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PROJECT MANAGEMENT AND SYSTEM ENGINEERING HANDBOOK

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1. INTRODUCTION

1.1 Scope. This handbook provides a description of the basic processes and general guidance for managing and implementing the life cycle of all projects managed at Marshall Space Flight Center (MSFC) and executing the system engineering processes employed at MSFC. Its intended use is for projects that provide aerospace products, technologies, data, and operational services (aeronautics, space, and ground). It also serves as an information source for projects such as non-flight infrastructure, Construction of Facilities (CofF), and Small Business Innovation Research (SBIR), and also for research and analysis projects. Several topics will be repeated throughout the handbook to emphasize their continued importance during the life cycle of the project.

While many of the management and system engineering principles and practices described in this book apply to both programs and projects, the emphasis of the document is to describe the management and system engineering necessary for project development. Therefore, in general the document refers only to project management and system engineering. Readers interested in program management principles should be able to also apply this information to the program level.

While all process activities and general guidance are addressed, project managers, working with their system engineers, should tailor implementation to the specific needs of the project consistent with project size, complexity, criticality and risk. Tailoring is a mechanism to encourage innovation and achieve products in an efficient manner while meeting the expectations of the customer. Results of the tailoring will be documented in Program Commitment Agreements (**PCA**s), Program Plans, and Project Plans. All projects must comply with applicable MSFC directives, requirements established by law, regulations, Executive Orders, and Agency directives.

Figure 1 provides an outline of the handbook. It should be noted that the core of the document lies in Section 4., Project Management and System Engineering. In Figure 1, Sections 4.1 and 4.4, Project Development Processes and Project Reviews are arranged in a time-phased order, but Sections 4.2 and 4.3 deal with team organization and functions, and are not in any order. However, Figures 2 and 3 will yield substantial insight into timing of organizational support and functional requirements for the project team. Finally, Appendix A has an extensive listing of representative items that may be considered for a number of reviews, and Appendix B lists representative Technical Performance Metrics (TPMs).

1.2 Purpose. The purpose of this handbook is to describe the basic processes and to provide general guidance for managing and implementing projects managed at the MSFC. The handbook also defines the contemporary practices and policies employed at MSFC in the management of projects and execution of the system engineering

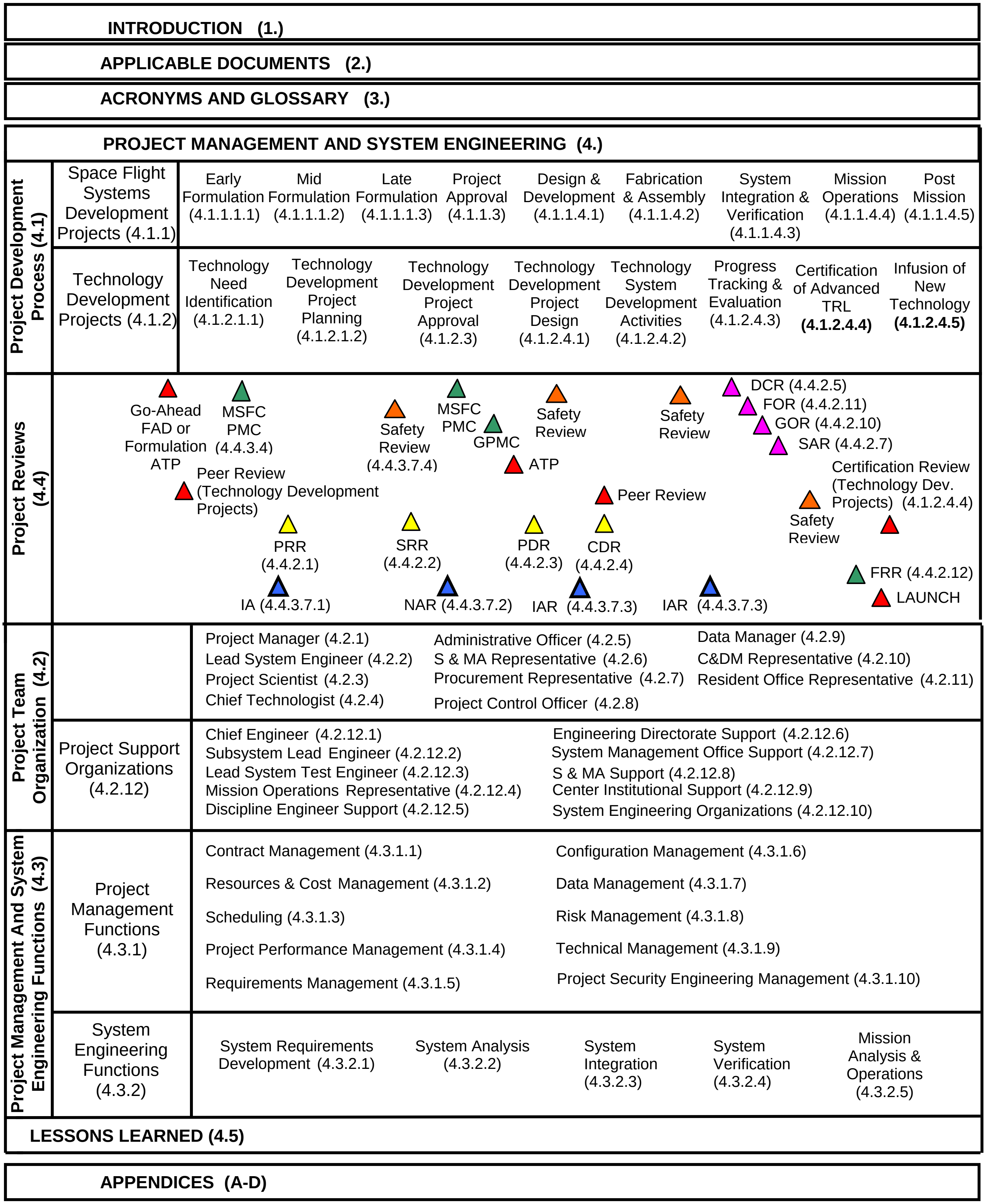

Figure 1. Handbook Organization and Guide

processes. This document is not intended to be a specification for future projects, but is to be used as a guide both in the management of projects and in the development of plans for future projects. It will also serve as an orientation for newcomers and outsiders to the processes used at MSFC in the project management and system engineering employed in the development of space systems.

1.3 Background. Historically for National Aeronautics and Space Administration (NASA) research and development programs, there have been three primary interrelated variables that have determined project success or failure. These are cost, schedule, and technical performance. Of the three factors, cost was the one that was permitted to vary to compensate for technical or schedule uncertainties. Today's political and economic environment is substantially different from that of the Apollo/Saturn era. Cost along with schedule and technical performance are solid anchoring factors in the project management and system engineering process. This suggests that managers and system engineers of future projects will have to do adequate up-front planning, as defined herein, to successfully achieve the projects' goal in today's faster, better and cheaper environment. The objective of the planning activity is to develop the detailed definition of the project requirements and to establish project control to manage the project development. The planning must also include the Agency's number one goal of safety.

Over the last several years, the MSFC and the Agency have undergone many changes. The Agency has employed a strategic planning process divided into a series of Enterprises to efficiently utilize the Agency to pursue the various major areas of emphasis. Program and Project development and management have evolved as documented in NPG 7120.5, the *NASA Program and Project Management Processes and Requirements*, to ensure that programs and projects are not only in concert with the Enterprise's charters, but are also efficiently planned, budgeted, and implemented. The Agency and MSFC implemented the International Organization for Standardization's (ISO) ISO 9000 Quality Management System to guide the organizations in ensuring that quality products and services are delivered, and the MSFC modified its organizational structure to more efficiently implement its missions. As part of the Center's reorganization in 1999, the project system engineering functional responsibilities were also modified. Many of the system engineering functions previously performed by the former Systems Analysis and Integration Laboratory were directed to the newly formed product line directorates. Systems requirements development, systems integration, and verification requirements and compliance are now implemented by the product line directorates, and were clearly made the responsibility of the Project Manager to ensure that they are implemented on his/her project.
This handbook combines the project management and system engineering principles and practices in a fashion compatible with the Agency project management guidelines and directives, and in concert with the MSFC Management System, and the MSFC organizational structure.

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2. APPLICABLE DOCUMENTS

2.1 NASA Documents

Number	Title	Paragraph
NPD 2190.1	NASA Export Control Program	4.2.12.7
NPD 7120.4	Program/Project Management	4.1
NPD 8010.2	Use of Metric System of Measurement in NASA Programs	4.1.1.2
NPD 8070.6	Technical Standards	4.3.2.1
NPD 8710.3	NASA Policy for Limiting Orbital Debris Generation	4.3.2.2.8
NPD 8720.1	NASA Reliability and Maintainability (R&M) Policy	4.3.1.9.1.2
NPD 8730.4	Software Independent Verification and Validation	4.1.1.4.3.2
NPD 9501.3	Earned Value Performance Management	4.3.1.4.1
NPG 1441.1	NASA Records Retention Schedules	4.3.1.7.4
NPG 5600.2	Statement of Work (SOW): Guidance for Writing Work Statements	4.3.1.1.1
NPG 7120.5	NASA Program and Project Management Processes and Requirements	1.3, 4.1, 4.1.1, 4.1.3
NPG 8621.1	NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping	4.3.1.9.1.3
NPG 8735.2	Management of Government Safety and Mission Assurance Surveillance Functions for NASA Contracts	4.3.1.9.1.2
NPG 9501.2	NASA Contractor Financial Management Reporting	4.3.1.1.3
NSTS 1700.7	Safety Policy and Requirements for Payloads Using the NSTS	4.3.1.9.1.1, 4.4.3.7.4
NSTS 1700.7, ISS Addendum	Safety Policy and Requirements for Payloads Using the International Space Station	4.4.3.7.4
NSTS 5300.4(1D-2)	Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program Change No. 2	4.3.1.9.1 4.3.1.9.1.2
SSP 50021	Safety Requirements for the ISS Program	4.4.3.7.4
FAR Part 27	Federal Acquisition Regulation	4.2.12.9.3
NASA FAR Supplement Parts 19-27	Federal Acquisition Regulation	4.2.12.9.3
No Number Assigned	NASA WBS Reference Guide	4.3.1.2.1

2.2 MSFC Documents

Number	Title	Paragraph
MPD 1130.1	Roles and Responsibilities of the MSFC Project Scientist	4.2. 3
MPD 1280.1	Marshall Management Manual	4.2.12.7
MPD 1380.1	Release of Information to News and Information Media	4.2.12.9.3
MPD 1394.1	Control of Audiovisual Products	4.2.12.9.3
MPD 2190.1	MSFC Export Control Program	4.2.12.7, 4.3.1.10
MPD 8720.1	MSFC Maintainability and Maintenance Planning for Space Systems	4.3.1.9.1.2
MPG 1230.1	Center Resources Management Process	4.2.12
MPG 1371.1	Procedures and Guidelines for Processing Foreign Visitor Requests	4.2.12.9.3
MPG 1440.2	MSFC Records Management Program	4.3.1.7.4
MPG 2190.1	MSFC Export Control Program	4.2.12.7, 4.3.1.10
MPG 6410.1	Handling, Storage, Packaging, Preservation, and Delivery	4.3.2.6
MPG 7120.1	Program/Project Planning	4.1, 4.1.1.1.1, 4.2.12.7, 4.4.1, 4.4.3.4
MPG 7120.3	Data Management, Programs/Projects	4.2.9, 4.3.1.7, 4.3.1.7.3
MPG 8040.1	Configuration Management, MSFC Programs/ Projects	4.3.1.6
MPG 8060.1	Flight Systems Design/Development Control	4.1.1.4.1
MSFC-HDBK-2221	MSFC Verification Handbook	4.1.4.3.2
MSFC-STD-506	Materials and Process Control	4.1.4.1
MSFC-STD-555	MSFC Engineering Documentation Standard	4.3.1.6
MWI 1050.3	Policy and Authority to Take Actions Related to Reimbursable and Non-Reimbursable Space Act Agreements	4.1.3
MWI 1280.5	MSFC ALERT Processing	4.3.1.9.1.2
MWI 1700.1	Payload Safety Readiness Review Board	4.4.3.7.4
MWI 1700.2	System Safety Program	4.3.1.9.1.1
MWI 5100.1	Procurement Initiators Guide	4.3.1.1.1
MWI 5115.2	Source Evaluation Board/Committee (SEB/C) Process	4.3.1.1.1
MWI 5116.1	Evaluation of Contractor Performance Under Contracts with Award Fee Provisions	4.3.1.1.2, 4.3.1.4.1

MWI 6410.1	Packaging, Handling, and Moving Program Critical Hardware	4.3.2.6
MWI 6430.1	Lifting Equipment and Operations	4.3.2.6
MWI 7120.1	Program/Project Quality Plan	4.1.1.1.2 4.3.1.9.1.2
MWI 7120.2	Data Requirements Identification/Definition	4.3.1.7.1
MWI 7120.4	Documentation Preparation, Programs/Projects	4.3.1.7.2
MWI 7120.6	Program/Project Risk Management	4.1.1.1.3 4.3.1.8
MWI 8040.1	Configuration Management Plan, MSFC Program/Projects	4.3.1.6
MWI 8040.2	Configuration Control, MSFC Program/Projects	4.3.1.6
MWI 8040.3	Deviation and Waiver Process, MSFC Programs/Projects	4.3.1.6
MWI 8040.5	Floor Engineering Orders and Floor Engineering Parts Lists (FEO/FEPLs)	4.3.1.6
MWI 8040.6	Functional and Physical Configuration Audits, MSFC Programs/Projects	4.3.1.6, Appendix A, FCA/PCA
MWI 8040.7	Configuration Management Audits, MSFC Programs/Projects	4.3.1.6
MWI 8050.1	Verification of Hardware, Software and Ground Support Equipment for MSFC Projects	4.1.4.3.2
TBD	Managing a Technology Development Program	4.1.2, 4.1.2.1.2

2.3 KSC Documents

KHB 1700.7C	STS Payload Ground Safety Handbook	4.4.3.7.4

2.4 Military Documents

MIL-HDBK-881	Work Breakdown Structure	4.3.1.2.1

2.5 Other Documents

ANSI/ISO/ASQ 9001-2000	Quality Management System-Requirements	4.3.1.9.1.2
SAE AS9100	Quality Systems-Aerospace-Model for Quality Assurance in Production, Installation and Services	4.3.1.9.1.2
	Manual of Regulations & Procedures for Federal Radio Frequency Management	4.1.1.1.2
Title 14 CFR 1213	Release of Information to News and Information	4.2.12.9.3

	Media	

3. ACRONYMS AND GLOSSARY

A list of acronyms is included in this document as Appendix C. A glossary is included as Appendix D.

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4. PROJECT MANAGEMENT AND SYSTEM ENGINEERING

Project management is the function of planning, overseeing, and directing the numerous activities required to successfully achieve the requirements, goals, and objectives of NASA's customers. Two types of projects managed at MSFC are space flight system projects that may vary from a major stage of a launch vehicle to a small experiment to be flown aboard the National Space Transportation System (NSTS) or housed on the International Space Station (ISS), and technology development projects that develop a particular technology or advance a particular technology to enable future capabilities. Although the scope, complexity, cost, development processes, and specific project management tasks for projects will vary, the basic structure of the project life cycle for the various types of projects and the project management tasks are basically the same. System engineering is the function that systematically considers all aspects of a project in making design choices and is a continuous, iterative process with a built-in feedback mechanism that is used throughout a project's life cycle to arrive at the best system architecture and design possible. The success of complex space vehicles and space vehicle projects is highly dependent upon the system engineering process being properly exercised at all levels of design and management.

This section provides a description of the project development process including project Formulation (including planning), Evaluation, Approval, and Implementation. This section also discusses the organization and team description required to implement the life cycle process, and describes the various project management and system engineering functions that comprise project management and system engineering responsibilities. Significant variances between technology development projects and classical engineering development projects are also discussed.

4.1 <u>PROJECT DEVELOPMENT PROCESSES</u>. The major goals and objectives of the NASA are divided into categories known as Enterprises at the Agency level (see Appendix C). The NASA Enterprises, as defined in the NASA Strategic Plan, achieve their goals and objectives through the implementation of "programs." Once a NASA program is established, its goals and objectives are normally partitioned into groups such that one or more "projects" may fulfill a partitioned group of the program goals and objectives. New project goals and objectives may be offered to parties interested in managing and/or fulfilling the project needs. NASA Centers, commercial industries, and/or academic organizations may pursue the management and development of projects through responding to opportunities offered through the release of NASA Research Announcements (NRAs), or Announcements of Opportunity (AOs), or through other means.

The project life cycle of the project development process is the orderly progression of activities that results in an efficient utilization of resources to accomplish an identified set of project goals and objectives. The NPG 7120.5 provides the Agency guidelines and requirements for project development management. The responsible Enterprise Associate Administrators (EAAs) in consultation with the appropriate Center management normally

select new project initiatives. The EAAs are accountable to the Office of the Administrator for assuring that new projects have been adequately defined, assessed, and planned before being included in the Agency's budget submission.
A Formulation Authorization Document (FAD) is an important document that formalizes a program initiation. See NPG 7120.5, Appendix E.1. The FAD is concisely written direction by the EAA authorizing resources for formulation with a scope of work for the study, any cost targets or constraints, and schedules. The FAD can be used for the authorization of a project to be consistent with the Program Plan, developed during program formulation.

Another top-level document that defines the basic scope, resources, and contents of programs (and sub-tier projects) is the **PCA**, which is developed during program formulation. The **PCA** is an agreement between the Administrator and the EAA that documents the Agency's commitment to execute the program requirements within established constraints. The **PCA** includes: (1) a comprehensive definition of the program or project concept and program/project performance objectives, and (2) agreements, approaches, and plans for meeting the technical, budget, schedule, risk management, commercialization, acquisition, and related management system requirements (see MPG 7120.1, *Program/Project Planning*, NPD 7120.4, *Program/Project Management*, and NPG 7120.5). The **PCA** is the starting point for all project activity and sets the stage for projects to emerge and exist to fulfill the needs of the program. The Program Plan provides program inputs to project formulation including, program requirements allocated to the project and budget direction/constraints. Structuring, streamlining, and focusing the definition phase of any project will reduce the total lead-time and cost between concept and flight. Both the **PCA** and Program Plan will be submitted for approval as part of the program approval process.

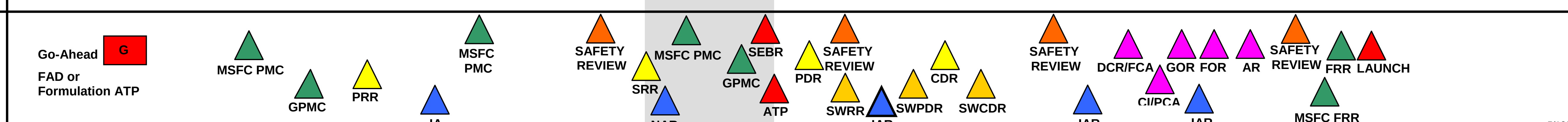
The following sub-paragraphs describe the typical project life cycle for projects at MSFC. The project life cycle is defined in some degree, chronologically, and each sub-process may be viewed as a phase.

4.1.1 Space Flight System Development Projects. This section describes the processes followed by projects that are basically engineering development projects that generally utilize existing technology. Although many of these projects at MSFC also require some advancement in technology to achieve their objectives, the process described in the following paragraphs is generally followed. Paragraph 4.1.2 describes the general process for technology development projects. Some projects may require a combination on the two types described. The following sub-paragraphs provide a description of the project's development processes including project Formulation (including planning), Evaluation, Approval, and Implementation. Figure 2 depicts an overview of the various phases, activities, phased products, milestones, reviews, and control gates associated with a typical space flight system project life cycle.

Project Development Process

Phase	Pre-Formulation Studies	Formulation: Early Formulation	Formulation: Mid Formulation	Formulation: Late Formulation	Formulation / Implementation: Project Approval	Implementation: Design & Development	Implementation: Fabrication & Assembly	Implementation: System Integration & Verification	Implementation: Mission Operations	Implementation: Post Mission
Major Activities	Explore Wide Range of Potential Missions or Technology Thrusts Through Advanced Studies with Industry and/or Academia Develop Preliminary User or Mission Needs Statement Receive Program Plan and/or PCA inputs for project formulation	Refine Mission Needs Statement & Strategic Plan Links Identify initial concepts for further study Develop project objectives Assess overall feasibility Preliminary mission definition studies Identify technology requirements Identify support requirements Identify relationships with other programs Perform trade-off studies Develop preliminary system requirements Identify feasible concepts Perform environmental impact analysis LCC analyses Operations & business opportunities studies Develop Preliminary schedules Develop WBS Develop TPMs	Perform concept trade studies in areas of performance, LCC, schedules, & Safety Increase depth of analyses Continue system requirements development Project planning refinement Develop project schedules Assess procurement options Operations & logistics planning Develop resources & budget requirements **Formulation Source Selection Process** - Release RFP - Evaluate Proposals - Select Contractor(s) - Negotiate Contract(s) - Award Contract(s)	Down selection of single concept Refinement of WBS Perform trade studies Perform system analyses & simulations Refinement of system requirements Develop support requirements Develop software requirements Development of SEMP Update the Project Plan Develop preliminary manufacturing requirements Confirm technology requirements Refinement of preliminary schedules Refinement of cost estimates Refinement of project risks assessments & management plans Reaffirm Mission Needs Statement Resource Planning	Prepare Implementation Phase final Statement of Work Prepare Implementation Phase RFP Develop Source Selection Plan Present to MSFC PMC Review Present & obtain approval of GPMC Confirm resources appropriated, budgeted & programmed Release Implementation Phase RFP Evaluate proposals Negotiate Contract Award Implementation contract Issue Implementation Phase ATP	Baseline of system requirements Definition of interfaces Allocation and flow-down of requirements to design level Design trade studies Refinements of software requirements Development of hazard analyses & safety assessments Development of verification program Development of verification requirements Completion of preliminary design Completion of detail design Release design drawings for fabrication Develop final fabrication, testing, operations, logistics, supporting systems and facilities plans Continue update of system analyses Refinement of schedules and cost estimates Refinement and Baseline of Quality Plan	Continued release of detail design drawings for manufacture/fabrication Procurement of fabrication Continued system performance analyses Development of hazard analyses and safety assessments Component level verification Qualification of components Refinement of schedules and cost estimates Finalize test planning Assembly of components into subsystems Finalize operations, handling, transportation, and storage plans Finalize supporting systems and facilities Software design & development System assembled Mission operations team identified	Development and test of prototype/protoflight hardware Implementation of system safety compliance Development of ground systems Develop test procedures Qualification of flight system Integration of flight system Verification of flight and ground systems Verification/validation of flight software Verification compliance reporting DCR preparations Mission simulations Mission operations finalized Contingency planning Mission operations team organized Operations training FRR preparations	FRR conducted Launch operations conducted Payloads integrated with launch vehicle/spacecraft Experiments integrated with spacecraft/carrier Mission launched On-orbit verification of system Conduct of mission operations Experiments initiated Payload sample change out Real time analyses of data Identification of anomalies Real time trouble-shooting and adjustments to timelines	Payload de-integrated Experiments results removed On-board data collected Data processes and analyzed Flight anomalies identified and analyzed System de-integrated System serviced for turn around (if required) Lessons learned documented Storage or disposal of system hardware Required system modifications identified Requirements changes initiated (if required) Design modifications initiated Test plan modifications identified
Products	Preliminary User/Mission Needs Statement Basis for Center Director to Propose Further Formulation Studies Budget Submittal for Formulation Phase (First Year)	Concept definition Preliminary configuration layouts Preliminary mission definition Preliminary Work Breakdown Structures Preliminary integrated project summary Preliminary Project Plan Technology development road map Preliminary system requirements Preliminary schedules Preliminary operations planning Independent cost estimate Preliminary risk analysis Environmental impact Mission Needs Statement Preliminary System Safety Analyses Updated budget submittal Preliminary TPMs	Updated concept definition Configuration layouts Detailed Project Plan Updated WBS Updated system requirements Updated project schedules Risk identification & management plans Operations & logistics plans Preliminary Quality Plan System Safety analyses Preliminary Hazard Analysis Preliminary FTA	Project Plan WBS Project Schedule Prelim. System Requirements Prelim. Support Requirements Prelim. Software Requirements Concept of Operations Make or Buy Decisions Prelim. Implementation RFP Contractor Proposal Evaluation Criteria Risk Management Plan Proposed Quality Plan Project Surveillance Plan Configuration Management Plan Data Management Plan Independent Assessment Report Non-Advocate Review Report Project System Safety Plan Logistics Plan SEMP Prelim. Orbital Debris Analysis	SOW RFP Source Selection Plan Proposal Evaluation Records Contract Implementation Contractor ATP	System Requirements Documents Contract End Item Specifications Interface Control Documents Quality Plan Materials & Processes Selection, Implementation, and Control Plan Preliminary design drawings Design review packages Manufacturing & Assembly Plan Final design drawings Revised Project Plan Verification Plan Verification requirements Contamination Control Plan TPM Reports Hazard Analysis FMEA/CIL FTA Updated Orbital Debris Analysis	Components fabricated and delivered Components verified Subsystems assembled Test Plans Updated verification requirements Updated Verification Plan Preliminary Mission Plan Support Operations Plan Training Plan TPM Reports	Test procedures Verification Reports Compliance Reports Verified subsystems System accepted by government (DD-250) Verified operational system Mission Operations Plan DCR Package FRR Package TPM Reports	On-orbit Verification Report Processed Science Samples Mission data Lessons learned	Flight Analyses Report Failure Reports

Milestones & Control Gates



AR: Acceptance Review
ATP: Authorization to Proceed
CDR: Critical Design Review
CI: Configuration Inspection
DCR: Design Certification Review
FAD: Formulation Authorization Document
FCA: Functional Configuration Audit
FOR: Flight Operations Review
FRR: Flight Readiness Review
GOR: Ground Operations Review
GPMC: Governing Project Management Council
IA: Independent Assessment
IAR: Independent Annual Review
MSFC PMC: MSFC Project Management Council
NAR: Non-Advocate Review
PCA: Physical Configuration Audit
PDR: Preliminary Design Review
PRR: Project Requirements Review
SEBR: Source Evaluation Board Review
SRR: System Requirements Review
SWCDR: Software Critical Design Review
SWPRD: Software Preliminary Design Review
SWRR: Software Requirements Review

Figure 2. Space Flight System Project Development Process

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4.1.1.1 Project Formulation. The project formulation is the initial process for project development. Project formulation is the process that defines an affordable concept, expands the given goals and objectives specified in the **PCA** and the Program Plan into a set of requirements, and develops the planning to convince both advocates and non-advocates that a feasible and practical approach can be implemented to fulfill project requirements.

During the formulation process, the various implementation conceptual options, available technology, development risks, and estimation of budget and schedule requirements are identified and investigated. A proper understanding of risk, technology needs, top-level requirements including interfaces, and adequate Life Cycle Cost (LCC) estimates is necessary during the formulation activity. A comprehensive project development risk identification and assessment is developed and provided to establish a high level of confidence for the project cost. The cost estimate established during formulation will provide NASA Headquarters with the funding requirements that will require approval from Congress to begin the implementation process.

The project formulation process may be divided into three phases: the early formulation phase, the mid formulation phase, and the late formulation phase. These three phases are defined by the activities being performed during each phase and are described in the following paragraphs.

4.1.1.1.1 Early Formulation Phase. While a preliminary mission needs may have been generated during pre-formulation studies, the more thorough studies of the early formulation confirms the mission needs, defines mission concepts, and establishes mission feasibility. The mission need determination is the first step in a multi-faceted preliminary concept definition activity. This is the step that may be first performed by or sponsored by NASA Headquarters or Center level (or industry, university, etc.) and is the precursor to concept development. The mission need determination is that part of early mission planning that identifies a national need or gap (i.e., scientific knowledge, access to space) that could be met with some kind of NASA sponsored activity. These needs are captured in a Mission Needs Statement.

Once the mission needs are established, a concept definition activity is begun to explore candidate concepts that may meet the documented mission needs. These concepts could have come from a pre-formulation study or from other sources within or external to NASA. The majority of concepts that are studied at MSFC are assigned by NASA Headquarters and funded accordingly. Competition and innovation should be employed to ensure that a wide variety of options are identified and examined. The goal of a concept definition activity is to determine the best and most feasible concept(s) that will satisfy the mission and science requirements. Modeling and computer analysis are required to assess the best concepts. Where possible, a utility analysis is conducted to determine the value of a project. This requires a best estimate of the LCC of the project and benefits versus existing alternatives. At this stage of the process the utility analysis may be more qualitative than quantitative because of the uncertainties in the knowledge base at this stage. The following criteria are considered during this study, as appropriate: the program needs are met, the scientific knowledge acquired, and potential technology spin-offs and applications are identified. Project planning is accomplished during early formulation and includes establishing project control for oversight and reporting, which integrates the cost, schedule, and technical performance of the project. This process is repeated and updated as more in depth knowledge is obtained. As concepts and project planning becomes clearer, a preliminary Work Breakdown Structure (WBS) and WBS dictionary (see paragraph 4.3.1.2.1) are developed to serve as the basis for project technical planning, scheduling, cost estimating and budgeting, contract scope definition, documentation product development, and status reporting and assessment. Development of a set of TPMs during the early planning activities provides a mechanism for tracking and maintaining successful project performance. Establishment of the TPMs should include meaningful milestones with a connection to a project-oriented WBS that quantitatively measures progress of the project. The TPMs are updated as the process continues through formulation and into implementation to include appropriate metrics for project control of the additional activities. Examples of TPMs are shown in Appendix D.

Activities typically occurring during early formulation are as shown in Figure 2. The outputs from the early-formulation studies become the inputs into the mid/late formulation activities, and those typical outputs are also shown in Figure 2.

Ensuring safety is primary for all projects, and doing so begins in the early formulation phase. The following is a brief summary description of principal system safety tasks and outputs during the early formulation phase:

a. Perform preliminary top-level hazard analyses and safety assessment of each project approach. Hazard analyses must:

    - Identify hazards and evaluate the method by which the hazards may be eliminated or controlled for each concept;
    - Evaluate each proposed approach or concept and provide recommendations for the selection of one or more approaches or concepts. Rationale for solution must be clearly submitted; and
    - Serve as a baseline for hazard analyses later in the formulation phase.

b. Develop safety criteria and requirements for inclusion in design concept(s). Once the criteria and requirements have been established they are documented in the Preliminary System Requirements Document. These criteria and requirements must be continually evaluated throughout the life of the project.

Another activity that should be initiated during this phase is the development of a project risk management summary containing as a minimum a composite listing of project development areas that have a high potential of causing project schedule delays, cost increases, and/or technical performance short comings, as well as safety risks, hazards, and associated control actions.

4.1.1.1.1.1 Project Plan One of the key documents that captures and establishes the baseline for the project implementation activities is the Project Plan. As evidenced from the list in Figure 2, the Project Plan begins development during the early formulation phase and matures with the continuation of the formulation process. A Project Plan is the basic planning document that documents the products of the formulation process and describes the overall plan for implementation of a project. Project Plans are unique to each project, and the format and level of detail may vary with the size, complexity, sensitivity, and other particular characteristics of the project. Project Plans for conventional flight hardware development projects will show the projected requirements development, design, reviews, fabrication, verification, launch plans, schedules, costs, and other criteria. Project Plans will be prepared in accordance with MPG 7120.1. MPG 7120.1 is the Centers' documented approach to program/project management, however, innovation of the MPG 7120.1 process is encouraged. Tailoring of the project's activities will be identified in the Project Plan. The Project Plan will serve as the basic agreement for the project between the Project Manager, the Center managing the project, and the program management.

4.1.1.1.2 Mid Formulation Phase. The mid formulation phase verifies that concepts being considered will meet top level project requirements, meet budget and schedule constraints, and are feasible. All feasible concepts are studied and trade studies are performed to determine the viable concepts for the project application considering objectives, and budget and schedule requirements.

Throughout the mid and late formulation period, the concepts and requirements that were developed and risks that were identified during early formulation are iteratively reviewed and analyzed. Through trade studies, the concepts' capabilities are compared to the requirements. Those concepts that consistently satisfy the requirements are identified and refined. Concepts that do not meet performance and other requirements are analyzed for possible elimination. Following the examination of those that do not perform well, assessments are made regarding their augmentation to discover the degree of change necessary to bring their performance into scope. Concepts that have to change too much or would experience severe budgetary and/or schedule impacts are deleted from the concept definition and analysis cycle. Verification of design concepts through the performance of detailed analyses and tests utilizing mockup and/or subscale hardware can be extrapolated to provide confidence in a particular approach.
These trade studies, through the use of tailored evaluation criteria that are used as concept discriminators, provide a more detailed look at the architectural concepts, which may consist of certain satellites and/or instruments, space flight vehicles, or technology demonstrators, and result in a narrowing of the field of candidates for a more detailed level of design. Trades performed during this time consider such things as performance, cost, schedule, lifetime, and safety. The evaluation criteria used to assess alternative concepts

are developed to a finer level of detail than for earlier system trades. Trade study results are input to the risk management summary updates.

Cost estimates are refined as further detailed requirements are identified during the mid formulation phase. The cost estimating process is still dependent on parametric analysis. The Systems Management Office (SMO) works closely with the project formulation team in evaluating costing methodology and continuously compares government cost estimates with those of the study contractors, if contracted. Should a large discrepancy occur, the assumptions and schedule inputs of the study contractor are examined. If this examination yields valid assumptions and schedules, the NASA estimates are reconciled. The cost estimation process goes through continuous iterations during the study to reflect the refinement resulting from trade studies. For every project there are unknowns that may affect cost. A project management reserve must be included in the cost estimation process to cover these unknowns.

Preliminary quality planning and generation of a preliminary Quality Plan (as defined in MWI 7120.1, Program/Project Plan), and preliminary Hazard Analysis, Fault Tree Analysis (FTA), and functional Failure Mode and Effects Analysis (FMEA) is accomplished during the mid formulation phase. Quality planning activity results are also input to the risk management summary updates.

The mid formulation phase continues through the determination of all viable concepts for project application and the refinement of project requirements. The outputs of the mid formulation phase are refinements to the inputs to the phase. Also by this phase, certain long-range programmatic aspects must be considered (if not already). Some of these may be technical, but have impact upon overall project requirements, planning, and costs. An example of this is the Radio Frequency (RF) spectrum requirements and licenses that must be approved by the National Telecommunications and Information Administration (NTIA). The NTIA Conceptual review (Stage 1 of 4) is due after initial planning has been completed (reference *Manual of Regulations & Procedures for Federal Radio Frequency Management*). Another example is the decision to utilize (or not) the International System of Units (Metric) in accordance with NPD 8010.2, *Use of the System of Measurement in NASA Programs*.

4.1.1.1.3 <u>Late Formulation Phase</u>. The late formulation phase refines the viable concepts and verifies that the concepts will meet project requirements, budget, and schedule. After all alternative concepts have been analyzed, a primary concept is chosen for further development and project planning. Also during this phase, mission analyses are performed and mission concepts and operations are formulated. Requirements for support systems and availability of existing infrastructure to support the project are determined to capture total system implementation requirements.

