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MULTIPROGRAM/PROJECT COMMON-USE
DOCUMENT

PROJECT MANAGEMENT
AND
SYSTEM ENGINEERING HANDBOOK

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PROJECT MANAGEMENT AND SYSTEMS ENGINEERING HANDBOOK

Prepared by:

John Brunson
Systems Management Office
Space Management Systems Engineering

Approved by:

Axel Roth
Director (Acting), Systems Management Office

Approved by:

John W. Kilpatrick
Chairman, Multiprogram/Project Common-Use Document Control Board

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PROJECT MANAGEMENT AND SYSTEMS ENGINEERING HANDBOOK

1. INTRODUCTION

1.1 Scope. This handbook provides the basic processes and general guidance for the life cycle of all programs and projects managed at Marshall Space Flight Center (MSFC). It is intended to be used 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 lifecycle of the project.

While many of the management principles and practices described in this book apply to both program and project management, the emphasis of the document is to describe the management and systems engineering necessary for project development. Therefore, in general the document refers only to project management and systems 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, program and Project Managers, working with their systems engineers, should tailor implementation to the specific needs of the program/project consistent with program/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 (PCAs), Program Plans, and Project Plans. All programs and projects must comply with applicable MSFC directives, requirements established by law, regulations, Executive Orders, and Agency directives.

1.2 Purpose. The purpose of this handbook is to combine the MM 7120.2, *MSFC Project Management Handbook*, and the MSFC-HDBK-1912, *MSFC Systems Engineering Handbook*, and define the contemporary practices and policies employed at MSFC in the management of projects and execution of the systems engineering 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 systems 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

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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 systems engineering concept. This suggests that managers and systems 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 planning must also include the Agency's number one goal of safety.

Previously, project management principles and systems engineering practices were documented in separate documents. Project management practices were documented in the MM 7120.2. The MSFC-HDBK-1912 described the processes and practices employed by the former Systems Analysis and Integration Laboratory in supporting project development. Since those documents were published, 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 Standards Organization (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 systems engineering functional responsibilities were also modified. Many of the systems 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 systems 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

		<u>Paragraph</u>
NHB 5601.1	NASA Handbook for Preparation of Work Breakdown Structures	4.1.2.2.1
NMI 5350.1	Maintainability and Maintenance Planning Policy	4.3.7.1.1
NPD 7120.4	Program/Project Management	4.1
NPD 8010.2C	Use of Metric System of Measurement in NASA Programs	4.1.1
NPD 8070.6A	Technical Standards	4.1.3.1
NPD 9501.3	Earned Value Performance Management	4.3.2.5
NPG 5600.2	Statement of Work (SOW): Guidance for Writing Work Statements	4.1.2.2.2
NPG 7120.5	NASA Program and Project Management Processes and Requirements	1.3, 4.1, 4.1.2
NPG 8621.1	NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping	4.3.7.1.3b
NPG 8715.3	NASA Safety Manual	4.3.6.3.4
NPG 8735.2	Management of Government Safety and Mission Assurance Surveillance Functions for NASA Contracts	4.3.7.1.2
NPG 9501.2C	NASA Contractor Financial Management Reporting	4.3.1.2
NSTS 1700.7B	Safety Policy and Requirements for Payloads Using the NSTS	4.3.6.3.4
NSTS 1700.7B, ISS Addendum	Safety Policy and Requirements for Payloads Using the NSTS	4.3.6.3.4
NSTS 5300.4(1D-2)	Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program Change No. 2	4.3.7.1.1, 4.3.7.1.2
SSP 50021	Safety Requirements for the ISS Program	4.3.6.3.4
FAR Part 27	Federal Acquisition Regulation	4.2.2.5.3
NASA FAR Supplement Parts 19-27	Federal Acquisition Regulation	4.2.2.5.3
No Number Assigned	NASA WBS Reference Guide	4.1.2.2.1

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2.2 MSFC Documents

		<u>Paragraph</u>
MM 7120.2B	MSFC Project Management Handbook	1.2, 1.3
MPD 1130.1A	Roles and Responsibilities of the MSFC Project Scientist	4.2.1.3
MPD 1280.1	Marshall Management Manual	4.2.2.3
MPD 1380.1E	Release of Information to News and Information Media	4.2.2.5.3
MPD 1394.1	Control of Audiovisual Products	4.2.2.5.3
MPD 2190.1	MSFC Export Control Program	4.3.7.6, 4.2.2.3
MPD 8720.1	MSFC Maintainability and Maintenance Planning for Space Systems	4.3.7.1.1
MPG 1230.1	Center Resources Management Process	4.2.2.2
MPG 1371.1B	Procedures and Guidelines for Processing Foreign Visitor Requests	4.2.2.5.3
MPG 2190.1	MSFC Export Control Program	4.3.7.6, 4.2.2.3
MPG 6410.1A	Handling, Storage, Packaging, Preservation, and Delivery	5.4.6
MPG 7120.1B	Program/Project Planning	4.1, 4.1.1, 4.1.2.1, 4.2.2.3
MPG 7120.3C	Data Management, Programs/Projects	4.3.4.5
MPG 8040.1B	Configuration Management, MSFC Programs/Projects	4.3.4, 4.3.4.2
MPG 8060.1B	Flight Systems Design Control	4.1.3.2
MSFC-HDBK-1912A	MSFC Systems Engineering Handbook	1.2,1.3
MSFC-HDBK-2221	MSFC Verification Handbook	5.4.4
MSFC-STD-506C	Materials and Process Control	4.1.3.2.2
MWI 1050.3	Policy and Authority to Take Actions Related to Reimbursable and Non-Reimbursable Space Act Agreements	4.1.2.2
MWI 1280.5A	MSFC ALERT Processing	4.3.7.1.1
MWI 1700.1B	Payload Safety Readiness Review Board	4.3.6.3.4
MWI 1700.2	System Safety Program	4.1.3, 4.3.7.1.2
MWI 5100.1A	Procurement Initiators Guide	4.1.2.2.2
MWI 5115.2A	Source Evaluation Board/Committee (SEB/C) Process	4.1.2.2.2
MWI 5116.1A	Evaluation of Contractor Performance Under Contracts with Award Fee Provisions	4.3.1.1, 4.3.2.5

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MWI 6410.1B	Packaging, Handling, and Moving Program Critical Hardware	5.4.6
MWI 6430.1B	Lifting Equipment and Operations	5.4.6
MWI 7120.2A	Data Requirements Identification/Definition	4.3.4.5
MWI 7120.5B	Data Management Plans, Programs/Projects	4.3.4.5
MWI 7120.6	Program/Project Risk Management	4.3.5
MWI 8040.1C	Configuration Management Plan, MSFC Program/Projects	4.3.4
MWI 8040.2B	Configuration Control, MSFC Program/Projects	4.3.4
MWI 8040.3	Deviation and Waiver Process, MSFC Programs/Projects	4.3.4
MWI 8040.5	Floor Engineering Orders and Floor Engineering Parts Lists (FEO/FEPLs)	4.3.4
MWI 8040.6	Functional and Physical Configuration Audits, MSFC Programs/Projects	Appendix A, FCA/PCA
MWI 8050.1B	Verification of Hardware, Software and Ground Support Equipment for MSFC Projects	5.4.4
QS01-QA-004	Quality Assurance Plan for In-House Manufacturing and Test	4.3.7.1.1

2.3 KSC Document

KHB 1700.7C	STS Payload Ground Safety Handbook	4.3.6.3.4
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2.4 Military Document

MIL-HDBK-881	Work Breakdown Structure	4.1.2.2.1
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2.5 Other Documents

ANSI/ASQ 9001	Quality Management System Requirements	4.3.7.1.2
ANSI/ASQ 9002	Quality System-Model for Quality Assurance in Production, Installation and Services	4.3.7.1.2

3. ACRONYMS/DEFINITIONS AND GLOSSARY

A list of acronyms and their definitions is included in this document as Appendix B. A glossary is included as Appendix C.

