and policies.

**Agreement.** The statement (oral or written) of an exchange of promises. Parties to a binding agreement can be held accountable for its proper execution and a change to the agreement requires a mutual modification or amendment to the agreement or a new agreement.

**Analysis of Alternatives.** A formal analysis method that compares alternative approaches by estimating their ability to satisfy mission requirements through an effectiveness analysis and by estimating their life-cycle costs through a cost analysis. The results of these two analyses are used together to produce a cost-effectiveness comparison that allows decision makers to assess the relative value or potential programmatic returns of the alternatives. An AoA broadly examines multiple elements of program/project alternatives (including technical performance, risk, LCC, and programmatic aspects).

**Approval.** Authorization by a required management official to proceed with a proposed course of action. Approvals need to be documented.

**Approval (for Implementation).** The acknowledgment by the decision authority that the program/project has met stakeholder expectations and formulation requirements and is ready to

proceed to implementation. By approving a program/project, the decision authority commits the budget resources necessary to continue into implementation. Approval (for Implementation) needs to be documented.

**Baseline (general context).** An agreed-to set of elements (e.g., requirements, cost, schedule, designs, documents) that will have changes controlled through a formal approval and monitoring process.

**Baseline Design.** The mission design of a project, when it is sufficiently mature to comply with all requirements, has an implementation and operational schedule, and is consistent with approved/planned funding. Within the project life cycle, the baseline design is expected at or shortly before the end of the formulation phase, i.e., in time for a Preliminary Design Review.

**Budget.** A detailed statement of anticipated revenues and expenditures for a specified period of time with information on the purposes for which the funds will be used.

**Categorization.** A means of establishing Agency expectations of project managers relative to oversight council and planning detail; projects are either Category 1, 2, or 3, with Category 1 receiving the highest level of scrutiny. (See section 2.1.5 of the NID for NPR 7120.5D.)

**Center Management Council.** The council at a Center that performs oversight of programs and projects by evaluating all program and project work executed at that Center.

**Change Request.** A change to a prescribed requirement in an Agency or Center document that is recommended for all programs and projects for all time.

**Concept of Operations.** The description of the system being developed and how it will be operated.

**Concurrence.** A documented agreement by a management official that a proposed course of action is acceptable.

**Configuration Management.** A management discipline applied over a product's life cycle to provide visibility into and to control changes to performance, functional, and physical characteristics.

**Construction of Facilities Program.** NASA's congressionally mandated process for the review and approval of facility construction and refurbishment projects; applicable to projects greater than \$500,000.

**Continuous Risk Management.** A systematic and iterative process that efficiently identifies, analyzes, plans, tracks, controls, communicates, and documents risks associated with implementation of designs, plans, and processes.

**Contract.** A mutually binding legal relationship obligating the seller to furnish the products, supplies or services (including construction) and the buyer to pay for them. It includes all types of commitments that obligate the Government to an expenditure of appropriated funds and that, except as otherwise authorized, are in writing. In addition to bilateral instruments, contracts include (but are not limited to) awards and notices of awards; job orders or task letters issued under basic ordering agreements; letter contracts; orders, such as purchase orders, under which

the contract becomes effective by written acceptance or performance; and bilateral contract modifications. Contracts do not include grants and cooperative agreements.

**Cost Analysis Data Requirement.** A formal document designed to help managers understand the cost and cost risk of space flight projects. The CADRe consists of a Part A "Narrative," and a Part B "Technical Data" in tabular form, both provided by the program/project to the ICE team. A "Project Life-Cycle Cost Estimate," produced by the project team, is appended as Part C, but the ICE team does not see Part C until it has produced its own independent estimate.

**Critical Path Analysis.** Critical path assessment, including verification of the primary schedule critical path and any secondary critical paths that are less than the available schedule slack behind the primary critical path.

**Decision Authority.** The Agency's responsible individual who authorizes the transition of a program/project to the next life-cycle phase.

**Decommissioning Review.** An evaluation that confirms a decision to terminate or decommission a system and assesses the readiness of the system for the safe decommissioning and disposal of system assets.