During the late formulation phase, schedules are further refined. Schedules are expanded from the early and mid formulation phases' overall project schedules to lower levels of the

WBS to include subsystem development, project management, manufacturing, verification, logistics planning, operations planning and other technical areas. In addition, other schedules are developed that include implementation procurement strategies, cost phasing and project manning requirements. The overall project schedules show the phasing of all major activities through launch and the follow-on operations. The activities occurring during the late formulation phase are typically as shown in Figure 2. The typical outputs from these activities, which become the inputs into the Approval and Implementation activities, are also shown in Figure 2.

The following is a brief summary description of principal system safety tasks and outputs of the late formulation phase:

a. Develop a project system safety assessment in which the proposed system safety effort in formulation is integrated with other formulation program elements. Prepare a preliminary hazard and safety assessment for each proposed approach in order that comparative studies may be utilized in the final concept. These assessments will be used as a baseline for performing detailed hazard assessments during the Implementation phase. The preliminary hazard assessments shall consider mission profile and environments, abort and rescue/escape, critical time periods for each subsystem, system/subsystem interfaces, man-machine interfaces, and caution and warning system. The identified hazards will be evaluated and recommended corrective actions issued in the form of design criteria, design requirements, or operational constraints.

b. Prepare and submit a comparative assessment providing safety rationale for recommending one concept or approach over the others.

c. Define specific safety requirements and criteria to be included in Implementation Process requirements.

d. Expand the project risk management summary commensurate with the Phase 0/1 (see 4.3.6.3.4) hazard analyses. Residual risks and rationale for acceptance are identified and documented in accordance with MWI 7120.6, *Program/Project Risk Management.* (See paragraph 4.3.1.8.)

e. Perform Preliminary FMEA and FTA.

4.1.1.2 Project Evaluation. Project evaluation occurs throughout the life cycle of the project to ensure the successful completion of the formulation, approval, and implementation processes. The purpose of the evaluation process is to provide an Independent Assessment (IA) of the continuing ability of the program or project to meet its technical and programmatic commitments and to provide value-added assistance to the project managers. This process uses the benefits of peer experiences, customer appraisal, and management expertise and tools in independent review of project concepts, plans, status, risk levels and performance. Requirements for the reviews and assessments should be tailored, based on such factors as program and project size, criticality, and risk and are detailed in program/project plans. The outcome of the evaluation process is a set of conclusions regarding the ability to meet commitments and recommendations for proceeding with, modifying, or terminating the project. Where appropriate, recommendations are also provided for enhancing overall technical and programmatic performance.

Evaluation reviews are planned and conducted as specified in the Project Plan and in accordance with NPG 7120.5. Projects in formulation must undergo Non-Advocate Review (NAR) and/or other successful Evaluation Reviews (such as IA) before proceeding into implementation, or to continue in the formulation process in which iterative formulation is required. For MSFC managed projects, these independent reviews are normally led by the SMO as described in MPG 7120.1. When the Project Manager and the Center Director determine that project formulation is of proper maturity, a formal evaluation review will be conducted. The overall content of the review will vary according to the project. As a minimum, the purpose of such a review will focus on mission concept and objectives, mission implementation planning, status of elements design definition and assessment of technical risks, projected schedules and total project LCC. The review team will be composed of experienced project management, technical, and fiscal personnel drawn on an ad hoc basis from organizations who are independent of the implementation of the proposed project. The review will assess the actual stage of project definition in terms of the clarity of objectives, thoroughness of technical and management plans, technical complexity, evaluation of technical, cost and schedule risks, and contingency reserve allowances in schedule and cost. The review team will provide an evaluation to the MSFC Program/Project Management Council (PMC) and the Governing Program/Project Management Council (GPMC).

4.1.1.3 Project Approval. The objective of the approval process is to determine whether a project is ready to proceed from formulation activities to the implementation activities. If it is determined that a project is not ready to proceed into implementation, approval for a project to continue in the formulation process may be provided. Approval for a project to continue in the formulation process in which iterative formulation is required, or approval of changes to the Project Plan based on budgetary or technical considerations, may also be provided. The NASA recognizes the need for a certain degree of a project's technical and programmatic maturity prior to approval into implementation. NPG 7120.5 requires the conduct of at least one NAR, and as mentioned above, the NAR supports the MSFC PMC and GPMC approval process. The findings from the independent review team and the project's presentation containing their response to the review team findings are included in the approval process presentation material. The MSFC PMC provides guidance and direction, as required, based on the material presented. When the MSFC PMC is not the GPMC, projects will schedule a GPMC meeting and the review team and project team will present their material along with any MSFC PMC recommendations. The result will be an approved Project Plan and Authority to Proceed (ATP) into implementation, or additional formulation activity instructions.

Prior to proceeding into implementation, project requirements are continually refined, project planning continues, final make or buy decisions are made, and for contracted projects, funding agreements and types of contracts are finalized.

Items to be considered prior to implementation include types of agreements in which MSFC may engage with foreign nations, academia, industry (including commercial space companies), or other government organizations for the conduct of space or non-space flight projects. The features of these agreements may vary to include ventures in which management and fiscal responsibilities are shared, or situations in which MSFC provides services on a reimbursable basis (see MWI 1050.3, *Policy and Authority to Take Actions Related to Reimbursable and Non-Reimbursable Space Act Agreements).* The MSFC Technology Transfer Department should be contacted and advice sought on the proper type agreement to be used. Added emphasis, however, must be placed during the early planning stage on a clear and mutual understanding of program definition, authorities, responsibilities, interfaces, and funding requirements. Center resources commitments must be well planned, coordinated, and approved. Also, a mutual understanding should be attained on the extent to which NASA/MSFC management and design specifications and procedures will be applied.

4.1.1.4 Project Implementation. As the project proceeds into implementation, the activity focuses on further refinement and approval of a set of baseline system requirements. Once the system requirements are baselined, the design activity is initiated, and plans are refined for final development, fabrication, test and operations. The TPMs are updated to include appropriate metrics for the activities during the implementation process. The project implementation process may be divided into phases: the design and development phase, the fabrication and assembly phase, the system integration and verification phase, the mission operation phase, and the post-mission phase. These phases are defined by the activities being performed during each phase and are described in the following paragraphs.

4.1.1.4.1 Project Design and Development. Design and development is the process of converting design and performance requirements and concepts into a set of drawings that are manufacturable, and eventually into a collection of subsystem components and required software that are integrated into a functional system. The MPG 8060.1, *Flight Systems Design/Development Control,* provides the MSFC guidelines and procedures to be followed in controlling the design during implementation. The early period of design and development is devoted to the fostering of a mutual understanding with the contractor or in-house team of requirements and plans, technical and schedule risks, cost estimates, and other matters related to the setting of a solid foundation.

Depending on the complexity of the project, the project plan may require more detailed plan(s) to define and schedule the design and development activities. For contracted projects, the initial version of this plan is typically submitted by the contractor with the proposal. This plan can be useful in the development of a mutual understanding of the total design and development process. Prior to the completion of contract negotiations, all project requirements and plans should be as complete and detailed as possible. Also early in the design and development phase, prior to the Preliminary Design Review (PDR), manufacturing and materials and processes control plans are prepared. To help assure producibility, it is important that personnel with manufacturing skills are involved in the design effort. The Materials & Processes Selection, Implementation, and Control Plan delineate the manner in which the contractor will meet the requirements imposed by MSFC-STD-506, *Materials and Process Control*. The Manufacturing and Assembly Plan specifies the tooling, facilities, schedule, critical processes, and the scheme for subsystem and final system assembly.

The design of a flight system evolves as system architectures are defined in more depth and refined by system analyses and trade studies. Design and development progress is tracked by a well-defined series of reviews (see 4.4). During this process much of the project resources (time and dollars) will be expended, many of the problems will surface and, to a large degree, eventual success or failure of the project will be determined. It is during design and development that many techniques and tools discussed elsewhere in this handbook are implemented. This design evolution begins in the late formulation phase with the baseline of system requirements and initiation of preliminary design. This design activity includes the process of functional analysis and requirements allocation, the accomplishment of trade studies and optimization, system synthesis, and configuration definition in the form of top-level specifications. Identification and acquisition of long lead item components is started. Software requirements refinement begins in formulation and extends to late in the implementation phase for the final builds. It should be noted that software requirements may be impacted by any changes in system requirements. Software development is separate but closely related to the system development as depicted in Figure 2. Once the system functions are allocated to hardware and to software, the software implementation process begins. As the preliminary design continues into the early implementation phase, the emphasis of the design analyses and trade studies shifts from the requirements definition to proving that the design meets the requirements. The preliminary design process allows the models used for analyses to be defined more realistically. This process is iterative as models are constantly improved. The outputs of the analyses that use these models are applied in the refinement of the design. Throughout the design and development phase, project risk assessments are evaluated and any new risks identified are documented and incorporated into the risk management process.

Detail design begins after assessment of the preliminary design and approval of the design approach. Design margins are allocated for each system and subsystem. During the detail design process, system engineering analyzes system allocations (e.g., mass properties, electrical power) to ensure compliance with system requirements and design margins are maintained.

As the design evolves, the subsystems, boxes and components must be examined through analyses and trade studies to determine the effects on the total system. The design becomes more refined as analyses, utilizing models that incorporate the refined designs, verify the performance of the system as designed. Detailed mathematical models determine if the system, as designed, will meet the system requirements. Tests of critical technology are conducted to verify the design and model's accuracy. Through this iterative process the models become more refined and confidence is gained that the results from the analyses are accurate. System design drawings, schematics, and interconnect diagrams are maintained current with design refinement to aid the analysis process. All equipment and hardware items are specified. The engineering drawings for component fabrication and acquisition are completed as designs are refined.

A prototype of a flight system or a subsystem may be developed if feasible and cost effective to build one-of-a-kind full scale hardware to check performance, human engineering, fit and installation, and the physical operating range of moving elements. The prototype hardware can be used to verify the flight software if sufficient hardware is developed.

The activities typically occurring during design and development and products of these activities are shown in Figure 2.

4.1.1.4.2 Fabrication and Assembly. The production of an end item which meets project requirements and mission objectives is a milestone in the overall system engineering process. Production planning and production capabilities must be factored into the system design from the beginning of the project if the activities are to be cost effective. Consideration must be given to production functions such as materials and materials usage, processes, process control, integration and assembly, testing, preservation, packaging, storage, shipping, and disposition of unused materials. Early and continuous consideration must be given to these production functions in trade studies, cost analysis, risk management, schedules, and other products of the system engineering process.

As design is completed and drawings are released, fabrication of piece parts of the project begins. Earlier make or buy analysis has been accomplished, and decisions on whether fabrication will be performed in-house or by the project contractor have previously been made. Concurrent engineering has ensured that the drawings have properly identified the materials, processes, and quality sensitivity of the items to be produced, and that fabrication facilities have properly ordered the materials and scheduled the fabrications. During this period, the responsible design engineer follows the fabrication progress and will assist the fabricator if any production questions and/or issues arise. The software is developed through coding and testing after the Software Critical Design Review (SWCDR). This level of testing is commonly referred to as "debugging." Designers, system engineers, and configuration management must be ready to assess and make any adjustments to design if necessary. The Project Configuration Management Plan has identified the change process to be followed. Thorough earlier coordination and analyses will minimize required changes during the fabrication process; however, Floor Engineering Orders (FEOs) may be required for "make-work" changes. Since FEO changes may preclude thorough analyses prior to their incorporation, FEOs should be kept to a minimum. The system analysis of proposed changes during this phase is important to ensure that any last minute changes will not adversely affect the overall function and performance of the system.

System performance analyses continue during this period to finalize mission planning and to ensure that all mission aspects have been analyzed and integrated. Safety analyses are continually worked to ensure that the proper mitigations have been established and recorded in the proper form. Verification planning is finalized, and tests planning procedures are prepared. Software test reviews may be scheduled at the conclusion of software coding and debugging, to assure conformance to test requirements and plans in the subsequent verification, validation, and system integration tests.

The fabrication and assembly processes are the critical final steps during which hardware is acquired (either manufactured in-house, contracted out-of-house, or purchased off-the-shelf). As piece parts and components are produced or acquired, assemblies are initiated. As assemblies are produced, close coordination with verification requirements and procedures are necessary to ensure the proper performance and fit of the assemblies. The assembly of subsystems into a system is accomplished as components become available, and as planning schedules dictate.

The activities typically occurring during fabrication and assembly and products of these activities are shown in Figure 2.

4.1.1.4.3 System Integration and Verification.

4.1.1.4.3.1 System Integration. System integration is that process which takes place to ensure that the various segments, elements, and/or subsystems of a functional entity are in accordance with system requirements and will properly function as a total system. System integration also ensures proper internal and external interfaces. System integration is both an analytical and a physical process and encompasses all elements associated with the project, including the flight system, software, ground systems, associated launch interfaces, and mission operations. The process begins with the interface definitions arising from the design concept and may not be completed until on-orbit operations in some cases. As subsystems become available and are verified as called for at that level, they are transported to the location for integration into the final assembly where total system verification is accomplished.

The analytical integration process is the design integration analyses that ensure the various components, subsystems, and associated external systems interface and function together as required. The physical integration is the assembly of all piece parts, components, subassemblies, and subsystems into a functional entity. The physical integration of subassemblies and subsystems may occur at different locations, with final integration at an integration site or at the launch site.

A program establishes and implements analytical and physical integration processes for integration of multiple systems of a program. The processes are similar to the processes for system integration. System external interfaces, driven by program design, are ensured during system integration. Physical integration of the program systems generally occur at the launch site, but for a major payload the integration may occur an integration site.

4.1.1.4.3.2 System Verification. Verification is a process in which defined activities are accomplished in a manner that will ensure that a product meets its design and performance requirements. The planning, definition, and execution of a comprehensive verification program are essential to the success of a project. The basis for the verification process is the product's requirements. A verification program is established through in-depth verification planning, development of verification requirements and success criteria, and definition of verification compliance data. For MSFC managed projects, MSFC Management System MWI 8050.1, *Verification of Hardware, Software, and Ground Support Equipment for MSFC Projects*, must be followed in the development of verification programs. Additionally, MSFC-HDBK-2221, *MSFC Verification Handbook*, provides guidance and examples in developing verification programs. The verification process begins in the early phases of a project with planning activities that will outline the verification approach and organizational structure for implementing the verification program. For a system verified by test, testing procedures based on the verification requirements are generated for each test. Flight software is subjected to Independent Verification and Validation (IV&V) in accordance with NPD 8730.4, *Software Independent Verification and Validation.* The hardware and software are brought together for system integration testing and software validation. (Software validation is system integration testing with emphasis on assuring software performance within the system environment.) The data resulting from a test is assessed to ensure all verification success criteria have been met. The results of the testing are documented in a test report that, along with the test data and as-run test procedure, becomes the compliance information that is documented as showing flight system performance is in compliance with system level design and performance requirements and with verification requirements. The verification process is completed when compliance to all verification requirements is documented. For some projects, verification compliance may not be completed until on-orbit operations.

Verification functions are further discussed in paragraph 4.3.2.4. The activities typically occurring during integration and verification and products of these activities are shown in Figure 2.

4.1.1.4.4 Mission Operations (Launch and On-Orbit Operations). Implementation of the mission includes launch operations and on-orbit operations. During launch operations the flight system is prepared for shipping to the launch site for integration into the launch vehicle, or to some other site if the item is to be integrated with another spacecraft.

Simultaneous with the shipping and final post-shipping and integration testing, the mission operations preparations are finalized. Final project reviews including the Flight Readiness Review (FRR) are conducted (see 4.3.6.1.11) and launch is approved.

During on-orbit operations, the mission is executed. The execution of on-orbit operations begins with liftoff of the launch vehicle and consists of all of the in flight activities necessary for the flight article to perform its intended mission. This may include a period of subsystem checkout, whereby all of the subsystems are powered and checked out and scientific payloads are calibrated. There may be both flight system stand alone operations and operations associated with the launch vehicle. On-orbit operations may vary from the project being autonomous (requiring no ground or flight crew intervention) to requiring continuously active flight or ground crew operations for commanding the flight system and receiving and processing flight system data.

The most important part of the mission operations, other than safety, is the data collection from the mission. Data may either be collected and stored for post mission analysis, or transmitted to ground collection and distribution sites during the mission. Many missions require that data be collected during the mission and analyzed for system performance and/or science data. Some projects may have a post-mission activity that includes satellite disposal (atmospheric burn-up or controlled de-orbit).

The activities typically occurring during mission operations and products of these activities are shown in Figure 2.

4.1.1.4.5 Post-Mission. For project flight systems returned to Earth in a controlled manner after flight, ground operations processing also includes the process of de-servicing, de-integrating, and returning the flight systems to the site where they re-enter processing for another launch or are otherwise dispositioned. For NSTS payload projects, experimental results may be required to be extracted from the Orbiter very soon after landing. For payload projects, in the event that the payload and/or payload carrier requires reconfiguration or refurbishment, the payload is returned to the integration site or developer's facilities for these activities. Other hardware will be stored until final disposition is determined.

Prior to and during the hardware de-integration activities, the hardware is inspected for general condition and failures or anomalous conditions. Flight anomalies may require some limited testing of the system prior to complete de-integration. The condition of the hardware is carefully observed and documented at completion of the de-integration activity.

Another post-mission activity is the processing of engineering and science data that are typically collected during a mission. In some cases data are retrieved post-mission. Data are processed and distributed for analysis as soon as possible. Mission operations personnel evaluate system performance including any operations activities, and will document any observations, anomalies, and/or lessons learned in mission evaluation reports.

The post-mission phase also includes programmatic activities, such as contract closeouts, that may last for a period of time after the actual mission is completed.

The activities typically occurring during post-mission and products of these activities are shown in Figure 2.

4.1.2 Technology Development Projects. This section describes the processes followed by projects that have technology advancement as the project's primary goal. Many of these projects at MSFC also support space flight system development projects. While many of the processes for space flight hardware also apply to technology development processes, the intent of the following sub-paragraphs is to highlight the differences between the two types of projects. A technology development project's processes, including project formulation (including planning), evaluation, approval, and implementation, are discussed. Figure 3 depicts an overview of the various phases, activities, reviews, and milestones associated with a typical technology development project's development. A more detailed description of technology development project management is contained in MSFC document, *Managing a Technology Development Program.*

4.1.2.1 Technology Project Formulation. The formulation process for technology development projects is similar to the formulation process for space flight system development. The process consists of identifying the need for the project, exploring the full range of implementation options involving varying concepts and approaches, and performance analyses of feasible concepts. The process also establishes the internal management control functions that will be used throughout the life of the project, assesses requirements and develops plans that include options for partnering and commercialization, and performs total cost estimates (Total Investment Cost (TIC) in the case of technology development projects). The outcome of the formulation process is documented, as in a flight project, in a **PCA** and Project Plans. For technology development projects, the formulation process can be divided into the following phases.

4.1.2.1.1 Technology Need Identification. In the normal course of the NASA Enterprises fulfilling their separate functions, technology gaps and/or shortfalls are identified. These gaps/shortfalls emerge as a result of the NASA Enterprises' visions of activity needs to conduct their missions. As these technology gaps and shortfalls are identified, studies are performed to determine priority on needs for expending NASA's resources to fill the gaps. This process confirms the validity of the need and also identifies a technology development project's objectives and content. As NASA related technology needs, gaps and their priorities are defined, opportunities for internal NASA organizations, academia, and commercial enterprises are given for developing the needed technologies. These opportunities come in the form of NRAs or AOs. Technology development projects can also be identified through Request For Proposals (RFPs) associated with a space flight system development project.

4.1.2.1.2 Technology Development Project Planning. As in the formulation of other type projects, up front analysis and project planning is key in convincing independent evaluators and NASA management that a technology development project is ready to proceed to the implementation phase. Activities that are performed during the planning phase are described in the following sub-paragraphs.

The technology development project must have aggressive, yet feasible, goals/ requirements. In many cases, the goals/requirements are dictated to the project manager at the outset by definition of the need, or gap. The concept and usage of the term “requirements” has a different meaning in technology development compared to the development of flight hardware. In a technology project, requirements are goals that may or may not be met. Schedules are set on the basis of “predicted” times to resolve problems that are only partially known, and costs (as well as schedules) are in the end dictated by overcoming problems that were unknown at the beginning of the program. This is in contrast to a space flight system project where requirements lead to a derived set of costs and schedules with interim milestones, and the milestones are accomplished in an orderly fashion, on schedule and within cost. In a technology project the expectation is that the product may or may not meet the requirements, and this expectation drives the planning for the program. A technology project has multiple paths to success, fallback positions, and quantifiable milestones with periodic “gates” for changing program directions when needed.

Part of setting the goals of a technology development project is to first determine the Technology Readiness Level (TRL) of the present state of the technology being pursued. The TRL describes the state-of-the-art of a given technology, and provides a “baseline” from which development is leveraged. The current state of maturity, or TRL, of the technologies being undertaken for development, and a determination of the

Technology Development Project

Phase	Formulation	Formulation	Formulation / Implementation	Implementation	Implementation	Implementation	Implementation	Implementation
	Technology Need Identification	**Technology Development Project Planning**	**Technology Development Project Approval**	**Technology Development Project Design**	**Technology System Development Activities**	**Progress Tracking & Evaluation**	**Certification of Advanced TRL**	**Infusion of New Technology**
Major Activities & Products	Needs identified from Enterprise Strategic Plans, Program/Project Plans, or PCA, AO, or NRA Propose technology development for formulation approval Develop preliminary technology development goals Develop preliminary technology development road map Generate budget submittal for further planning	Establish Independent Advisory Panel Develop technology development goals Identify support requirements Update technology development road map Identify facility requirements Assess degree of difficulty for advancing TRL TIC analyses and estimates Develop an Earned Value Management system and TPMs Estimate schedules Identify candidate architecture paths Assess most promising paths Identify alternate paths Develop WBS Make or buy decisions Identify decision points Define success criteria Prepare NRA, AO response proposal Obtain independent assessment of plans Obtain Center management approval to continue	Update plans and proposals Present to MSFC PMC Review Present to GPMC Submit proposals Confirm budget committed Negotiate any modifications to technology develop plans Issue ATP for contracted efforts; or, obtain ATP for in-house efforts	Conduct Initial Project Review Establish detailed development path architecture Establish schedules to lowest level Identify critical paths Establish TPMs Analytical proof of concept Initiate required procurements Design advanced technology system Design experiments Fabricate advanced technology system Test planning	Test specimens prepared Development of breadboards Test preparations Conduction of experiments Conduction of breadboard tests Generate test reports Review of test results Fabrication and assembly of prototype advanced technology system Prototype technology system tests	Review test results Review TPM reports Evaluate problem reports Comparison of progress with predictions/success criteria Evaluate modifications to development path Determine cost and schedule adjustments Path adjustment decisions Schedule updates Cost prediction adjustments Update IAR Update PMC Update GPMC Continue technology development on adjusted paths	Evaluate successful tests Assess advanced technology against goals Assess success criteria Certify advanced technology when Independent Advisory Panel deems success criteria met. or, Determine need for any additional development testing	Inform Enterprises and Technology Utilization of advanced technology. Assist Technology Utilization Office in commercializing new technology Provide assistance in infusing new technology into flight hardware projects.
Evaluation Reviews	G Go-Ahead FAD or Formulation ATP	PEER REVIEW IA MSFC PMC GPMC PEER REVIEW	MSFC PMC NAR GPMC ATP	INITIAL PROJECT REVIEW PEER REVIEW	IAR PEER REVIEW	IAR PEER REVIEW	CERTIFICATION REVIEW MSFC PMC	GPMC

11/18/02

AO: Announcement of Opportunity
ATP: Authorization to Proceed
IA: Independent Assessment
IAR: Independent Annual Review
GPMC: Governing Project Management Council
MSFC PMC: MSFC Project Management Council
NAR: Non Advocate Review
NRA: NASA Research Announcement
PCA: Program Commitment Agreement
TIC: Total Investment Cost
TPM: Technical Performance Metric
TRL: Technology Readiness Level
WBS: Work Breakdown Structure

Figure 3. Technology Development Project Process

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advanced TRL target are assessed and identified. Table I depicts the definition of the various TRLs that the Agency uses to define the state of technology maturity. The process for establishing the TRL is defined in MSFC document, *Managing a Technology Development Program*.

Table I. Technology Readiness Levels

TRL Level	Description Summary
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and “flight qualified” through test and demonstration (ground or flight)
9	Actual system “flight proven” through successful mission operations

Once a TRL has been established for the various elements of the system/subsystem or component under development, an assessment of what will be required to advance the technology to the level required by the project must be performed. The ability to prepare realistic schedules, make accurate costs projections, meet milestones, and ultimately produce the desired results depends directly upon determining the difficulty of advancing the technology to the desired advanced TRL. The term Advancement Degree of Difficulty (AD^2) is an assessment of the effort required to raise a technology from its present TRL to a desired higher TRL. The degree of difficulty in advancing the TRLs must consider aspects such as materials development, manufacturing capabilities, processes development, anticipated testing difficulties, whether the advanced TRL must be human rated, and many other aspects that may affect the advancement progress. The process for assessing the degree of difficulty in moving the required technology forward is described in MSFC document, *Managing a Technology Development Program*.

A technology road map charts the development path of a specific technology or suite of technologies. The road map identifies key technologies and describes the steps necessary to bring the technologies to a TRL that will permit them to be successfully integrated into a program. In a technology program, the road map serves as the initial guide, quantifying the activities to be undertaken, the steps to be followed and providing the overall direction of the effort. The road map is initially laid out based on technology needs and serves to provide the basis for initial program costing and scheduling. The road map is developed after the completion of the TRL and AD^2 assessments and is the basis for the subsequent implementation plan. The TRL assessment and the AD^2 assessment provide the data required for the road map. The road map is a hierarchical collection of maps that starts at the highest system level and follows the breakdown into subsystems and components as established in the TRL assessment.

The TRL assessment identifies the key technologies to be incorporated into the program and the AD^2 assessment provides the most important aspect of establishing the relative priorities of these key technologies. The AD^2 assessment is also used to determine where parallel approaches should be put in place, and provides insight into what breadboards, engineering models and or prototypes will be needed and what type of testing and test facilities will be needed. The AD^2 assessment process identifies concepts that will produce the advanced technology. Once candidate concepts have been identified, further studies are necessary to identify the paths thought to produce the best chance for successful advancement. Detailed architecture studies are then performed. The architecture studies refine end-item system design to meet the overall scientific requirements of the project. Continued technology assessments are done in parallel with the architecture studies to identify those critical technologies that were not identified in the initial assessment and to investigate new technologies required as the design evolves.

Project risk identification and mitigation planning must also be accomplished during the technology development project planning. One common risk that has to be considered is underestimating the degree of difficulty in achieving the new technology level. This emphasizes the importance of the AD^2 assessment because the project success from this point forward will depend upon the accuracy of the assessment. The ability to prepare realistic schedules; make accurate costs projections; meet milestones; and ultimately produce the desired results, all depend directly upon the AD^2 assessment. Inaccurate assessment of AD^2 can contribute to cost and schedule overruns and to project failure. Sufficient time and effort must be expended in performing this assessment to ensure that the most accurate assessment possible is obtained.
To maximize probability of success, a technology development project must provide plans for making adjustments to the development path during the course of the development. A successful technology development project plan must enhance its flexibility by:

a. Planning for parallel development paths.

b. Scheduling decision gates at appropriate times to decide on any adjustments to the development paths.

c. Having alternate paths planned to respond to development problems.

d. Having fallback positions as part of the response to unsuccessful events.

Technology development project planning includes earned value management. Earned value management requires that a firm time-phased performance baseline be developed that is based on target cost and schedule. Meaningful and quantifiable TPMs are established to track and measure project progress toward the delivery of a product within a given time frame and for a given cost. The establishment of TPMs requires in-depth knowledge of the technology development being undertaken, the current status, and the desired result. TPM development is discussed in paragraph 4.1.1.1.1, and TPM examples are shown in Appendix D.

In a technology project, the earned value management system must be responsive to changes that affect cost, schedule, and technical requirements if it is to be at all effective. As is the case in a flight hardware development project, the framework for earned value management is the WBS, and the earned value management system must have milestones that quantitatively measure progress where the focus is on maximizing the probability of success. A technology assessment provides the basis for establishing the critical elements in preparing an earned value management system. The process for performing a technology assessment is described in the *Managing a Technology Development Program* document. Earned value management is discussed in more detail in paragraph 4.3.1.4.

The technology development project planning must also include the establishment of the WBS. The importance of the WBS and other information is contained in paragraph 4.3.1.2.1.

A difference between a technology program and a flight hardware program is in the concept of LCC. For a pure technology development project, an analogous term is the TIC. Actual technology development project costs are dictated by overcoming problems that were unknown at the beginning of the program. However, technology development project planning must define to the maximum extent possible the TIC. This requires detailed activity planning estimates. Upon project approval, the TIC typically reflects the predetermined amount the Agency is willing to invest in order to obtain the needed technology. The LCC comes back into play as the technology is incorporated into a flight hardware program. In fact, the LCC should be taken into account in the initial stages of technology development since the technology may have a large impact on the LCC of the flight program into which it is subsequently incorporated.

4.1.2.2 Technology Development Project Evaluation. The evaluation process for a technology project is much the same as for a flight project (see 4.1.2). Periodic comparison of cost and schedule performance against planned budgets and schedules must be done in order to determine variances, isolate factors causing deviations, provide corrective actions, and to stay abreast of cost and schedule estimates to completion. The evaluation process uses the benefits of peer experiences, customer appraisal, and management expertise and tools in independent review of program or project goals, objectives, concepts, plans, status, risk levels and performance. Requirements for the reviews and assessments should be tailored based on such factors as program and project size, criticality, and risk, and are detailed in program/project plans. Effective evaluation processes are extremely beneficial in the development of technology programs. Since the very nature of technology programs is to create what does not exist, the evaluation teams must be well grounded in the topic and intimately familiar with the technology development process. The evaluation process can be broken down into two elements, an initial review for transition from formulation to implementation and annual reviews to assess progress and direction.

4.1.2.3 Technology Development Project Approval. The approval process for a technology project is the same as for a flight project (see 4.1.1.3). The proposed project must have been successfully reviewed by a NAR, the PMC, and the GPMC.

4.1.2.4 Technology Development Project Implementation. The implementation process develops, integrates, and provides management control for the overall implementation approach; works closely with customers to ensure mutual understanding of plans, objectives, and requirements; converts and controls project and program requirements into implementation specifications; establishes supporting infrastructure; and develops the technology. The implementation team is as key to a successful technology project as it is to a flight project. The primary difference lies in the experience base of the individuals involved. In a technology project, project management should have extensive experience in research and technology development. Once a project has been approved, detailed implementation plans are updated based upon the technology assessments from the formulation process. The next step is to begin the implementation process. Activities occurring during the implementation process are discussed in the following paragraphs.

4.1.2.4.1 Technology Development Project Design. The implementation road map is updated based on the approved budget and schedule. The road map lays out the overall plan for the project showing critical elements, parallel approach paths, interim milestones, decision gates, fallback positions, and critical tests. Road map updating is the first activity undertaken after overall budget and schedule issues are resolved.

Similar to flight hardware projects, design of concepts and technology development architectures are initiated. Technology assessments continue in parallel with the architecture designs to identify those critical technologies that were not identified in earlier assessments, and to investigate new technologies required as the design evolves. There is a continuous relationship between architectural studies and technology development. The architectural designs incorporate the results of the technology developments, planning for alternate paths, and identifying new areas required for development as design activities continue. The technology development process identifies requirements that are not feasible and development routes that are not fruitful and transmits that information to the architecture designs in a timely manner. Similarly, the architecture designs provide feedback to the technology development process.

Also during the initial design phase, schedules are developed on the basis of predicted times to accomplish tasks since not all problems have been identified. However, schedules are generated to the lowest level possible in order to measure and stay abreast of problems encountered as soon as possible. At the top level, the milestones on the schedule are the major events in the life of the project that are used to measure progress toward the end product of the project. At the level of finest granularity, the milestones become the steps of the process involved in manufacturing a component or testing a subsystem. Consequently, the identification of meaningful, quantifiable milestones (and intermediate sub-steps) that measure progress toward project goals is critical. Although establishing these intermediate progress markers is difficult, an effective Earned Value System (EVS) cannot be established without them. Establishing quantifiable metrics is the only way a project manager can measure progress toward the final objective. Once the schedule hierarchy and elements are developed based on the WBS, the critical paths are defined and highlighted.

4.1.2.4.2 Technology System Development Activities. Based upon the continued technology assessment, architecture studies and technology system design, a breadboard of the new technology is developed and tested. Test specimens are developed for testing the new technology. Breadboard models and test specimens are updated as testing progresses to enhance the technical performance of the new technology. These activities may require multiple cycles depending on changes in requirements, architecture, and/or design dictated by results of the tests and as defined in the implementation road map, or as directed by an evaluation review. Development paths may be adjusted and requirements may be modified based on testing results. Engineering models and/or prototypes of the advanced technology system are fabricated, assembled, and tested. With successful demonstration of the prototype advanced technology system, the final activity is the fabrication, test, and acceptance of the advanced technology system for the target TRL certification.

4.1.2.4.3 Progress and Evaluation. As with a flight development project, project evaluation for a technology development project occurs throughout the life of the project to ensure the successful completion of the formulation, approval and implementation processes. During the implementation phase, the evaluation of progress for a technology project is significantly different from a flight project. In a project where some failure is expected, the determination of progress becomes somewhat problematic. Evaluation is made easier, however, by the previous effort expended in defining the lowest level of development activities and the schedules for these activities. The task is also enhanced by the selection of TPMs that are used to measure progress.

There are two basic types of reviews necessary for a successful technology development project, internal project reviews and independent reviews. Independent reviews can be further divided into reviews that are set up by the project itself, and reviews that are conducted by external organizations (independent academia, industry experts, and other Agency or other government organizations).

Internal reviews are set up to periodically review project TPMs to keep abreast of progress, successes, and problems being encountered. Special reviews are held at any time a significant event such as a critical test has occurred. Internal review teams consist of both project management and technology experts in the technology being pursued, and the team should have experience in developing technology. The team will evaluate progress and problems and be proactive in decisions on any adjustments to the implementation road map. Decisions may consist of venturing to alternate paths, or curtailing a path (off-ramping). The reviews also are useful in gaining a consensus on successes.

External Independent Annual Reviews (IARs) are held to review the project's overall progress and to assess the progress and expenditures of the project. The IARs provide an important endorsement of the progress and plans for the future. The IARs are also important in assessing the need for additional funding and providing concurrence of path adjustments and schedule changes.

4.1.2.4.4 Certification of Advanced TRL. Once a technology has achieved its goals, it is important to obtain consensus that the new TRL has been achieved. A special review by a panel of technology experts is held to review test results, the goals of the project, the success criteria, and ascertain that the new TRL has been reached. The results of such a review will certify the target TRL, or identify any need for additional development, and/or testing.