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4. PROJECT MANAGEMENT

Project management is the function of overseeing, orchestrating, and directing the numerous activities required to successfully achieve the requirements, goals, and objectives of NASA's customers. This section provides an overview of the full-scale development process including project formulation, planning and evaluation, approval, and implementation, organization and team description required to implement such a process, and discusses the various project management functions that comprise project management responsibility.

4.1 Project Development Process. NASA programs are established as a means of fulfilling the goals and objectives of the NASA Enterprises as defined in the NASA Strategic Plan. The Enterprise Associate Administrators (EAAs) are accountable to the Office of the Administrator for assuring that new projects have been adequately defined before being included in the Agency's budget submission. Structuring, streamlining, and focusing the definition phase of any project will reduce the total lead-time between concept and flight. The responsible Enterprise Associate Administrators in consultation with the appropriate Center management normally select major new project initiatives. Projects are established as a means to implement the goals and objectives of a NASA program. The NPG 7120.5 provides the Agency guidelines and requirements for project development.

The top level agreement from NASA Headquarters that captures the basic scope, resources, and contents of programs (and projects) is the PCA. The PCA is an agreement between the Administrator and the EAA. The PCA documents the baseline content for designated programs/projects and control items identified by the Administrator as critical and which require subsequent approval for change. The programs/projects that require PCAs will be designated by the Administrator. These normally include all large programs/projects and projects involving complex organizational arrangements or international participation (see MPG 7120.1, *Program/Project Planning*, NPD 7120.4, *Program/Project Management*, and NPG 7120.5). The PCA is the starting point for the genesis of all project activity and sets the stage for projects to emerge and exist to fulfill the needs of the program.

Figure 1 illustrates the process flow of a project and the interaction with the "Evaluation" activity.

The following sub-paragraphs capture the process required for projects at MSFC. The process is defined somewhat chronologically, and each sub-process may be viewed as a phase.

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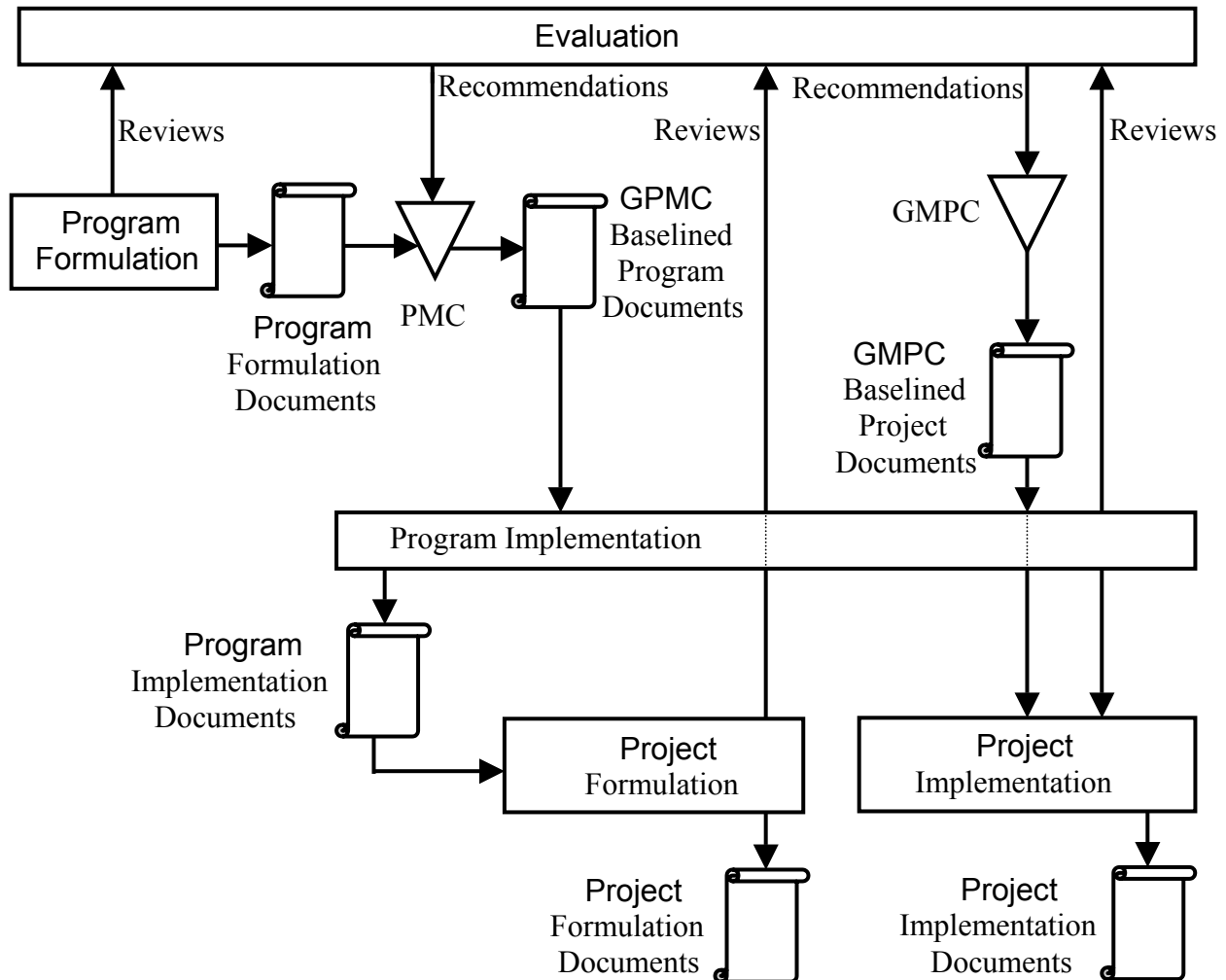


Figure 1. Program/Project Review

4.1.1 Project Formulation. The initial process for project development is the formulation process as depicted in Figure 2. Once a NASA program has established its goals and objectives, those goals and objectives may be partitioned into compatible groups such that one or more projects may fulfill those partitioned goals and objectives. This results in a set of top-level (Level I) requirements for a project. Project formulation is the process that is required to define an affordable concept and expand the given goals and objectives into a set of requirements and planning to convince both interested parties and non-advocates that a feasible and practical approach can be implemented to fulfill project requirements. An important document, which formalizes a project initiation, is a Project Formulation Authorization (PFA). A PFA is a documented agreement between the Project Manager, Program Manager and the Center(s) participating in the project. The PFA outlines, at a top level, a new project's management and technical interfaces,