**Derived Requirements.** Requirements that arise from constraints, consideration of issues implied but not explicitly stated in the high-level direction provided by NASA Headquarters and Center institutional requirements, factors introduced by the selected architecture, and the design. These requirements are finalized through requirements analysis as part of the overall systems engineering process and become part of the program/project requirements baseline. They are established by and are the responsibility of the Programmatic Authority.

**Development Costs.** The total of all costs from the period beginning with approval to proceed to implementation through the achievement of operational readiness.

**Deviation.** A documented authorization releasing a program or project from meeting a requirement before the requirement is put under configuration control at the level the requirement will be implemented.

**Dissenting Opinion.** A disagreement with a decision or action that is based on a sound rationale (not on unyielding opposition) that an individual judges is of sufficient importance that it warrants a specific review and decision by higher level management, and the individual specifically requests that the dissent be recorded and resolved by the Dissenting Opinion process.

**Earned Value Management.** A tool for measuring and assessing project performance through the integration of technical scope with schedule and cost objectives during the execution of the project. EVM provides quantification of technical progress, enabling management to gain insight into project status and project completion costs and schedules. Two essential characteristics of successful EVM are EVM system data integrity and carefully targeted monthly EVM data analyses (i.e., risky WBS elements).

**Engineering Requirements.** Requirements defined to achieve programmatic requirements and relating to the application of engineering principles, applied science, or industrial techniques.

**Entrance Criteria.** The criteria imposed by NPR 7123.1 on programs/projects for all life-cycle reviews; these criteria are used as a helpful reminder by programs/projects as they prepare for each life-cycle review.

**Evaluation.** The continual self-evaluation and independent assessment of the performance of a program or project and incorporation of the evaluation findings to ensure adequacy of planning and execution according to plans.

**Formulation.** The identification of how the program or project supports the Agency's strategic needs, goals, and objectives; the assessment of feasibility, technology and concepts; risk assessment, team building, development of operations concepts and acquisition strategies; establishment of high-level requirements and success criteria; the preparation of plans, budgets, and schedules essential to the success of a program or project; and the establishment of control systems to ensure performance to those plans and alignment with current Agency strategies.

**Formulation Authorization Document.** The document issued by the MDAA (or MSOD) to authorize the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan, Mission Directorate Strategies, or Mission Support Office Functional Leadership Plans. In addition, a FAD or equivalent is used to authorize the formulation of a project.

**Funding (Budget Authority).** The authority to incur financial obligations that will result in outlays. Authority is delegated through the formal funds distribution process.

**Governance.** The combination of processes and structures implemented by NASA to inform, direct, manage, and monitor the activities of the organization toward the achievement of its objectives.

**Health and Medical Requirements.** Requirements defined by the Office of the Chief Health and Medical Officer.

**Host Center.** The Center with defined responsibility for a program/project at the Acquisition Strategy Planning meeting and documented in the Formulation Authorization Document.

**Implementation.** The execution of approved plans for the development and operation of the program/project and, the use of control systems to ensure performance to approved plans and continued alignment with the Agency's strategic needs, goals, and objectives.

**Independence.** Unbiased and outside the advocacy chain of the program or project. The freedom from conditions that threaten objectivity or the appearance of objectivity. Such threats to objectivity need to be managed at the individual reviewer and organizational levels.

**Independent Assessment(s) (includes reviews, evaluations, audits, analysis oversight, investigations).** Assessments in which involved personnel apply their expertise impartially, without any conflict of interest or inappropriate interference or influence, particularly from the organization(s) being assessed.

**Independent Cost Analysis.** An independent analysis of program resources (including budget) and financial management associated with the program content over the program's budget horizon, conducted by an impartial body independent from the management or advocacy chain of the program. ICA includes, but is not limited to, the assessment of cost estimates, budgets, and schedules in relation to the program and its constituent projects' technical content, performance,

and risk. ICAs may include independent cost estimates (ICEs), assessment of resource management, distribution and planning, and verification of cost-estimating methodologies. (ICAs are not life cycle cost estimates but are assessments of the adequacy of the budget and management practices to accomplish the work scope through the budget horizon; as such, ICAs can be performed for programs/projects when a life-cycle ICE is not warranted.)