4.1.2.4.5 Infusion of New Technology. Upon completion of obtaining the advanced technology, the final phase of the project is the assistance of the project in dispersing knowledge of the new technology to potential customers. The project will work with the Technology Transfer Department by providing information and transferring knowledge to the users of the technology. The project will assist and serve as consultants in infusing the new technology into space system development programs/projects. Documentation of new technological developments and current lessons learned/best practices may be accomplished through the development of NASA Technical Standards to capture this knowledge for the Agency.

4.2 PROJECT TEAM ORGANIZATION. Organization is the establishment of authority relationships between positions that have been assigned specific tasks required for the achievement of project objectives. A full understanding of the project objectives is necessary to identify the specific tasks required. Delegation of authority is the key to organization, and is one of the most elementary and important managerial arts. Unless authority is effectively delegated, duties requiring coordination of group activities cannot be effectively assigned to a subordinate supervisor, who must have adequate authority to accomplish those tasks and to assign them to those who necessarily look to him or her for supervision.

A project's organizational structure and staffing are dependent on the character of the project and may change as the project matures and areas of emphasis shift. The Project Manager is responsible for planning, organizing, staffing, directing, and controlling all project activities. A typical project team organization is shown in Figure 4. There may be variations to this representative organization. For example, depending on the requirements of the project, a Project Scientist may or may not be required. A Resident Office may not be needed at a contractor's plant if the Project Office personnel maintain cognizance of the project activities and status through travel or other communications, or if resident personnel from other government agencies are available at the plant who can accept delegation of authority relative to product assurance, property management, contract administration, etc., as may be needed.

The WBS will affect the project's organization as well as the contractor's organization. Since the objective of most projects will be to develop and deliver specific end items, the WBS will be structured to include the tasks leading to these end items; that is, it will be end item (product) oriented rather than discipline oriented. As a result, the project can be most effective if its organization is structured such that each major task in the WBS is assigned to a single individual. For a contracted project, the contractor's organization will also reflect points of commitment or assignments of responsibility for the various WBS elements. The WBS tends to align the contractor and project office working-level interfaces. The relationships among the WBS, the project office organization, and the contractor (functional) organization are addressed in Section 4.3.2.5.

4.2.1 Project Manager. The Project Manager is the individual accountable for project execution. The Project Manager is responsible for all aspects of the project, ultimately making sure the project requirements are met within budget and schedule, and that the team members who support the project are properly recognized for the achievement of

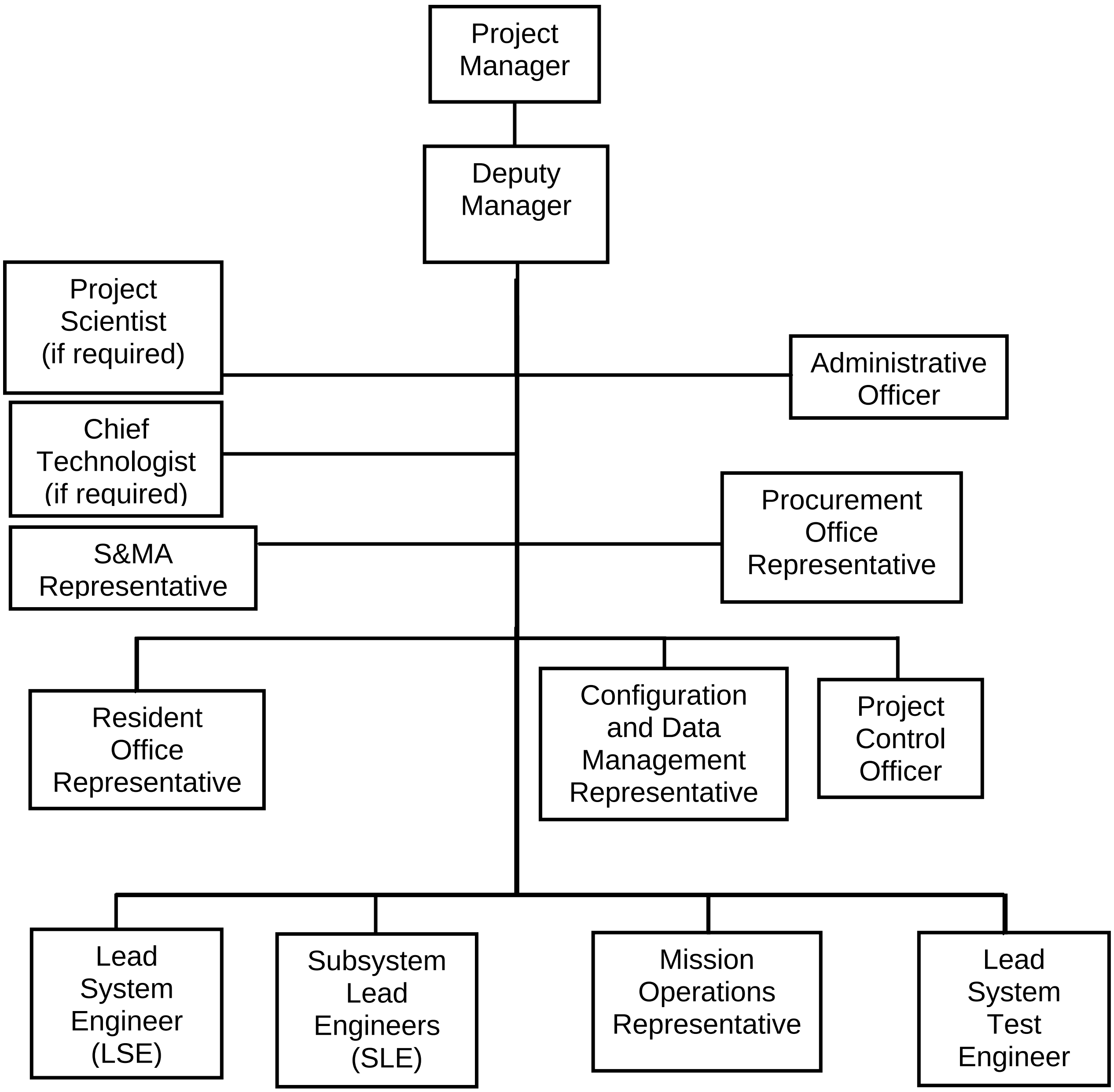


Figure 4. Typical Project Team Organization

those goals. The Project Manager is responsible, in accordance with NASA and MSFC management directives, for the successful planning and implementation of project resources, schedule, and performance objectives. The Project Manager is also responsible for overall project safety and risk management. The Project Manager receives authority via a chain of delegation beginning with the **PCA** and the Program Plan, which is the agreement between the Center Director, Program Manager and the EAA. The agreement between the Center Director, Program Manager and the Project Manager is documented in the Project Plan and approved prior to implementation of the project. The Project Manager has the authority and responsibility to execute the Center Director's commitment as reflected in the Project Plan.

The Project Manager penetrates all aspects of project development to develop a clear perception and intuitive grasp of progress and problems. For a contracted project, the Project Manager must develop and maintain an understanding of the contractor's activities.

4.2.2 Lead System Engineer. The Lead System Engineer (LSE) is a key member of the project team. The LSE is functionally responsible to the Project Manager for assuring that the system implementation fulfills the system requirements and that proper engineering activities, including in-house and contractor responsibilities, to assure that system engineering practices are being followed. The LSE oversees that the project system is adequate and is in compliance with the project system requirements, cost, and schedule constraints. Although the Project Manager will look to the subsystem managers as the authorities on the subsystem's performance, it is the responsibility of the LSE to ensure the analytical and physical integration of the subsystems, and the technical performance of the overall system. In this role, the LSE oversees the system integration functions such as interfaces definition and implementation, system thermal analyses, system performance, mass properties, error budgets, timelines, system communications, system instrumentation, electrical power budget, and other system level analyses.

The LSE often directs and coordinates applicable system engineering tasks within the Center in support of the project assignments and assures that technical cognizance is maintained over associated contractor and in-house activities. The LSE constantly reviews and evaluates technical aspects of the project to assure that the system/subsystems are properly designed, integrated, verified, and meet project performance requirements.

The LSE is responsible for directing the following activities: requirements development, requirements flowdown, configuration management, verification planning, interface control, system level risk management, system level trade studies, and integration. (Many of the product lines have established system teams within their Directorate that are responsible for performing these tasks.)

4.2.3 Project Scientist. The Project Scientist is deemed necessary for Center science projects when no Principal Investigator (PI) exists, when multiple PIs exist, when the PI is external to the Center, or when the MSFC PI cannot serve in the function. The Project

Scientist's role, duties and responsibilities are in accordance with MPD 1130.1, *Roles and Responsibilities of the MSFC Project Scientist*. The Project Scientist is primarily responsible for overseeing the scientific integrity of the project's mission within the constraints of the project. The Project Scientist ensures that science requirements are adequately documented, and that the project definition, implementation, and operations comply with the science requirements. The Project Scientist serves as the scientific advisor to the Project Manager, advises on proposed changes to science objectives when necessary, participates in appropriate project reviews, and acts as the science interface for data analysis and plans. It should be noted that when a PI serves in the role of Project Scientist, the PI may also serve as the Project Manager.

4.2.4 Chief Technologist. The Chief Technologist is part of the project management team for Center technology development projects. The Chief Technologist oversees the technology assessment and establishment of the TRL and Technology Road Map. The Chief Technologist ensures that the technology requirements are adequately documented and that the project definition, implementation, and operations comply with the technology requirements. The Chief Technologist serves as the technology advisor to the Project Manager, advises on proposed changes to technology objectives, participates in appropriate project reviews, and acts as the technology interface for data analysis and plans.

4.2.5 Administrative Officer. The Administrative Officer is responsible for assisting the Project Manager in a variety of administrative activities for the project. Responsibilities may vary depending upon the size and complexity of the project and the Project Manager's delegation of assignments. Responsibilities may include the tracking of project related correspondence, handling of personnel actions, oversight and maintenance of in-house Collaborative Workforce Commitments (CWCs), recording and tracking of action items, and serving as the official records officer for the project.

4.2.6 Safety and Mission Assurance Representative. Safety and Mission Assurance (S&MA) project support is provided through the S&MA Office by an assigned representative, usually co-located with the Project team. An S&MA representative may also be co-located in a resident office for a contracted project. In this capacity, the S&MA Representative will: (1) assist the Project Manager in assuring that all S&MA requirements are appropriately defined and implemented; (2) provide for an independent S&MA oversight and assessment function for the project; and (3) serve as the single point-of-contact between the Project team and the S&MA Office, assuring proper coordination of all safety, reliability, maintainability, and Quality Assurance (QA) responsibilities and practices. See paragraphs 4.2.12.10.6 and 4.2.12.8 for more details on the S&MA Office and its support provided to the project.

4.2.7 Procurement Representative. The Project Manager's interface to the Procurement Office is a Procurement Office Representative in a co-located assignment to the project team. The Procurement Office Representative is responsible for development of the

Master Buy Plan submission; the Acquisition Strategy Meeting with NASA Headquarters; the Procurement Plan, if required; SOW; draft RFP; and the formation and operation of a Source Evaluation Board (SEB). The Procurement Office Representative is also responsible for contract negotiation for a contracted project. The representative supports the development of a change order control system to implement contract changes.

4.2.8 Project Control Officer. The Project Control Officer is the individual responsible to the Project Manager for providing direction, assessing progress and assisting the Project Manager in control of project resources and activities, including budget, schedules, customer agreements and overall project management to ensure that project implementation execution is consistent with approved project customer agreements, budgets, schedules, and acquisition strategies. Other areas where the Project Control Officer assists the Project Manager include management information systems, programmatic reviews, and performance measurement surveillance including earned value management.

4.2.9 Data Manager. The Data Manager is appointed by the Project Manager to establish and administer the data management activities for a specific program, project, activity, or contract. The specific responsibilities of the Data Manager are defined in MPG 7120.3, *Data Management, Programs/Projects*. If the Project Manager does not appoint a Data Manager, the Project Manager assumes these responsibilities. The Configuration and Data Management Representative(s) will assist the Data Manager in implementing and administering the data management system.

4.2.10 Configuration and Data Management Representative. The Project Manager's contact for configuration and data management is the Configuration and Data Management Representative, co-located from the Engineering Systems Department to the project. The Configuration and Data Management Representative is responsible for implementing project configuration and data management systems, and reviewing and auditing contractor configuration and data management systems for adequacy. The configuration management system must address configuration identification, configuration control, configuration accounting, and configuration verification. Typical tasks associated with configuration management are preparing the configuration management plan, identifying configuration items, establishing and serving as Secretariat of configuration control boards, administering the control process and configuration accounting databases, engineering release, maintaining control and release records, and conducting audits.

The data management system must address data identification/definition, preparation, control, and disposition (access and records). Typical tasks associated with data management are preparing the data management plan, establishing data receipt and tracking mechanisms for the project's data requirements, establishing and administering document control processes, monitoring data preparation, releasing approved data to the project master list(s), and helping the project identify project records and record custodians. The configuration and data management representative assists the Project Manager and/or

Data Manager in planning the overall project data requirements and collecting and managing information consistent with project needs.

The Configuration and Data Management Group within the Engineering Systems Department also provides Center level support for the Center Data Requirements Manager (CDRM) functions of standard data requirements description (DRD) maintenance and data procurement document (DPD) development support, and for administration of the Multi-Program/Project Common-Use Documentation control system.

4.2.11 Resident Office Representative. A resident office is established at a project's contractor facility for some projects to provide an on-site interface with the contractor. The resident office is headed by a representative of the Project Manager's office and serves as the liaison between the Project Manager and contractor management. The responsibilities of the Resident Office Representative are delegated by the Project Manager and are dependent on the particular project and the manager. The representative is generally tasked to assist the Project Manager with contract administration, contractor activity oversight, and provides the Project Manager with contractor status and continuity. As in all functions of the project, the Project Manager is responsible for project contractor management and for contract execution.

4.2.12 Project Support Organizations. Many of the Center's organizations provide technical and institutional support to the Project as described in the following paragraphs. Project support from organizations other than the managing organization is documented in CWCs. (See MPG 1230.1, *Center Resources Management Process,* for guidance in resource planning.)

4.2.12.1 Chief Engineer. The Chief Engineer is a key member of each Product Line Directorate and supports the projects within his/her Directorate. The Chief Engineer is functionally responsible to the Directorate Manager for all technical aspects of the projects within the Directorate and provides a peer-review of the technical aspects of the projects, for both in-house and contracted projects, to assure technical adequacy and ensure that the right technical skills and tools are applied to accomplish the project's technical requirements. The Chief Engineer participates in the final selection of project TPMs developed as a mechanism for tracking and maintaining successful performance of the project. The Chief Engineer often serves as a mentor to Directorate system and discipline engineers and LSEs and as advisor to project management. The Chief Engineer may lead, direct and coordinate applicable tasks within the Engineering Directorate (ED) and relevant engineering disciplines in product line directorates in support of the Directorate/ Project assignments, and assures that technical cognizance is maintained over associated contractor activities. The Chief Engineer works with the LSE to constantly review and evaluate technical aspects of the project to assure that the system/subsystems are properly defined, verified, integrated, and meet project performance requirements.

4.2.12.2 Subsystem Lead Engineer. The Subsystem Lead Engineer (SLE) provides a significant benefit in the technical and cost management of a project. The SLE is the Project Manager's primary contact on the management of a particular subsystem, and is responsible for the subsystem engineering functions as described in 4.3.1.9.3. The SLE is responsible for the technical performance of assigned subsystem(s). The SLE is also responsible for cost and schedule status and should make appropriate use of the management tools (e.g., Earned Value Management, Critical Path Analysis, Stop Light Reports, etc.) that pertain to his or her subsystem. Depending on end item complexity and staffing constraints, a SLE may be responsible for more than one subsystem.

4.2.12.3 Lead System Test Engineer. The Lead System Test Engineer is accountable to the Project Manager and is the system test team individual responsible for ensuring that system performance is in compliance with system level test requirements. The Lead System Test Engineer is responsible to ensure facility and Ground Support Equipment (GSE) availability, development of integration and testing plans, system test procedures, and equipment logistics. The Lead System Test Engineer is also responsible for system level testing, and the functions described in 4.3.1.9.4.

4.2.12.4 Mission Operations Representative. The project team normally requires a person to lead the efforts associated with ensuring that the project mission operations are properly defined, planned and executed. Mission operations encompass the personnel, software, procedures, hardware, and facilities required to execute the flight mission. Ground operations are included as the ground segment of mission operations. The responsibilities of this team member are also to lead the efforts associated with defining the operations team and ensure that the operations team is trained. The representative is the project's interface with the mission and operations discipline organizations and personnel.

4.2.12.5 Discipline Engineering Support. The product line directorates provide support in the following discipline engineering areas:

- System Engineering for requirements management, integration and verification
- Propulsion Engineering
- Attitude Control Engineering
- Orbital Mechanics Analysis
- Trajectory Analysis
- Mission Operations
- Test Facilities and Test Conduct
- Environmental Control and Life Support -
- Cargo Integration

4.2.12.6 Engineering Directorate Support. Discipline engineering expertise will normally be provided by ED through a matrix management arrangement using CWCs and Strategic Planning Agreements. By this approach, in-house technical support is supplied by personnel administratively assigned to functional organizations who have been given tasks in support of a given project. For technical support from the ED, assignments are made within the framework of the CWCs developed initially by the Project Office using inputs provided by the ED. Matrix support provided by the ED, as opposed to a “projectized” approach, whereby the Project Office is staffed to be independent and self-sufficient, allows for more efficient use of manpower and also permits the application of specific talents to specific problems. The features, however, of responsiveness, continuity, and allegiance, frequently characteristic of a “projectized” group, are often less apparent in a matrix management environment. A 1999 MSFC reorganization was initiated to help address these issues and allowed projects to become more “projectized” while still leveraging off the benefits of a limited matrixed group.

The ED includes the Avionics Department, the Structures, Mechanical and Thermal Department, the Materials, Processing and Manufacturing Department, and the Engineering Systems Department. Tasks performed by the ED in support of a project can range from technical surveillance of a contracted project to an arrangement where the ED performs the project engineering tasks. This range of tasks provides the Project Manager, in concert with the ED management and within guidelines from Center management, an opportunity to involve the ED in varying degrees of participation. The degree of participation (level of insight) will depend on the needs of the project, skill levels available, risk tolerance, in-house workload, and resources available.

Task agreements or CWCs between the Project Offices and the ED define the structure (work to be performed, schedules, manpower, funding) of technical support required by the project. The CWCs are the contracts between the Project Office and the ED, and are established for a term of one year. The CWCs are updated and re-established each year to reflect the latest known technical support needs of the project. To assure that a proper complement of technical resources is allocated, MSFC management requires the project to clearly define the tasks and milestones.

The ED coordinates with the project to prepare a detailed projected allocation of the ED resources that are proposed to satisfy the indicated project support needs. In subsequent management reviews, the proposed tasks versus resource allocations are reviewed, justification rationale examined, and a refined final allocation of resources for the project is established. These final allocations for each ED department involved are entered into the Center’s manpower and resources information system for a monthly comparison with actual project support expenditures.

4.2.12.7 Systems Management Office Support. The SMO provides support and independent evaluations of projects and programs for compliance with and implementation of MPG 7120.1, and, as appropriate, MPD 1280.1, the *Marshall Management Manual*. The

SMO determines consistency across product lines for Center system engineering functions related to space systems program/projects, including requirements development and requirements flow-down, system verification and integration. The SMO provides leadership, consultation services, and technical expertise on system engineering and project management processes. The SMO also provides support in forecasting costs to advanced program/project planning initiatives, and conducts IAs, NARs, IARs, and develops policy for Red Team Reviews.

In addition, the SMO Cost Office develops and maintains an Agency database of historical cost, schedule and technical data from completed and ongoing programs/projects, and develops NASA-wide cost and schedule estimating techniques that are used by MSFC and other NASA Centers' projects. The Cost Office also supports the Center and Agency by providing expert cost, schedule, and economic analysis services.

The SMO is also responsible for execution of the Center's Export Control activity. The purpose of the Export Control Program at MSFC is to ensure compliance with NASA's export control directive, NPD 2190.1, *NASA Export Control Program,* and the export control requirements of the Departments of State, Commerce, and other agencies. The MSFC's export control is implemented in accordance with MPD 2190.1, *MSFC Export Control Program*, and MSFC's implementation procedures and guidelines, MPG 2190.1, *MSFC Export Control Program*. The export control function covers all MSFC projects and encompasses all products technologies, and technical information with the potential for export outside of the United States. The SMO provides export control consultation and guidance to the Center.

4.2.12.8 Safety and Mission Assurance Office Support. The S&MA Office support includes the planning, establishment, implementation and verification of the assurance program. For each MSFC project, the S&MA Office provides safety, reliability, maintainability, and QA technical services, surveillance of MSFC in-house and contracted design, manufacturing, and testing activities, continuous risk management support via consulting, training, process participation, and an independent oversight and assessment function. The independent oversight and assessment is accomplished by providing a continuous review and evaluation of S&MA activities at all levels throughout the Center and associated contractors. The S&MA Office develops documentation and specialized analyses such as FMEAs, hazard analyses, maintainability predictions, FTA, Limited Life Items Lists (LLIL), and Critical Items Lists (CIL) to ensure the safety and mission success of the project. The S&MA Office support for the project is led by the S&MA representative assigned to the project. Other S&MA personnel assigned to support the project team reporting through the S&MA representative are described in the following paragraphs.

A system safety engineer supports the project team in development of the safety requirements for the project and participates in assessing the adequacy of the resulting safety effort. System safety support for contracted projects is initiated with a thorough review of all RFPs prior to their release to verify that the proper safety requirements are being applied. The system safety engineer also: (1) assists in the evaluation of proposed safety programs; (2) assists in a technical safety assessment of the proposed configurations; (3) participates in program reviews (Project Requirements Review (PRR), PDR, Critical Design Review (CDR), etc.) to assure the developing design is in compliance with the program safety requirements; (4) assists the project in preparing appropriate submittals to he Center Payload Safety Readiness Review Board as well as to Agency Safety Review Panels (SRPs) (both flight and ground operations); (5) participates in safety audits of the prime contractor and selected subcontractors (when practical, the safety audits will be conducted as part of a joint audit with reliability and QA elements.); (6) participates in preflight, launch, and operational phases; and (7) participates in any project accident/incident investigations.

A reliability/maintainability engineer supports the project team in development of the reliability/maintainability requirements for the project and participates in assessing the adequacy of the resulting reliability/maintainability effort. Reliability/maintainability support for contracted projects is initiated with a thorough review of all RFPs prior to their release to verify that the proper requirements are being applied. The reliability/maintainability engineer also: (1) assists in the evaluation of proposed reliability/maintainability programs; (2) assists in a technical reliability/maintainability assessment of the proposed configurations; (3) participates in program reviews (PRR, PDR, CDR, etc.) to assure the developing design is in compliance with the program reliability/maintainability requirements (4) assists the project in preparing appropriate submittals to Agency reliability/maintainability panels; and (5) participates in reliability/maintainability audits of the prime contractor and selected subcontractors. (When practical, the reliability/maintainability audits will be conducted as part of a joint audit with safety and QA elements.)

A quality engineer supports the project team in development of the quality requirements for the project and participates in assessing the adequacy of the resulting quality effort. Quality support for contracted projects is initiated with a thorough review of all RFPs prior to their release to verify that the proper quality requirements are being applied. The quality engineer also: (1) assists in the evaluation of proposed quality programs; (2) assists in a technical assessment of quality for the proposed configurations; (3) participates in program reviews (PRR, PDR, CDR, etc.) to assure the developing design is in compliance with the program quality requirements; and (4) participates in quality audits of the prime contractor and selected subcontracts. (When practical, the QA audits will be conducted as part of a joint audit with safety and reliability/maintainability elements.)

4.2.12.9 Center Institutional Support.

4.2.12.9.1 Procurement Office. The Procurement Office provides procurement expertise throughout the life of a project, often through co-location of one or more procurement representatives to the Project Office. Initially, support will be provided in development of the Master Buy Plan submission; the Acquisition Strategy Meeting with NASA

Headquarters; the Procurement Plan, if required; SOW; draft RFP; and in the formation and operation of a SEB. In addition, the Procurement Office will negotiate the contract that would, as required, provide for provisioning of spares, facilitate system problem resolution, and, as appropriate, include in the terms and conditions, a dollar threshold for processing changes. Support will be provided in the development of a project change order control system to implement contract changes. Timely development of change requirements and technical evaluation of change proposals by the Project Office will permit early change order negotiations and ensure a firm contract baseline. Formal authority to enter into and modify contracts rests with the Procurement Office.

4.2.12.9.2 Center Operations Directorate. The Center Operations Directorate provides support to the project when planned project activities have the potential for environmental impact. The Directorate provides the capability to perform analyses and make assessments of the potential environmental impact. For new facilities it is critical that all the requirements be identified in any budget submission and that the impact on other funding sources (e.g., institutional) be defined. New facility requirements should be split between non-recurring (outfitting) and recurring (operations and maintenance).

Considerable foresight must be given to facility requirements. Most requirements, ideally, can be accommodated with minimal changes to existing facilities. Where changes are required, however, cost and schedule considerations will determine the procedure for effecting the change. Facility projects may be funded by project or CofF funds. Project funding can be utilized only by use of an “Unforeseen Programmatic Document” which explains the urgency of the requirement and gives reasons the requirement has not been included in the CofF Budget Cycle. The CofF cycle requires a minimum of three years from initial submission of the requirement to completion of construction. Initially, the project requirements are specified for inclusion in the CofF Budget Cycle. A Preliminary Engineering Report further defines the requirements during the first year, design is accomplished during the second year, and construction is started during the third year. In most instances the construction can be completed in one year. The using office(s), the S&MA Office and the Information Services Office all participate in the Preliminary Engineering Report and design phases ensuring that the completed project will satisfy all requirements and meet Center objectives.

Computational support requirements should be provided to the Information Services Department as early as they can be identified to assure timely support from the Center’s institutional computer systems. If requirements necessitate Project Office acquisition of automatic data processing equipment, there are a number of procedural steps mandated by law that will involve the Project Office and the Information Services Department. For automatic data processing acquisition, utilization, and maintenance, the Information Services Department provides Center-wide overview and acts as coordinator in the areas of procurement, facilities, and telecommunications. Specialized maintenance enhancement and operational support is provided for the automated configuration management and account system (i.e., Standard Change Integration and Tracking (SCIT)/Configuration Management Accounting (CMA).

The Information Services Department implements and administers all the Center's communications programs that include administrative communications such as Federal Communications System, local telephone service, public address, radio, RF management, data and video supporting the Center management, Project and Program Offices. In addition, the Information Services Department manages the Agency's Program Support Communications Network that interconnects NASA Headquarters, field installations and NASA's prime contractors for voice teleconferencing, transmission of facsimile, data (terminal and computer interconnection) and video. The office is also the primary interface for MSFC's operational communications requirements, utilizing the NASA Input/Output Network (I/O Net) managed by Goddard Space Flight Center (GSFC). Communications requirements should be identified early in the definition of Program Formulation for effective long-range implementation and budget planning as a part of the Agency and MSFC five-year communications forecast. Timely scheduling to include communications in the program planning will permit the required communications support to be available to support the project for management, scientific, technical, and operational requirements thus minimizing peak workloads.

The Logistics Services Department provides a variety of key services and products to a project beginning with SEB activities and continuing into the operational phases with increasing involvement. Some of the earlier services and products provided include office furniture and equipment, printing and reproduction, mail services, photographic, records management, and documentation repository. As the project matures, other services are provided which require advance planning, some requiring more lead time than others, such as: transportation and handling of program critical hardware to include outsized cargo by land, sea, or air; graphics; institutional/industrial property management; and environmental health services, including evaluation of related aspects of contracts and facility design documentation, and environmental health surveys. These services and equipment can be tailored to satisfy unique project requirements when pertinent data are exchanged between the Logistics Services Department and project personnel with sufficient lead-time to allow development of plans and procedures.

The Project Security Manager is a member of the Center's Protective Services Department staff and is appointed by the manager of that department. The Project Security Manager will serve as liaison between the Project Office and the Protective Services Department. The Project Manager will look to this individual to advise the Project Office in the development of security requirements for the Project using established System Security Engineering methods. Additionally, this individual will participate in assessing the adequacy of the resulting security effort and will determine the need to participate in all critical project reviews.

4.2.12.9.3 Customer and Employee Relations Directorate. The Customer and Employee Relations Directorate provides support to projects through employee training and other personnel services, managing the project's appropriate transfer of technology information to public and commercial organizations, and serving as liaison for project information with the public through the media.

The Technology Transfer Department promotes and encourages the identification, evaluation, publication, transfer, application, and use of the project technology throughout the U. S. economy. The Technology Transfer Department, with cooperation from the Project Manager, maintains a New Technology Reporting Program which establishes the administration of the Patent Rights and New Technology contract clauses in accordance with Federal Acquisition Regulation (FAR) Part 27 and NASA FAR supplement Part 19-27. The Technology Transfer Department is also responsible for identifying the proper External Customer Agreement used by the projects.

The Media Relations Department (MRD) is the focal point for the widest practicable and appropriate dissemination of information for the project. The MRD's responsibility is discharged through the news, videotape, film, publication mediums, and through such direct public contacts as speeches, exhibits, and facility tours. (For additional information on Media Relations see MPD 1380.1, *Release of Information to News and Information Media*). Information is provided to the news media through printed releases, fact sheets, TV clips, and radio tapes that are prepared by the MRD. Project Managers should work closely with the MRD to ensure access to the information needed to effectively prepare the information products. Project Managers will be called upon to review products, especially those containing information not previously released, for accuracy and balance.

Another method of releasing information is through direct contact with the news media. Project Managers are called upon from time to time to participate in or designate someone to participate in interviews and press conferences. Normally such activities are arranged through the MRD. Sometimes the media will contact managers directly. Managers should keep the MRD informed of such developments and should not hesitate to consult with the MRD regarding any aspect of news issuance. In accordance with the *Code of Federal Regulations*, *Title 14 CFR 1213*, *Release of Information to News and Information Media*, information given to the press will be on an "on the record" basis and attributable to the person(s) making the remarks, and any NASA employee providing material to the press will identify himself/herself as the source. Project Managers are encouraged to consider the Media Relations specialist assigned to be a member of their project team.

The production of exhibits, films and videotapes, or brochures for public exposure, or with potential for public informational usage, must be originated by or coordinated with the MRD. Quite often, cost-sharing arrangements can be made between the Project Manager and the MRD. Film and video productions, even of a non-public project nature, should be processed through the MRD for presentation to the MSFC Audio-visual Review Board (Reference MPD 1394.1*, Control of Audiovisual Products*) for approval.

Hardware items (including models and mockups) which are no longer needed in the official conduct of a project, but have potential for public interest, should be reported to the MRD, the MSFC historian, and Property Management for potential use as an exhibit or artifact. The MRD also operates a speaker's bureau, and Project Managers should participate and encourage project participation in outside speaking engagements.

Public requests of a non-technical nature for information, photographs, philatelic events, etc. may be forwarded to the MRD for disposition.

For all foreign national visits, follow the procedures outlined in MPG 1371.1, *Procedures and Guidelines for Processing Foreign Visitor Requests."* For assistance, contact the Center International Visit Coordinator in the Protective Services Department.

4.2.12.9.4 Office of Chief Financial Officer. The Office of the Chief Financial Officer (CFO) is the organization of record for all financial status of program activity including the control of available resources authority. This responsibility entails the receipt and balancing of budget from Code BR at NASA Headquarters through the Integrated Financial Management (IFM) Systems, Applications, and Products (SAP) Core Financial System, notification of receipt of Budget to the project offices and distribution of Budget to lower level cost pools in the SAP financial management system. Assists the Center in the development of financial reports reflecting commitment, obligation (contract and cost status) through the Business Warehouse from the SAP. The CFO likewise approves and assists in the development of contractor cost reporting requirements, NASA Form 533. With regard to contractor cost data, the CFO coordinates with the Project Offices in formulating the best performance/cost estimates available for monthly cost accruals and works closely with these offices in establishing work subdivisions for resource control and tracking.

The CFO is responsible for the IFM SAP Core Financial System, Center level oversight of project management application and development programs as well as earned value management system requirements, and independent assessments of all Center projects.

4.2.12.9.5 Office of Chief Counsel. The Project Manager maintains close liaison with the Chief Counsel on all issues or developments with legal implications, or involving legal policy or legal issues. Matters that could give rise to claims or litigation should be coordinated as early as possible. Any correspondence or contacts by outside legal counsel should be referred to or reported immediately to the Chief Counsel. Any court or administrative legal papers affecting NASA, such as lawsuits, claims, subpoenas, or summons, shall be referred to the Chief Counsel for advice and guidance. Intellectual Property Counsel in the office of Chief Counsel shall be consulted on matters pertaining to intellectual property (i.e., patents, copyrights, trademarks, trade secrets, rights in technical data, and rights in computer software).

4.2.12.10 System Engineering Organizations. Within the MSFC organizational structure, the total system engineering process involves seven organizational elements: (1) the Project Office, which includes the LSE, for project system engineering management, (2) the Product Line Directorates for overall technical guidance, the Chief Engineers, the LSE, and for the task performance and system documentation at the overall system level, including requirements development, verification program development, integration and system test (3) the ED for specialized and general system engineering tasks in support of all MSFC managed projects, (4) the Flight Projects Directorate for ISS operation and mission analysis, (5) the design disciplines within the Center Directorates for analysis and trade studies, subsystem and component design, and system test and verification support, (6) the S&MA Office for FMEA, hazard analysis, fault trees, and risk assessment and, (7) SMO as the central system engineering organization for methodology, discipline, and guidance to the Center for accepted system engineering policies and processes.

For projects supported by design and development contractors, it is equally essential to project success that the contractor(s) properly exercise(s) the system engineering process. Normally, design and development contractors reflect organizational levels of system engineering activity similar to those of MSFC, as appropriate to the scope of their contracted activity. The role of the MSFC directorates for a contracted project will vary in accordance with the Project Plan.

The LSE is the individual responsible for the system engineering and the system integration for a project. The Chief Engineer evaluates the Directorate's system engineering policy/processes and the LSE implements the process consistent with the basic objectives, priorities, and guidelines within which system engineering will seek to optimize the system design. The LSE makes the recommendation on design trade-offs where performance, cost, and schedule must be balanced. Through responsibility for the technical adequacy of all system related activities of the project, the LSE must strive to ensure that system engineering is exercised in all project decisions. Through their responsibility for all project system related work, the LSE may direct the system engineering tasks of the project.

4.2.12.10.1 Systems Management Office. The SMO provides support and independent evaluations of projects for compliance with Project Management directives and guidelines. SMO determines consistency across product lines for MSFC system engineering functions related to space systems projects, including requirements development and flow-down, system verification and integration. SMO provides technical expertise and guidance on system engineering policies and processes. They also provide support in forecasting costs to advanced project planning initiatives.