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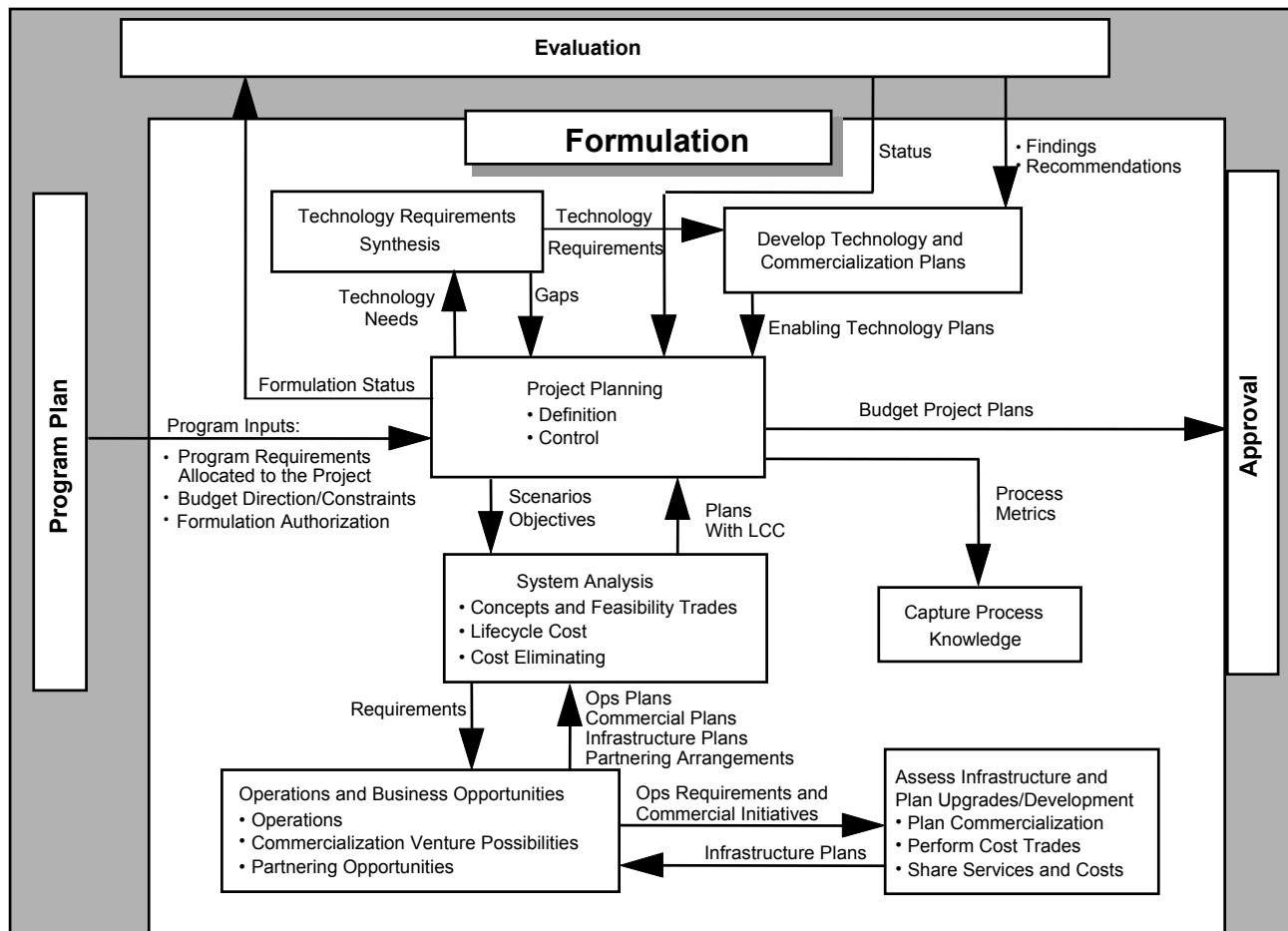


Figure 2. Project Formulation Process

procurement or in-house acquisition strategy, schedules, resource estimates, uncertainty (technical, schedule, environmental, and cost risks), contingency reserves and other key ground rules, The PFA is eventually superseded by the Project Plan.

During the formulation process, the various implementation conceptual options, available technology, development risks, and estimation of budget and schedule requirements are identified and investigated. The early formulation phase verifies that a concept that will meet top level project requirements as well as budget and schedule constraints are feasible.

As the formulation phase continues, all feasible concepts are studied and trade studies are performed to determine the optimal concept for the project application considering objectives, budget and schedule requirements. 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. Supporting systems requirements and availability of existing

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infrastructure to support the project are determined to capture total system implementation requirements.

An early formulation study is the preliminary analysis of a space concept. 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. This activity and the mid-formulation activities are principally to establish mission need and a comprehensive definition of the project. Documentation resulting from these studies consists of study reports and briefing charts.

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.

A utility analysis is conducted to determine the value of a project. Analysis may also include comparison of life cycle costs and benefits with existing systems. 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. During this time frame, a determination is made regarding utilization of the International System of Units (Metric) in accordance with NPD 8010.2, *Use of the Metric System of Measurement in NASA Programs*. System architecture which may consist of certain satellites and/or instruments, space flight vehicles, or technology demonstrators are selected for a more detailed level of design. Schedules including an overall program schedule and a top-level technical schedule are developed during this formulation period.

As part of the study activity, the study team develops and provides a comprehensive risk analysis and assessment to establish a high level of confidence for the project cost. The cost estimate established during this phase will provide NASA Headquarters with the funding requirements that will require approval from Congress to begin the development program.

The Center's Program/Project Management Council (PMC) will review the early formulation material including the Mission Needs Statement to approve the project to continue further into formulation. This phase of the project consists of the refinement of project requirements, cost estimates, schedules and risk assessments, and a first draft of the systems requirements.

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Once the feasibility of an idea is established, the concept definition is begun to explore concepts, which meet the documented mission need. Competition and innovation should be employed to ensure that a wide variety of options are identified and examined. Modeling and computer analysis are required to assess the best concepts. 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.

Other processes occurring during early formulation include:

- Development of project objectives
- Assessment of project feasibility
- Identification of research and advanced technology requirements
- Identification of support requirements areas
- Performance of trade-off analyses
- Definition of relationships to other programs (e.g., mission objectives, common hardware, facilities)
- Selection of systems concepts
- Identification of maintenance, new technology insertion, and disposal concepts of payload and orbital debris
- Environmental impact analysis
- Life cycle cost analysis
- Operations and business opportunities studies

The outputs from the early-formulation studies become the inputs into the mid/late formulation activities. Those outputs include:

- Concept definition (including software),
- Preliminary configuration layouts,
- Work Breakdown Structure (WBS) (see 4.1.2.2.1),
- Preliminary integrated project summary,

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- Preliminary Project Plan,
- Preliminary Program Commitment Agreement,
- Preliminary system requirements,
- Preliminary schedules,
- Preliminary operations planning,
- Independent cost estimate,
- Preliminary risk analysis and assessments,
- Environmental impact, and
- Mission Needs Statement.

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 above, the Project Plan begins development during the early formulation process and matures with the continuation of the formulation process. A Project Plan is the basic planning document that 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 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.

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

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- Be 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 “Draft” System Requirements Document. These criteria and requirements must be continually evaluated throughout the life of the project.
 - c. Develop a Project Risk Management Summary containing as a minimum a composite listing of all identified safety risks and hazards and associated hazard control actions.

The MSFC’s PMC and Governing Program/Project Management Council (GPMC) will review the early formulation material including the Mission Needs Statement to approve the project to continue further into formulation. This phase of the project consists of the refinement of project requirements, cost estimates, schedules and risk assessments and a first cut of the systems requirements.