**Independent Cost Estimate.** An independent project cost estimate prepared by an office or other entity that is not under the supervision, direction, advocacy, or control of the project (or its chain of command) that is responsible for carrying out the development or acquisition of the program/project. An ICE is bounded by the project scope (total life cycle through all phases), schedule, technical content, risk, ground rules, and assumptions and is conducted with objectivity and the preservation of integrity of the cost estimate. ICEs are generally developed using parametric approaches that are tailored to reflect the project design, development state, and difficulty and the expertise of team members.

**Independent Life-Cycle Review.** The analysis of a proposed program or project by a (nonadvocate) team composed of management, technical, and resources experts from outside the advocacy chain of the program or project. It provides Agency management with an independent assessment of the readiness of the program/project to proceed. NPR 7120.5 provides a complete list of program/project life-cycle reviews in Tables 2-5/2-6 and describes the purpose of each of these reviews.

**Information Technology.** Any equipment or interconnected system(s) or subsystem(s) of equipment that is used in the automatic acquisition, storage, analysis, evaluation, manipulation, management, movement, control, display, switching, interchange, transmission, or reception of data or information by the Agency.

**Infrastructure Requirements.** The facilities, environmental, aircraft, personal property, equipment, and information technology resources that are needed to support programs and projects. Utilization of the capability afforded by the infrastructure includes consideration of the maintenance and other liabilities it presents.

**In-House Project.** A project that is conducted onsite or in the immediate vicinity of a NASA Center in which most major technical, business, and management tasks are performed primarily by the Center's civil service workforce.

**Institutional Authority.** Authority belonging to the Headquarters and Center organizations, including the Technical Authorities (Engineering, Safety and Mission Assurance, and Health and Medical), and the Mission Support Authorities (made up of all of the remaining Mission Support Offices, including the Chief Financial Officer and associated Center Chief Financial Officers). Individuals in these organizations are the official voices for their respective areas of responsibility. Institutional Authority sets, oversees, and ensures conformance to applicable institutional requirements.

**Integrated Baseline Review.** A joint assessment by the offeror/contractor and the Government to verify the technical content and the realism of the related performance budgets, resources, and schedules. It should provide a mutual understanding of the inherent risks in offerors'/contractors' performance plans and the underlying management control systems, and it should formulate a plan to handle these risks.

**Integrated Master Schedule.** An integrated set of schedule data that reflects the total project scope of work as discrete and measurable tasks/milestones that are time-phased through the use of task durations, interdependencies, and date constraints and is traceable to the WBS.

**Joint Cost and Schedule Confidence Level.** (1) The probability that the program/project cost will be equal to or less than the targeted cost and that schedule will be equal to or less than the targeted schedule date. (2) A process and product that helps inform management of the likelihood of a project's programmatic success. (3) A process that combines a project's cost, schedule, and risk into a complete picture. JCL is not a specific methodology (e.g., resource-loaded schedule) or a product from a specific tool.

**Key Decision Point.** The event at which the decision authority determines the readiness of a program/project to progress to the next phase of the life cycle (or to the next KDP).

**Life-Cycle Cost.** The total of the direct, indirect, recurring, nonrecurring, and other related expenses incurred, or estimated to be incurred, in the design, development, verification, production, operation, maintenance, support, and disposal of a project. The LCC of a project or system can also be defined as the total cost of ownership over the project or system's life cycle from formulation through implementation. It includes all design, development, deployment, operation and maintenance, and disposal costs.

**Life-Cycle Phase.** The life cycle of NASA programs/projects is divided into phases, each of which defines the activities/achievements to be accomplished before proceeding to the next phase; at the highest level there are two phases for both programs and projects: the formulation phase, followed by the implementation phase; for programs, the formulation phase entails preprogram acquisition, while the implementation phase involves program acquisition and operations; for projects, the formulation phase entails presystems acquisition (Phases A and B), and the implementation phase involves system acquisition (Phases C and D), operations (Phase E), and decommissioning (Phase F).

**Logistics.** The management, engineering activities, and analysis associated with design requirements definition, material procurement and distribution, maintenance, supply replacement, transportation, and disposal that are identified by space flight and ground systems supportability objectives.

**Management Baseline.** The integrated set of requirements, cost, schedule, technical content, and associated JCL that forms the foundation for program/project execution and reporting done as part of NASA's performance assessment and governance process.