4.2.12.10.2 Space Transportation Directorate. The Space Transportation Directorate provides propulsion engineering and other system engineering support to space transportation systems, including earth-to-orbit and in-space transportation systems. The Directorate provides system analysis, system integration, requirements development, and verification to the space transportation projects. The Directorate also provides sustaining engineering for the space transportation projects. Additionally, the Directorate provides launch vehicle flight dynamics analyses, stabilization analyses for space tethers, attitude control system analyses and design guidance system algorithms development, orbital mechanics analysis, and launch vehicle aerodynamics definition.

4.2.12.10.3 Flight Projects Directorate. The Flight Projects Directorate provides system engineering support to projects in areas of design, development, integration, and operations. More specifically, the Flight Projects Directorate performs engineering analysis, design, development, integration, test, verification, and delivery of flight systems (e.g., multi-user hardware, habitable modules, and subsystems) for assigned projects.

The Directorate also performs mission operations engineering and analysis support for operations control, mission data management, mission operations flight and ground requirements, and mission integration. In addition, the Directorate performs operations engineering development for microgravity experiments payloads and other flight projects, providing early inputs to hardware and software design, mission operations integration, and support to mission execution.

4.2.12.10.4 Science Directorate. The Science Directorate provides general system engineering support to the microgravity flight experiments and other projects under the Science Directorate's purview. The directorate provides system engineering associated with the formulation and system analyses for biotechnology and space materials research. System engineering areas include flight experiments concept development, requirements development, design and integration, and system review and verification. The directorate also utilizes the facilities and capabilities of their Microgravity Development Laboratory to perform flight experiment development and verification testing.

4.2.12.10.5 Engineering Directorate. The ED provides system engineering support in addition to subsystem, component, and specific engineering discipline expertise. The directorate is comprised of four departments organized along engineering discipline lines. The system engineering support that each department provides is described in the following paragraphs.

4.2.12.10.5.1 Avionics Department. In addition to subsystem expertise in the electrical power, instrumentation, and RF subsystems, the department also provides system support in software development and verification, and integrated flight components and software integrated testing.

4.2.12.10.5.2 Structures, Mechanics, and Thermal Department. The Structures, Mechanics, and Thermal Department, as its name implies, provides system engineering support in the areas of system structural dynamics and loads, modal and control dynamics, vibroacoustics, system structural design and capability analysis, mechanisms, system thermodynamics and heat transfer, thermal control, system venting analysis, and system environmental testing including thermal-vacuum.

4.2.12.10.5.3 Materials, Processes and Manufacturing Department. The Materials, Processes and Manufacturing Department provides system engineering support in the areas of materials selection (including support in ensuring non-toxic materials for manned systems), contamination avoidance and analysis, and defining the effects of space environments on selected materials.

4.2.12.10.5.4 Engineering Systems Department. The Engineering Systems Department provides system engineering expertise and support to generally all of the MSFC managed projects. The system engineering disciplines housed within the department include system modeling and simulations, mass properties analysis, electrical power system capability and consumption analysis, human engineering and integration analysis, system supportability and logistics analysis, system communication analysis, RF licensing, configuration management, data requirements management, data management, natural terrestrial environments definition and analysis, space environments definition and effects analysis, electromagnetic environments and effects analysis and testing, and spacecraft charging analysis.

4.2.12.10.6 Safety and Mission Assurance Office. The S&MA Office provides the planning, establishment, implementation, and ensures verification of the project's assurance program. See paragraph 4.2.12.8 for a more detailed description of the support provided by the S&MA Office. In addition to overall surveillance of a project's assurance program, the S&MA Office also provides special system analyses in the areas of safety, hazard analyses, reliability, maintainability, FMEA, and FTA. The S&MA Office also maintains a LLIL and a CIL for the project.

4.3 PROJECT MANAGEMENT AND SYSTEM ENGINEERING FUNCTIONS

4.3.1 Project Management Functions. The primary function of project management is to ensure that the project is implemented to meet the established budget, schedule, safety, and performance requirements to satisfy its objectives. As discussed in 4.2, it takes an organized team to fulfill this primary function. Vital to successful project management is the role of the Center's engineering organizations. The well-planned use of technical expertise and "corporate memory" in not only the detailed assessment of contractor approaches but also in the performance of independent design analyses can be an invaluable (and less expensive) resource. Other techniques considered in project management are the establishment of a Problem/Action Item Tracking System, and the use of consultants for problem resolutions. Even though it takes a team to implement, many of the project management functions have been partitioned into the basic functions discussed in the paragraphs below.

4.3.1.1 Contract Management.

4.3.1.1.1 Request for Proposal. The RFP for the implementation process is prepared based on the technical and programmatic results determined during the formulation effort and on the current agency plans regarding mission need and budgets. The RFP may be prepared during the late formulation phase or early in the implementation phase. The project planning must decide what the appropriate RFP schedule is for the project. There will typically be a team composed of technical, procurement, programmatic, and project personnel organized to prepare the RFP. In a gross sense, the RFP is composed of general instructions (including instructions for preparation of proposals and a general description of the factors to be used in proposal evaluation), proposed contract schedule articles, a SOW, and other pertinent documents (project requirements and specifications, Data Procurement Document (DPD), Interface Control Documents (ICDs), etc.). The SOW defines the product and services to be provided under the contract. NPG 5600.2, *Statement of Work (SOW): Guidance for Writing Work Statements*, contains guidance on preparation of the SOW and defines the need for an identifiable relationship between the SOW and the WBS.

RFPs that are subject to SEB procedures are issued to prospective sources only after review and approval by the SEB. In addition, the MSFC SEB Advisory Council provides information and guidance to SEB Chairmen to ensure that SEBs follow prescribed procedures. The Council assists all SEBs in reporting their findings to the MSFC Director, or higher authority. MWI 5100.1, the *Procurement Initiators Guide*, and MWI 5115.2, *Source Evaluation Board/ Committee (SEB/C) Process*, describe the responsibilities and procedures.

For contracted efforts, the procurement for the contract is executed and the proposal evaluation process is completed. After project implementation proposals are evaluated, negotiations are initiated with the remaining eligible contractors, and eventually final recommendations are determined by the SEB. Once the project implementation contractor is selected, the contractor is given the ATP. The contractor's initial activities will be to proceed with performing any actions levied upon the contractor by the proposal evaluation process. After these actions are performed to the satisfaction of the GPMC, the selected contractor initiates the project implementation activity.

It is typically at the beginning of the design implementation activity that many formal documentation requirements are contractually implemented. This is when industry is heavily involved in the project design and may propose requirement changes. This can contribute to large cost increases over previous estimates in formulation, and dictates the need for early inputs from the project system engineering team to assure that design and performance requirements, specifications, and data requirements are incorporated into initial cost estimates. Many of these documents are generated by the contractor as defined in the SOW; however, some are also developed in the early design phase. A list of generic Data Requirements Descriptions (DRDs) can be found at

https://masterlist.msfc.nasa.gov/drm/,

and all online technical standards including the "preferred" (Agency-endorsed) list of core specifications and standards can be found at

http://standards.nasa.gov/.

4.3.1.1.2 Contract Types. In the development of the RFP for a project, choosing the appropriate contract type is one of the most crucial decisions to be made in the procurement process. In the field of space research and development, efforts to be undertaken by a contractor are often technically complex. It would be unreasonable, therefore, to require a contractor to assume all of the cost risk. Cost reimbursement contracts provide for payment to the contractor for all allowable and reasonable items of cost incurred in the performance of the contract. There are several types of cost reimbursement contracts; however, for the major development projects, NASA generally uses either a Cost Plus Award Fee (CPAF) or a Cost Plus Incentive Fee (CPIF) contract. Each of these contracts has advantages and disadvantages to the Project Manager. For example, the CPAF contract allows the Project Manager to change areas of emphasis as the development work progresses under the contract (e.g., by periodically restructuring the performance evaluation criteria against which the contractor's fee is determined) and permits a significant amount of technical penetration and direction by the government. If the contract is a CPAF type, the Project Manager must comply with the performance evaluation procedures as outlined in MWI 5116.1, *Evaluation of Contractor Performance under Contracts with Award Fee Provisions*. On the other hand, under a CPIF contract a lesser degree of technical penetration is expected since the criteria for selecting this type of contract is that the design goals are clearly achievable and no state-of-the-art advances are required. The selection of either of these types is driven by the degree of accurate cost estimating that is directly related to the degree of definition of the requirements. The Contracting Officer and Contract Specialist assigned to the project during the Formulation activities will assist the Project Manager in determining the type of contract to be utilized. Table II shows the types of contracts and their applications.

Table II. Contract Types and Their Application

Type	Application
Firm Fixed Price (FFP)	For standard items of low risk; where valid cost/pricing data exists; where uncertainties and risks can be accounted for in price; where adequate price competition exists
Fixed Price Incentive (FPI)	When FFP is desired by buyer but risks make seller reluctant; when risk is insufficient to warrant CPIF; when buyer wishes to prioritize the results
Fixed Price Award Fee (FPAF)	When specific seller attention is desired by the buyer
Cost Plus Fixed Fee (CPFF)	Research or development with advancing technology; Where significant risks exist; where buyer wants ultimate flexibility in redirecting seller
Cost Plus Incentive Fee (CPIF)	Development contracts with quantifiable cost, schedule, or technical performance requirements
Cost Plus Award Fee (CPAF)	Service, research and study contracts where results are difficult to quantify; where buyer wants high responsiveness to seller
Cost Sharing	Seller shares cost for use of technology
Time and Material	Not possible to size or estimate the task
Labor Hours	Like Time and Material, but labor only
Indefinite Quantity	Establishes price of deliverable when quantity and schedule are uncertain
Letter	Limited project start without full negotiation completed

Having gone through the procurement process leading up to a baseline contract, it is most important that the contract be kept current. The contractor and the government will identify the need for changes in various parts of contract requirements as design, fabrication, and testing progress. Changes in contract requirements can be issued only by a Contracting Officer. These changes in contract requirements result in cost proposals from the contractor. The timeliness and meaningfulness of the evaluation of these proposals are the keys to maintaining a negotiated contract baseline.

The MSFC utilizes the services of several Department of Defense (DoD) elements in the management of contracts. The most widely used agencies are the Defense Contract Management Agency (DCMA) and the Defense Contract Audit Agency (DCAA). Services performed by these agencies are on a reimbursable basis from NASA. Close cooperation is maintained with these agencies since they are an arm of the procuring organization and work under formal delegation from the Contracting Officer. The FARs identify the functions involved in contract management and specify those functions that (1) are mandatory to be delegated to DoD, (2) cannot be delegated to DoD, or (3) are optional functions that may be delegated to DoD. The DoD performs such functions as audit on pricing proposals over a specified dollar amount; accounting system reviews; functional reviews; cost monitoring; QA; industrial safety; and other functions that may be delegated by the Contracting Officer.

4.3.1.1.3 Contractor Cost Reporting. Cost is of vital interest to all levels of management and is an integral part of financial management reports. In addition, there are targets and limitations imposed on the amount of cost that will be accrued on a program within a Fiscal Year (FY). The Program Manager has the responsibility to provide an accurate monthly-accrued cost report to higher management. The NASA Form 533 series was designed as one of the tools for the Project Manager's use in providing these data and are applicable to all cost-type and fixed-price-incentive-type contracts. NASA's NPG 9501.2, *NASA Contractor Financial Management Reporting*, provides the basic guidelines and instructions to the contractor for the preparation of cost performance and financial reports (NASA Form 533) to the Project Manager.

4.3.1.2 Resources and Cost Management. The Project Manager has funding and civil service manpower reflected in his or her resources plan to accomplish the project. The management and efficient utilization of both categories of these resources are keys to a successful project. The following paragraphs describe the resources and cost management functions.

4.3.1.2.1 Work Breakdown Structure. The WBS and WBS Dictionary are critically important project management tools that should be finalized prior to implementation. The WBS serves as the basis for project technical planning, scheduling, cost estimating and budgeting, contract scope definition, documentation product development, and status reporting and assessment (including integrated cost/schedule performance measurement). The WBS must be a product oriented family tree type structure composed of hardware, services, and data which result from project engineering efforts during the development and production of an end item, and which completely defines the project. A WBS displays and defines all work, both governmental and contractual, included in the life cycle and the product(s) to be developed or produced and relates the elements of work to be accomplished to each other and to the end product. A WBS is essential in preparation of the Implementation RFP, in evaluation of proposals, in negotiations (both of the initial contract and subsequent changes), in the structuring and implementation of the contractor's work authorization system, and in contract cost, schedule, and technical performance measurement. The WBS also provides a framework for project work definition to a level of detail consistent with cost, schedule, technical, and risk oversight as desired by management and required by earned value management and for assignment of responsibility (both in-house and contractor) and resource allocation. A companion WBS dictionary that narratively describes the overall structure and content of each individual element of the WBS is developed during the formulation phase, with the final WBS following contractor selection or approval for implementation. The *NASA WBS Reference*

Guide, can be found at http://appl.nasa.gov/tools/tools_wbs.htm. The MIL-HDBK-881, *Work Breakdown Structure,* also provides guidance for preparation of the WBS.

4.3.1.2.2 Center Resource Planning System. The Center's civil service manpower provides the management and technical expertise to manage the project's contracted efforts and in-house tasks. The amount of civil service manpower employed to participate on each project must be determined and factored into the resources for the project. The role of civil service involvement is a key factor in determining manpower resources required. It is important that the MSFC level of penetration is sufficient to assure that the project is successfully accomplished. This level of penetration can vary from no penetration to total penetration. The strategy should be to deploy MSFC's workforce with the emphasis on highest risk areas using a risk management approach. Table III describes the penetration levels used at MSFC.

Table III. MSFC Penetration Level

Penetration Level	Definition and description of activity
0	No Penetration (Accept contractor performed tasks at face value)
1	Low Penetration (-Participate in reviews and Technical Interchange Meetings (TIMs) and assess only that data presented -Perform periodic audits on pre-defined process(es) – Chair board or serve as board member, or Review Item Discrepancy (RID) writer at formal reviews)
2	Intermediate Penetration (Includes level 1 activities plus – Daily or weekly involvement to identify and resolve issues
3	In-depth Penetration (Includes level 2 activities plus – Methodical review of details - independent models to check and compare vendor data "as required")
4	Total Penetration (Perform a complete and independent evaluation of each task)

The CRPS is the official system for presenting and determining workforce planning numbers. The CRPS is an integral part of MSFC's budget execution process that aids both MSFC management and the Project Offices in civil service workforce allocations. Currently, the CRPS captures workforce planning data by the execution and interplay of

CWCs, which essentially are task agreements between Center requesting and Center support organizations. The ultimate objective of the system is to produce "actual versus planned" data that captures both civil service full time equivalents per man-month and all other project cost information (prime contractor, project support, etc).

4.3.1.2.3 Cost Planning and Control. In varying degrees, virtually all of the topics discussed in this handbook can be related to the understanding and control of cost. Among the critical elements of successful cost planning and control efforts are:

- Requirements: The availability of complete, accurate, and realistic performance and interface requirements at an early stage is very desirable. Well-defined requirements breed mature designs and cost estimates and less risk of problems downstream.

- WBS: Work planning and accounting, earned value management, cost reporting, and scheduling at the various levels are all interrelated through the WBS. The contract WBS should be developed to the cost account level, that is to the level at which the performance of a single functional organization on a well-defined and scheduled task can be measured (typically level V or VI).

- Planning and Scheduling: Project work should be planned, scheduled, and authorized at the cost account level. For each cost account, resources are specified (dollars, material, manpower) and a firm schedule established. Performance at level III (subsystem) is reported based on the aggregate performance of the sub-tier cost accounts. The interdependence of cost account schedules must be clear and be supportive of the overall project schedule. The critical path should be defined and monitored.

- Cost Tracking and Analysis: Early identification of potential cost problems rests to a large degree on thorough analyses of not only the NASA Form 533 reports but also monthly reports, program review material, and other data. It is important to note that this function is not limited to the Program Control Office. The SLE, LSE and WBS Element Managers in the Project Office and/or the ED must be made responsible for a certain degree of understanding of not only technical but also cost and schedule matters. Trend analyses at the subsystem level of individual cost categories (direct labor, overtime, engineering, etc.) and comparative analyses of cost to schedule and cost to technical performance (e.g., value of work planned vs. value of work accomplished) are effective means for the early identification of cost problems which the contractor may not be inclined to voluntarily identify. The Project Manager integrates the opinions and recommendations of the Project Office personnel involved in technical/cost assessment, and those of the LSE, with his or her own observations, to arrive at a timely, thorough, and realistic understanding of project status. Once a potential problem is identified, it must be thoroughly understood and alternative solutions defined, including performance, cost, and schedule impacts. The contractor or

WBS Manager (if in-house) prepares a recovery plan (or alternative plans) showing what must be done, when, associated cost, and impact on other work.

- Management of Changes: Proposed changes must be thoroughly understood and questioned. Potential impacts on performance, cost, and schedule must be defined. Work planning and scheduling and performance and cost reporting procedures should also be employed in tracking the progress of major changes.

4.3.1.2.4 Budget Process. Well-defined project requirements form the basis of the budget process. These requirements, both external and internal, should be specified and baselined for control purposes. Estimated resources to satisfy these requirements are developed by the Project Manager using the integrated time-phased plan that results in a Program/Project Operating Plan (POP). The NASA uses this approach to plan, balance, and allocate funds. The POP process begins with a request, (the FY-1 call), issued by the NASA Headquarters Chief Financial Office (Code B) in the February timeframe. As a result of the NASA Headquarters request, Centers provide their resource requirements for the budget year (current FY plus two years) and also for four additional years. (For example, POP 2001 included resource requirements for budget years through 2007.) After a thorough integration and review within the Center, the resulting Center's submittals thus form the basis for the Agency's budget submittal to the Office of Management and Budget (OMB), and are ultimately reflected in the President's budget to Congress. After review and mark-up by the Congress, the resulting budget year becomes the basis for the FY POP. Subsequent to review and approval by the Center Director, this plan represents the official project resource plan for reporting actuals and requesting funds release from NASA Headquarters. Once the monthly phasing of the operating plan has been approved by NASA Headquarters, the flow of funds is controlled through two authority documents. These documents are NASA Form 506, the *Resources Authority Warrant*, which provides program authority to the program offices and field Centers, and NASA Form 504, *Allotment Authorization*, which allots appropriated funds to the Centers. The appropriation (NASA Form 504) can only be used as authorized by a warrant (NASA Form 506). Resource authority received at the Center must be obligated within one year subsequent to the year appropriated by Congress. (For example, FY 2003 authority must be obligated no later than September 30, 2004.)

4.3.1.2.5 Integrated Financial Management Core Financial System. The IFM Core Financial System R/3 is the financial computerized system used by NASA. System output is the official MSFC and Agency position regarding actual charges to MSFC/NASA programs to be reported externally in the Financial Accounting and Tracking System, POPs budget estimates and miscellaneous reports. The MSFC labor system is the IFM SAP labor dollars for reporting performed by the CFO.

4.3.1.3 Scheduling. Scheduling starts with defining the technical content of project activities and establishing the project logic, i.e., the sequence in which activities are to be accomplished and the interfaces and interdependencies of the various activities. Once the project logic is established, time spans for activities and event dates can be applied to develop the project schedule.

The preparation and monitoring of schedules at various levels is necessary in the evaluation of progress and problems and to help assure efficient flow among interrelated tasks. For any given project, there will be a hierarchy of interdependent schedules ranging in detail from the top-level program schedule to the individual cost account schedules. Each is logically supported by sub-tier schedules and, in turn, compatible with the next higher level. This hierarchy of schedules is given structure by the WBS, which to a large extent is a hierarchy of products. For each WBS element from project level through system, subsystem, assembly, component, and cost account level, there should be a corresponding schedule, the total collection of which composes an integrated interdependent set.

Since the lowest level of schedule status reporting is frequently limited to subsystem level (WBS, level III), it is advisable to periodically audit the contractor's work planning procedures to assure the existence of an effective system at lower levels of the WBS.

The existence of a detailed logic diagram (precedence network) and the use of critical path analysis serve to demonstrate that the contractor is properly planning and managing the work. These techniques provide the interrelationships of the various project tasks and the ability to identify critical areas of schedule maintenance. Use of the schedule and critical path on the schedule is an effective tool in managing a project and is sometimes critical to getting the job done and meeting schedule.

4.3.1.4 Project Earned Value Management. Earned value management as described in this section applies only to MSFC contracted projects; however, the WBS concept described would apply to in-house projects also. The CFO is responsible for Center-wide oversight of earned value management, which includes the RFP and proposal evaluation, implementation, validation/re-validation team leadership and formation, training, documentation maintenance, surveillance, and support to the Project Offices in the area of cost, schedule, and technical performance measurement. The Project Manager should work with the CFO to assure that requirements governing this activity are implemented on MSFC acquisitions. As soon as possible after contract award, representatives of the validation team should visit the contractor's plant and review the contractor's plan for implementing the required EVS.

The requirements of MWI 5116.1 are applied to MSFC's major cost-type/award fee development contracts. Cost, schedule, and technical reporting techniques largely identified with government acquisition programs of the 1960's required the interpretation and transposition of data from the contractor's internal management system into the framework of a government-imposed system for reporting to the government. These systems were difficult to evaluate since there was no accurate method of correlating cost to schedule status. Cost was always a relationship (expressed in dollars) of total contract cost to the amount spent at a particular time. Schedule was a comparison (expressed in days, weeks, and months) of project accomplishment against a schedule plan. Analysis of these two elements was time-consuming and did not always indicate the true project status.

NPD 9501.3, *Earned Value Performance Management*, requires the contractor to establish and maintain a firm time-phased performance measurement budget baseline based on the contract target cost and schedule; to periodically compare cost and schedule performance against planned budgets and schedules; to determine variance, isolate factors causing deviations from plans, and provide corrective action; to project cost and schedule estimates for contract completion; and to utilize the resultant system. These requirements are considered fundamental to the successful management of any project. For the contractor to assure that their system will meet the criteria, he or she must concentrate effort on system integration, internal discipline, and simple but adequate internal procedures. This management process is referred to as “Earned Value.” The system must, therefore, be responsive to changes that affect cost, schedule, and technical requirements during the life of the contract.

When establishing the baseline, and since primary budget assignments are to functional organizations rather than to pieces of hardware or tasks, it is necessary to determine what work will be performed by each organizational element. The work to be performed can be defined through the use of the WBS. Once the work is defined, the organizational elements responsible for the work must be identified. This identification effectively integrates the organizational structure with the WBS and forms a key intersection for control purposes, usually referred to as the “cost account”. One way to visualize this intersection is to think of a matrix with all of the tasks to be performed listed along the horizontal axis and organizational elements along the vertical axis (see Figure 5). Each organization can then be identified with the task that it must perform.

The intersection of the organizational structure and the identified WBS task forms a natural control point for cost/schedule/technical planning and control. The intersection provides a point at which actual costs can be accumulated and compared to budget costs for work performed before summarization to higher reporting levels.

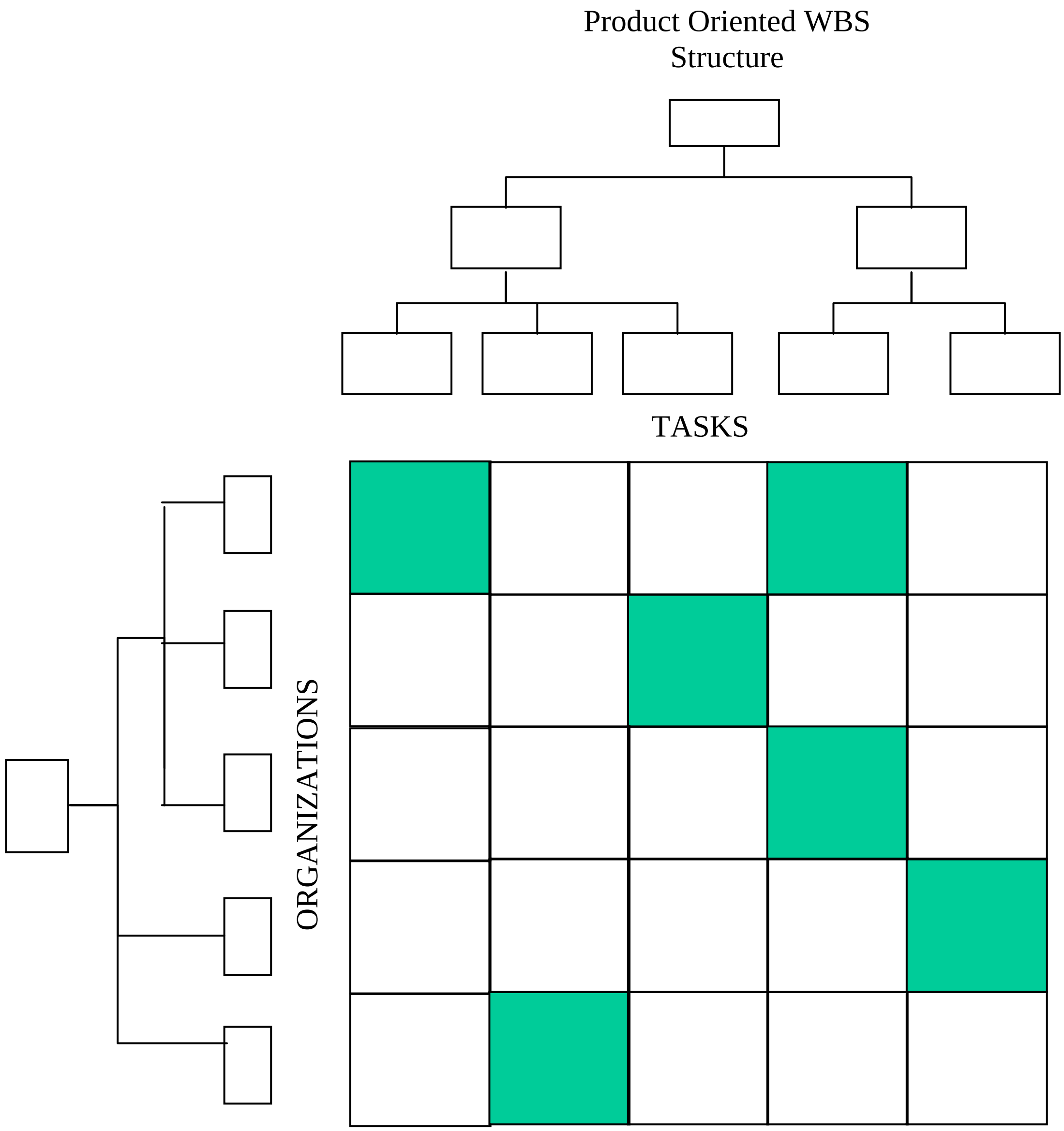


Figure 5. WBS Element/Functional Organization

While certain changes may be necessary during the life of an activity, change to cost account budgets should not be made arbitrarily. Some factors that cause a change to be made to baseline budgets are as follows:

- A change in the scope of work;
- The final negotiated price for authorized work differs from that estimated and budgeted;

- Reprogramming to accommodate schedule changes or other factors that may have caused the original plan to become unrealistic;
- Budget is transferred from one WBS element to another; and/or
- Budget is transferred from one organization to another.

The effect on the EVS of rebaselining (i.e., a restructuring of project performance requirements and/or cost and/or schedule and the resultant revising of cost account/work package budgets and schedules) is to reset the system to zero.

Of equal importance to cost/schedule requirements is the satisfaction of project technical requirements and specifications. Therefore, these technical requirements must be made to correlate the cost and schedule factors so that the impact of significant change to one of these factors will relate to the others, and trade-offs can also be made. When correlating cost, schedule, and technical performance, it is apparent that unfavorable cost or schedule conditions are usually caused by technical difficulties rather than the inverse. Thus, the impact of technical progress or problems must reflect on cost and schedule. In a technology project, the earned value management system must include evaluation of the project performance in the following areas:

- Progress along planned parallel development paths.
- Implementing scheduled decision gates for adjustments to the development paths.
- Implementation of planned alternate paths in response to development problems.
- Implementation of planned fallback positions as part of the response to unsuccessful events.

The contractor is required to develop a system that provides visibility to contractor and government of actual and potential technical problems and provides system, subsystem, and critical item tracking and trend data for physical and performance parameters assessment. Development of a set of TPMs provides a mechanism for tracking and maintaining successful performance. TPM examples are shown in Appendix D.

4.3.1.5 Requirements Management. Requirements Management is the process of establishing the project requirements and then providing the management control over those requirements to ensure that as project implementation proceeds, the original objectives and Program level requirements are achieved. Paragraph 4.3.2.1 discusses the process for establishing the project system requirements.

Once projects have been through the formal PRR and/or System Requirements Review (SRR) and the project requirements are formally established by CCB approval (baselined), management of the requirements through the configuration management function becomes the primary control mechanism to ensure that project implementation adheres to the established requirements. As project implementation proceeds through design, the design reviews provide the opportunities to ensure that system design meets the intent of the requirements. It may become necessary to modify the baseline requirements as project design, fabrication, and testing are implemented, but only after changes are justified on an individual basis. It is important that the Project Manager work closely with the LSE to approve only those requirement changes that are justified on a cost, or technical "change to make work" basis. If the system**,** based on present requirements**,** is adequate, proposed requirement changes must be cautiously considered by project management. Improvements in system performance may not be worthwhile considering potential cost/schedule impacts.

Requirements flow-down and resource allocation are accomplished where higher level functional and performance requirements and system resources are allocated to end items or functional subsystems that make up the system and are documented in a system specification, CEI specifications and/or other lower level specifications. To ensure traceability of requirements from the highest-level requirement to the lowest level requirement, the requirements flow-down is normally documented in a requirements traceability matrix (DRD STD/SE-RFM) that defines the parent/child relationship of each requirement at the different levels.

4.3.1.6 Configuration Management. Configuration management is a formal and disciplined system for the establishment and control of the requirements and configuration of hardware/software developed for NASA.

The configuration management activities provide the discipline necessary for the initial establishment and subsequent control of project requirements and design evolution. Such activities consist of generating Center configuration management policies, requirements, and procedures and assisting with the development of project and contractor plans and manuals. In addition, support functions associated with baseline identification, change processing, tracking, accounting, reviews, and audits are provided. To assure consistency across projects a standardized baseline and change status and accounting system is maintained and supported. Co-located configuration management support personnel are provided to projects, and direct configuration management support is maintained for in-house activities. Support includes change control and integration, and provision and maintenance of a comprehensive document release system.

MPG 8040.1, *Configuration Management, MSFC Programs/Projects;* MWI 8040.1, *Configuration Management Plan, MSFC Program/Projects;* MWI 8040.2, *Configuration Control, MSFC Program/Projects*; MWI 8040.3, *Deviation and Waiver Process, MSFC Programs/Projects*; MWI 8040.5, *Floor Engineering Orders and Floor Engineering Parts Lists (FEOs/FEPLs)*; MWI 8040.6, *Functional and Physical Configuration Audits, MSFC Programs/Projects*; MWI 8040.7, *Configuration Management Audits, MSFC Programs/Projects*; and MSFC-STD-555, *MSFC Engineering Documentation Standard*, establish the basic policy and assigns responsibility for implementation of configuration management at MSFC.

Configuration management is composed of the following four major areas:

- Configuration identification
- Configuration control
- Configuration accounting
- Configuration verification

4.3.1.6.1 Configuration Identification. Configuration identification is the definition and establishment of the total technical requirements of a Configuration Item (CI) or Computer Software Configuration Item (CSCI) and encompasses performance and functional requirements as well as the detailed configuration definition. It is mandatory that this identification be formally defined and documented throughout the life of the project. The accepted method of documentation includes specifications, engineering drawings, and basic requirements documents (e.g., Military Standards, processes, Interface Requirements Documents (IRDs), etc.). Configuration identification also includes identification of CI/CSCI's, establishment of configuration baselines (i.e., Functional, Development, and Product), and identification numbering (i.e., CI, CSCI, part numbers, serial and lot numbers). Configuration identification is established incrementally and is a product of the various project reviews as discussed in 4.4. The evolution of the configuration baselines must be planned and enforced by the project. For a contract, NASA must specify what configuration documentation produced by the contractor will be placed under NASA control and the schedule for these NASA baselines.

4.3.1.6.2 Configuration Control. Configuration control is the formal process used to establish and control the baseline. This control is maintained through a hierarchy of formal CCBs that are established at each level of hardware/software management responsibility. The CCB hierarchy normally includes five levels as shown in Figure 6. Level I resides at NASA Headquarters and is responsible for the overall program requirements. Level II usually resides at the Lead Center. Level II CCB is responsible for the detail program requirements which Level I has allocated to it. The program requirements apply to all of the applicable elements, flight, ground, launch sites, test sites, etc., including element to element interfaces. Level III CCBs are established to control the respective element's/projects requirements and interfaces. Each Level III has control of its element's unique requirements and interfaces, but the Level III CCBs may not make final disposition of any change that affects a higher level CCB. The Level IV CCB is the System CCB, and the Project Manager may delegate the chairmanship to the LSE. The Level IV CCB may be the controlling CCB for in-house design, and/or serve as an engineering review board responsible for evaluating and providing technical recommendations pertaining to changes requiring disposition by a higher level CCB. A Level V CCB may reside with the developing contractor or WBS Manager (for in-house activities), and has control for all changes that

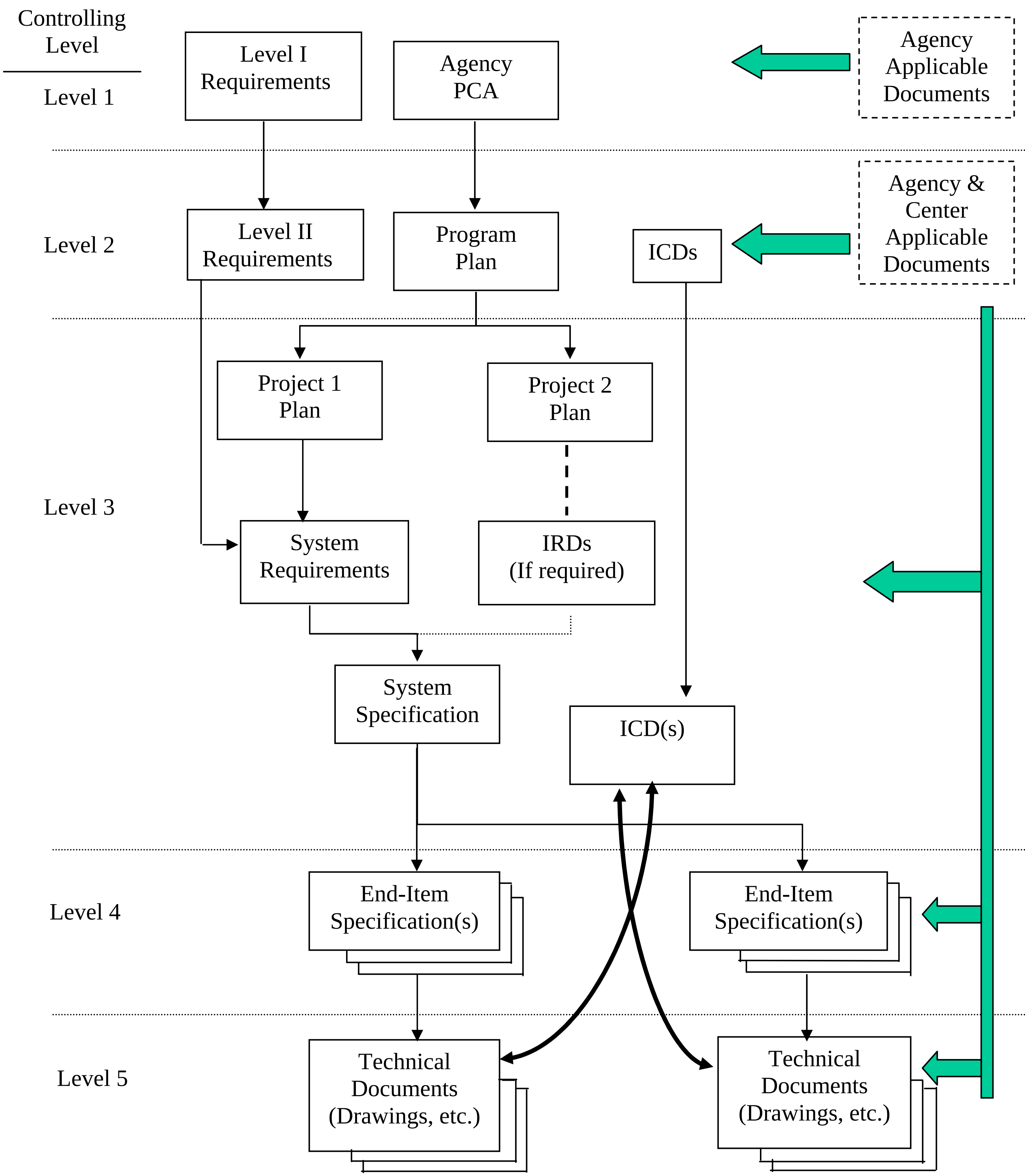


Figure 6. Project Baseline Documentation

are not controlled by any of the higher level CCBs. Each board can make decisions within its own authority, so long as it does not violate the cost, schedule, technical, or programmatic authority of higher level CCBs. MWI 8040.2 defines the configuration control process and responsibilities for MSFC projects. Figure 7 is a generalized representation of a flow for a typical change.