Throughout the mid and late formulation period, the concepts and requirements that were developed 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. Any concepts that do not meet performance and other requirements are scrutinized 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 and result in a narrowing of the field of candidates. 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.

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

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are examined. If this examination yields valid assumptions and schedules, the NASA estimates are adjusted. 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.

During the late formulation stage, schedules are refined by the MSFC team and by the study contractors. Schedules developed by MSFC are expanded from the early formulation's overall project schedules. In addition, other schedules are developed that include implementation procurement strategies, cost phasing and project manning requirements. Schedules are expanded to lower levels of the WBS to include subsystem development, program management, manufacturing, verification, logistics planning, operations planning and other technical areas. The schedule detail would show the phasing of all major activities through launch and the follow-on operations. The processes occurring during the late formulation phase include:

- Development of a System Engineering Management Plan (SEMP)
- Refinement of selected system concepts, and down selection to a single concept,
- Refinement of the Work Breakdown Structure,
- Performance of trade-off analyses,
- Performance of system analyses and simulations
- Refinement of system and support requirements,
- Development of software requirements
- Definition and assessment of preliminary manufacturing requirements,
- Identification of advanced technology and advanced development requirements for focused funding,
- Refinement of preliminary schedules,
- Refinement of preliminary cost estimate and trade study results which support selection of baseline for cost estimate,
- Assessment of technical, cost, performance, and schedule risks,
- Reaffirmation of the Mission Need Statement.

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The outputs from this activity, which become the inputs into Approval and Implementation activity, include:

- Work breakdown structure,
- Preliminary System Specification,
- Preliminary Software Requirements Document,
- Concept of Operations,
- Program Commitment Agreement,
- Preliminary Request for Proposal,
- Project Schedule,
- Project Plan,
- Contractor Proposal Evaluation Criteria, if applicable,
- Make or Buy Decisions,
- Resource Planning (Contractor and In-house)
- Configuration Management Plan,
- Data Management Plan,
- Independent Assessment (IA) Report,
- Risk Management Plan, and
- Non-Advocate Review Report.

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 Plan 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

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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 Phase 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 shall be identified and documented.

A proper understanding of risk, technology needs, top-level requirements including interfaces, and adequate life cycle cost estimates are necessary during the formulation activity. The lack of proper understanding of these during formulation has been the demise of many projects during implementation. A comprehensive performance requirements/cost/risk assessment must be completed early.

Formulation studies must determine if technology is available to support the project. This determination includes evaluation of the current state and projected readiness for utilization of the technology being developed, or needing to be developed. If technology has to be developed, necessary resources must be determined and considered in project planning, budget, and schedules. Table I depicts the definition of the various Technology Readiness Levels (TRLs) that the Agency uses to define the state of technology maturity.

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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

4.1.2 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. The result will be clear project direction or additional formulation activity instructions, and an approved Project Plan.

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 and in the following paragraph, it supports the MSFC PMC and GPMC approval process.

4.1.2.1 Project Evaluation Reviews. Projects in the formulation phase must undergo a successful Headquarters or Lead Center Project Evaluation Review during formulation (IA and/or NAR) before proceeding into full-scale development. For MSFC managed projects, these independent reviews are normally led by the SMO as described in MPG

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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 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 life cycle costs. 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 PMC and the GPMC.

The approval sub-process includes the findings from the independent review team. It also includes the project's presentation containing their 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.

4.1.2.2 Preparation for Implementation. Once a project has been reviewed by the PMC and approved by the GPMC, the project receives authority to proceed into implementation. 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.

4.1.2.2.1 Work Breakdown Structure. The WBS and WBS Dictionary are critically important project management and system engineering tools that should be finalized

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prior to implementation. The WBS must be a product oriented family tree 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 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 assignment of responsibility (both in-house and contractor) and for allocating resources. The NASA WBS Reference Guide, which can be found at <http://appl.nasa.gov/>, and MIL-HDBK-881, *Work Breakdown Structure*, provides guidance for preparation of the WBS.

4.1.2.2.2 Request for Proposal. The RFP for the implementation phase 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 formulation phase or 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 Statement of Work (SOW), and other pertinent documents (project requirements and specifications, Data Procurement Document (DPD), interface control documents, 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 Source Evaluation Board (SEB) procedures are issued to prospective sources only after review and approval by the SEB. In addition, the MSFC Source Evaluation Board 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 Authority to Proceed (ATP). The contractor's initial activities will be to proceed with performing any actions levied upon

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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 (DRs) 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. For a list of system engineering DRs and core specifications and standards, go to <http://masterlist.msfc.nasa.gov/drm/> and <http://standards.nasa.gov/>, respectively.

4.1.3 Project Implementation. Once the project proceeds into implementation, the activity focuses on further refinement and approving a set of baseline system requirements. The design and development of the full-scale project is then executed. The project development phasing during implementation is shown in Figure 3.

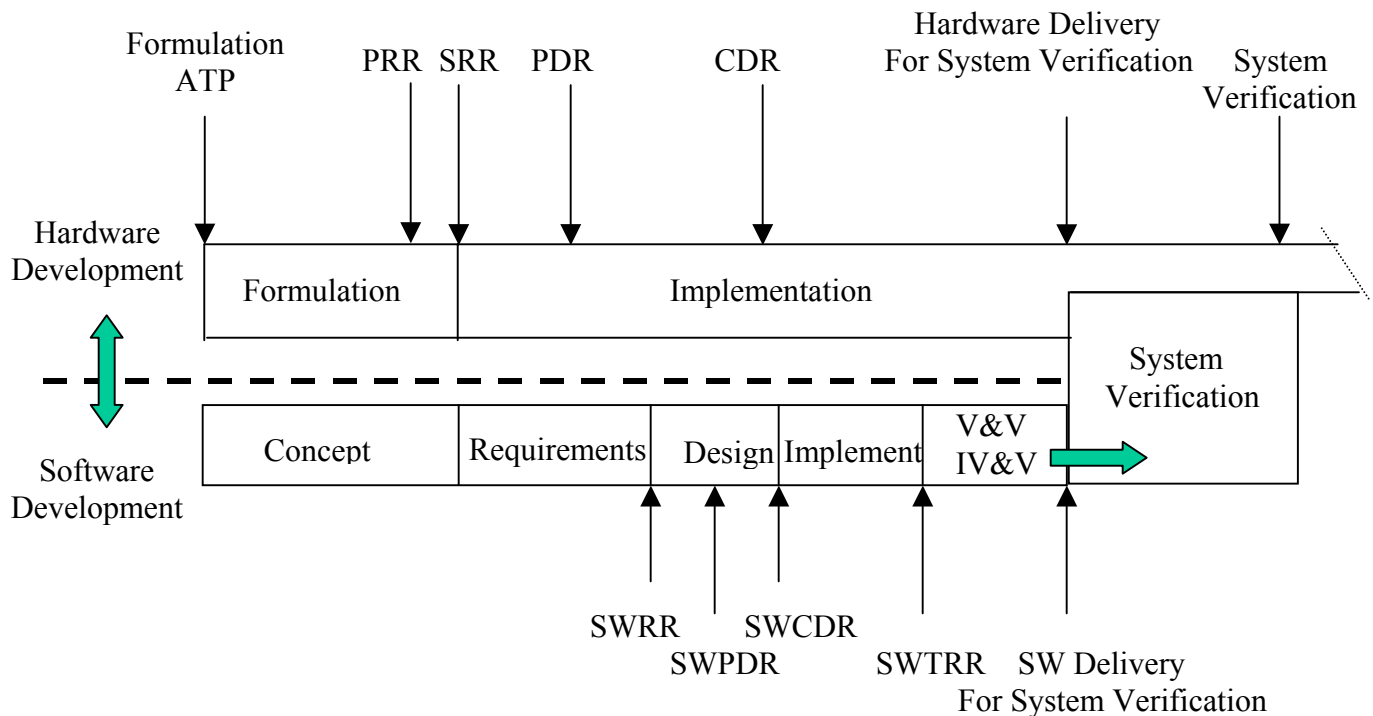


Figure 3. Project Development Process and Phasing

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Early in the implementation phase, the system requirements are baselined, the design activity is initiated, and plans are refined for final development, fabrication, test and operations. The processes occurring during early implementation include:

- Baseline of System Requirements (See Appendix A for Project Requirements Review (PRR) and/or System Requirements Review (SRR) products.)
- Refinement of software requirements
- Development of hazard analyses and safety assessments
- Development of verification program
- Development of verification requirements
- Development of Contamination Control Plan
- Completion of preliminary design (50% design complete, 10% drawings released, normally for long lead items). See Appendix A for Preliminary Design Review (PDR) products.
- Completion of detail design (90-95% design complete, >95% drawings available). See Appendix A for Critical Design Review (CDR) products.
- Development of final manufacturing, testing, verification, integration, operations, handling, transportation, storage, supporting systems, and facilities plans.
- Release of detail design drawings for hardware manufacture/fabrication,
- Refinement of schedules and cost estimates.

Late in the detailed design phase, flight hardware and software are developed, manufactured/coded, tested and qualified for flight. The design activity can overlap with the development activity. The resulting activity takes the design data, refines it into the final design, develops and fabricates the hardware, performs tests and flight qualification, and supports the flight/mission operations.

The processes occurring during this activity include:

- Development and test of prototype/protoflight hardware,
- Implementation of system safety compliance,

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- Development of ground operations,
- Development of ground systems,
- Qualification of flight hardware
- Verification/validation of flight software
- Manufacture and integration of flight hardware,
- Verification of flight and ground systems,
- Launch operations, and
- Initial flight operations including deployment, engineering evaluation, and operational acceptance characterization.

The outputs from this activity include:

- Successful turnover of the system to the user,
- Documentation and evaluation of the on-orbit verification results and anomalies, and
- Documentation of lessons learned.

During the mission operations activity of a project, support is provided for the flight operations to satisfy the mission needs. The processes occurring during mission operations include:

- Flight operations, and
- Retrieval or disposal of payload and orbital debris.

The outputs from the operations activity include:

- A successful mission,
- Documentation and evaluation of the results and anomalies, and
- Documentation of lessons learned.

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4.1.3.1 Requirements Development. In order for a project to be approved for implementation, the formulation process must have defined the project level system requirements to the extent necessary to convince independent review teams that the project is ready for implementation. Those requirements will have also been flowed down into a set of lower level requirements in order to understand and define subsystems and other elements of the project. One of the first activities in the implementation phase will be to further refine and update the system requirements to establish a formal baseline set of requirements that the project will control throughout the remaining project lifecycle.

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 and performance of systems 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 products, converted NASA Center-developed standards, and pending adoption of other Government (non-NASA) standards and non-Government Voluntary Consensus Standards. While these standards are preferred, they are not mandatory for use on NASA programs/projects except for some designated areas such as safety. Limitations to standards may be stated in the project requirements documents. Users should verify correct revision by checking the current revision status. Refer to NPD 8070.6, *Technical Standards*. Access to NASA Preferred Technical Standards may be found at: <http://standards.nasa.gov/>.

The process for establishing the baseline requirements consists of conducting requirements reviews to allow the project implementation team (either prime contractors, in-house civil service and institutional engineering support contractors, or a combination) to scrutinize the requirements and identify any that may need clarification, are in conflict with other requirements, ensure they are verifiable, or otherwise may need to be modified. The PRR and the SRR are the two primary events that perform the function of establishing the project requirements. The PRR and SRR are further described in 4.3.6.1.1 and 4.3.6.1.2. Details of the PRR, SRR, and other project reviews can be found in Appendix A.

4.1.3.2 Project Design and Development. Design and development is the process of converting performance requirements and concepts into a design, manufacturable, and integratable collection of subsystem components (reference MPG 8060.1, *Flight Systems Design Control*). It is based on the requirements, plans, and early concepts developed during the formulation phase, the content of the proposal, and the results of contract negotiations (if contracted). It is tracked by a well-defined series of reviews

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(see 4.3.6). 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 must be implemented.

4.1.3.2.1 Elements of Project Design and Development. The elements of project design and development can be described as follows:

- The refinement of performance and interface requirements. As the design matures and fabrication of hardware approaches, changes to requirements will become more and more expensive. The purpose of the SRR is to promote understanding and solidification of requirements. An approved system specification is frequently a product of this review.
- Allocation of flowdown of requirements.
- Long lead items are identified early in the process and procurements initiated.
- Trade-off and sensitivity studies. Studies will address performance requirements versus design complexity versus weight versus cost versus risk. The studies are of a continuing nature but are primarily oriented toward the preparation of a preliminary design.
- Design and performance analyses
- Preliminary design (see 5.2.7.1)
- Detailed design (see 5.2.7.3)
- Fabrication and assembly (see 5.2.8)
- Development and qualification testing. The purpose of these tests is to verify that components, subsystems, and systems meet design requirements. The development and qualification test programs require early planning. An adequate amount of hardware must be identified early in the program for component development. Qualification testing can be performed at the component level, at the subsystem or at the system level. Special test facilities to perform the development and qualification tests must be considered. The testing philosophy should be based on the idea that failures on the ground are much less costly than those in flight. The Project Manager must realize that, although test planning must be done scrupulously, it is possible to be too cautious (e.g., testing only to nominal conditions).

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The elements of design and development are described and scheduled in a Design and Development Plan. For contracted projects, the initial version of this plan is typically submitted by the contractor with the proposal. This document can be useful in the development of a mutual understanding of the total design and development process. The Project Manager assures that, prior to the completion of contract negotiations, all project requirements and plans are as complete and detailed as possible.

4.1.3.2.2 Design and Development Management Tools. The early period of the design and development phase 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. Tools for performance measurement, configuration management, and the clear definition of Project Office and the engineering organization's responsibilities and tasks should be established.

The major milestones of the design and development activities are the design reviews (see 4.3.6). Successful reviews require thorough planning and are a major means for measuring success and progress of the project. For contracted efforts, it is normally preferred that design reviews take place at the contractor's plant. Part I Contract End Item (CEI) specifications and Interface Control Documents (ICDs) are normally placed under official configuration control at, or before, the PDR. However, if design changes affecting the ICD(s) are anticipated, baselining of the ICD(s) may not occur until after the CDR. This will avoid unnecessary formal change traffic. Major products of the PDR are the establishment of the integrity of the design approach, and confirmation of project budget and resource guidelines. The PDR also confirms the follow-on project planning and schedules. PDR is a critical milestone; technical, cost, and schedule performance (as measured, for example, by the Earned Value Measurement system) in addition to the configuration control process will henceforth be founded on the baseline established by the PDR. See Appendix A for guidance in design review details.

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. Risk analysis is a systems engineering task, which must receive early serious attention.

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 the management of design and development are the

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establishment of a Problem/Action Item Tracking System, and the use of consultants for problem resolutions.