**Management Council.** NASA maintains three levels of management councils to ensure the appropriate level of management oversight of programs/projects; proceeding from lowest to highest these councils are: 1) the Center Management Council (CMC), 2) the Mission Directorate Program Management Council (MDPMC) (also known as the DPMC), and 3) the Agency Program Management Council. The purpose of these councils is to assess the status of programs/projects and recommend to the next higher council—or the Decision Authority (DA)—as ultimately appropriate, recommendation for continuation/termination of programs/projects, typically at each KDP; for a more complete description of these management councils, consult Section 2.4.3 of the NID for NPR 7120.5D.

**Margin.** The allowances carried in budget, projected schedules, and technical performance parameters (e.g., weight, power, or memory) to account for uncertainties and risks. Margins are allocated in the formulation process, based on assessments of risks, and are typically consumed as the program/project proceeds through the life cycle.

**Metric.** A measurement taken over a period of time that communicates vital information about the status or performance of a system, process, or activity. A metric should drive appropriate action.

**Mission.** A major activity required to accomplish an Agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an Agency goal. Mission needs are independent of any particular system or technological solution.

**Mission Directorate Program Management Council.** The senior management group, chaired by an MDAA or designee, responsible for reviewing project formulation performance, recommending approval, and overseeing implementation of Category 2 and 3 projects according to Agency commitments, priorities, and policies.

**Performance Measurement Baseline.** The time-phased budget plan against which contract performance is measured. It is formed by the budgets assigned to scheduled cost accounts and the applicable indirect budgets. It equals the total allocated budget less management reserve.

**Phase Requirements.** NPR 7120.5 specifies requirements for each life-cycle phase of programs/projects that need to be completed before proceeding to the next phase; these requirements are broken down into life-cycle review entrance criteria within each phase by NPR 7123.1.

**Prescribed Requirement.** A requirement levied on a lower organizational level by a higher organizational level.

**Principal Investigator.** A person who conceives an investigation and is responsible for carrying it out and reporting its results. In some cases, PIs from industry and academia act as project managers for smaller development efforts with NASA personnel providing oversight.

**Procurement Strategy Meeting.** A forum where management reviews and approves the approach for the Agency's major and other selected procurements. Chaired by the Assistant Administrator for Procurement (or designee), the PSM addresses and documents information, activities, and decisions required by the FAR and NFS and incorporates NASA strategic guidance and decisions from the ASP and ASM strategic procurement meetings to ensure the alignment of the individual procurement action with NASA's portfolio and mission.

**Program.** A strategic investment by a mission directorate or Mission Support Office that has a defined architecture and/or technical approach, requirements, funding level, and a management structure that initiates and directs one or more projects. A program defines a strategic direction that the Agency has identified as critical.

**Program Commitment Agreement.** The contract between the Associate Administrator and the responsible MDAA that authorizes transition from formulation to implementation of a program.

**Program Plan.** The document that establishes the program's baseline for implementation, signed by the MDAA, Center Director(s), and program manager.

**Program (Project) Team.** All participants in program/project formulation and implementation. This includes all direct reports and others that support meeting program/project responsibilities.

**Programmatic Authority.** Programmatic Authority includes the Mission Directorates and their respective program and project managers. Individuals in these organizations are the official voices for their respective areas. Programmatic Authority sets, oversees, and ensures conformance to applicable programmatic requirements.

**Programmatic Requirements.** Requirements set by the Mission Directorate, program, project, and PI, if applicable. These include strategic scientific and exploration requirements; system performance requirements; and schedule, cost, and similar nontechnical constraints.

**Program/Project Management Requirements.** Requirements that focus on how NASA and Centers perform program and project management activities.

**Project.** A specific investment identified in a Program Plan having defined requirements, a life-cycle cost, a beginning, and an end. A project yields new or revised products and services that directly address NASA's strategic needs. A project also has a management structure and may have interfaces to other projects, agencies, and international partners. (See Section 2.1.2 of the NID for NPR 7120.5D.)

**Project Plan.** The document that establishes the project's baseline for implementation, signed by the responsible program manager, Center Director, project manager, and the MDAA, if required.

**Rebaselining.** The process by which a program/project updates or modifies the Commitment Baseline. Rebaselining occurs as a result of drivers that are either internal or external to the Agency.

**Replanning.** The process by which a program or project updates or modifies the Management Baseline.

**Request for Action.** A formal written request from the Standing Review Board that asks for additional information from, or action by, the program/project team.