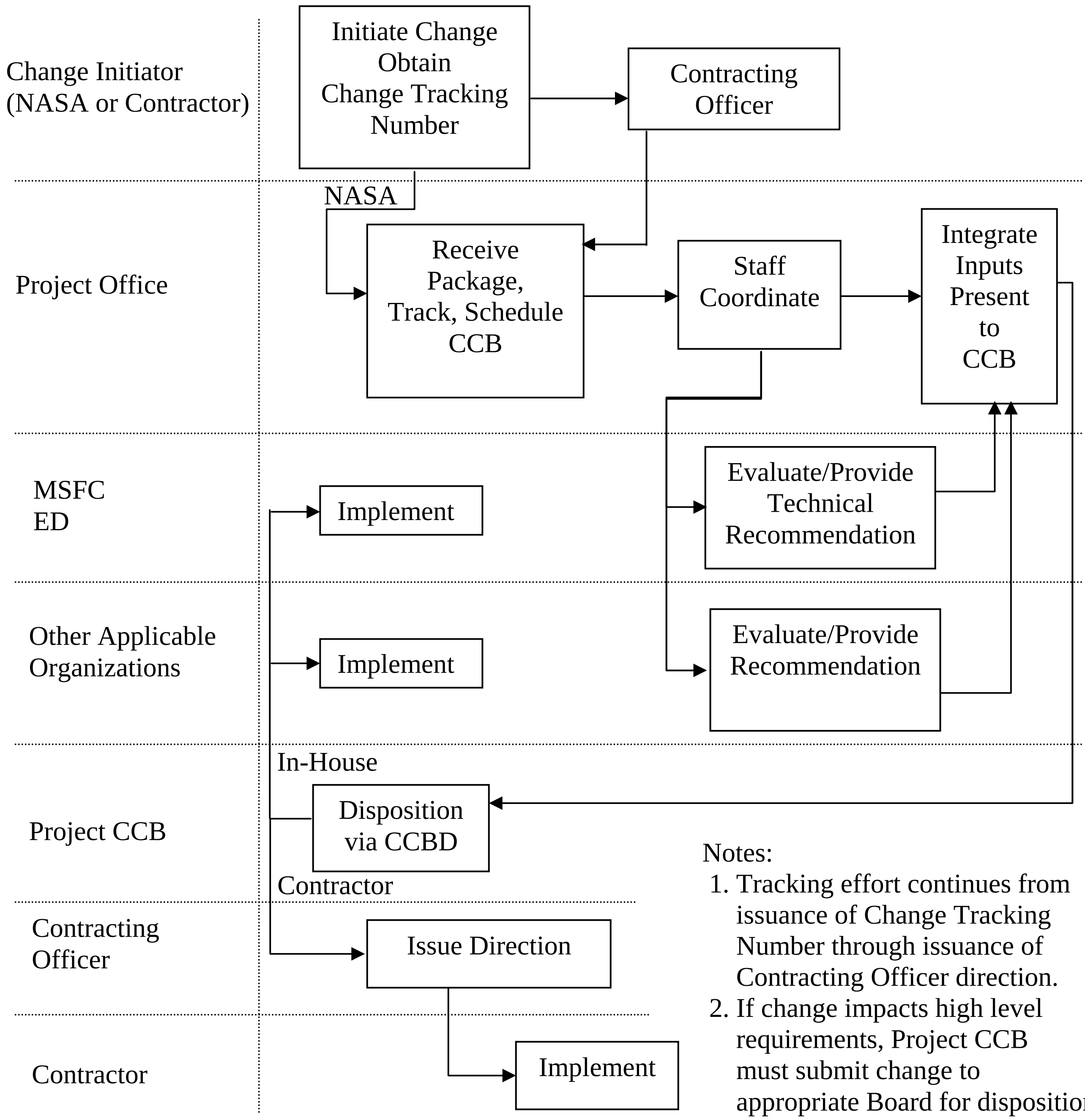
4.3.1.6.3 Configuration Accounting. Once the baseline is formally established, it is imperative that accounting of that baseline and subsequently authorized changes be processed. The accounting, as a minimum, is capable of defining the exact baseline on a continuing basis and includes appropriate data that will provide a clear audit trail from authorization of the baseline/changes into the affected documentation and hardware/software.

MSFC utilizes the Change Processing, Tracking, and Accounting System (CPTAS) for configuration status accounting, and the Integrated Configuration Management System (ICMS) for engineering release and recording the "as-designed" configuration (i.e., the indentured parts list for the configuration item). The NASA accounting system is recognized as the single authoritative source for the NASA-controlled baseline definition.

4.3.1.6.4 Configuration Verification. Configuration verification is the task of ensuring that established baselines and subsequent changes have been incorporated and that resulting configuration items meet these established requirements. Total configuration verification requires the involvement and use of the NASA accounting systems and the various contractor systems (e.g., baseline accounting, engineering release, build records, etc.). Progressive configuration verification is accomplished by utilizing the incremental configuration identification baselines established by the formal technical reviews during the implementation phase. The details of these reviews are addressed in 4.4.

Verification is an ongoing process as the project matures. In each of the aforementioned reviews, the product of the specific review is compared to the baseline requirements, and thus the requirements are verified as being satisfied, or discrepancies are identified and tracked through resolution. Likewise, as engineering changes are authorized, they must be verified as being correctly implemented and tested.

The configuration verification process shall demonstrate that: (1) the required qualification verification has been accomplished and that it substantiated compliance of the "as-verified" design with the original performance and configuration baseline and approved changes thereto; and (2) the required acceptance verification has been accomplished and that it substantiated compliance of the performance and configuration of the article being delivered with the "as-qualified" design. The Design Certification Review or Functional Configuration Audit is used to perform this verification that the configuration item functions in accordance with its requirements.



Notes:
1. Tracking effort continues from issuance of Change Tracking Number through issuance of Contracting Officer direction.
2. If change impacts high level requirements, Project CCB must submit change to appropriate Board for disposition.

Figure 7. Change Process Flow

Configuration verification also includes verifying the "as-built" configuration against the "as-designed" configuration to ensure that the design was built to the requirements. The Configuration Inspection or Physical Configuration Audit is the review utilized to perform this verification. For MSFC in-house design and manufacture, the "as-designed" configuration is contained in the Integrated Configuration Management System, and the "as-built" is provided by MSFC Safety and Mission Assurance from the As-Built Configuration Status System.

4.3.1.7 Data Management. The required data management functions at MSFC are defined in MPG 7120.3, *Data Management, Programs/Projects*. At MSFC, Data Management is defined as: *The timely and economical identification/definition, preparation, control, and disposition of documents and data required by a program, project, or activity.* Each Program/Project Manager or Data Manager shall develop a Data Management Plan during the Program/Project formulation phase that describes the specific program/project implementation of the data management requirements. The Data Management Plan shall identify/define required data, and establish data preparation requirements, control processes, and disposition processes. For smaller projects and activities, the data management processes may be included as part of the Program/Project Plan as long as the requirements identified in MPG 7120.3 are satisfied.

4.3.1.7.1 Data Identification/Definition. The identification/definition of data requirements is one of the most important components in the formulation and planning of any program/project. Data requirements are levied on MSFC contractors and in-house development activities through the use of Data Procurement Documents (DPDs), Data Requirements Lists (DRLs) and Data Requirement Descriptions (DRDs) in accordance with MWI 7120.2, *Data Requirements Identification/Definition*. Standard DRDs are provided at MSFC to ensure that mandatory data requirements (e.g. safety, financial reporting, FAR/NFS reporting requirements) are applied consistently to MSFC contracts and solicitation packages. A Standard DRD is a data requirement that has been identified for repetitive use, either in-house or on contracts. Standard DRDs are maintained by the Center Data Requirements Manager (CDRM) and are available on the MSFC Data Requirements Management System at the following location: https://masterlist.msfc.nasa.gov/drm/.

4.3.1.7.2 Data Preparation. As the implementation phase of the Program/Project begins, proper preparation of data is critical for technical and administrative accuracy. MWI 7120.4, *Documentation Preparation, Programs/Projects,* describes format and numbering requirements for MSFC in-house prepared documentation. Contractor data is prepared in accordance with contract requirements and the contractor's internal procedures. A key element of preparation is the Office of Primary Responsibility Designee (OPRD) assessment and marking of the data availability limitation (e.g., export controlled, NASA sensitive, proprietary, etc.). The availability limitation marking sets the stage for proper handling, distribution, and access controls during the control phase.

4.3.1.7.3 Data Control. Data is central to all Program/Project processes and therefore must be properly evaluated, authorized, and protected. The data control process must address the following elements: receipt, checking to ensure proper preparation and numbering, tracking and accounting, storage, Center Export Representative (CER) approval of availability limitation markings, access/distribution, evaluation, approval authorities (e.g., Project Manager, Document Control Board, Configuration Control Board, Contracting Officers Technical Representative, Office of Primary Responsibility, etc.), release, and records of the data processed and the control process itself. At the end of the control process, the latest approved version of each document should be listed (and preferably made available electronically) on the Program/Project Master List(s) as required by MPG 7120.3. MPG 7120.3 contains the requirements for control processes, and points to other MSFC requirements such as Administratively Controlled Information (ACI), Export Control, and Scientific and Technical Information (STI) which contain specific requirements for processing and handling these categories of data.

4.3.1.7.4 Data Disposition (Access and Records). Data disposition includes storage, data access, and maintenance of records. NASA records must be retained and retired in accordance with NPG 1441.1, *NASA Records Retention Schedules,* and MSFC records management is defined in MPG 1440.2, *MSFC Records Management Program*. Programs/projects must identify the records they are producing and ensure they are stored appropriately. Records/data must be available for current use, stored so that records may be retrieved and utilized on future Programs/Projects, provided to Government customers (as approved and in accordance with data sensitivity), and retired and retained appropriately to contribute to the knowledge base of the United States and NASA.

4.3.1.8 Risk Management. Project risks are inherent in NASA projects. An important function of project management is to manage those risks to minimize the impact upon the project implementation. Risk management includes the related activities of risk identification, risk assessment, planning, risk mitigation, and documentation. MWI 7120.6 provides management instructions for project risk management.

Risk identification begins and develops during the formulation process. As concepts are defined and technology assessed, certain project risks become apparent. Generally, items are identified as risks if events can prevent the project from meeting its performance, cost, or schedule goals. Project management must ensure that the project team participates in the identification of project risks for their area of expertise and quantifies the impact upon the project. Risk assessments are conducted continuously to identify the risks to a project due to technology considerations (i.e., new designs, materials, processes, operating environments), availability of vendors, test failures, schedule optimism, margin allocation, and requirement stringency.

System engineering is heavily involved in assisting the Project Manger in assessing risks and identifying mitigations. Proper project planning will then strive to mitigate the identified risks. A justification for project cost and schedule reserves will be based partially on risk mitigation analysis. The management of risk, while maintaining performance and schedules at minimum cost, is a major challenge to the Project Manager. Traditional techniques for minimizing risk include the addition of redundancy, the use of proven hardware, and the execution of a thorough qualification test program. In consideration of performance and cost, some risk-taking is inevitable. In cases where advanced designs are pursued, the test program is structured to allow for periodic assessment of progress and a back-up approach is maintained.

As project implementation proceeds, project risk must be assessed on a continuous basis and reported at appropriate intervals (e.g., Project Reviews, Red Team reviews, and TIMs) using existing risk management tools (e.g., Hazard Analysis, FMEA/CIL, FTA, and Probabilistic Risk Assessments). Project events such as development testing, schedule deliveries, and cost expenditures are also monitored. Any deviation from expected results will trigger alternate implementation actions if the proper identification and mitigation planning has been accomplished.

4.3.1.9 Technical Management. Technical management of the project refers to the management functions associated with transforming the project requirements into a full-scale system which functions as necessary to meet the project requirements. Technical management consists of managing the project personnel responsible for the detailed over-sight of project development as well as being cognizant of technical activities, progress, and problems encountered in the development process. The Project Manager's role is to rely on the project team, stay personally involved, and be ready to act if and when problems requiring Project Management intervention are encountered. However, the Project Manager has overall responsibility and accountability for successful project technical performance. The TPMs developed for the project provide an effective means for tracking and maintaining successful performance of the project. The TPMs provide an indicator of status in time to take corrective action, when necessary. Examples of TPMs are shown in Appendix D. For the purpose of this document, technical management has been partitioned into the functions discussed in the following paragraphs.

4.3.1.9.1 Safety and Mission Assurance. A primary objective of any project is to implement the project in a safe manner for all personnel involved and to successfully conduct the mission of the project. While depending upon the S&MA organizations and the supporting project team to ensure that safe and best practices are followed to provide assurance that the project system will perform its mission, project management's overview and guidance are key in implementing S&MA technical management. The following paragraphs describe the S&MA functions and activities managed by project management.

4.3.1.9.1.1 System Safety. System safety is concerned primarily with the safety aspects of ground and flight personnel safety, aerospace flight systems, associated GSE, facilities and software. All phases of a program are addressed, including concept studies, design, manufacturing/assembly, transportation, test, flight, and post flight operations, whether for manned or automated systems. System safety is to be emphasized throughout the life cycle of a project flight system, from inception through completion.

System safety responsibilities for project management and all Center elements are presented in MWI 1700.2, *System Safety Program*. System safety activities include:

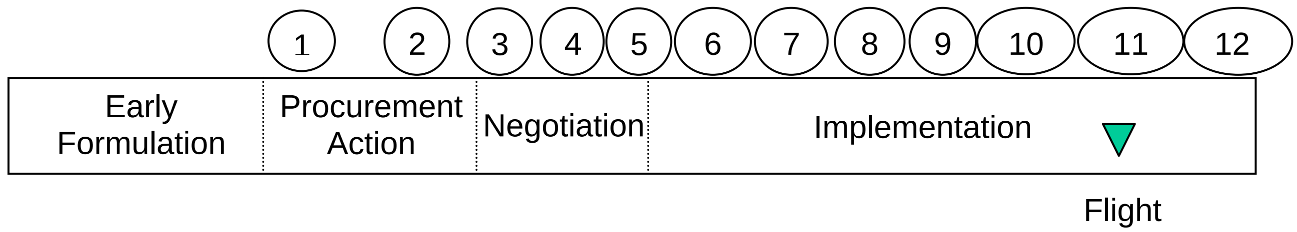
- Submit a Final System Safety Plan in compliance with the guidelines provided in MWI 1700.2.
- Prepare a detailed design hazard analysis and safety assessment.
- Prepare an operational hazard analysis including flight and ground activities.
- Prepare an integration hazard analysis.
- Establish an accident/incident reporting system, and participate in the investigation and resolution of any occurrences.
- Participate in SEBs.
- Participate in project milestone reviews (i.e., PRR, SRR, PDR, CDR, Design Certification Review (DCR), FRR).
- Continue the Project Risk Management Summary as outlined in the Formulation Phase.
- Prepare safety review packages and participate in the Center safety reviews as well as the NSTS/ISS Safety Panel reviews with Johnson Space Center (JSC) and Kennedy Space Center (KSC), as applicable.

Payloads that use the NSTS and ISS will have to interface with the NSTS/ISS Payload Safety Review Panel (at JSC) and the NSTS Ground Safety Review Panel (at KSC). (For multiple payload missions, this interface may be accomplished through a Mission Manager or another NASA Center responsible for a payload.)

The prime contractor will have a major role in the system safety activities of the project. The system safety requirements will be defined and applied to the earliest contractor efforts to assure that competing concepts will have the proper safety considerations in their design.

Assurance must be provided that RFPs include applicable programmatic system safety requirements adapted in compliance with NSTS 5300.4 (ID-2), *Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program Change No.* 2, and other S&MA requirement documents. NSTS payloads must incorporate the hazard control requirements from NSTS 1700.7, *Safety Policy and Requirements for Payloads Using the NSTS*.

4.3.1.9.1.2 Mission Assurance. Mission Assurance functions for a project include the quality, reliability, and maintainability activities described below. The total QA activities that are to be utilized during any project phased planning activity at MSFC for major contracts are depicted in Figure 8. Smaller contracts are handled similarly.



1. Prepare Quality Assurance (QA) Requirements
2. SEB Participation (Technical Evaluation)
3. QA Plan Evaluation and Approval (*)
4. QA Procedures Evaluation (*)
5. QA Delegations/Characteristics for Inspection
6. On-site Evaluations
7. Project Review Participation (PDR, CDR, FCA, PCA, Etc.)
8. Progress Reports
9. Surveys
10. Problem Investigation
11. Reuse/Refurbishment Assessment
12. Production/Operations Surveillance

(*) Prepare for In-house Projects

Figure 8. Quality Assurance Activities

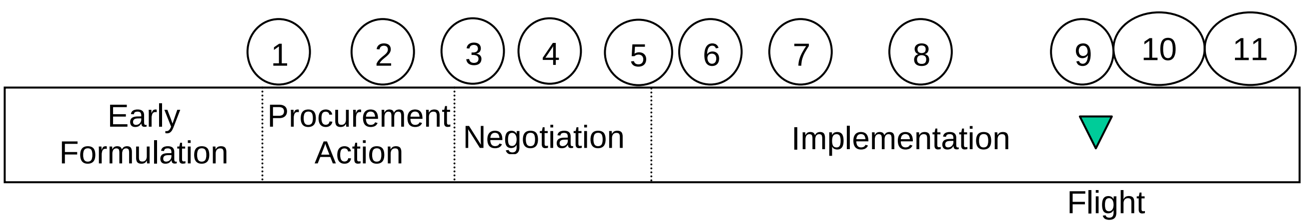
An aspect of prime importance during any phased project planning activity is the incorporation of the QA hardware and software requirements into the Project Quality Plan, the project requirements and specifications, and RFP (for contracted projects). The proof of importance of early emphasis on QA planning is realized by the adequacy of the QA data delivered during the Functional Configuration Audit (FCA) and Physical Configuration Audit (PCA). To ensure that the required data will be available, early QA planning must coordinate with the FCA and PCA process to define the required data. Assurance of the incorporation of applicable portions of the NSTS 5300.4(1D-2) ANSI/ISO/ASQ Q9001-2000, *Quality Management System - Requirements,* SAE-AS9100, *Quality Systems Aerospace - Model for Quality Assurance in Design, Development, Production, Installation, and Servicing,* and other appropriate QA requirements is accomplished by a complete review of the requirements, the Project Quality Plan and specifications prior to their release. The project's Quality Plan in conjunction with the MSFC quality management system defined by MPD 1280.1, *Marshall Management Manual* govern the QA requirements for in-house projects at MSFC.

Contractor's QA hardware and software plans are evaluated during the SEB phase, and the recommendations to accept or revise the submitted plans are provided. QA hardware and software plans required of the contractor are Type 1 documents, i.e., require MSFC approval. QA plans must comply with MWI 7120.1.

When ATP has been authorized and the contract has been signed, a letter of delegation may be prepared to other government agencies to perform QA activities on the project. The delegation includes direction to the agency to review contractor procurement requests to vendors and subcontractors, perform receiving and in-process inspection of flight and GSE hardware, act on Material Review Board action, monitor all test activities, and other quality activities described in NPG 8735.2, *Management of Government Safety and Mission Assurance Surveillance Functions for NASA Contractors.* A Project Surveillance Plan defining the required surveillance activities is prepared in accordance with NPG 8735.2.

When the project enters the production phase, the QA functions will continue with some adjustments to the overall QA effort to facilitate a production program. In addition, a reuse/refurbishment assessment will be performed on flight hardware, which may be selected for further flight service.

System reliability is also a function of project technical management. Reliability assurance requirements define the reliability tasks to be incorporated into RFPs, SOWs, and data requirements. See Figure 9 for the reliability assurance activities.



1. Prepare Reliability Assurance Requirements
2. SEB Participation (Technical Evaluation)
3. Reliability Assurance Plan Evaluation and Approval (*)
4. Reliability Assurance Procedures Evaluation (*)
5. FMEA/CIL Evaluation and Approval (*)
6. Project Review Participation (PDR, CDR, etc.)
7. ALERTs Process
8. ECP Evaluations/CCB Support
9. Surveillance
10. Progress Reports
11. Problem Investigation

(*) Prepare for In-house Projects

Figure 9. Reliability Assurance Activities

The SEB/Technical Evaluation Board (TEB) participation consists primarily of an evaluation of the proposals received from potential contractors for the performance and cost of accomplishing the tasks below. A Reliability Program Plan is prepared by the successful bidder and submitted to NASA for approval. The Plan is the primary control instrument for the life of the contract. The Reliability Plan describes the contractor's methods for accomplishing the following tasks:

a. Procedures for accomplishing the tasks outlined in the Reliability Plan should be developed for the tasks that require standard format; i.e., the FMEA, CIL, and Problem Reporting.

b. Trade Studies to develop optimum system configuration through cost effectiveness methods, and reliability vs. cost, or weight are accomplished during formulation and early implementation.

c. Reliability Design Criteria for each subsystem are developed and reviews utilized to ensure specification compliance to the criteria.

d. Preliminary hardware FMEA/CILs are developed and submitted during PDRs. The baseline hardware configuration is reflected in the CDR FMEA/CILs.

e. Engineering Change Packages are assessed for the effect of the change on reliability. Changes that affect the FMEA/CIL will be reflected in change update sheets to the documents.

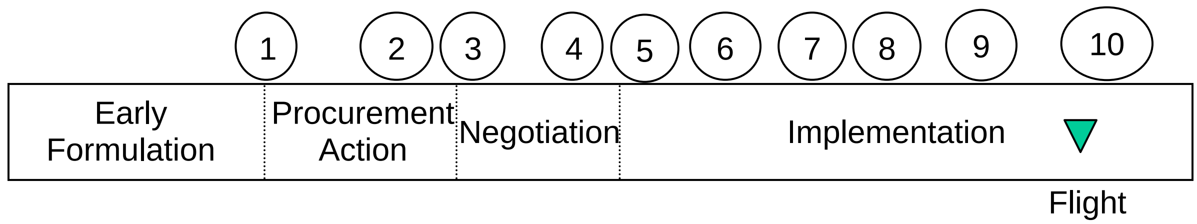
f. Reliability Progress Reporting and Reviews are accomplished through periodic reports and meetings as a part of the overall management information system.

g. Problem Reporting and Corrective Action provides a closed-loop system for reporting all problems and the establishment of corrective action for problems on flight/flight type hardware. The Problem Assessment System (PAS) is utilized by MSFC on all Space Shuttle elements and selected other projects that provide a documented review of significant problems.

h. Surveys of contractors' reliability programs are made as a part of the total S&MA effort. Primary objectives of the surveys/audits are the determination of compliance to contract requirements and approved procedures.

i. Participation in the Acute Launch Emergency Restraint Tip (ALERT) program in accordance with MWI 1280.5, *MSFC ALERT Processing*, provides assurance that potential problems against critical hardware are properly evaluated and dispositioned.

The total maintainability engineering activities (consistent with MPD 8720.1, *MSFC Maintainability and Maintenance Planning for Space Systems,* and NPD 8720.1, *NASA Reliability and Maintainability (R&M) Policy*) that are to be utilized during any project-phased planning activity at MSFC for prime contractors are depicted in Figure 10. The maintainability requirements will be established and implemented into the contracts. These requirements define the maintainability tasks to be incorporated into RFPs, SOWs, and data requirements.



1. Prepare Maintainability Requirements
2. SEB Participation (Technical Evaluation)
3. Maintainability Plan Evaluation and Approval (*)
4. Maintainability Procedures Evaluation (*)
5. Program Review Participation (PDR, CDR, Etc.)
6. ECP Evaluations
7. Progress Reports
8 Maintainability Analyses
9. Surveys
10. Problem Investigation relative to Maintainability

(*) Prepare for In-house Projects

Figure 10. Maintainability Activities

The SEB/TEB participation consists primarily of a review and evaluation of the proposals received from the potential contractors for the methodology effectiveness and cost of accomplishing the tasks required under the maintainability discipline.

A Maintainability Program Plan is prepared by the successful bidder and submitted for NASA approval. The Plan is the primary guiding and controlling instrument for the life of the contract.

4.3.1.9.1.3 Industrial Safety. Center, agency, and federal policies require that employees be provided with a safe and healthful work place and that government property be protected from damage or loss. An Industrial Safety and Health Plan detailing the industrial safety and health program should be part of the Formulation Phase project/program planning activity. Employee safety programs must consider the working environment, training, and safety awareness activities, safety implications of new equipment or processes, and the possible safety impact of any changes in the work place.

Project management is responsible for (1) the development and implementation of the proper industrial safety requirements for contractual efforts, (2) jointly with the responsible MSFC supervisors, the proper application of MSFC industrial safety requirements for in-house project activities, and (3) the evaluation and reporting of accepted risks to personnel and property.

Industrial safety tasks require project interfaces with the prime contractor, Center Directorates, and the S&MA Office.

For contracted efforts, the prime contractor will have primary responsibility for assuring that the proper industrial safety requirements are applied to activities at the contractor's facilities. The prime contractor shall demonstrate compliance with industrial safety requirements through the following interface with the Project Office:

a. Industrial Safety and Health Plan. The prime contractor will prepare and implement an Industrial Safety and Health Plan that meets the requirements of the contract safety and health provisions.

b. Accident and Incident Reports. The prime contractor will prepare and submit accident and incident reports in compliance with NPG 8621.1, *NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping*.

c. Program Reviews. The prime contractor will report the status of industrial safety activities as part of program reviews with MSFC program management. The status report will also include evaluation of any program activities that pose a health hazard to the general public plus any Occupational Safety and Health Administration (OSHA) recorded violations.

Project management will develop the proper interface with Center supporting organizations to assure that project activities at MSFC are in compliance with Center industrial safety and health requirements. Supporting documentation will include:

(1) Hazard Analysis – Hazard assessment of planned program activities at MSFC will be provided.

(2) Safety Critical Procedures - Detailed procedures are prepared for any operation that is identified as potentially hazardous.

Project management will develop the necessary interfaces with the Center Operations Directorate to assure that project activities present no health hazards to personnel at MSFC.

Project management closely coordinates project industrial safety and health activities to assure compliance with industrial safety and health requirements. Interface activities include:

(1) Hazard Assessment - Project activities at MSFC will be evaluated to assure that industrial safety and health hazards have been identified and properly controlled.

(2) Occupational Safety and Health Survey - Periodic occupational safety and health inspections and surveys of project activities at MSFC will be conducted.

(3) Incident Investigations – Project management must ensure that project incidents are investigated and resulting proposed corrective actions are evaluated and implemented when approved.

The following elements and activities are considered for inclusion in any project development contract.

(1) Requirement for a formal hazard recognition and control system.

(2) Requirement for formal committee review of new and modified facilities and equipment to assure that a safe posture exists prior to activation and that a system exists to maintain a safe posture for the active life of the facility or equipment.

(3) Program for certification of personnel whose activities require them to interface with MSFC hardware.

(4) Requirement for investigation of incidents involving personnel and property to determine causes and corrective action to prevent recurrence.

(5) Safety motivation plans including training and awareness.

(6) Requirement for a corporate policy on safety and the commitment of higher management to its implementation.

(7) Contractor's safety organization involvement in day-to-day activities.

For a prime contractor on a large project, the above would be the minimum requirements. For small projects, some may not be appropriate.

4.3.1.9.2 System Engineering Management. A system engineering function is needed on every development and operational project. The planned system engineering and integration activities for a project are normally described in a System Engineering Management Plan (SEMP) that is used in managing the system engineering functions. (A SEMP is normally not required for small, research type projects.) System engineering is responsible for ensuring the top project system requirements are ultimately met and the system performs as required. The system engineering functions are described in paragraph 4.3.2.

4.3.1.9.3 Subsystem Engineering Management. In addition to the overall system engineering management (as discussed above) the development of each subsystem must also be managed. As the system requirements are defined, the subsystem requirements must be flowed down from the system requirements. Subsystem examples include structures, thermal, propulsion, attitude control, electrical power, guidance and navigation, communications, and instrumentation. The project must ensure the subsystem risks are identified, risk management activities are properly executed, and the subsystem requirements are achieved within budget and schedule. This includes development of subsystem design documentation to support scheduled design reviews, and the planning and conducting subsystem fabrication and verification activities.

Analysis of the integration of the subsystem into the overall system must be done to ensure functional and physical compatibility. Subsystem technical issues must be evaluated for system level impacts and all issues must be resolved.

4.3.1.9.4 System Integration and Verification Management. The integration of components/subsystems and their verification at planned levels are critical to final system acceptance. The project must ensure that all assembly and integration activities and support are identified, planned, scheduled, and executed to support the overall project mission schedule.

The system level testing is the key activity that verifies, to the extent possible, in the Earth environment, that the total integrated system will fulfill its requirements and perform on-orbit as intended. The project must ensure testing facilities are developed and verified ready to support the project schedule. Identifying any special equipment required for test support must be accomplished early to ensure its availability. The project must ensure the development of all system level test procedures, conduction of Test Readiness Reviews (TRRs), and conduction of the tests and that the test data collected meets the success criteria as defined by the test requirements. After completion of system testing, the testing results must be documented in a test report.

4.3.1.9.5 Mission Operations. All mission operations preparations must be regarded as essential parts of project responsibility, but where activities are performed by other NASA Centers, the degree of control will be largely limited to the project requirements and budget.

Operations responsibilities, because of the unique institutional facilities, funding channels, and skills often involved, sometimes tend to be less subject to direct control than other facets of a project. The NASA has by intent a limited number of launch sites, a limited number of Operations Control Centers (OCCs), and only one Space Tracking and Data Network (STDN).

The assignment of a project to MSFC may or may not include directed use of specific operational facilities that are operated by other NASA Centers. The project assignment may or may not also include assignment or delegation of operations responsibilities (or portions thereof) to a NASA Center other than MSFC. Within the responsibilities given there may be further negotiations for use of the resources of other Centers, the operations functions may be contracted with development or other contractors, or the performance of operations functions may be contracted with other MSFC Directorate's resources and facilities.

The ultimate test of the flight article is its performance in space, and due attention must be given to ensure that the ground and mission operations are properly planned, prepared, and executed.

Operations execution is the carrying out of the required operations functions by the operations teams with the flight article(s). During this phase of operations activity, the operations team and flight article perform and enjoy the fruit of mission success. However, the operations team will be operating within project policy guidelines and criteria established. After consultation with technical expertise on any deviations from these criteria, project management must concur in major operations modification decisions (unless contingencies dictate immediate action). If design questions or problems occur during operations, resources of the design organizations in supporting the operations organization will be directed. The Project Manager will also normally serve as the information channel with higher management, and to control the information flow to Media Relations. While these parties will have legitimate communication needs with the operators, these communications must be managed to allow the operators to accomplish their tasks without distraction.

4.3.1.10 Project Security Engineering Management. Security plays a critical role in a successful program. Protection of the resources of the Agency, regardless of their form, must be provided.

System Security Management is an integral part of the Project Management function and involves the systematic review of a program, throughout its life cycle, to identify, qualify and quantify inherent vulnerabilities to the entire system. These vulnerabilities are then compared to known and forecasted threat models. This comparison allows the option of (1) addressing the vulnerability through the use of one or more of the protective disciplines or (2) assuming the vulnerability as a known, documentable risk. The option selected is based on constraints such as time, money, or technology. A systematic blend of this process with the S&MA process should result in total Mission Assurance.

MPD 2190.1 and MPG 2190.1 are the directives and guidelines that the Center employs to control the distribution and transfer of technical information and products. Assurance must be provided that any technical releases (including Web sites), transfers of technical information, and /or products are in compliance with the Agency and Center export control policies and procedures. The SMO is responsible for execution of the Center's export control activity (see 4.2.12.7).

4.3.2 System Engineering Functions. System engineering is as an engineering approach that systematically considers all aspects of a project in making design choices. More specifically, system engineering is the application of scientific and engineering efforts to:

(a) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and assure compatibility of all physical, functional, and program interfaces in a manner which optimizes the total system definition and design; and (c) integrate reliability, maintainability, safety, survivability, human aspects, and other such functions into the total engineering effort. System engineering as a methodology is applicable to all levels of a project, and to all levels of a design (i.e., system, subsystem, component). The success of complex space vehicles and space vehicle projects is highly dependent upon the system engineering process being properly exercised at all levels of design and management.

While the full system engineering process must involve the total project management and engineering organizations, certain key system engineering activities are essential. These key system engineering activities can be divided into six functional groups as depicted in Figure 11. Certain tasks tend to overlap in practice by the parallel and iterative time phasing of many tasks. Consideration of all aspects at the overall project system level and implementation of concurrent engineering are keys in accomplishing the system engineering functions. Concurrent engineering is the simultaneous consideration of product and process downstream requirements by multidisciplinary teams throughout the project life cycle from conception through implementation. Specialty engineers from all disciplines (reliability, maintainability, human factor, safety, logistics, etc.) whose expertise will eventually be represented in the product have important contributions throughout the system life cycle. The system engineer is responsible for ensuring that these personnel are part of the project team at each stage.