Early in the design and development phase, prior to the 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 and Processes Control Plan delineates the manner in which the contractor will meet the requirements imposed by MSFC-STD-506, *Materials and Process Control*, are met. The Manufacturing Plan specifies the tooling, facilities, schedule, critical processes, and the scheme for subsystem and final spacecraft assembly.

4.1.3.2.3 Software. Software is defined as the information content of a digital computer memory, consisting of sequences of instructions and data for the digital computer. (Firmware is this software converted into a form of read only memory, and becomes part of the system hardware.)

Software development is illustrated in Figure 3 as separate, but closely related to, the systems development. Once the systems functions are allocated to hardware and to software, the separate software implementation process begins. Finally, the hardware and software are brought together for systems integration testing and acceptance. Every software development proceeds through a sequence of life cycle phases.

Software contractual requirements are specifically detailed in the RFP, DPD, WBS, and SOW. The MSFC software organization is required to review the project's approach, to concur in the contractual implementation of the software development and management approach, and to participate in the SEB activity and contract negotiation.

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 systems requirements. The Preliminary Systems Requirements Specifications are updated during this phase, and the ICDs are drafted. Figure 4 illustrates the software functional requirements flow process.

Software design begins after the Software Requirements Review and concludes with a software design baseline at the Software Critical Design Review (SWCDR). A Software Preliminary Design Review (SWPDR) is an intermediate milestone during this phase. The results of the detailed design include the Software Detailed Design Specification, a Programmers Handbook, and the Software Test Specification and Procedure. These documents are baselined at the SWCDR.

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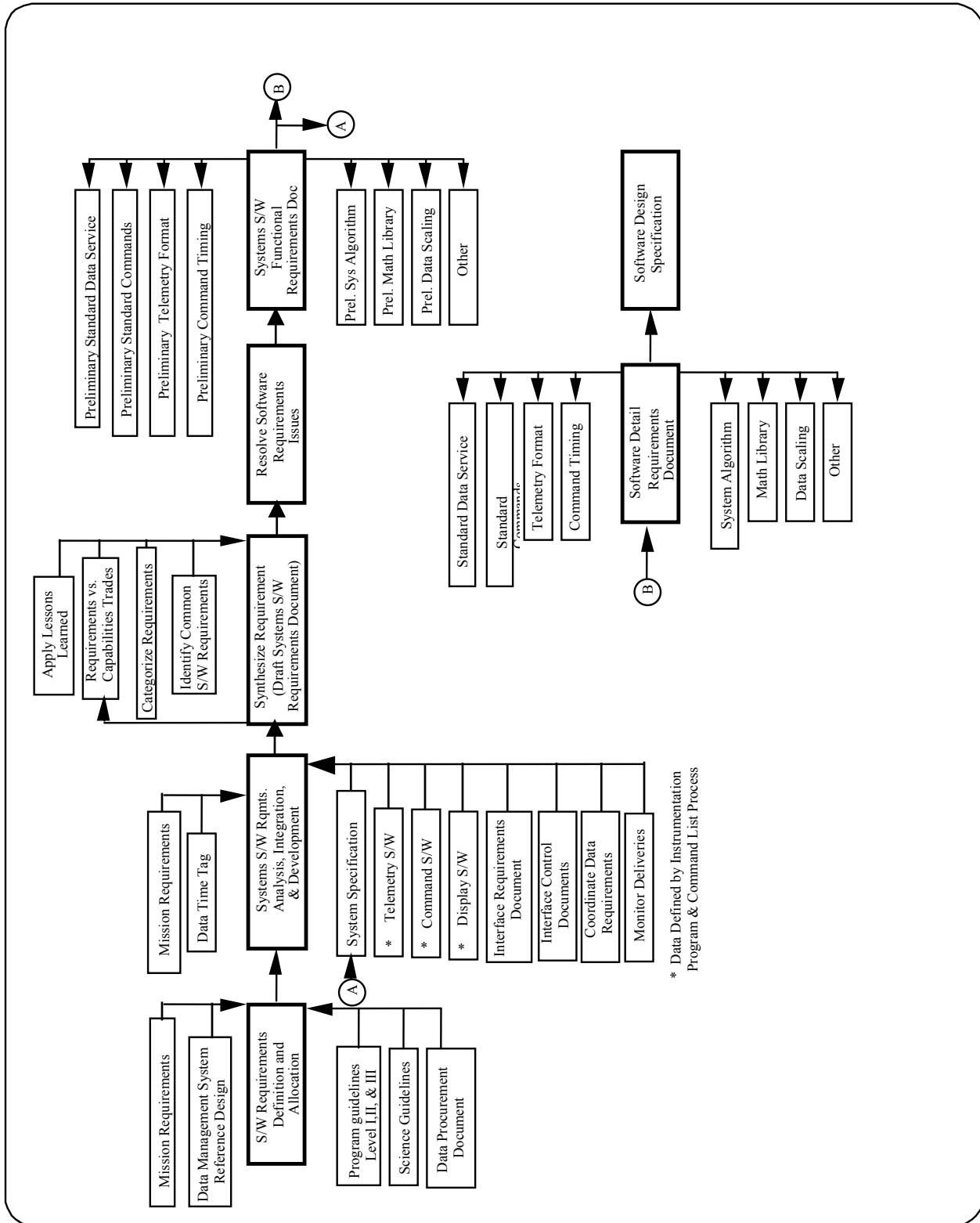


Figure 4. Systems Software Functional Requirements Process Flow

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The software is developed through coding and testing after the SWCDR. This level of testing is commonly referred to as “debugging.” At the conclusion of coding and debugging, a test review may be scheduled to assure conformance to test requirements and plans in the subsequent verification, validation, and systems integration tests.

Software verification is conducted on the debugged software by a group independent from the “coders and debuggers.” The software is checked against the Software Requirements Specification in a facility, which simulates a closed loop system using as much system or prototype hardware as feasible.

Software validation is a level beyond software verification in that more hardware is used in the testing. Emphasis is on system/software compatibility and subsystem performance. Validation is system integration testing with emphasis on assuring software performance within the system environment. In many projects, software validation is performed on the final product hardware (flight and ground) to ensure system compatibility. If validation is performed on an intermediate set, an additional validation is required: systems testing on the final hardware product. Systems level testing provides a final test of the software at the highest possible level of testing. The final software delivery and configuration inspection conclude this phase.

Software operations and maintenance runs for the life of the project and demands that the configuration control process be maintained. At the end of the project, the final software configuration and documentation become a permanent MSFC record in case a project is re-activated or the software is used in future projects.

Projects with software can be categorized into three types according to size: (a) small, (b) medium, and (c) large. The three categories also correspond to the degree of complexity: (a) simple, (b) moderate, and (c) complex; and to the number of interfaces either with external systems/subsystems and organizations: (a) none, (b) some, and (c) many.

These generic project models (Category a, b, or c) must be selected with great care by the project, with the assistance of the MSFC software organization. This selection is very critical in determining the degree of MSFC technical monitoring, cost control, and visibility into the software development. For example, the project/program must avoid a false sense of low cost by choosing too simple a category in hopes of less documentation costs. The software costs will seek their own level in accordance with their real complexity despite a wrong choice of category. A proper choice will aid the project in controlling and minimizing costs by application of the proper degree of management controls at the outset instead of retroactively. The same approach is applied to in-house MSFC projects as it is to contracted, inter-Center, or inter-Agency projects.