**Reserves.** For the purposes of this handbook, used generically for resources not yet specifically allocated. See Unallocated Future Expenses.

**Review Item Discrepancy.** An issue that indicates a failure to meet a review success criterion.

**Review Manager.** The individual with the responsibility to ensure the objectivity, quality, integrity, and consistency of each assigned independent review, who will define the scope of the review (with the convening authorities); facilitate the identification and approval of the Chair and team members; participate on the SRB as an authority in the programmatic aspects (compliance to NPR 7120.5 and generally accepted rules of good project management, cost, schedule, and risk), and in specific technical areas, if appropriate. The RM will facilitate the

review process; ensure that the scope of the review is fully exercised; and be accountable for ensuring that the results of the review have been properly vetted, documented, and reported.

**Risk.** The combination of the probability that a program or project will experience an undesired event and the consequences, impact, or severity of the undesired event were it to occur. The undesired event may come from technical or programmatic sources (e.g., a cost overrun, schedule slippage, safety mishap, health problem, malicious activities, environmental impact, failure to achieve a needed scientific or technological objective, or success criterion). Both the probability and consequences may have associated uncertainties.

**Risk Assessment.** An evaluation of a risk item that determines: (1) what can go wrong, (2) how likely is it to occur, (3) what the consequences are, and (4) what are the uncertainties associated with the likelihood and consequences.

**Risk Management.** Risk management includes risk-informed decision making and continuous risk management in an integrated framework. This is done in order to foster proactive risk management, to better inform decision making through better use of risk information, and to more effectively manage implementation risks by focusing the CRM process on the baseline performance requirements emerging from the RIDM process. (See NPR 8000.4, *Agency Risk Management Procedural Requirements*.)

**Safety.** Freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.

**Safety and Mission Assurance Requirements.** Requirements defined by the SMA organization related to safety and mission assurance.

**Schedule.** The time-phased sequence of activities performed by a program/project over its life cycle; project schedules are particularly important since they are a means of measuring formulation/implementation progress and can reveal bottlenecks and/or resource drivers through critical path analyses; they are also essential to planning multiyear funding of budgets.

**Security.** Protection of NASA assets, including physical assets, personnel, IT, communications, and operations.

**Segment** (of a Program). A major program segment represents a part of a program that may build on earlier parts but when accomplished could be considered a completed mission (e.g., Constellation—establishing full ISS capability, lunar exploration).

**Stakeholder.** An individual or organization having an interest (or stake) in the outcome or deliverables of a program/project.

**Standards.** Formal documents that establish a norm, requirement, or basis for comparison—a reference point to measure or evaluate against. A technical standard, for example, establishes uniform engineering or technical criteria, methods, processes, and practices.

**Standing Review Board.** The board responsible for conducting independent reviews (life cycle and special) of a program/project and providing objective, expert judgments to the convening authorities. The reviews are conducted in accordance with approved Terms of Reference (ToR) and life cycle requirements per NPR 7120.5 and NPR 7123.1.

**Standing Review Board Chair.** The independent leader of the SRB; the SRB Chair is nominated by the TA, approved by TAs, DAs, and AA PA&E (as specified in NPR 7120.5), nominates the members of his/her board, and usually presides over the program/project life-cycle reviews.

**Success Criteria.** That portion of the top-level requirements that defines what needs to be achieved to successfully satisfy NASA Strategic Plan objectives addressed by the program/project.

**System.** The combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose.

**Systems Engineering.** A disciplined approach for the definition, implementation, integration, and operation of a system (product or service). The emphasis is on achieving stakeholder functional, physical, and operational performance requirements in the intended use environments over its planned life within cost and schedule constraints. Systems engineering includes the engineering processes and technical management processes that consider the interface relationships across all elements of the system, other systems, or as a part of a larger system.

**Tailoring.** The process used to adjust or seek relief from a prescribed requirement to accommodate the needs of a specific task or activity (e.g., program or project). The tailoring process results in the generation of deviations and waivers depending on the timing of the request.

**Technical Authority.** Technical Authorities are part of NASA's system of checks and balances and provide independent oversight of programs and projects in support of safety and mission success through the selection of individuals at delegated levels of authority. These individuals are the Technical Authorities. Technical Authority delegations are formal and traceable to the Administrator. Individuals with Technical Authority are funded independently of a program or project.