This section focuses on the functions of the system engineering activities, as implemented within MSFC and depicted in Figure 11. These same functions apply to the design activities of individual subsystems and components. System engineering consists of applying iterative processes throughout the life cycle of the project. The overall system engineering approach for the project is described in a SEMP developed as part of the system requirements development function. At the project system level, the function begins with an input (usually a requirement or group of requirements) and proceeds through a functional analysis of the requirements to decide what has to be

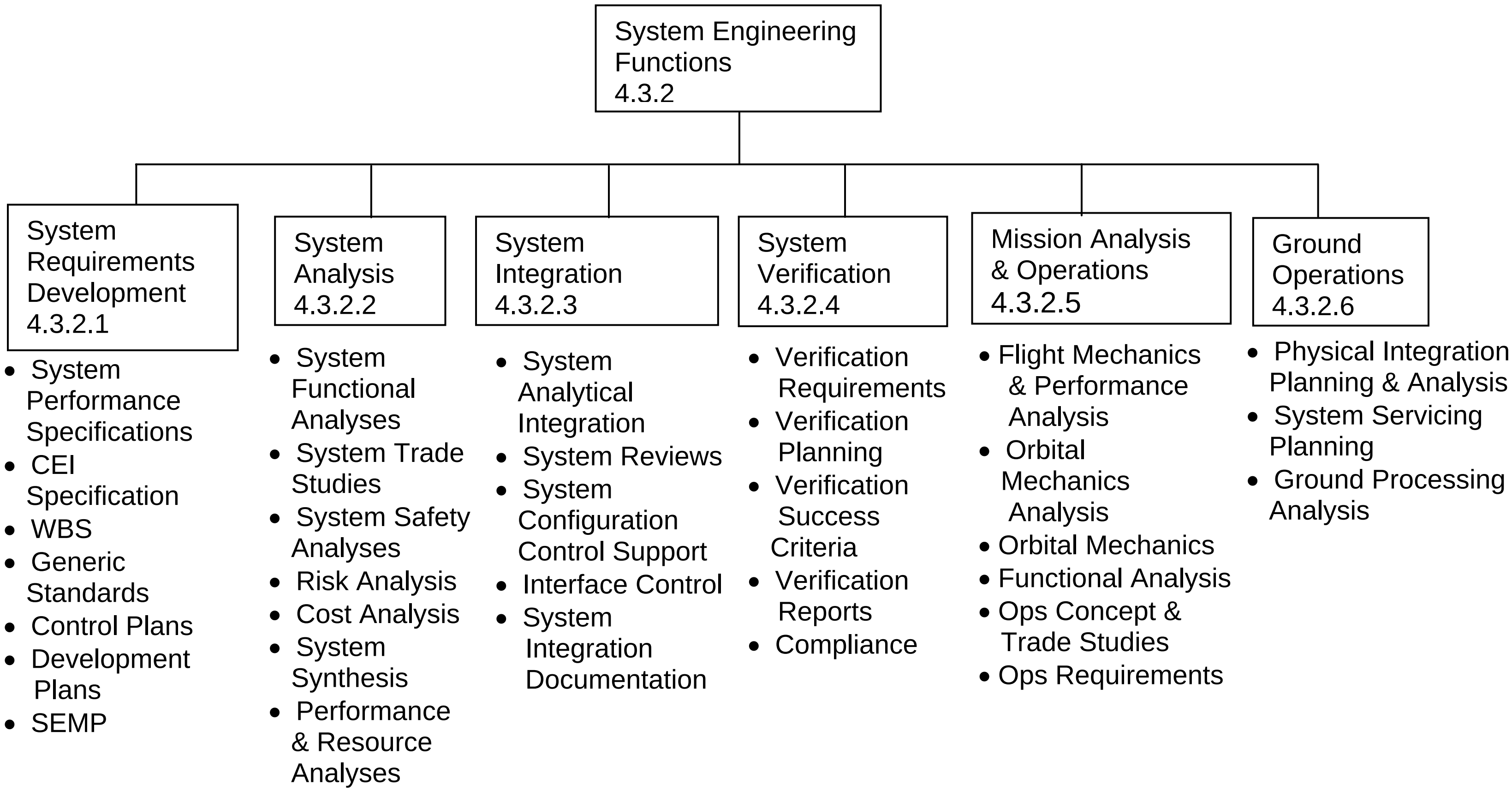


Figure 11. System Engineering Functional Task Breakdown

done to satisfy them. After deciding what must be done, a synthesis process of deciding how it is to be done (concept definition and preliminary design) is followed by a decision process of selecting among alternative solutions. The selected solution then is designed in detail, manufactured, verified and deployed to perform the mission or meet the original requirements (or the current version of the requirements). Throughout this series of activities there is a provision for looping back to any previous stage and applying new knowledge gained to the refinement of the results and products of those stages.

4.3.2.1 System Requirements Development. System requirements development encompasses the activities required to transform a customer need or mission need, as established in a top level Project Requirements Document or equivalent, into a comprehensive and definitive set of system performance requirements. These activities begin with the collection of project objectives and guidelines, and proceed, supported by system analyses, to define detailed performance requirements, a preferred system configuration, and technical standards to be used for the project. Typical products of the system requirements activity include:

- System Engineering Management Plan (SEMP)
- System Requirements Document
- System Specification
- Interface Requirements Documents (IRDs)
- Software Requirements Documents
- End Item Specifications
- Requirements Flow-down and Traceability
- Project WBS
- Design Reference Mission (DRM)
- Logistics Support Requirements
- Control Plans (Mass Properties, Contamination, Configuration Management)

The System Requirements Document and the System Specification contain the system level functional requirements and the design and performance specifications. The process flow for developing a System Requirements Document or a System Specification is shown in Figure 12. Figure 13 illustrates the software functional requirements process flow.

Application of technical standards to a system design consists of selecting and applying the requirements detailed in specifications and standards necessary for achieving the optimum design, fabrication, and performance of the system or equipment. Standards must be adequate to ensure safety, performance, reliability, and maintainability. Individual provisions of a technical standard may be tailored (i.e., modified or deleted) by contract or program specifications to meet specific program/project needs and constraints. Compatibility of form, fit, and function, or assessment of comparability of essential information must be ensured. The NASA Preferred Technical Standards should be considered. The NASA Preferred Technical Standards are composed of

NASA-developed standards, other Government (non-NASA) standards, and non-Government standards that have been adopted or are pending adoption. While these standards are "preferred", or endorsed by the Agency, they are not mandatory for use on NASA programs/projects except ~~for~~ when designated in selected areas (e.g., safety, environmental). Limitations to standards may be stated in the project requirements documents. Refer to NPD 8070.6, *Technical Standards*. Access to NASA Preferred Technical Standards may be found at http://standards.nasa.gov/.

4.3.2.2 System Analyses. System analyses are activities that support both the definition of system requirements and the conduct of system integration. System analysis accepts project objectives and provides system concepts, trade studies, performance analysis, cost analysis, and other analyses necessary to define a preferred system configuration and to assess the performance characteristics of the system as it proceeds through formulation and implementation.

The system analyses activity maintains a close working relationship with the engineering discipline centers of expertise residing in the design organizations. This working relationship is essential for the transfer of practical state-of-the-art knowledge into the system engineering process, and to ensure validity of analyses performed. System analyses cover a broad spectrum of objectives and products. The following paragraphs synopsize typical system analyses.

4.3.2.2.1 System Functional Analyses. System functional analyses are performed in support of system requirements definition and to assess system capabilities to perform their mission and satisfy project requirements. These analyses analytically confirm design performance in their application. Key analyses common to many projects are described in the following paragraphs.

4.3.2.2.1.1 Functional Decomposition Analyses. Functional decomposition is performed to determine what the system should do from a functional standpoint before development of requirements or design of the system is begun. Functional decomposition begins by defining the top-level functions the system must perform. These functions have a direct influence on the system's design and are described in more detail by taking each top level function and decomposing it to increasingly lower levels until an appropriate level is obtained that defines a functional mission. The functional decomposition represents what an operational system should do and the system level of performance.

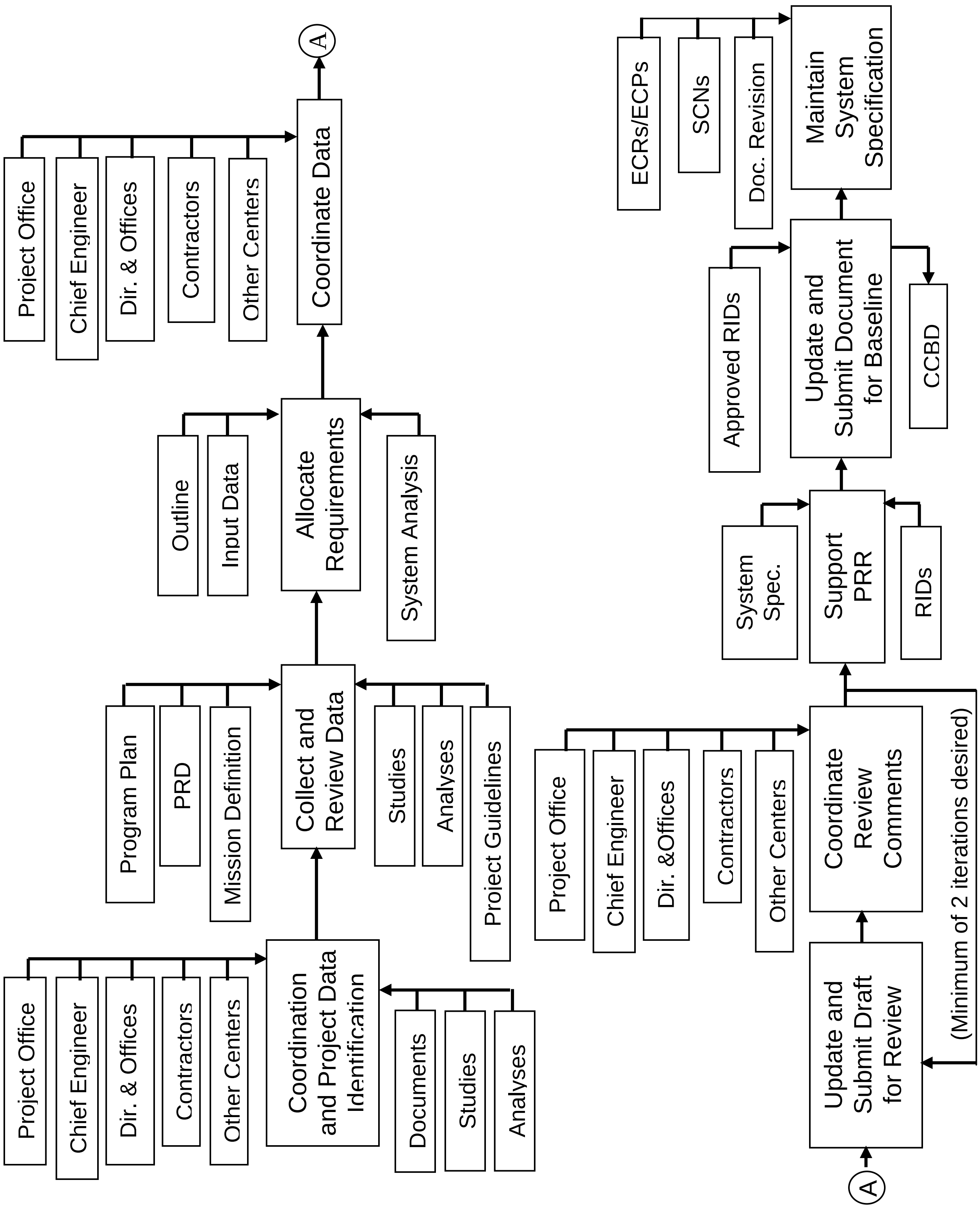


Figure 12. System Requirements Development Flow

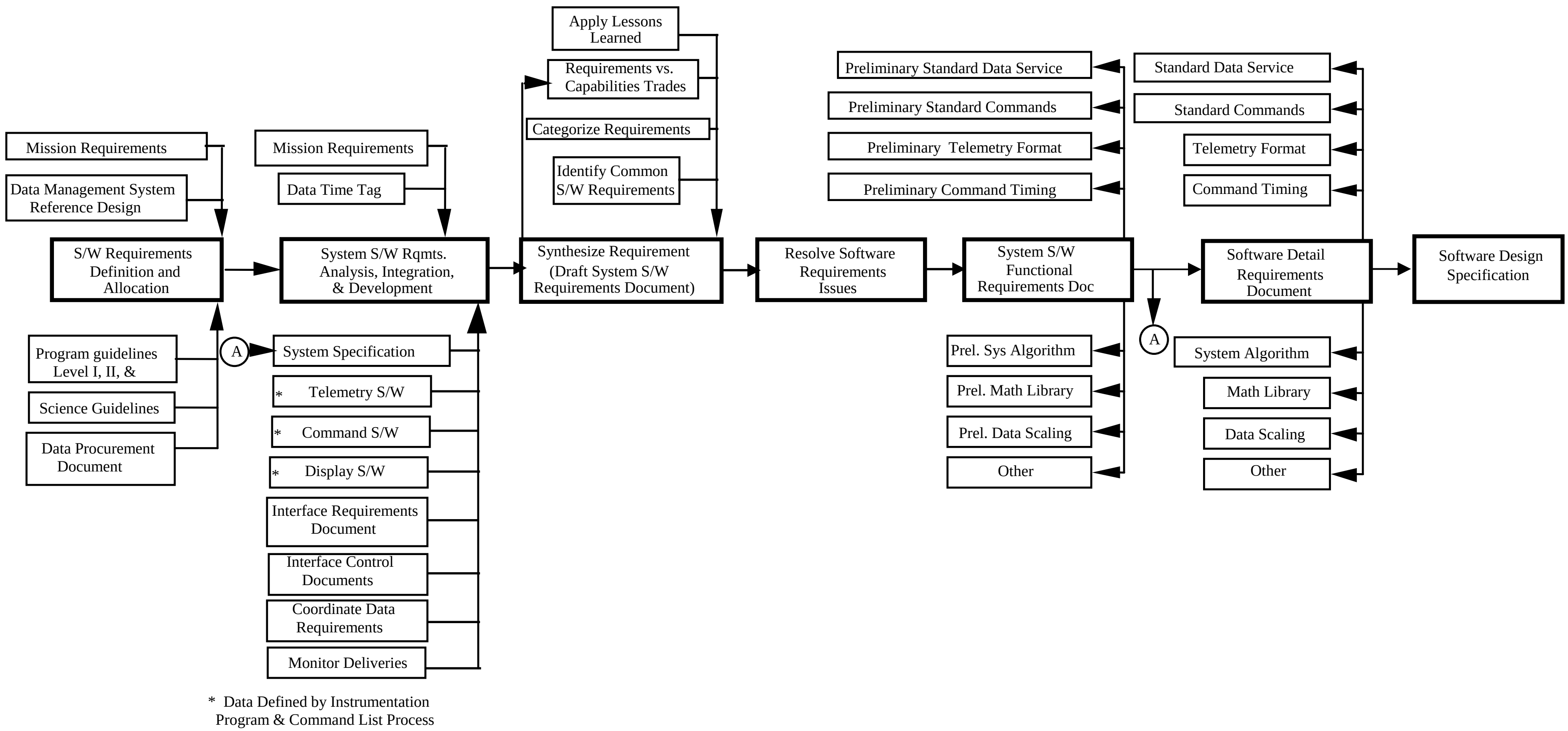


Figure 13. System Software Functional Requirements Process Flow

4.3.2.2.1.2 System Layout and Sizing. Through coordination with the design organizations, the various subsystem designs are integrated into a total system layout. This system layout is done within allowable system envelopes. These layouts are iterated with the design organization as the subsystem designs mature. This iteration process supports optimization of the designs for sizing to meet maximum allowable envelopes, for providing any required operational envelopes, for providing accessibility for maintenance, and for providing proper interfaces between subsystems.

4.3.2.2.1.3 Natural Environment Definition Analyses. Natural environment definition analyses include both space and terrestrial environments. These analyses support the definition of the natural environment requirements for the system. For a particular mission, each natural space environment is defined using specific mission characteristics as inputs to the natural space environment analysis. The natural space environment includes: gravitational field, ionizing radiation, magnetic field, meteoroids/space debris, neutral thermosphere, plasma, solar environment and thermal environment.

The natural terrestrial environment includes near surface, ascent, and descent environmental definitions such as: atmospheric constituents (gasses, sand, dust, sea salt), atmospheric electricity, sea states, severe weather, near-surface thermal radiation, temperature, pressure, density and winds, and wind shear. These analyses require the manipulation of computer model and databases particular to space environment and terrestrial environment. The results of these analyses are documented in a natural space environment definition and requirements document and a natural terrestrial environment definition and requirements document.

4.3.2.2.1.4 Human Engineering Analyses. Human engineering analyses are performed to define applicable human factor requirements to support the development of system requirements and to assess the capability of the design to satisfy the human factor requirements. These analyses include man-system integration associated with both ground operations and on-orbit operations of the system.

4.3.2.2.1.5 Life Support and Environmental Control Analyses. Life support and environmental control analyses are performed for manned systems requiring an environment to sustain life. These analyses support the definition of system requirements and assess the system design for meeting the requirements.

4.3.2.2.1.6 Functional Instrumentation and Command Analyses. Functional instrumentation and command analyses are performed to support the development of the Instrumentation Program and Command List (IPCL) and assess the capability of the system design to provide the defined instrumentation and commands. All telemetry and command data that enter and exit the system are compiled and the resource utilization of communication and telemetry subsystems are determined.

4.3.2.2.1.7 Electromagnetic Compatibility/Electromagnetic Interference Analyses. Electromagnetic Compatibility (EMC) /Electromagnetic Interference (EMI) analyses are performed to predict system-level performance based on equipment-level EMC test data. Conducted emissions/susceptibilities and turn-on transients are examined and margins are determined.

4.3.2.2.1.8 Spacecraft Charging Analyses. Spacecraft charging analyses are assessments of a spacecraft's ability to cope with the electrical charge build up resulting from exposure to the ionizing radiation of space. These analyses combine the space environment the spacecraft is predicted to encounter with the materials and protective coating characteristics of the spacecraft, and combined with the conductive paths within the spacecraft. These analyses may result in a choice of different materials or protective coating for the spacecraft.

4.3.2.2.1.9 Induced Environments Analyses. Induced environments analyses are performed to determine the thermal, pressure, structural loads, vibration, acoustics and shock environments to which the system is exposed during launch, on-orbit operations and landing as applicable. These induced environments analyses support the definition of the system requirements, and provide inputs to establishing induced test criteria.

4.3.2.2.1.10 Lightning Protection Analyses. Lightning protection analyses are performed to determine the effects on the system electrical circuits if a lightning strike occurs. Both direct and indirect strike effects are examined. These analyses assess the system design to ensure proper lightning protection.

4.3.2.2.1.11 Contamination Control Analyses. Contamination control analyses are performed to determine and identify contamination sensitive areas that influence the system design, to define contamination control requirements and to assess the system design for providing control to meet the contamination requirements.

4.3.2.2.1.12 Structural/Coupled Loads Analyses. Structural/coupled loads analyses are performed to examine the loads supported by the structure and the forces applied to the system, especially during phases where there are induced loads.

4.3.2.2.1.13 System Communication Analyses. System communication analyses include RF link margin analysis, flux density analysis, Tracking and Data Relay Satellite System (TDRSS) coverage analysis and communication requirements analysis. The link margin analysis supports the system design of a data link and examines the link margin to ensure that the link will maintain signal fidelity and synchronization. The link margin permits the establishment of the feasibility and suitability of a desired communication link before proceeding with design and development. The flux density analysis assesses the TDRSS return service special Power Flux Density (PFD) generated at the surface of the Earth by the user system to ensure conformance with established limits. The TDRSS coverage analysis determines the line of sight access to TDRSS in terms of orbit access time. The communications requirements analysis supports the development of the system requirements. This analysis examines the mission and functions the project will perform, the objectives of the project and other support required. Communication needs to support the mission functions and objectives are defined.

System communication analyses also support the supplying of RF requirements, and planning information to the NTIA for applying for approval and licensing of the proper RF allocations by the NTIA. (The NTIA requires that projects submit information and applications for licensing in four stages (see 4.1.1.2.)

4.3.2.2.1.14 Attitude Control Analyses. Attitude control is required on any launch vehicle, spacecraft, or experiments that require that stabilization of attitude as part of their mission. Attitude control analyses, associated with the design and assessments of the system**,** require knowledge of and combination of the system's mass properties, structural dynamics, attitude measuring, system disturbances, and control forces of the system. The effects of local dynamics and/or vibrations must be considered in attitude control analyses.

4.3.2.2.1.15 Dynamic Analyses. System structural dynamics analyses are required for ensuring understanding of the interactions of the system under dynamic conditions. Structural dynamics information is used as an input in attitude analyses as well as determining system integrity under loads. Tether dynamic stability analyses are also performed for projects utilizing tethers.

4.3.2.2.1.16 Guidance and Navigation Analyses. The normal missions of launch vehicles and spacecraft require that certain orbits be obtained. The ability of a system to be inserted in those orbits requires a navigation system to be aware of where it is with respect to a reference, and what actions the system requires to obtain the desired position. These analyses associated with designing and assessing the ability of a system to successfully achieve guidance and navigation require combining the characteristics of the navigation sensors, the system propulsion characteristics, and the attitude control system.

4.3.2.2.1.17 Supportability Analyses. Supportability analyses provide an assessment of a system's reliability, availability of components, parts and/or materials that may be required for maintaining the system, maintainability (the ability of the system to be maintained), and logistics requirements and planning. Supportability analyses ensure that sufficient spares (flight hardware and GSE) are available to support a given system throughout the system's operational life. The sparing philosophy results in an optimum mix of Line Replaceable Units (LRUs), shop replaceable units, Orbital Replaceable Units (ORUs) and piece parts.

4.3.2.2.2 Trade Studies. Trade studies are used to compare a number of options. Weighted factors trade studies are performed when each of the options under consideration is well defined and there is good definition of what is important to a specific project. Factors that are important are identified and a weighted factor is assigned to each. A determination is then made as to how well each of the options meets each of the factors.

Finally, the weights are taken into account, the scores are totaled and the selection is based on the final score.

Advantages/disadvantages is one type of trade study used when there is not much information about the options under consideration, or it is difficult to quantify how well each option satisfies the criteria selected. In this study, each option is evaluated, identifying the advantages and disadvantages of each. The results are then presented for a subjective decision, based on the information available, as to which option is selected.

4.3.2.2.3 System Safety Analyses. System safety analyses activities are an integral part of the system analyses efforts. Close coordination between system safety engineering personnel and system engineering personnel is required to assure timely, effective design solutions that eliminate or properly control hazards. The S&MA and other Center engineering organizations provide supporting technical rationale to aid the Project Manager in the assessment of residual hazards for safety risk acceptance decisions. Key system safety analyses are system hazard analyses and the FMEA/CIL.

4.3.2.2.4 Risk Analyses. Risk analyses are the processes of describing and quantifying the risks that a developing system may encounter and developing alternatives for mitigating or eliminating those risks. Cause, effect, and magnitude of the risk are key outputs of these processes, and these can be documented and tracked through a mitigation plan and a "watch list." These analyses identify the risks, their consequences, the warning signs or events that will trigger the risk, and risk handling steps. The "watch list" must be continually reviewed and revised during the project life cycle. Risk assessments are conducted continuously to identify the risks to a project due to technology considerations (i.e., new technology, new designs, materials, processes, operating environments), availability of vendors, failure modes, schedule optimism, margin allocation, and requirement stringency. Risk assessments are also necessary to identify any potential risks that arise as a result of design implementation and to incorporate risk mitigation. In the case of technical standards, changes to standards can have major impacts on the safety, performance, reliability, and cost of the program/project. Therefore, the Standards Update Notification System (SUNS) is in place to mitigate risks by providing notification as requested by the program/project when standards products change.

4.3.2.2.5 Cost Analyses. Costs are estimated during the formulation phase of a project. Cost and performance monitoring and tracking is continuous through the implementation phase. The cost estimating activity can be performed with varying degrees of resolution and accuracy depending on the fidelity of the project definition. For example, a cost estimate can be generated using only the estimated weight of the completed system. Other parameters that define the system such as computing requirements, mass storage, and similarity to past projects, etc. can also be used by the cost estimating software. As more information (such as percent new design, performance characteristics, schedules, and better definition of the system) is generated, the cost estimates are refined. Cost analyses are highly iterative processes, and are continuous throughout the project life cycle.

4.3.2.2.6 System Synthesis. System synthesis is conducted for all candidate systems to identify the preferred system configuration and feasible performance characteristics. Using knowledge of available technology and feasible subsystems, candidate systems are hypothesized and analytically tested against project requirements. Trade studies are performed to optimize the preferred system configuration and to resolve problems.

4.3.2.2.7 Performance and Resource Analyses. Performance and resource analyses support system synthesis, as well as system requirements and system integration functions after the system configuration is baselined. Products of these analyses will include not only performance predictions but also resource budget allocations among system elements. Key analyses are described in the following paragraphs.

4.3.2.2.7.1 System Thermal Analyses. System thermal analyses are performed to support the definition of system requirements and to determine the capability of the thermal control subsystem to meet the requirements. The system thermal analyses may also provide verification compliance of the thermal control requirements and are utilized to support thermal vacuum testing criteria.

4.3.2.2.7.2 Electrical Power Analyses. The electrical power analyses are performed to assess the system electrical power generation, storage, and utilization to determine if adequate power and energy margins exist to support system operations. The electrical power analyses include solar array analysis, voltage drop analysis, fault/fusing analysis and system grounding analysis. In general, normal and worse case subsystem/system interface conditions (voltage, current and power) are used to evaluate the design for proper performance and compatibility. A grounding analysis assures that the grounding configuration of all the elements of the system is consistent with design and performance specifications.

4.3.2.2.7.3 Mass Properties Analyses. Mass properties analyses are performed on all elements of a flight system to ensure allocated masses are maintained. The total weight of the flight system as specified in the project requirements is allocated to lower management level subsystems and piece parts with a reserve maintained. The mass properties analyses are repetitive activities that occur throughout formulation and implementation. The allocated weights and reserve are used to begin the mass properties process. As subsystems and piece parts are developed and fabricated, actual weights are included in the analyses to refine the results. Maintaining a comprehensive mass properties database allows the Project Manager and SLE to revise allocations as subsystems and piece part designs mature. The mass properties analyses continue until the flight system is developed and a measure of total mass is performed.

4.3.2.2.7.4 Onboard Computer Timing and Memory Utilization Analyses. The onboard computer timing is a critical factor to ensure that onboard events that are controlled by the computer are properly implemented. Computer task analyses are conducted to ensure that the timing of events and the stack up of computer processing tasks satisfies the event timing requirements and can be properly processed by the onboard computer. Computer memory utilization is also analyzed to ensure that adequate memory is available throughout the implementation phase to allow for growth and implementation of computer program changes that may be required as a result of testing.

4.3.2.2.7.5 Attitude Control Propellant/Momentum Analyses. Attitude control propellant and/or momentum utilization analyses are conducted to ensure that the available, or budgeted, attitude control propellant or control moment gyro momentum is adequate to perform the mission of the system. Analysis integrates the mission operations attitude requirements with other factors that may require propellant usage (misalignments, contingencies, mission ground rules) to determine the adequacy of the system performance.

4.3.2.2.7.6 Pointing and Alignment Error Analyses. The pointing and alignment error analyses are performed to identify sources for error in the system performance and attempts to conservatively quantify the effects of each. Statistical or other methods are used to model how individual (subsystem) errors are combined into total (system) errors.

4.3.2.2.7.7 Propulsion System Performance Analyses. Propulsion system performance analyses are the assessments required to ensure that the operation of the propulsion system is adequate in terms of efficiency (thrust and specific impulse) and quality and quantity of propellant. The analyses combine the engines/thruster characteristics with the volume, temperature, and pressure of the propellants to predict mission performance. Propellant allowances for flight dispersions, loading uncertainties, and any other contingencies are also estimated and analyzed. Post flight analyses are also performed to compare predictions with flight data, and to account for any differences.

4.3.2.2.7.8 Data Management Analyses. The data management analyses are performed to assess the IPCL database against a mission scenario to determine the real time and data storage requirements. These analyses provide assurance that adequate measurement and command data handling capability exists.

4.3.2.2.7.9 Orbital and Flight Mechanics Analyses. Orbital and flight mechanics analyses are performed for mission planning purposes. These analyses not only define the orbit parameters required to perform the desired mission, but are also used to predict orbital lifetimes. These analyses also support mission timelines and define orbit pointing and attitude control requirements. Thermal analyses also utilize the results of orbital attitude analyses for generating sun angles, eclipses, and exposure times.

4.3.2.2.7.10 Materials Analyses. Materials analyses are performed to provide support in the areas of materials selection for the system (including ensuring non-toxic material use for manned systems) and contamination avoidance. The materials analyses also include assessments of the system design to ensure the use of approved materials.

4.3.2.2.8 Orbital Debris Analyses. For flight systems that have the potential to create orbital debris, orbital debris analyses are developed in accordance with the requirements of NPD 8710.3, *NASA Policy for Limiting Orbital Debris Generation.*

4.3.2.3 System Integration. System engineering must ensure the elements of a system are properly integrated, both physically and functionally. The system engineering activities supporting system integration are described in the following sub-paragraphs.

4.3.2.3.1 System Analytical Integration. System analytical integration is performed by analyses to ensure that the various segments and elements of the total system are in accordance with requirements and specifications, operate together, and interface with the external environment as expected. This effort is primarily directed at identification of interfaces and an accompanying analytical assessment that considers all elements of a airborne support system (e.g., spacecraft, payload, launch vehicle, ground systems, equipment, TDRSS, flight planning and operations, and mission objectives) for compatibility and compliance with interface requirements. The system analytical integration process encompasses all elements associated with the given project and begins with the interface definitions arising from the design concept. The system analytical integration tasks typically involve a high level of penetration of the products of other organizations and, in the case of contracted projects, are an important mechanism by which the project evaluates contractor performance.

The analytical integration function not only occurs between elements, but also internal to the elements. This latter process is known as design integration and is defined as the action(s) taken to ensure the various subsystems and components of a given system meet and operate together as required and expected. Design integration in any given element can occur independently of other elements. The principal function of design integration is to support the system integration requirements in the generation and documentation of ICDs, mass properties, reports, configuration layout drawings, thermal budgeting and analyses, and electrical power reporting and assessments.

As part of the system analytical integration function, conducting design reviews and ensuring that the design is compatible with requirements are important tasks to be accomplished prior to drawings release.

4.3.2.3.1.1 Interface Analyses. Interface analyses are performed to determine and identify where hardware and/or software elements must interact at a common boundary. These analyses identify the physical and functional characteristics that must exist at all of the interfaces to facilitate the fit and function compatibility of all hardware and/or software elements. The interface analyses also assess the system design to ensure the interfaces (internal and external) are compatible with the applicable interface requirements.

4.3.2.3.1.2 System Simulations. System simulations are performed to verify the designs and the accuracy of the models used in the design analyses. The simulations are performed especially when critical technology is involved. The system simulations are performed through the use of computer software and/or simulators. System software simulations are performed to assess and verify the system design. Software models of the end-to-end system design are developed and operated in a simulated mission scenario to determine the system design capability to meet system requirements. Software models of subsystem design may also be developed to operate as an electrical simulator with other subsystem hardware items, simulating the electrical interface.

Simulators are also breadboard operational pieces of hardware that are in their various operational and off-nominal modes. This could be a breadboard of a subsystem or-system and may include flight hardware/software elements. The breadboard is maintained current with the design and models as they are refined. A mockup to scale and/or three-dimensional models are used to verify hardware layouts, interface fits, and tolerances.

Mission operations simulations are performed to exercise and validate system operational capability, verify interfaces, demonstrate overall system readiness, and provide operational system training. Operational simulation capabilities are developed concurrent with design. The operations requirements and models are refined as system design progresses. Operations mockups are used to verify the man-system interface.

4.3.2.3.2 System Reviews. System engineering participation in reviewing the total system is imperative. Participation in the PRR ensures that the project requirements have been thoroughly defined, clearly documented, and will be verifiable upon implementation completion. System engineering participation in the SRR confirms that the requirements and allocations contained within the system specification are sufficient to meet the project objectives, and that sufficient planning to implement the project has been or is scheduled to be performed. System engineering involvement in the PDR ensures that the preliminary design meets system requirements with acceptable risks, and that all interfaces and verification methodologies have been identified. System engineering involvement in the CDR confirms that the system design has properly progressed from the preliminary design and detail is sufficient to allow for orderly hardware/software fabrication, integration and testing with acceptable risks. Similarly, system engineering participation in the Ground Operations Review (GOR), Flight Operations Review (FOR), DCR, and all other project reviews ensures that the system implementation will meet the system objectives and be ready to perform the mission in an orderly fashion.

4.3.2.3.3 System Configuration Control Support. Once requirements have been established and a system configuration has been defined, an important function of the system engineer is support to managing any change to the requirements and system design. System engineering support consists of performing system assessments of any proposed changes, determining any impacts of the proposed change, and making recommendations based on analysis of the overall effect of the proposed changes. This activity may involve acting as the Change Package Engineer on engineering change requests or providing technical approval on drawing packages

4.3.2.3.4 Interface Control. Interface control is the process that ensures compatible physical and functional characteristics of hardware elements or software modules where they interact at a common boundary. The process identifies the characteristics of an item during its life cycle, controls changes to those characteristics and provides information on the status of change actions. The control process can be applied to any element of a hierarchy from piece parts to system level or from software subroutines to an operating system. Generally, the process consists of system engineering and formal configuration management practices such as: interface identification, interface requirements development and baseline, interface control documentation development and baseline and configuration audits to compare the configuration of the as-built product with the interface design solutions controlled by the ICDs. Interface control provides a means of identifying, presenting and resolving incompatibilities and determining the interface impact of design changes. Once an ICD is baselined, the parties on both sides of the interface are bound by the interface design contained in the ICD. Should it be determined that a change is required for the equipment to operate properly, a change package must be prepared. The change package is processed by the appropriate CCB to assess resulting impacts and ensure that interface compatibility is maintained.

4.3.2.3.5 System Integration Documentation. System integration documentation is the documentation developed to describe the project system and provides the necessary information to ensure system physical and functional performance when integrated with other systems. System integration documentation developed includes system functional schematics and interconnect diagrams. The system schematics provide end-to-end functional definition of electrical and fluid subsystems for analysis and troubleshooting. The system interconnect diagrams graphically depict the arrangement of external plumbing/electrical cabling which connects assemblies and equipment. System engineering is involved in both the generation of and utilization of the diagrams in analyzing a system to understand and resolve system integration problems that occur.