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4.1.3.3 System Integration and Verification.

4.1.3.3.1 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, 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.

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.

4.1.3.3.2 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. 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. 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.

4.1.3.4 Mission Implementation (Launch and Mission Operations). Once verification is accomplished, the project is ready to proceed into implementation of the mission, which includes launch operations and mission 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 testing, the mission operations preparations are finalized.

Final project reviews including the FRR are conducted (see 4.3.6.1.11) and launch is approved. During mission operations, the mission is executed. The execution of mission 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

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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. Mission operations may vary from the project being autonomous (requiring no ground intervention) to requiring a continuously active crew of ground operations personnel for commanding the flight system and receiving and processing flight system data.

The most important part of the mission implementation, 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 analysis.

4.1.3.5 Post-Mission Phase. Some projects may have a post-mission activity that includes satellite disposal (atmospheric burn-up or controlled de-orbit). 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 disposed. 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, it 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 is typically collected during a mission. In some cases data is retrieved post-mission. Data is 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.

4.2 Project Team Organization.

4.2.1 The Project Organization. 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

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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 will find that it 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.

4.2.1.1 Project Manager. The Project Manager is the accountable individual charged with 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 those goals. The Project Manager is responsible, in accordance with NASA and MSFC management directives (many of which are referenced herein), 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 his or her authority via a clear 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.

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 will 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 Office organization is shown in Figure 5. There are

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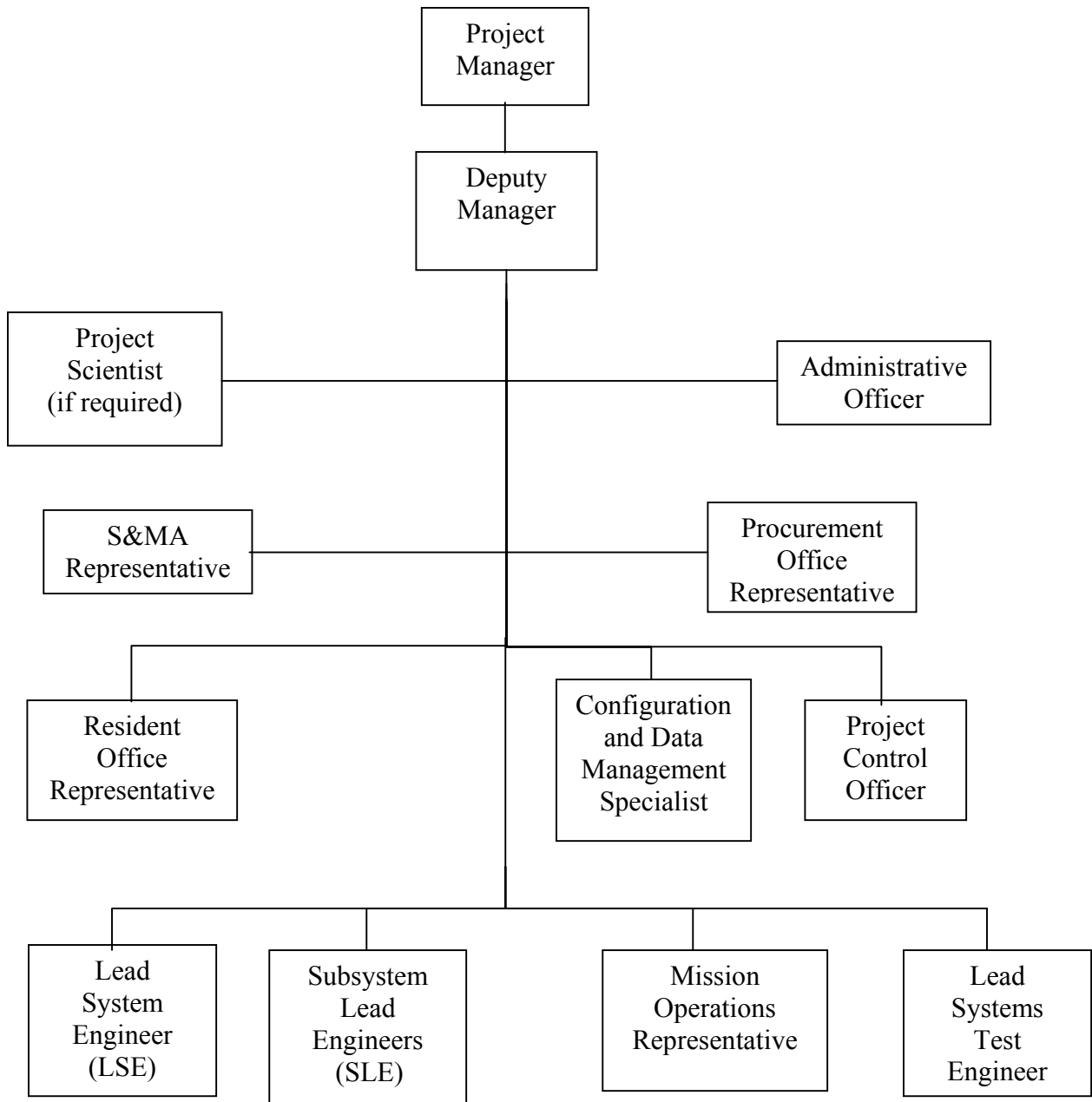


Figure 5. Typical Project Office Organization

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some 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.

4.2.1.2 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 system engineering practices are being followed. The LSE oversees the project system engineering activities, including in-house and contractor responsibilities, to assure they are adequate and are 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 subsystems 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 systems 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 requirements development, verification planning, interface control, system level risk management, and integration activities. Many of the product lines have established a Systems Team within their Directorate that is responsible for developing requirements documentation, verification documentation, and interface control documentation. The LSE also is responsible for identifying and overseeing system trade studies to determine the overall system effects of proposed changes to requirements and/or design. The LSE also leads the team effort of flowing system level requirements to the subsystem level, and works with the Subsystem Lead Engineers (SLEs) to ensure that system level requirements flow to the component level. The LSE is responsible for establishment of the Level IV Configuration Control Board (CCB) (see 4.3.4.2 for CCB descriptions) as authorized by the Project Manager.

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4.2.1.3 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 PIs serve in this role rather than a Project Scientist, the PI may also serve as the Project Manager.

4.2.1.4 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.

4.2.1.5 Safety and Mission Assurance Representative. Safety and Mission Assurance (S&MA) project support is provided through an S&MA individual in a co-located assignment to the Project Office. This individual will serve as the representative for the project. In this capacity, the S&MA Representative will: (1) assure an independent S&MA overview and assessment is provided for the project; (2) be responsive to requirements and needs of the Project Manager; and (3) serve as the communications channel between the Project Office and the S&MA Office assuring proper coordination of Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA) requirements and practices. If no co-located assignment is made, the S&MA Office will assign an individual as the primary point of contact for S&MA activities.

A system safety engineer will be assigned to advise the Project Office in development of the safety requirements for the project and to participate in assessing the adequacy of the resulting safety effort. System safety support is initiated with a thorough review of all RFPs prior to their release to verify that the proper safety requirements are being applied. The S&MA Office will also: (1) assist in the evaluation of proposed safety programs; (2) assist in the technical assessment of the safety of the proposed configurations; (3) participate in program reviews (PRR, PDR, CDR, etc.) to assure the developing design is in compliance with the program safety requirements; (4) review (and prepare for in-house projects) project submittals to the Center Payload Safety Readiness Review Panel and to payload safety panels for NSTS payloads (both flight and ground operations); and (5) participate in safety audits of the prime contractor and

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selected subcontractors. When practical, the safety audits will be conducted as part of a joint audit with reliability and quality assurance elements.