**Technical Authority Requirements.** Requirements invoked by OCE, OSMA, and OCHMO documents (e.g., NPRs or standards specified as NASA core or mandatory standards) or contained in Center institutional documents. These requirements are the responsibility of the office or organization that established the requirement unless delegated elsewhere.

**Technical Standards.** NASA documents that contain common and repeated use of rules, conditions, guidelines, or characteristics for products or related processes and production methods and related management systems practices. **Terms of Reference.** A document specifying the nature, scope, schedule, and ground rules for an independent review or independent assessment; each SRB has a Baseline ToR and multiple Addendum ToRs; the Baseline ToR defines the scope of the SRB and its activities; the Addendum ToRs specify the detailed schedule and activities of the SRB for each of the program/project life-cycle reviews.

**Unallocated Future Expenses.** The portion of estimated cost required to meet specified JCL that cannot yet be allocated to the specific project Work Breakdown Structure (WBS) sub-elements because the estimate includes probabilistic risks and specific needs that are not known until these risks are realized.

**Validation.** Proof that the product accomplishes the intended purpose based on stakeholder expectations. May be determined by a combination of test, analysis, demonstration, and inspection.

**Verification.** Proof of compliance with design solution specifications and descriptive documents. May be determined by a combination of test, analysis, demonstration, and inspection.

**Waiver.** A documented authorization releasing a program or project from meeting a requirement after the requirement is put under configuration control at the level the requirement will be implemented.

**Work Agreement.** The Center form (or equivalent), prepared for each program/project cost account and used to document agreements and commitments for the work to be performed, including scope of work, receivables/deliverables, schedule, budget, and assumptions.

**Work Breakdown Structure.** A product-oriented hierarchical division of the hardware, software, services, and data required to produce the program/project's end product(s), structured according to the way the work will be performed, and reflective of the way in which program/project costs, schedule, technical and risk data are to be accumulated, summarized, and reported.

**Appendix B: Acronyms**

AA	Associate Administrator
ACE	Advanced Composition Explorer
ADP	Advanced Development Project
AO	Announcement of Opportunity
AIT	Assembly, Integration and Test
ASM	Acquisition Strategy Meeting
ASP	Acquisition Strategy Planning
CADRe	Cost Analysis Data Requirement
CCB	Configuration Control Board
CDR	Critical Design Review
CDRL	Contract Deliverable Requirements List
CERR	Critical Events Readiness Review
CGRO	Compton Gamma Ray Observatory
CHMO	Chief Health and Medical Officer
CI	Configuration Item
CM	Configuration Management
CMC	Center Management Council
CO	Contracting Officer
COBE	Cosmic Background Explore
CoF	Construction of Facilities
CoFR	Certification of Flight Readiness
COTR	Contracting Officer's Technical Representative
CPR	Contract Performance Report
CS	Civil Service
CSO	Chief Safety Officer
DA	Decision Authority
DAP	Decision Analysis Process
DCMA	Defense Contract Management Agency
DPM	Deputy Project Manager
DR	Decommissioning Review
DRD	Data Requirements Document

EAC	Estimate at Completion
EAR	Export Administration Requirements
ELV	Expendable Launch Vehicle
EMI	Electromagnetic Interference
ETA	Engineering Technical Authority
EVA	Extra Vehicular Activity
EVM	Earned Value Management
EVMFP	EVM Focal Point
FACA	Federal Advisory Committee Act
FAD	Formulation Authorization Document
FAR	Federal Acquisition Regulations
FCOD	Flight Crew Operations Directorate
FFP	Firm Fixed Price
FRR	Flight Readiness Review
GOES	Geostationary Operational Environmental Satellite
GPMC	Governing PMC
GSE	Ground Support Equipment
HMA	Health and Medical Authority
HQ	Headquarters
HST	Hubble Space Telescope
IBR	Integrated Baseline Review
I&T	Integration and Test
ICA	Independent Cost Analysis
ICD	Interface Control Document
ICE	Independent Cost Estimate
ICP	Interface control Plan
IDD	Interface Definition Document
IDIQ	Indefinite Delivery, Indefinite Quantity
IEMP	Integrated Enterprise Management Plan
ILS	Integrated Logistics Support
IM	Instrument Manager
IMS	Integrated Master Schedule
IPAO	Independent Program Assessment Office