Projects that utilize the NSTS for their mission, or that will be integrated into the ISS are required to submit certain project information. The NSTS utilizes a Payload Integration Plan (PIP) to document the project's pertinent system information. The ISS utilizes an electronic database, the Payload Data Library (PDL), to gather the pertinent integration information required by the ISS. System engineering oversees the generation of and ensures the accuracy of the integration documentation such as the inputs to the PIP and the PDL.

4.3.2.4 System Verification. Verification is a process in which defined activities are accomplished in a manner that will ensure that a product (e.g. vehicle, payload, software, GSE, etc.) meets its design input requirements (i.e. safety, performance, interface, etc.) and that the product is ready for a particular use, function, or mission. The basis for the verification process is the product's requirements. No verification program can be developed without a set of requirements. Once the product's requirements are established, a thorough verification program can be developed based on the establishment of (1) verification requirements, (2) verification planning, (3) verification success criteria, (4) verification reports, and (5) verification compliance, which is discussed in subsequent paragraphs. The information outlined in the following paragraphs has been historically captured and communicated via documents (e.g. Verification Plan, Verification Requirements and Specification Document (VRSD), Verification Compliance Document). However, in recent years the development and use of electronic databases (e.g., Requirements, Verification and Compliance (RVC) Database) has provided system engineering with a more effective and efficient tool for development and communicating the verification program. Using either media, documents or electronic databases, the emphasis should be on the content contained within the verification program and not so much the format.

4.3.2.4.1 Verification Requirements. The verification requirements identify "what" is required to satisfy each of the design input requirements. The content of the verification requirements identifies (1) the verification method (e.g., test, analysis, inspection, demonstration, validation of records, similarity), (2) the verification level (e.g., component, subsystem, or system), and (3) the verification phase (e.g., qualification, acceptance). A comprehensive review of all design input requirements is required as well as close coordination with technical design disciplines to reach an agreement on the methods, levels, and phases to ensure compliance with requirements. The verification requirements will be established and maintained along with the design input requirements that are normally contained in a specification document and placed under change control following the SRR. The verification requirements become the basis for developing the verification planning information.

4.3.2.4.2 Verification Planning. Verification planning begins in the early phases of the program/project with the objective of providing an in-depth discussion and visibility into each of the planned activities for the identified verification requirements. Additionally, the verification planning information will outline the verification approach and organizational structure for implementing the verification program. The content of the verification approach and organizational structure will include information such as the following:

- Protoflight program vs. qualification/acceptance program,
- Spares verification,
- Refurbishment verification,
- Re-flight verification,

- Mockup hardware usage,
- A description of the verification facilities, GSE, software necessary to execute the verification activities,
- A time correlated sequence of verification activities, and
- The compliance data review and approval process.

All of this verification planning information is documented (e.g., Verification Plan, RVC Database), made available for review during SRR, PDR, and CDR, and placed under configuration control by the project following CDR.

4.3.2.4.3 Verification Success Criteria. The verification success criteria provide the detail/specific criteria that determine successful accomplishment for the identified verification planning activities. The content of the verification success criteria includes information such as performance criteria, environmental test limits, verification constraints, mandatory inspection points, hardware effectivity, and verification location. The verification success criteria is documented (e.g., VRSD, RVC Database), made available for review during PDR and CDR, and placed under configuration control by the project prior to beginning of the verification activities.

4.3.2.4.4 Verification Reports. Verification reports (i.e., Compliance Data) record the results of verification activities (e.g. as-run test procedure, analysis report, inspection report, test deviation). These reports provide the evidence that the product, via the verification activity, meets the requirements. The content of the verification reports includes information such as specific results, conclusions, recommendations, deviations, waivers, graphs, plots, pictures, etc. These reports are records of compliance and are maintained by the project.

4.3.2.4.5 Verification Compliance. The process of verification compliance involves the evaluation, tracking, and statusing of submitted verification reports against the design input requirements. As verification reports are submitted by the initiator (i.e., Compliance Data Contact), the reports are routed through the compliance data review and approval process established in the verification planning information. Compliance is established when the submitted verification reports certify the adequacy of the method used in the verification process, and the verification result is compliant with requirements and criteria. The verification process is completed when compliance to all verification requirements defined by the flow down of Level I requirements to Level IV is documented.

4.3.2.5 Mission Analyses and Operations.

4.3.2.5.1 Mission Analyses. Mission analyses are the system engineering disciplines that develop, analyze and document mission requirements leading to the definition of the most effective and efficient methods of satisfying mission objectives. Mission analyses may be defined as the process of translating the high level project requirements (Level I and II) into a carefully analyzed, detailed mission profile. The activities required to perform mission analyses are divided into three separate analyses as discussed in the following paragraphs:

a. Mission Requirements Analyses are the orderly transformation of mission objectives into detailed mission requirements. This effort includes the identification, interaction, and documentation of overall mission objectives, the breakdown of objectives into detailed mission requirements, the analyses of those requirements, and finally, the development of finely detailed mission requirements and their allocation to individual mission operation system elements. These steps are summarized as follows:

1) Delineate the overall mission objectives.
2) Translate mission objectives into requirements.
3) Analyze and expound mission requirements.
4) Allocate the mission requirements and input to the overall requirement allocation process.

b. Mission Planning and Profile Generation Analyses are the activities accomplished to analyze mission objectives, define system capabilities, and generate a mission profile that maximizes the achievement of mission objectives within hardware, software and mission constraints. Detailed mission requirements provide an input to this activity. The output of this process will be a preliminary mission profile or a detailed DRM. The processes for mission planning and profile generation analyses are as follows:

1) Perform mission/system assessment
   (a) Trade studies – Mission objectives vs. system capabilities
   (b) Define target conditions, data return, and other parameters

2) Conduct preliminary hardware/software assessment
   (a) Launch vehicle size/weight
   (b) Propulsion, guidance, and navigation subsystems

3) Develop trajectory design
   (a) Trajectory analyses
   (b) Guidance, navigation, and maneuver analyses
   (c) Optimization analyses
   (d) Range safety and reentry impact analyses
   (e) Tracking/telemetry coverage study
   (f) Performance capability analyses

4) Generate mission profile and input to the system design processes and the flight operations processes.
   (a) Mission timeline design
   (b) Launch window

(c) Trajectory event profile
(d) Ground track generation

The mission of the end item system under study is more clearly defined during project formulation, but still not baselined. The purpose of defining the mission more clearly is to develop performance targets for the design team. Baselining does not occur at this point because there may still be multiple concepts under consideration. Once a single concept is selected, during late formulation and early implementation, the mission will be baselined.

c. Mission Performance Analyses assess the capabilities of the system design to satisfy mission requirements. These analyses define and prioritize specific mission performance parameters and perform feasibility trade studies to determine and evaluate performance versus cost and risk. The scope of this activity can range from straightforward parametric studies to sophisticated system simulation models. The steps in this process are described below:

1) Interpret mission requirements into a set of measurable performance parameters,

2) Identify system design features that affect mission performance,
3) Assess mission performance of system design,

4) Determine sensitivities of mission performance parameters to selected system design parameters and operational constraints,

5) Iterate, process, and provide feedback as design and operations concepts evolve.

4.3.2.5.2 Mission Operations. Mission operations activities permeate system organizational boundaries. The results of mission operations trade studies and analysis can have a significant impact upon system hardware and software design. Throughout the system developmental process, from pre-proposal studies through final delivery, mission operations is directly involved in system design, development and decision-making activities. This involvement is critically important during the early phases of system development when the basic structure of the system is being defined and the initial system documentation is drafted. Even though actual system operations may be years in the future, the operational concept must be established as early as possible to ensure that system development is based upon valid and comprehensive operations scenarios. This operations concept is maintained as a living document to grow and mature as the total project follows its development course.

The system engineering contribution to mission operations during the flight covers the following tasks:

- Providing flight hardware system expertise.
- Monitoring the health of the hardware and software.
- Monitoring the engineering performance of the system.
- Performing the ground analysis/calibration for subsequent uplink.
- Responding to anomalies that affect system performance.
- Coordinate software patches for anomaly correction.
- Providing status information to/from the science operations leads and management as appropriate.
- Generation of the Flight Data Files (FDFs)

4.3.2.5.2.1 Design Reference Mission. During the late formulation and early implementation phase, the study team assembles numerous DRMs. The project office chooses the DRMs that have the greatest impact upon the design and performance specifications of the flight article. The DRMs are realistic missions (i.e., not three-sigma excursions). They are determined by cognizant authority (project management) in concert with the user community, usually through a Preliminary Requirements Specification Document (PRSD). These DRMs allow the designers to satisfy the mission objectives with the concepts under active consideration. The shortcomings of the individual concepts are identified and reevaluation must take place. The concepts have to be augmented to satisfy the objectives, or the objectives must be re-scoped, changed, or eliminated completely. The DRMs are also used to place bounds on the anticipated mission drivers for each subsystem.

Early in a project, specific missions may not be finalized. To allow the design process to proceed, a series of DRMs will bound the various performance requirements. As the project matures and specific missions are baselined, the DRMs are phased out, and FDFs are eventually generated to define the final mission.

4.3.2.5.2.2 Operations Planning. Operations planning is a critical function that defines the functional requirements for operations, defines and baselines the interfaces between operations facilities and the flight system, and defines the resource and schedule required to prepare and execute the operations. Operations planning must be conducted as a joint activity between the organizational elements of the project responsible for system engineering and for operations implementation (preparation and execution), with final approval by the Project Manager. The specific analysis tasks and products required will be project-dependent, as will the division of responsibilities for producing those products. The following types of products will be generated:

- Operations Functional Requirements
- Mission Operations Facility Requirements
- Interface Definition
- Project Operations Plan
- Engineering Support Plans

- NSTS and ISS Required Integration Documentation
- Mission Timeline
- Operations Concepts
- Operations Sequence Diagrams
- Software specification requirements for Flight Operations and Ground Control
- Training Assessments/Training Plans
- Mockup Definition
- Human Factors Analysis
- Mission Flight Rules
- Crew Procedures
- Crew Training Materials
- Crew Aids Definition (for manned flight programs)
- Ground Support Staff Definition and Requirements
- Ground Operator Workstation Definition
- Launch Commit Criteria

4.3.2.6 Ground Operations. Ground operations planning begins in the mid formulation phase to define the functional requirements for GSE and ground operations activities, to define and document the GSE to flight interfaces, to define and document handling and transportation requirements, and to define the support requirements for pre-launch and launch operations, including servicing and maintenance. If the flight system is to be returned to Earth in a controlled manner after flight, ground operations planning must include assessment and definition of the inverse process for flight system de-integration and handling and transporting to a designated site.

Ground operations planning and analyses continue into the implementation phase with some activities being performed late into the implementation phase. The interfaces between GSE systems and GSE and the flight system are defined and documented. The interface requirements are defined. Physical integration analyses of the interfaces and assessments of interface requirements are performed to ensure the compatibility of all the ground interfaces and compliance to the interface requirements. Assessments of launch site and launch vehicle (for payload launch) requirements are performed to ensure that ground operations and the flight system are in compliance. Responsible personnel on each side of the interface must be knowledgeable of the interface requirements and definitions to ensure compatibility.

Flow diagrams are developed as an integral part of the ground operations system engineering. The ground operations flow diagram is a visual representation of the process of a project and shows the relationship between ground operations activities and project milestones and relates the schedule of support and engineering teams to the project. Ground processing analyses are performed to validate the ground processing flow. Ground operations, servicing, and launch site support requirements are defined and documented. Accessibility for performing all integration and ground operation activities is verified.

The elements of ground operations are a mixture of the varied skills, facilities, equipment, and other capabilities necessary to physically transport, functionally integrate, test, and service the flight subsystems/system. Certification of both supporting personnel and applicable support equipment is required to perform many of the activities associated with handling and transportation of flight hardware. MPG 6410.1, *Handling, Storage, Packaging, Preservation, and Delivery*, MWI 6410.1, *Packaging, Handling, and Moving Program Critical Hardware*, and MWI 6430.1, *Lifting Equipment and Operations*, are management guidelines and instructions that apply to project ground operations. The specific ground operation elements applicable to a project are a function of the ground processing flow for that project. The ground operations processing flow for a flight system is dependent upon characteristics of that system.

4.4 PROJECT REVIEWS

Project reviews generally fall into three categories: (1) reviews associated with discharging design, development, delivery, and operational responsibilities; (2) reviews associated with reviewing status, acquiring resources, reporting utilization, and reporting program status; (3) reviews associated with external evaluation of the program by a non-advocate team.

Since no manager of a substantial project can maintain current, in-depth expertise in the multiplicity of technical and programmatic disciplines required, the importance of reviews in the program management process cannot be overemphasized. Reviews provide the mechanism by which one assesses performance, acquires managerial confidence, enforces technical and programmatic discipline, and conveys requirements and progress. Reviews also provide a means of assuring projects have addressed the TPMs correctly. Technical reviews, in particular, must be thoroughly planned and interrelated from near project inception. Caution should be taken, however, not to hold formal reviews at inappropriate times merely to meet the projected schedule. It is sometimes better to delay these reviews until proper design maturity is reached. The PDRs are typically held when design is approximately 50% with corresponding drawings available. The CDR is held when design and drawings are 90%-95% complete (drawings signed, but before submittal for configuration control). Actual design and drawing documentation required should be defined in the review plans. The PDR and CDR are to establish technical baselines for the purpose of controlling requirements/ configuration as the program evolves through the implementation phase. This control should not be confused with, and does not take the place of, contract scope control.

Each project will define the specific reviews for that project in the Project Plan. The project will need to phase the project reviews to correspond with the associated program reviews. The review list below is for a typical project, although a review may be called by another name on any given project, and other reviews, principally operational oriented, may be required depending on the specific project. The following reviews are listed below as technical or programmatic; however, some reviews listed may be properly categorized as either.

Technical Reviews:

- Project Requirements Review (PRR)
- System Requirements Review (SRR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Design Certification Review (DCR)/Functional Configuration Audit (FCA)
- Configuration Inspection (CI)/Physical Configuration Audit (PCA)
- Acceptance Review (AR)
- Pre-Ship Review
- Test Readiness Review (TRR)

- Ground Operations Review (GOR)
- Flight Operations Review (FOR)
- Flight Readiness Review (FRR)

Programmatic Reviews:
- Program/Project Operating Plan (POP) Review
- Annual Manpower Review
- Project Manager's Review
- Project Management Council (PMC)
- Program Manager's Review
- Performance Evaluation Board Reviews

Programmatic External Reviews:
- Independent Assessment (IA)
- Non-Advocate Review (NAR)
- Independent Annual Review (IAR)
- Phased Safety Reviews
- External Independent Readiness Review (EIRR)
- Red Team Reviews (may be internal)
- Special Reviews (Termination, Process Audits, etc.)

The Project Plan provides the name, purpose, content and schedule of all scheduled reviews for the project. A review plan that defines the details of the review is prepared for each review. The review plan describes the conduct of the review, the data included in the review with the data's expected maturity level, the documentation and disposition process for RIDs, the detailed schedule for the review, the review teams and their responsibilities, and the review Board and Pre-Board membership as applicable.

The conduct of a major review is not complete until all resulting RIDs and action items are dispositioned and their effect on the project resolved. Follow-up work should be pursued aggressively to ensure timely closure of RIDs and actions items. This follow-up effort will help assure that the results of the review are expeditiously reflected in the project and will also serve as a solid basis for the next review.

There is a subset of reviews that is inherent in each of the above technical and, to a lesser degree, programmatic reviews. Specifically, qualification, quality, reliability, risk management, supportability, maintainability, safety, and crew station (in the case of manned spacecraft) reviews must be an integral and identifiable part of each project review; or specific, separate provisions must be made for such subset reviews. It is assumed that these reviews are inherent in the project reviews. Involvement of upper management in the review process during Pre-boards and Boards keeps them informed, integrates corporate memory, and builds advocacy for the activity.

4.4.1 Project Evaluation Reviews. Projects in the formulation phase must undergo a successful Headquarters or Lead Center Project Evaluation Review (IA and/or NAR) before proceeding into implementation. For MSFC managed projects, these independent reviews are normally led by the SMO as described in MPG 7120.1. Results of these reviews are presented to center management through the use of the PMC. When the Project Manager and the Center Director determine that project formulation is of proper maturity, a formal formulation external review will be conducted. The overall content of these reviews will vary according to the project. As a minimum, the purpose of these reviews focuses on mission concept and objectives, mission implementation planning, status of design definition and assessment of technical risks, schedules and total project LCC. The review teams will be composed of experienced project management, technical, and fiscal personnel drawn on an ad hoc basis from organizations that are independent of the implementation of the proposed project. Review teams for technology development projects will include development experts with knowledge of the area to be addressed by the project. These reviews will assess the actual stage of project definition in terms of the clarity of objectives, thoroughness of technical and management plans, technical complexity, evaluation of technical, cost and schedule risks, and contingency reserve allowances in schedule and cost. The review teams provide an evaluation to the MSFC PMC and the GPMC.

The approval process includes the findings from the independent review team and the project's response to the review team findings. The MSFC PMC provides guidance and direction, as required, based on the material presented. When the MSFC PMC is not the governing PMC, projects will schedule a GPMC meeting and the review team and project team will present their material along with any MSFC PMC recommendations.

4.4.2 Technical Reviews. Many of the technical reviews, in particular the PDR and CDR, may be conducted on the overall system or incrementally on the subsystems. Incremental reviews are typically conducted on large programs where it is necessary or desirable to allow design of the system or its sub-elements to proceed in the most efficient manner or to allow initiation of long lead-time procurement or manufacturing. In those cases where incremental reviews are utilized, summaries of the results of these incremental reviews should be included in the overall, comprehensive reviews to assure that the incremental activity is compatible and satisfies project requirements.

The certification reviews (see 4.4.2.5 through 4.4.2.10) support the need for an incremental readiness verification covering key activities after development is complete and leading to flight readiness. This incremental approach builds upon previous data and certification status established at prior reviews.

The timing of the conduct of each of the reviews is ultimately left to the discretion of the project management, but typically reviews are conducted as identified in the following paragraphs. (See Appendix A for additional information and examples of data supporting many of these reviews).

4.4.2.1 Project Requirements Review. The PRR may be thought of as the culmination of the mid/late formulation phase of a project and is held prior to project approval for implementation. Its purpose is to review and establish or update project requirements and to evaluate the management techniques, procedures, agreements, etc. to be utilized by all project participants. During the PRR, configuration concepts, project/system requirements, mission objectives, the qualification approach, and the system safety and QA plans are evaluated. Careful consideration should be given to how the project addresses Certification of Flight Readiness (COFR) and the level of technical penetration required. Products from the PRR support the SRR.

4.4.2.2 System Requirements Review. The SRR evaluates the "formulation-phase" generated project requirements that have been decomposed into lower level system requirements. The review confirms that the requirements and their allocations contained in the system specification are sufficient to meet project objectives and that system engineering processes are in place. The SRR encompasses all major participants (NASA and contractors), and a product from this review will be the project system specification that is formally baselined and placed under configuration control. The SRR is chaired by the Project Manager.

4.4.2.3 Preliminary Design Review. The PDR is conducted when the basic design approach has been selected and typically when 10% of drawings are complete (all top level and long lead items drawings) and overall design maturity is approximately 50% with corresponding drawings available. Actual review documentation required should be defined in the PDR plan. The PDR is a technical review of the basic design approach for configuration items to assure compliance with program (Levels I and II) and project (Level III) requirements and is intended to accomplish the following:

- Establish the ability of the selected design approach to meet the technical requirements (i.e., Verifiability/Traceability).
- Establish the compatibility of the interface relationships of the specific end item with other interfacing items.
- Establish the integrity of the selected design approach.
- Establish producibility of the selected design.
- Identify components that are to be subjected to detailed value engineering analysis.
- Address test and demonstration planning, safety, risk, reliability and maintainability assessment, producibility, and cost and schedule relationships.

The Project PDR is chaired by the Project Manager and includes the major organizations of the Center and the prime contractor. A product of the project PDR is the official release and placement under configuration control of the Part I CEI Specification(s). In the event a

Part I CEI Specification(s) has been previously placed under configuration control, it will be updated accordingly as a result of the PDR. If available, and the preliminary design end-items are not expected to have much change traffic, ICDs should be baselined and placed under configuration control. As a minimum, the PDR should establish interface requirements and establish a basis for continuing the ICDs. The PDR also approves the design approach for proceeding to detail design.

4.4.2.4 Critical Design Review. The CDR is the technical review of the detail design of the selected configuration. The CDR provides assurance that the detail design is in accordance with the Part I CEI Specification prior to manufacturing. The CDR is generally held when the design and drawings are approximately 90% to 95% complete (drawings signed, but before submittal for configuration control). Actual review documentation required should be defined in the CDR plan.

Subjects that are addressed include finalization of system compatibility, design integrity, reliability assessments, maintainability assessments, safety assessments, and cost and schedule relationships. Test, verification/validation, and manufacturing and assembly plans should be available, as well as the Part I CEI specification(s).

The participants and chairmanships are basically the same as the project PDR. Generally, the level of NASA control following the completion of the CDR remains at the Part I CEI Specification and ICD level, and the detail drawing control remains with the design contractor for contracted items. If not previously baselined, all ICDs should be baselined and placed under configuration control at the conclusion of the CDR. The primary product of the review is the final technical approval for formal release of specific engineering documentation that will be authorized for use in manufacture of the end items.

4.4.2.5 Design Certification Review/Functional Configuration Audit. The DCR (sometimes referred to as FCA) is conducted to evaluate the results and status of verification planning, testing, and analyses to certify the design. Generally, the DCR is scheduled after CDR and prior to FRR; but depending on program structure, may occur subsequent to other significant events such as completion of verification flights. The DCR addresses the design requirements, makes an as-designed comparison, assesses what was built to meet the requirements and review substantiation, determines precisely what requirements were actually met, reviews significant problems encountered, and assesses remedial action taken. The ISS employs the FCA in lieu of the DCR to perform the same review function.

4.4.2.6 Configuration Inspection /Physical Configuration Audit. The CI (sometimes referred to as a PCA) is the formal review that is used to establish the product baseline and to verify that the end items have been, and other like items can be, manufactured, tested, etc. to the released engineering documentation. This is accomplished by a comparison of the "as-built" configuration to the "as-designed" requirements. The CI is a one-time review conducted for each family of CEIs.

The CI is normally not concerned with whether the end item can perform its intended function. This task is accomplished in the earlier reviews. The CI is chaired by the Project Manager and includes the same basic organizations as the previous reviews.

The product of the CI is the formal baselining of the Part II CEI Specification. The Part II CEI Specification defines the product baseline (detailed engineering documentation) for the item reviewed and all subsequent like items. The CI will be scheduled by project management to be compatible with implementation of the Part II CEI Specification and should always occur prior to turnover of responsibility from one organization to another (e.g., prior to NASA acceptance).

The ISS employs the PCA in lieu of the CI to perform the same review function.

4.4.2.7 Acceptance Review. The AR is the final review conducted for product delivery and NASA acceptance. The AR consists of a detailed configuration review of all major end items of deliverable hardware and software and encompasses not only flight hardware and GSE but also any deliverable test articles, spares, special test equipment, support software, etc. An Acceptance Data Package (ADP) is supplied by the developer to support the AR. All aspects of qualification, verification/validation, and acceptance testing are addressed. The ADP, with supporting documentation, is examined for compliance with project requirements and to ensure that all open/deferred work is identified and disposition plans have been developed and agreed upon. The ADP DRD defines the ADP contents. The combination of the configuration inspection and acceptance reviews will formally establish and document the as-built configuration of each item of hardware/software at the time of acceptance by NASA.

4.4.2.8 Pre-Ship Review. A Pre-Ship Review is similar to an AR but is normally conducted to ensure that subsystems/system(s) that have been developed are ready for shipment. The review consists of assessing the configuration of the article(s) being shipped, assessing the verification status to ensure that all planned testing has been successfully completed, and that all required paper associated with the article(s) is complete. All open/deferred work is identified and plans to complete the open work are agreed upon and documented. Shipping plan details such as method, special instrumentation requirements, and security are assessed and any open items that must be completed prior to shipment are identified.

4.4.2.9 Test Readiness Review. The TRR provides confidence that all test requirements are properly understood and addressed and that the test setup can safely accomplish the test objective. The review includes the examination of test requirements, test procedures, the article to be tested, test facilities, GSE, supporting software, instrumentation and data acquisition, hardware handling, and personnel certification requirements. A comprehensive institutional and system safety assessment will be of highest priority during the review process, to assure safety of personnel, facility, and test article hardware. The TRR must be conducted prior to all hazardous testing. TRRs for other non-hazardous testing are conducted as required by the Project Manager and the performing test organization.

4.4.2.10 Ground Operations Review. The GOR ensures that the ground operation requirements from hardware fabrication through delivery have been defined and that the necessary support has been defined and allocated. In addition, launch site planning documentation will be reviewed to allow finalization of support for the physical integration and launch of the system. Defined post-mission operations will also be reviewed to ensure necessary support provisions.

4.4.2.11 Flight Operations Review. The FOR ensures that the flight operations planning and flight support requirements have been defined and the necessary resources have been planned and allocated. The FOR occurs prior to hardware integration with the space system carrier (for payloads) or integration into the launch facility (for space transportation vehicles).

4.4.2.12 Flight Readiness Review. The FRR is a detailed review by which the system will be certified as flight worthy. Planning for the FRR is initiated during the formulation phase. The FRR includes a review of the system verification process (both testing and analyses), system compatibility, operational planning, and team preparedness. The review will result in certification of the flight readiness of the operational team, the acceptability of the system for flight, and the readiness of the system to achieve all flight objectives.

4.4.3 Programmatic Reviews. Programmatic reviews are less rigorously defined than technical reviews. Definition, frequency, content, and format will depend in large measure on the individual requirements of the project. There are, however, a number of typical programmatic reviews and review objectives associated with a MSFC-managed project that are discussed below. Periodic (e.g., monthly, quarterly) reviews whether intra-project, Center level, or at Headquarters, are focused on problems and concerns and only summarize progress and current activities.

4.4.3.1 Program/Project Operating Plan Review. Twice a year, as a minimum, each project is required to submit a current POP estimate updating funding, schedule, and manpower requirements. The plan encompasses every vestige of the project and establishes the Project Manager's contract with Center management and Headquarters. The POP creates a programmatic yardstick by which project performance is measured. The review process will begin with the Project Manager's review of the entire program. Included in the review is an assessment of any changes in requirements, an assessment of previous plan vs. performance, and adjustments for any delta between previous plan requirements and the operational mark provided. The POP is next reviewed by Center management for consistency and compliance with Center commitments and responsibilities and finally reviewed by Headquarters. Through this review process and subsequent POP marks, current operating plans and future year funding, manpower, and schedule requirements are established for each project.

4.4.3.2 Annual Manpower Review. Each fiscal year, each project will negotiate civil service manpower requirements for that fiscal year with all Center supporting organizations. Tasks will be developed specifically defining performance, funding, and schedule requirements. Manpower required to perform the tasks will be agreed to and subsequently presented to Center management, together with project office manpower requirements, in the annual Manpower Review. The review will include a description of the work to be performed, justification for the manpower levels requested, and any other factors that have a bearing on the requested manpower.

4.4.3.3 Project Manager's Review. The Project Manager holds comprehensive reviews periodically with all project participants. The review is normally relatively formal and addresses all major aspects of the project. Technical and programmatic progress, problems, and status are covered in sufficient depth to assure efficient and effective project coordination and common understanding of project objectives and directions. Formal action items are assigned and tracked on a day-to-day basis.

4.4.3.4 Project Management Council. Comprehensive project reviews are held with the MSFC PMC and the GPMC as defined in the **PCA** and/or the Project Plan, or as required by the PMC. These reviews typically encompass technical, programmatic, and management progress and problems; specific accomplishments; and near-term planning. Particular emphasis is placed on areas potentially requiring additional or revised Center-level assistance or support or Center-level decision. MPG 7120.1 describes how other project reviews interface with the PMC/GPMC. MPG 7120.4, *MSFC Program Management Council Process*, describes the content and format for presentations to the PMC.

4.4.3.5 Program Manager's Review. Projects are also reviewed periodically with the Program Manager. The review is structured to inform the Program Manager of general program progress, specific progress toward Level I and Level II milestones, and specific issues or problems requiring Level I or Level II action. Frequency, content, and structure of these reviews may vary for a given project, depending upon the size and complexity of the project. The Project Manager should assure that the Program Manager is provided all data required for effective direction and advocacy of the program.

4.4.3.6 Monthly Performance Evaluation and Reporting to Center Management. Project performance evaluations are conducted monthly throughout the life of the project and status is reported to keep Center management informed on activities supported by the Center. The use of "Stop Light" charts assists both the Project Manager and Center management in tracking monthly progress and alerts both to potential problems. The "Stop Light" tool is provided by the SMO and provides a standard approach using standardized criteria.

4.4.3.7 Programmatic External Reviews. This activity is identified in the Project Plan which is approved prior to implementation. The conduct of each review and assessment ensures the benefits of peer experiences and perspectives and provides opportunities for customer participation. The MSFC SMO is responsible for coordinating and conducting these reviews for MSFC managed projects. Results from these reviews are presented to the MSFC PMC and GPMC.

4.4.3.7.1 Independent Assessment. An IA is performed in support of the NASA PMC oversight of approved projects and is conducted during the formulation period. The IA is a validation of an advanced concept conducted by a team of highly knowledgeable specialists from organizations outside the advocacy chain of the project. The IA provides the NASA PMC with an in-depth, independent validation of the advanced concepts, project's requirements, performance, design integrity, system/subsystem trades, LCC, realism of schedule, risks and risks mitigation approaches, and technology issues.

4.4.3.7.2 Non-Advocate Review. The formulation sub-process for all projects includes a NAR that provides an independent verification of a candidate project's plans, LCC status, and readiness to proceed to the next phase of the program's life cycle. A NAR is conducted by a team comprised of highly knowledgeable specialists from organizations outside of the advocacy chain of the project being reviewed.

4.4.3.7.3 Independent Annual Review. The IAR is conducted annually throughout the implementation phase. The IAR is used to assess progress/milestone achievement against the original baseline. The cost, schedule, and technical content of the activity are reviewed over the project life cycle. The risk and risk mitigation approach is assessed to determine if deficiencies exist. The results of the IAR are presented to the MSFC PMC and appropriate GPMC.

4.4.3.7.4 Phased Safety Reviews. In addition to MSFC safety policies and requirements, projects that utilize the NSTS must meet the requirements of NSTS 1700.7. Payloads for the ISS must comply with the NSTS 1700.7, ISS Addendum, *Safety Policy and Requirements for Payloads Using the International Space Station.* The ISS hardware systems must comply with handbook SSP50021*, Safety Requirements for the ISS Program.* Projects utilizing the KSC facilities must comply with KHB 1700.7, *STS Payload Ground Safety Handbook*. MSFC also requires that all MSFC managed projects subject to the phased safety review process must also comply with MWI 1700.1, *Payload Safety Readiness Review Board*.

The NSTS and ISS projects require that all payloads proceed through a series of phased safety reviews (Phase 0, I, II, and III). The Phase 0 Safety Review is the initial safety assessment by the JSC Payload Safety Review Panel (PSRP). The Phase 0 Safety Review consists of an assessment of the conceptual design of the flight/payload hardware and mission. Data is generated by the Payload Element Developer (PED) for the Payload Safety Review and combined with other safety related data in an integrated payload safety package for review. The Phase 0 Safety Review will assist the payload organization in identifying hazards, hazard causes, and applicable safety requirements early in the development of the project. Phase 0 Safety Review also identifies the hazard potentials and provides a forum for answering safety related questions associated with NSTS 1700.7 and KHB 1700.7, and prepares the project for subsequent phased reviews.

The Phase I safety review is conducted near the PDR. The purpose of the Phase I Safety Review is to obtain Safety Panel approval of the updated safety analyses based upon the preliminary design and operations scenario of the project. Hazard reports are generated for each identified hazard and the means of eliminating, reducing, or controlling the hazards will identified for the Phase I Safety Review. The ISS SRP and/or the PSRP will either agree upon the safety analyses and controls, or will instruct the project in areas requiring further work.

The Phase II Safety Review is typically scheduled to follow the project CDR. The details addressed in the hazard analyses will reflect the final to-be-built design and planned operational scenario. At the Phase II Safety Review, the hazard assessment will identify all hazards and hazard causes as well as the methods for controlling and verifying the hazard controls.

The Phase III Safety Review, typically scheduled in the same time frame as the project DCR, is normally associated with completion of safety verifications and/or start of ground processing. The purpose of the Phase III Safety Review is to obtain safety panel approval of the completed safety analyses and of the safety verification data. The safety data package is based upon actual tested hardware and reflects the final configuration for the hardware.

The Ground Safety Reviews, which are also phased, are performed to ensure the GSE design and the ground safety aspects and practices do not compromise the safety of the launch site personnel, facilities, and the flight hardware. The Ground Safety Reviews are conducted prior to shipment of the flight system and supporting GSE to the launch site and may be held concurrently with the flight safety reviews at JSC or at KSC. The reviews provide for the delivery of ground system safety documentation and the approval by the Ground Safety Review Panel of the ground safety practices, and the elimination, control, or mitigation of identified hazards.

4.4.3.7.5 External Independent Readiness Review. The EIRR is performed in support of the EAA's oversight of approved programs and projects. The EIRR is generally used for projects with exceptional risk, high cost, or high visibility. The review is conducted by a team of highly knowledgeable specialists from organizations outside of the advocacy chain of the project. In addition, the EIRR team is generally from organizations outside of NASA. This approach allows for access to a larger pool of resources with potentially more focused skills, raises confidence of NASA Senior Management, elevates and obtains attention to issues, and highlights lessons learned from other programs/projects.

4.4.3.7.6 Red Team Review. The purpose of a Red Team Review is to provide an objective NAR of the plans and processes in place that ensure mission success and safety are being considered and implemented. The Red Team Review is not a design review or a program management process review except as necessary for the stated purpose. A team of experienced experts may review the entire design and development cycle from mission concept through operations as well as the design, development and operations team's work ethics, attitude, skills and staffing as required to fulfill mission objectives. A Red Team Review is typically organized and chaired by a Directorate Chief Engineer.

4.4.3.7.7 Special Reviews. Special reviews may be requested by the GPMC as a result of the project evaluation sub-process during the formulation and implementation phases. The review scope and evaluation criteria for a requested special review are provided by the GPMC. The SMO organizes and chairs the review. Review findings are coordinated with the Project Office and the Project Office briefs the GPMC. The GPMC decisions and identified actions are forwarded to the Project Office for disposition and response back to the GPMC.

A Termination Review is a special review that may be requested as a result of other scheduled programmatic reviews. This review is an independent assessment to determine technical feasibility, schedule realism and risk. A result of this review is a recommendation of whether or not to terminate the project.

4.5 LESSONS LEARNED. Lessons learned/best practices are important sources of information that permeate organizational boundaries and can have a significant impact upon project implementation, system design, development, and operations. Throughout project development, existing lessons learned/best practices should be reviewed. This involvement is critically important during the early phases of system development when the basic structure of the system is being defined. The NASA Lessons Learned Information System (LLIS) provides an electronic reference database for lessons learned/best practices from past projects. The LLIS can be accessed at http://llis.nasa.gov/. In addition to the LLIS, the NASA Technical Standards Program website**,** http://standards.nasa.gov/**,** provides access to lessons learned related to technical standards.

APPENDIX A
MAJOR MILESTONE REQUIREMENTS/DESIGN REVIEWS
(SUPPORTING DATA)

This Appendix provides a summary of many of the typical reviews that a project may employ.

The Project Plan will define the actual planned reviews for each project, and the project will prepare a review plan for each of the reviews that defines the detailed list of materials to be reviewed, the review schedule, the review process, review team membership, and a description of how pertinent findings will be processed and disposed.

I. Project Requirements Review (PRR)

II. Purpose

The purpose of the PRR is to review and establish or update project level requirements and to evaluate the management techniques, procedures, agreements, etc. to be utilized by all program participants.

III. Description

The PRR may be thought of as the culmination of the mid/late formulation phase of a project and is held prior to project approval for implementation. During the PRR, configuration concepts, project/system requirements, mission objectives, the qualification approach, and the system safety and QA plans are evaluated. This review is used to establish science requirements and approve the project requirements baseline. Careful consideration should be given as to how the Project will address COFR and what level of technical penetration is required. Products from this review will support the SRR.

The PRR is chaired by the Project Manager. In cases where large and complex programs/ projects require the utilization of major resources of multiple Centers, this program/ project management responsibility may be established at the Headquarters level or Lead Center by the Administrator. If PRR Pre-boards and Boards are required, they are chaired by management (one level above the Project Management for Pre-boards and Two levels above for Boards).

Representative items to be reviewed include results of the following (as appropriate). Typically these are based upon contractual documents, with involvement to varying degrees by NASA/MSFC.

- Overall program/project plan, schedule and WBS
- DRM (includes mission operations activities, feasibility and utility analysis)
- Preliminary requirements definition and allocation, in the form of a preliminary system specification
- Functional flow analysis
- System analyses and models, including performance and requirements analyses, technology/risk assessments, cost risk analyses and assessment
- System trade studies (e.g., cost, schedule, lifetime and safety)
- Configuration Concepts
- Design analyses and trade studies
- Preliminary interface requirements
- Preliminary operations planning
- Synthesis activities
- Preliminary Quality Plan
- Logistics support analyses
- Specialty discipline studies (i.e., structures and dynamics, safety and reliability, or maintainability analyses; materials and processes considerations; EMC/EMI, inspection methods/techniques analyses, or environmental considerations)

- Preliminary Data Management Plans
- Preliminary Configuration Management Plan
- Preliminary System Safety Plan
- Preliminary Reliability Plan
- Human factors analyses
- Value engineering studies
- LCC analyses
- Manpower requirements/ personnel analyses
- For manufactured items: producibility analyses, preliminary manufacturing plans

The total system engineering management activity and its output shall be reviewed for responsiveness to the SOW and project requirements. Procuring activity direction to the contractor will be provided, as necessary, for continuing the technical project and system optimization.

The PRR should encompass all major participants, both NASA and contractors.

Outputs from this review include:

- Preliminary System Requirements
- Preliminary Project Plan
- Qualification approach
- Concepts definition (including software)
- Safety assessment plans
- Risk assessment plans
- Determination of required support (logistics, transportability, etc.)

Coordination, review, and approval occur through the Project Manager. Products are dispositioned to NASA Center organizations and the NASA contractor team as required to support the Program or Project.

I. System Requirements Review (SRR)

II. Purpose

The SRR confirms that the requirements and their allocations contained in the System Specification are sufficient to meet program/project objectives.

III. Description

The SRR may be thought of as the culmination of the formulation of a program/project. For major programs, such as the NSTS, major subsystems can have their own SRR prior to a system-wide SRR. In addition, reviews may be held at any level of assembly, from components, to the complete program/project.

The SRR is chaired by the Program/Project Manager at the designated NASA Center. In cases where large and complex programs/ projects require the utilization of major resources of multiple Centers, this program/ project management responsibility may be established at the Headquarters level or Lead Center by the Administrator. If SRR Pre-boards and Boards are required, they are chaired by management (one level above the Project Management for Pre-boards and two levels above for Boards).

Representative items to be reviewed include results of the following (as appropriate). Typically these are based upon contractual documents, with involvement to varying degrees by NASA/MSFC.

- Overall program/project plan, schedule and WBS
- Mission and requirements analyses (includes mission operations activities, feasibility and utility analyses)
- Requirements definition and allocation, in the form of a system specification including requirements flow down
- Functional flow analyses
- Software system requirements
- System analyses and models, including performance and requirements analyses, technology/risk assessments, cost risk analyses and assessment
- System trade studies (e.g., cost, schedule, lifetime and safety)
- System Engineering Process/Plan
- Design analyses and trade studies
- IRD (if appropriate) or Preliminary ICD
- PDFs (ISS Payloads)
- Verification requirements and Verification Plan
- Flight and Ground Operations Plans
- Synthesis activities
- Quality Plan
- Logistics support analyses
- Specialty discipline studies (i.e., structures and dynamics, safety and reliability, maintainability, and hazard analyses; materials and processes considerations;

EMC/EMI, inspection methods/techniques analysis, or environmental considerations)

- Integrated test planning
- Updated Data Management Plan
- Updated Configuration Management Plan
- System safety reports
- Human factors analyses
- Value engineering studies
- LCC analyses
- Manpower requirements/ personnel analyses
- For manufactured items: producibility analyses, preliminary manufacturing plans

The total system engineering management activity and its output is reviewed for responsiveness to the SOW and system requirements. Procuring activity direction to the contractor will be provided, as necessary, for continuing the technical program and system optimization.

This review is typically held at the end of the formulation process. Outputs from this review include:

- Baselined System Specification (placed under configuration management control)
- Qualification approach
- Configuration concepts and requirements
- Safety assessment plans
- Risk Management Plan
- Determination of required support (logistics, transportability, etc.)

Coordination, review, and approval occur through the Project Manager. Products are dispositioned to NASA Center organizations and the NASA contractor team as required to support the Program or Project.

I. Preliminary Design Review (PDR)

II. Purpose

The PDR may be held at the system, subsystem, and component levels to demonstrate that preliminary designs meet system requirements with acceptable risk. All interfaces and verification methodologies must be identified.

III. Description

The PDR is a technical review of the basic design approach for configuration items to assure compliance with program (at Levels I and II) and project (Level III) requirements. PDRs may be conducted at the program or project level. The PDR is typically held when 10% of drawings are complete (all top level and long lead items drawings) and overall design maturity is approximately 50% with corresponding drawings available.

PDRs are conducted at the component, configuration item, subsystem, and system levels. Occasionally, a system-level PDR is held after incremental PDRs for the lower levels. Reviews at the configuration item level are normally contractually required and are attended by the customer. Development specifications are approved prior to PDR to minimize changes in the requirements. If the complexity of the design results in high technical risk, an in-house design review will be conducted prior to conducting the formal PDR.

The objectives of the PDR are to assure that:

- All system requirements have been allocated to the subsystem and component levels and the flow-down is adequate to verify system performance.
- The design solution being proposed is expected to meet the performance and functional requirements at the configuration item level.
- There is enough evidence in the proposed design approach to proceed further with the next step of detailed design phase.
- The design is verifiable and does not pose major problems that may cause schedule delays and cost overruns.

The program PDR is chaired by the Program Manager and includes all major participants (NASA and contractors). The project PDR is chaired by the Project Manager and includes the major organizations of the NASA Center and the prime contractor. If PDR Pre-Boards and Boards are required, they are chaired by management (one level above the Project Management for Pre-boards and two levels above for Boards).

The PDR will include a review of the following items, as appropriate:

- Preliminary design drawing,
- Development plans
- Flow diagrams
- Safety analyses/risk assessments
- Hazard analyses
- Preliminary FMEA/CIL
- Manufacturing and Assembly Plan
- Verification/validation plans including Verification Success Criteria

- Requirements flow down (update)
- Updated Configuration Management Plan
- ICDs
- System description document
- WBS and Dictionary
- Software documents
- Spares philosophy
- Preliminary launch site requirements
- Preliminary GSE requirements
- Quality Plan
- Part I CEI update
- Fracture Control Plan (updated)
- Preliminary strength and fracture mechanics analyses
- Proof of concept engineering analyses
- Data Management Plan

PDR GUIDELINES

The lack of a proper understanding of risk and technology improvement needs, incompletely defined performance, design, and interface requirements, or overly optimistic cost estimates have been the ruin of many projects apparently healthy in the early phases. The general statements of mission need are the foundation for the identification of alternative design and operational approaches and the update of performance specifications and preliminary IRDs. A comprehensive performance requirements/ cost/risk assessment should be completed early. Questions one should ask are, “Is the technology available to provide the required performance? If not, where is technology lacking and are the resources (time, dollars) necessary for recovery affordable?”

In the event the Part I CEI Specification has been previously placed under CCB control, it will be updated accordingly as a result of the PDR.

Outputs of the PDR process include:

- Update to the System Specification (for Program PDRs)
- Baselined Part I CEI Specification, placement under CCB control
- Preliminary ICD update
- Preliminary design drawings
- Development plans
- Flow diagrams
- Safety analyses reports
- FMEAs
- CIL
- Preliminary verification/validation plans
- Configuration Management Plan
- ICDs
- System description document
- WBS and Dictionary

- Software documents
- Spares philosophy
- Preliminary launch site requirements
- Preliminary GSE requirements
- Fracture Control Plan (updated)
- Preliminary strength and fracture mechanics analyses
- Proof of concept engineering analyses

Coordination, review, and approval occur through the Project Manager. Products are dispositioned to NASA Center organizations and the NASA contractor team as required to support the Program or Project.

I. Critical Design Review (CDR)

II. Purpose

The CDR confirms that the project's system, subsystem, and component designs, derived from the preliminary design, is of sufficient detail to allow for orderly hardware/software manufacturing, integration, and testing, and represents acceptable risk.

III. Description

The CDR is the technical review of the detail design of the selected configuration. The CDR is held when design and drawings are approximately 90%-95% complete. This review provides assurance that the detail design is in accordance with the Part I CEI Specification prior to its release to manufacturing. A CDR is normally required for a contracted hardware/software item and is attended by the customer. The CDRs are normally conducted on the same items as PDRs, and as such warrant an in-house review prior to the formal CDR.

The participants and chairmanships are basically the same as the project PDR, i.e., the CDR is chaired by the Project Manager and includes the major organizations of the NASA Center and the prime contractor. Generally, the level of NASA control, following the completion of the CDR, remains at the Part I CEI Specification, and the detail drawing control remains with the design contractor. However, NASA project management has the option of establishing control over the product baseline to include detailed engineering drawings of the items to be manufactured.

The objectives of the CDR are to assure that:

- The detailed design will meet performance and functional requirements.
- All recommendations from design audits by specialty engineering groups, manufacturing, safety, quality, operations, and test organizations have been answered and all action items are closed.
- The design can be smoothly transitioned into the manufacturing phase.
- The program is ready to commit to setting up tooling, facilities and manpower to fabricate, integrate and test based on this design baseline.

Outputs of the CDR process include:

- Formal identification of specific engineering documentation that will be authorized for use to manufacture the end items
- Authorized release of the baselined design and the required data, including as appropriate:
  - Verification Plan
  - Software definition
  - Detail design/drawings
  - ICDs
  - Preliminary test results
  - FMEA/CIL
  - Integration plans and procedures
  - Subsystem description document
  - Launch site requirements
  - Detail design specifications
  - Component, subsystem and system test plans
  - Analyses reports
  - Safety analyses/risk assessments
  - Hazard analyses
  - Spares list

- Fracture Control Plan (updated)
- Strength and fracture mechanics analysis

Coordination, review, and approval occur through the Project Manager. Products are dispositioned to NASA Center organizations and NASA contractor team as required to support the Program or Project.

I. Ground Operations Review (GOR)

II. Purpose

The purpose of the GOR is to ensure that the physical integration requirements have been defined and that the necessary support has been allocated. In addition, launch site planning documentation will be reviewed to allow MSFC to finalize their planning for support of the physical integration and launch.

III. Description

This review is generally held during the verification phase.

Documentation required for this review includes:

- Baselined ground integration requirements
- Baselined/updated Launch Facility Agreements and operations flows
- Baselined Integrated System Verification Plan
- Verification success criteria
- Baselined assembly and installation drawings
- Baselined interface schematics
- Preliminary Handling, Transportation, and Storage Plan
- Payload Operations Control Center (POCC) data base
- Launch Site Support Plan (Payloads)
- Baselined integrated payload safety compliance data.

I. Flight Operations Review (FOR)

II. Purpose

The purpose of the FOR is to ensure that the flight operations planning and flight support requirements have been defined and the necessary resources have been planned and allocated.

III. Description

This review occurs in conjunction with delivery of the hardware for integration with the space system carrier (for payloads) or integration into the launch facility (for space transportation vehicles).

Documentation required for this review:

- Baselined Operations and Integration Agreements/facility support agreements
- Baselined Flight Definition Document (ISS Payloads)
- Baselined flight supplement payload operations guidelines (ISS payloads)
- Baselined flight planning
- Baselined flight operations support
- Baselined Integrated Training Plan
- Baselined payload/vehicle data processing requirements
- Preliminary Payload FDF
- Baselined ground data system data base
- Baselined Data Flow and Data Configuration Document
- Baselined Post-flight Evaluation Plan.

I. Design Certification Review (DCR)/ Functional Configuration Audit (FCA)

II. Purpose

The DCR/FCA is conducted to evaluate the results and status of verification planning, testing, and analysis and to certify the design.

III. Description

The DCR/FCA is scheduled after CDR and prior to FRR; but depending on program structure, the DCR/FCA may occur subsequent to other significant events such as completion of verification flights.

The DCR/FCA should address the design requirements, make an "as-designed" comparison, assess what was built to meet the requirements and review substantiation, determine precisely what requirements were actually met, review significant problems encountered, and assess remedial actions taken.

Program/Project Offices are responsible for the initiation and overall conduct of the DCR/FCA, as they are for all design reviews. This responsibility includes preparing a Configuration Management Plan and preparing a detailed review plan for each review.

The DCR/FCA review criteria include the following:

- CEI Specifications
- Verification Plan and requirements (including success criteria)
- ICDs
- Design requirements (including Requirements Traceability)
- Configuration Control Board Directives (CCBDs)

Data required for this review are as follows:

- Drawings/Engineering Orders (EOs)
- Manufacturing records
- Verification reports
- Verification procedures
- CDR RIDs and dispositions
- Engineering analyses
- FMEAs/CIL
- Open Work List
- Non-conformance Reports/status
- Certification of Qualification (COQs)
- Hazard analyses/Risk assessments
- Waivers and Deviations
- Certificate of Configuration Compliance (COCC)
- Vendors Certificate of Flight Worthiness (COFW)
- Mission constraints
- Materials Usage Agreement (MUA)
- FDF
- All software development documentation
- Fracture Control Plan
- Strength and fracture mechanics for as-built hardware

I. Configuration Inspection (CI)/Physical Configuration Audit (PCA)

II. Purpose

The CI/PCA is the formal review used to establish the product baseline and to verify that the end items have been, and other like items can be, manufactured and tested to the released engineering documentation and standards.

III. Description

The CI/PCA is accomplished by comparing the "as-built" configuration to the "as-designed" requirements. A CI/PCA is done once for each family of CEIs. The product of the CI/PCA is the formal baselining of the Part II CEI Specification.

The CI/PCA will be scheduled by the Program/Project Office to be compatible with implementation of the Part II CEI Specification. The CI should always occur prior to turnover of responsibility from one organization to another (e.g., prior to NASA acceptance).

Review criteria include the following:

- CEI specifications
- Release records
- Test requirements and procedures
- Drawings and EOs
- CCBDs
- System schematics

Required data for this review are listed below:

- Deviations
- Inspection tags
- Test log book
- Test reports
- COQs
- Materials certification
- Special handling procedures
- Contamination control records
- Open Work List
- Work Orders
- Drawings and EOs
- CCBDs
- Materials Process Certification
- Materials Identification and Utilization List (MIUL)
- Vendor COFW
- Non-Conformance Reports/status
- Hardware shortages
- Installed non-flight hardware list
- Safety compliance data
- Software
- Fracture Control Plan
- Strength and fracture mechanics analysis for as-built hardware

I. Acceptance Review (AR) / Pre-Ship Review

II. Purpose

Both the AR and the Pre-Ship Review serve the same purpose: to transfer responsibility for a project from one organization to another. The AR transfers responsibility from the contractor to MSFC. The Pre-Ship Review transfers responsibility from MSFC to an external organization such as the integration or launch facility.

A more detailed purpose of these reviews is to certify that the payload/vehicle developer has complied with all safety and interface compatibility requirements and that the "as built" configuration of the hardware and software meets the interface requirements and is flight-safe. This certification is the result of the completion of the verification program, assembly and checkout of the flight hardware and software before delivery of the flight hardware to the launch site (or other integration site) for installation.

III. Description

These reviews occur at the completion of the verification phase and the carrier or range verification and integration phases, respectively.

Documentation required for this review:

1. ADP which must include:

   - As-built configuration assembly and installation drawings
   - Final Mass Properties Status Report including weight and balance sheets
   - Baselined interface schematic drawings
   - Phase III Safety Compliance Data Package (ISS payloads) which includes the final experiment safety package cover sheet, and complete hazard reports with supporting data
   - As-built certification data on Safety Critical Structures Data Package
   - Final Verification Closure Reports
   - Verification procedures (as-run)
   - Requirements traceability
   - Final Verification Test Reports
   - Update of pointing and control dynamics data requirements document

2. Open Items List which must include any open verification tasks and/or open hazard reports and:

   - Verification critique (i.e., as-built flight hardware vs. design requirements vs. verification plan) and results
   - Critique of as-built flight hardware vs. safety hazard sheets
   - Any design, safety, verification and/or operations issues not included in ADP.

3. Open Work List must identify and describe any work planned for completion before shipment to the integration/launch site but was actually not completed. It must also include any

work or test previously planned to be performed at the integration/launch site. These items must be categorized as follows:

- To be performed before shipment
- To be performed at the integration/ launch site
- Off-line/after turnover to the integration/launch site

4. Status and discussion of all:

- Waivers/Deviations/Engineering Change Requests (ECRs)
- MUAs
- Hardware modifications (planned/proposed)
- Phase-down/phase-up plans
- Open RIDs/ Discrepancy Notices DNs)
- All ALERTs

5. Response to any MSFC design and operations issues, Open Items List and identification of additional items

After the above documentation review is completed, there will be a physical inspection of the hardware. This inspection will be to verify:

- Completeness
- Interface safety requirements satisfied by inspection
- Pre-Ship configuration versus Flight configuration

Upon successful completion of all activities, a certificate of acceptance is signed by the Project Manager.

I. Test Readiness Review (TRR)

II. Purpose

The TRR is the evaluation of the state of readiness to support the performance of a major test (i.e. formal verification, acceptance article, etc.).

III. Description

The TRR must be conducted prior to the start of potentially hazardous test operations. The TRR should provide an independent review of proposed test operation, including: test article, facility and personnel readiness. The TRRs are typically chaired by the test manager with participation of responsible test article and applicable support organizations.

The TRR Board carries out the following functions:

1. Assess the effectiveness of steps taken to mitigate and hazards inherent in the test operations.

2. Determine the test risks in three separate categories:

   - Risk to personnel
   - Risk of major damage to the test facility
   - Risk of unacceptable damage to the test article

3. Judge the acceptability of incurring these risks to accomplish test program objectives.

4. Determine the adequacy of test preparation work and test operating procedures, review of open work and assign additional action as required.
5. Grant ATP by signing a Test Readiness/Risk Assessment sheet

TRR presentation material:

- Test requirements
- Test operations procedures
- Safety/risk assessment (personnel, facility, test article)
- Hazards identification
- Environmental Impact Statement
- Test readiness statements (personnel, facility, test article, test equipment)
- Waiver/Deviations
- Open work/issues
- ATP (Test Readiness/Risk Assessment Sheet) for signature

I. Flight Readiness Review (FRR)

II. Purpose

The FRR is the detailed review by which the system will be certified as flightworthy.

III. Description

The FRR includes review of the system verification process, system compatibility, operational planning, and team preparedness. This review concludes in the COFR of the operational team, the acceptability of the vehicle for flight, and the readiness of the total system to achieve flight objectives.

For payloads, the FRR is held in two phases. Phase I is held at the completion of satisfying the Level III/II payload integration requirements. It is typically held at the start of Level I payload integration requirements. Successful completion of the FRR Phase I review verifies:

1. Recertification of interface requirements.

2. Confirmation that required hazard control verifications have been completed, all potential safety issues have been properly disposed, and management has advised of any open or residual safety risk issues.

3. Level I integration requirements have been defined.

4. Payload is ready for Level I integration.

5. Payload ground integration requirements have been satisfied.

Phase II commences at completion of Level I integration and ensures that the payload and the operations team are ready for flight.

For space transportation, the FRR is held at the successful completion of vehicle/launch facility integration requirements. Successful completion of the FRR verifies:

1. Recertification of interface requirements.

2. Confirmation that required hazard control verifications have been completed, all potential safety issues have been properly disposed, and management has advised of any open or residual safety risk issues.

3. Vehicle ground integration requirements have been satisfied.

4. Vehicle and facility operations teams are ready for flight.

APPENDIX B
ACRONYMS

AD^2	Advancement Degree of Difficulty
ADP	Acceptance Data Package
ALERT	Acute Launch Emergency Restraint Tip
AO	Announcement of Opportunity
AR	Acceptance Review
ATP	Authority To Proceed
CCB	Configuration Control Board
CCBD	Configuration Control Board Directive
CDR	Critical Design Review
CEI	Contract End Item
CFO	Chief Financial Officer
CI	Configuration Inspection
CIL	Critical Items List
CMA	Configuration Management Accounting
COCC	Certificate of Configuration Compliance
CofF	Construction of Facilities
COFR	Certification of Flight Readiness
COFW	Certificate of Flight Worthiness
COQ	Certification of Qualification
CPAF	Cost Plus Award Fee
CPFF	Cost Plus Fixed Fee
CPIF	Cost Plus Incentive Fee
CRPS	Center Resource Planning System
CWC	Collaborative Workforce Commitment
DCAA	Defense Contract Audit Agency
DCMA	Defense Contract Management Agency
DCR	Design Certification Review
DN	Discrepancy Notice
DoD	Department of Defense
DPD	Data Procurement Document
DRD	Data Requirements Descriptions
DRL	Data Requirements List
DRM	Design Reference Mission
EAA	Enterprise Associate Administrator
ECP	Engineering Change Proposal
ECR	Engineering Change Request
ED	Engineering Directorate
EIRR	External Independent Readiness Review
EMC	Electromagnetic Compatibility

EMI	Electromagnetic Interference
EO	Engineering Order
EVS	Earned Value System
FAD	Formulation Authorization Document
FAR	Federal Acquisition Regulation
FCA	Functional Configuration Audit
FEO	Floor Engineering Orders
FEPL	Floor Engineering Parts Lists
FDF	Flight Data File
FFP	Firm Fixed Price
FMEA	Failure Mode and Effects Analyses
FOR	Flight Operations Review
FPAF	Fixed Price Award Fee
FPI	Fixed Price Incentive
FRR	Flight Readiness Review
FY	Fiscal Year
FTA	Fault Tree Analysis
GOR	Ground Operations Review
GPMC	Governing Program/Project Management Council
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
I/O Net	Input/Output Network
IA	Independent Assessment
IAR	Independent Annual Review
ICD	Interface Control Document
IRD	Interface Requirements Document
IFM	Integrated Financial Management
IPCL	Instrumentation Program and Command List
ISO	International Organization for Standardization
ISS	International Space Station
IV&V	Independent Verification and Validation
JSC	Johnson Space Center
KSC	Kennedy Space Center
LCC	Life Cycle Cost
LLIL	Limited Life Items List
LRU	Line Replaceable Unit
LSE	Lead System Engineer
MPD	Marshall Policy Directive
MPG	Marshall Procedures and Guidelines
MRD	Media Relations Department
MSFC	Marshall Space Flight Center
MUA	Materials Usage Agreement

MWI	Marshall Work Instruction
NAR	Non-Advocate Review
NASA	National Aeronautics and Space Administration
NPD	NASA Policy Directive
NPG	NASA Procedures and Guidelines
NRA	NASA Research Announcement
NSTS	National Space Transportation System
OCC	Operations Control Center
ODM	Organizational Data Manager
OMB	Office of Management and Budget
ORU	Orbital Replaceable Unit
OSHA	Occupational Safety and Health Administration
PAS	Problem Assessment System
PCA	Program Commitment Agreement
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PED	Payload Element Developer
PFD	Power Flux Density
PI	Principal Investigator
PMC	Program/Project Management Council
POCC	Payload Operations Control Center
POP	Program/Project Operating Plan
PRR	Project Requirements Review
PRSD	Preliminary Requirements Specification Document
PSRP	Payload Safety Review Panel
QA	Quality Assurance
RAD	Resources Authorization Directive
RF	Radio Frequency
RFP	Request for Proposal
RID	Review Item Discrepancy
RVC	Requirements, Verification and Compliance
S&MA	Safety and Mission Assurance
SAP	Systems, Applications, and Products
SBIR	Small Business Innovation Research
SCIT	Standard Change Integration and Tracking
SEB	Source Evaluation Board
SEBR	Source Evaluation Board Review
SEMP	System Engineering Management Plan
SLE	Subsystem Lead Engineer
SMO	Systems Management Office
SOW	Statement of Work
SRP	Safety Review Panel

SRR	System Requirements Review
STDN	Space Tracking and Data Network
SUNS	Standards Update Notification System
SWCDR	Software Critical Design Review
SWPDR	Software Preliminary Design Review
SWRR	Software Requirements Review
TEB	Technical Evaluation Board
TDRSS	Tracking and Data Relay Satellite System
TIC	Total Investment Cost
TIM	Technical Interchange Meeting
TPM	Technical Performance Metric
TRL	Technology Readiness Level
TRR	Test Readiness Review
VRSD	Verification Requirements and Specification Document
WBS	Work Breakdown Structure

APPENDIX C
GLOSSARY

Agency: Term referring to the NASA.

Baseline: Term used to describe a formally approved document or drawing; or, the act of formally approving a document, or drawing, after which any proposed changes have to be submitted, evaluated, and approved by a formal CCB before incorporation into the document, or drawing.

Classification of Contract Changes:

Class I: Changes that affect the Contract baseline (cost, schedule, tasks, requirements, applicable documents, Class I criteria specified in the contract) and require approval by the Government.

Class II: Changes that do not affect the Contract baseline (cost, schedule, tasks, requirements, applicable documents, Class I criteria specified in the contract) and may be approved by the Contractor.

Enterprises: NASA's overall program, as outlined in the Agency's *Strategic Plan* consists of five Strategic Enterprises. Each Enterprise covers a major area of research and development emphasis for the Agency. The five Strategic Enterprises are:

Aerospace Technology: The mission of this Enterprise is to maintain United States preeminence in aerospace research and technology.

Biological and Physical Research: The mission of this Enterprise is to use the synergy between physical, chemical, and biological research in space to acquire fundamental knowledge and generate applications for space travel and Earth applications.

Earth Science: The mission of this Enterprise is to develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations.

Human Exploration and Development of Space: The mission of this Enterprise is to expand the frontiers of space and knowledge by exploring, using, and enabling the development of space for human enterprise.

Space Science: The mission of the Space Science Enterprise is to discover how the universe began and evolved, how we got here, where we are going, and whether we are alone.

Integrated Configuration Management System: An interactive data processing system for MSFC that provides documentation release information for tracking configuration documentation. The Integrated Configuration Management System allows the user (designer/engineer) to integrate an assembly and its component parts on the Integrated Configuration Management System database, providing them with line item control and correlation of all related data elements.

Levels of Control: Term referring to the organizational level that is required to approve a baseline document, or a change to a baseline document.

Level I: Enterprise or Agency level.

Level II: Program level.

Level III: Project level.

Level IV: System level.

Level V: Subsystem level.

Part I CEI Specification: The Part I CEI specification is used to specify technical requirements peculiar to the performance, design, and verification of a CEI that are flowed down from the higher level specification and allocated to the CEI. “Part I is a product of the early design effort; and when completed and approved, establishes the design requirements baseline for the CEI.”

Part II CEI Specification: The Part II CEI specification is used to specify exact configuration requirements peculiar to the production, quality control, acceptance verification, and preparation for delivery of the CEI. “Part II is a product of development and operations; and when completed and approved, establishes the product configuration baseline.”

Prime Contractor: A contractor that has been given the role of not only delivering an end item, but also performing the role of purchasing sub-portions of the end item from sub-contractors.

Program: An activity within an Enterprise having defined goals, objectives, requirements, funding, and consisting of one or more projects, reporting to the NASA PMC, unless delegated to a GPMC.

Project: An activity designated by a program and characterized as having defined goals, objectives, requirements, LCCs, a beginning, and an end.

Review Item Discrepancy. A formal documentation of an item found during a formal review that is in conflict with the references for the review; e.g., documenting a conflict between a design and the design's performance requirements.

Types of Data/Documentation (for contractual efforts):

Type 1: Contractual data/documentation that all issues and interim changes to those issues require written approval from the requiring organization before formal release for use or implementation.

Type 2: Contractual data/documentation that MSFC reserves a time-limited right to disapprove in writing any issues and interim issues changes to those issues.

Type 3: Data/documentation that shall be delivered by a contractor as required by the contract and do not require MSFC approval. However, to be a satisfactory delivery, the data must satisfy all applicable contractual requirements.

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APPENDIX D
TECHNICAL PERFORMANCE METRICS

Technical Performance Metrics (TPMs) are sets of parameters that can be used to measure the progress, or accomplishment, of tasks against the expected progress, or plan. TPMs are specific parameters that are utilized as tools for implementing Earned Value Management. Although each project chooses the specific TPMs appropriate for that project as part of the project planning, there are many TPMs that may be common across projects. The following lists are examples of TPMs that may be helpful in choosing the appropriate TPMs for a project. The example lists are divided into the different process categories comprising project development.

Project Management Metrics

Projected LCC versus budgeted/constraints

Staffing level versus scheduled staffing

Cost expended versus cost scheduled

Overtime hours expended versus hours planned

Project development risks identified versus mitigations planned

Make or buy decisions versus open decisions

Procurements completed versus initiated/planned

Long lead procurements identified/initiated

Safety hazards identified versus approved mitigation plans

Independent reviews conducted

Budget reserves expended versus schedule

Mass properties management reserve versus schedule

Engineering Processes Metrics

Trade studies performed versus planned

Number of requirements flowed-down/traced to lower levels

Number of requirements modified after baselining

Number of TBDs in requirements versus scheduled definition

Interface documentation completed versus scheduled

Review items delivered on schedule versus planned

Review item discrepancies open versus closure schedule

Number of drawings produced, approved versus scheduled

Number of waivers against specifications/requirements written/approved

Engineering hours expended versus scheduled

Number of manufacturing problem reports, engineering change orders, redlined drawings versus formal drawings updates processed

Planned manufacturing completions versus actual completions

Preliminary Interface Revision Notices versus approved Interface Revision Notices

Safety analysis/hazard analysis completed versus still pending

Mass properties margins versus schedule

Verification plan complete versus open

Verification completed versus open

System Performance Metrics

Thrust versus predicted/specified

ISP versus predicted/specified

Propellant margins versus mission planning schedule

Thermal analyses completed versus open

Thermal margins predicted versus measured

Mass properties predictions versus requirements/specification

Mass properties measured versus analyses

Mass properties contingencies remaining versus scheduled

Materials selected versus open decisions

Electrical power margins over mission life versus project schedule

Control system stability margins

Mission timeline plans completed

Error budget defined versus predicted/allocated

Stress factors of safety predicted/measured

EMI/EMC susceptibility versus emissions margins

Trajectory performance predictions versus actual

Vibration specifications versus predicted/measured

Software Metrics

Software requirements defined

Software design/code completed

Software programs/modules tested/passed tests

Memory utilized/margin versus schedule

Software defects detected versus corrected

Software validated versus scheduled

Computation cycle margin versus schedule

Supportability and Logistics Metrics

Reliability predictions versus requirements

Percentage of reliability based on testing versus theoretical

Mean time between failures

Mean time before refurbishment required

Number of off-the-shelf components utilized

Number of LRUs/ORUs

Number of assessable components/modules

Standard support equipment utilized

Support equipment available

Spares available versus required

Materials/staples stock available versus required

Number of sources available for unique components/equipment

Autonomous systems versus crew intervention required

Crew time required

System turn around time

Fault detection capability

Percentage of system designed for on-orbit crew assess

Amount of system designed for ease of future upgrades

Training requirements versus personnel trained

Support agreements initiated/completed/open

Equipment downtime based on lack of supplies

Equipment downtime based on maintenance

List of hazardous materials utilized

Hazardous materials disposal rates

Technology Project Metrics

Variances between projected costs and schedules

TRL advancement progress

Test results versus predictions

Development path decision logic progress

Comparison of parallel development paths progress

Off-ramp decisions

MSFC DOCUMENTATION REPOSITORY - DOCUMENT INPUT RECORD

I. GENERAL INFORMATION

1. APPROVED PROJECT:	2. DOCUMENT/ DRAWING NUMBER:	3. CONTROL NUMBER:	4. RELEASE DATE:	5. SUBMITTAL DATE:
Multiprogram/Project Document	MSFC-HDBK-3173			

6. DOCUMENT/DRAWING TITLE:	7. REPORT TYPE:
PROJECT MGT & SYSTEMS ENG. HANDBOOK	

8. CONTRACT NUMBER / PERFORMING ACTIVITY:	9. DRD NUMBER:	10. DPD / DRL / IDRD NUMBER:

11. DISPOSITION AUTHORITY (Check One):	12. SUBMITTAL AUTHORITY:	13. RELEASING AUTHORITY:
☒ Official Record - NRRS 8/12/A ☒ Reference Copy - NRRS 8/5/A/3 (destroy when no longer needed)	John Brunson	W.H. Nabors

MJ

14. SPECIAL INSTRUCTIONS:

15. CONTRACTOR/SUBMITTING ORGANIZATION, ADDRESS AND PHONE NUMBER:	16. ORIGINATING NASA CENTER: MSFC 17. OFFICE OF PRIMARY RESPONSIBILITY: VS10/System Management Office

18. PROGRAMMATIC CODE (5 DIGITS):	19. NUMBER OF PAGES:

II. ENGINEERING DRAWINGS

20. REVISION:	21. ENGINEERING ORDER:	22. PARTS LIST:	23. CCBD:

III. REPORTS, SPECIFICATIONS, ETC.

24. REVISION:	25. CHANGE:	26. VOLUME:	27. BOOK:	28. PART:	29. SECTION:
A					

30. ISSUE:	31. ANNEX:	32. SCN:	33. DCN:	34. AMENDMENT:

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