IPT	Integrated Product Team
ISS	International Space Station
IT	Information Technology
ITAR	International Trafficking in Arms Regulations
IV&V	Independent Verification and Validation
JCL	Joint Confidence Level
JWST	James Webb Space Telescope
KDP	Key Decision Point
KPP	Key Performance Parameter
LCC	Life-Cycle Cost
LCCE	Life-Cycle Cost Estimate
LCROSS	Laser Crater Observation and Sensing Satellite
LLIS	Lessons Learned Information System
LOD	Letter of Delegation
LRD	Launch Readiness Date
LSE	Lead Systems Engineer
MAM	Mission Assurance Manager
MBP	Master Buy Plan
MCR	Mission Concept Review
MD	Mission Directorate
MDAA	Mission Directorate Associate Administrator
MDPMC	Mission Directorate Program Management Council
MDR	Mission Definition Review
MMT	Mission Management Team
MOA	Memorandum of Agreement
MOD	Mission Operations Directorate
MOU	Memorandum of Understanding
MRO	Mars Reconnaissance Orbiter
MSE	Mission System Engineer
NDA	Nondisclosure Agreement
NESC	NASA Engineering and Safety Center
NICS	NASA Instrument Capability Study
NPD	NASA Procedural Directive

NPR	NASA Procedural Requirements
NSM	NASA Structure Management
OCE	Office of the Chief Engineer
ORR	Operational Readiness Review
PBS	Product Breakdown Structure
PCA	Product Commitment Agreement
PCE	Program/Project Chief Engineer
PDR	Preliminary Design Review
PE	Program Executive
PI	Principal Investigator
PLAR	Post-Launch Assessment Review
PM	Program/Project Manager
PMB	Performance Measurement Baseline
PMC	Program Management Council
POP	Program Operating Plan
PP	Project Plan
PP&C	Project Planning and Control
PPBE	Planning, Programming, Budgeting, and Execution
PRACA	Problem Reporting and Corrective Action
PRT	Problem Resolution Team
PSM	Procurement Strategy Meeting
Q-TIPS	Quantitative Techniques for Incorporating Phase and Schedule
QA	Quality Assurance
PSR	Program Status Review
RFA	Request for Action
RFP	Request for Proposal
RID	Review Item Discrepancy
RVM	Requirements Verification Matrix
SAR	System Acceptance Review
SBIR	Small Business Innovation Research
SBU	Sensitive But Unclassified
SDR	System Definition Review
SE	Systems Engineering

SE&I	Systems Engineering and Integration
SEMP	Systems Engineering Management Plan
SIR	System Integration Review
SMA	Safety & Mission Assurance
SMD	Science Mission Directorate
SME	Subject Matter Expert
SOW	Statement of Work
SRB	Standing Review Board
SRR	System Requirements Review
TA	Technical Authority
TAA	Technical Assistance Agreement
ToR	Terms of Reference
TRL	Test Readiness Level
UFE	Unallocated Future Expenses
V&V	Verification and Validation
WBS	Work Breakdown Structure
WISE	Wide-field Infrared Survey Explorer

## Appendix C: Sample Documents

NPR 7120.5 has four appendices with templates for the following:

- Formulation Authorization Document (FAD) Template
- Program Commitment Agreement (PCA) Template
- Program Plan Template
- Project Plan Template

Appendix G of NPR 7120.5 also covers the NASA WBS structure.

Sample documents of each of the above are being identified and cleared for listing on a public Web site. These URLs will be added to this document when that process is complete.

NASA's Program/Project Online Library and Resource Information System (POLARIS) (<https://polaris.nasa.gov>), while not a sample document, provides easy access to NPR 7120.5 requirements and other information and tools for program/project management team members. Specifically, POLARIS contains:

- A searchable and sortable database of NPR 7120.5 requirements
- Interactive program and project life-cycle charts with links to guidance on reviews
- Electronic versions of the NPR 7120.5 templates
- Numerous links to general information useful to program and project managers

A public site, available to non-NASA users, is available at

<http://polaris-public.nasa.gov>

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