4.2.1.6 Procurement Representative. The Project Manager's interface to the Procurement Office is a Procurement Office Representative in a co-located assignment to the Project Office. 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 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.

4.2.1.7 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.

4.2.1.8 Configuration and Data Management Specialist. The Project Manager's contact for configuration and data management is the Configuration and Data Management (CDM) Specialist, co-located from the Engineering Systems Department to the Project Manager's office. The CDM Specialist is responsible to the Project Manager for ensuring initial baselining and control of project requirements and design evolution configurations, and the implementation and administration of project data requirements. The CDM Specialist also ensures direct configuration management support for in-house change control and integration and for document/drawing release. The Specialist is responsible for implementing the project's applicable CCBs. The Specialist, or an individual designated as the Organizational Data Manager (ODM), assists the Project Manager in structuring and developing the data requirements and collecting information consistent with project needs.

4.2.1.9 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. The representative does not generally provide

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contractor technical oversight. As in all functions of the project, the Project Manager is responsible for project contractor management and for contract execution.

4.2.1.10 Subsystem Lead Engineer. The 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 4.3.7.3. The SLE is responsible for the technical performance of their subsystem. 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.

4.2.1.11 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 systems 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 4.3.7.4.

4.2.1.12 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.

4.2.2 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.)

4.2.2.1 Product Line Directorates Organization.

4.2.2.1.1 Chief Engineer. The Chief Engineer is a key member of the Product Line Directorates 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. They provide a peer-review of the technical aspects of the projects, for both in-house and contracted projects, to assure technical adequacy

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and ensure that the right technical skills and tools are applied to accomplish the project's technical requirements. The Chief Engineer often serves as a mentor and advisor to Directorate systems and discipline engineers, and 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. They work 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.

4.2.2.1.2 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
- Human Engineering

4.2.2.2 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, these 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

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become more projectized while still leveraging off the benefits of a limited matrixed group.

The ED includes the Engineering Systems Department, the Materials Processes and Manufacturing Department, the Structures, Mechanical & Thermal Department, and the Avionics 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 will depend on the needs of the project, skill levels available, 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 task is the contract between the Project Office and the ED and is established for a term of one year. It is 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.

4.2.2.3 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 systems engineering functions related to space systems program/projects, including requirements development and requirements flow-down, systems 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 Independent Assessments, Non-Advocate Reviews, Independent Annual Reviews, 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. They continue to develop NASA-wide cost and schedule estimating

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techniques that are used by MSFC and other NASA Center's 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, *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*. This important function covers all MSFC projects and encompasses the export control to 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.

4.2.2.4 Safety & Mission Assurance Office Support. The S&MA Office includes the planning, establishment, and implementation of the assurance program. For each MSFC project, the S&MA Office provides safety, reliability, maintainability, continuous risk management, and quality assurance technical services, an independent overview and assessment, S&MA status/concerns, and special analyses such as Failure Mode and Effect Analyses (FMEA) and hazard analyses, and development of a Critical Items List (CIL). This 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 support for the project is led by the S&MA representative assigned to the project.

4.2.2.5 Center Institutional Support.

4.2.2.5.1 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.

4.2.2.5.2 Center Operations Directorate. The Center Operations Directorate provides support to the project when planned project activities have the potential for

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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. This will 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 in 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 coordinators 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, radio frequency 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

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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. Early communications feasibility engineering for lease or contracting workloads for Implementation Phase is essential. 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 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. This individual will determine the need to participate in all critical program reviews and will function as a program management team member.

4.2.2.5.3 Customer and Employee Relations Directorate. The Customer and Employee Relations Directorate provides support to projects through employee training and other personnel services, managing the projects 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

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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. They are 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 that they have access to the information needed to effectively prepare these 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 newsmen. 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 newsmen will contact managers directly. This is acceptable, but managers may want to keep the MRD informed of such developments and should not hesitate to consult with the MRD regarding any aspect of news issuance. Information given to the press shall in all cases be "on the record" and attributable to the NASA spokesman. Any NASA employee providing material to the press will be identified as the source and may not request non-attribution. Project Managers are encouraged to consider the Media Relations specialist assigned to their particular functional area as a public and media relations advisor, 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 speakers bureau, and Project Managers should participate and encourage project participation in outside speaking engagements.

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

It is the Center's policy that all persons visiting MSFC will be accorded every courtesy, special protocol as entitled, and assisted in every way practicable. Relations with foreign nationals should be conducted so as to maintain authorized scientific and technical information interchange on a reciprocal basis. This Center supports visits by foreign nationals/representatives for the conduct of technical discussions and/or the advancement of mutual work under agreements or memorandums of understanding. It is a basic requirement, however, that all such visits be planned and conducted in strict compliance with the current MPG 1371.1, *Procedures and Guidelines for Processing Foreign Visitor Requests*, when these visits pertain to areas of technical information identified for early domestic dissemination only. Furthermore, any foreign national/representative visit should reasonably be expected to result in some degree of benefit to NASA and must be approved in advance by appropriate management levels at MSFC and NASA. MSFC security requires two weeks lead time to process all foreign national visitor requests. For any foreign national/representative visit where information of a technical nature may be discussed, prior approval must be obtained through the Center Export Administrator in the SMO. This is especially true for the dissemination of non-verbal technical information.

The Project Manager should ensure project related foreign national visit approval by NASA Headquarters (in accordance with MPG 1371.1) prior to the visitor's arrival at the Center. The MRD is available to assist with visitor requirements, including tours and social activities.

4.2.2.5.4 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 establishment of Resources Authorization Directives (RADs), assigning resources authority to the Project Offices, tracking procurement requests and other commitment activity against the RADs, and preparing the recurring and ad hoc financial reports reflecting commitment, obligation (contract), and cost status. 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 Center Resource Planning System (CRPS), the Marshall Accounting and Resource Tracking System (MARTS), Center level oversight of project management application and development programs as well as earned value management system requirements, independent assessments of all Center projects,

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and the design and development of the NASA Integrated Financial Management Program (IFMP).

4.2.2.5.5 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).

4.3 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. 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 Contract Management.

4.3.1.1 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, *The Evaluation of Contractor Performance under Contracts with Award Fee Provisions*. This document describes the responsibilities of the Project Manager. 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

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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.

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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 Federal Acquisition Regulations identify these functions involved in contract management and specifies 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; quality assurance; industrial safety; and other functions that may be delegated by the Contracting Officer.

In addition to deciding on the type of contract, 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 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 2 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)

4.3.1.2 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

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and limitations imposed on the amount of cost that will be accrued on a program within a fiscal year. 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.

Costs are defined by cost element (direct or indirect), function (engineering, manufacturing, etc.), and WBS element. It is imperative that the contractor's cost reports be compatible with the technical and schedule reports at the prescribed WBS level and with the contractor's disclosure statement.

Direct costs are those costs that can be identified to a specific contract. These costs normally include direct labor, material, purchased equipment, travel, etc. Indirect costs are those costs that cannot be identified to a specific contract but are required for contract performance. These costs include fringe benefits, overhead (or burden), material procurement expenses, and General & Administrative (G&A) expenses (i.e., plant management, general office employees, legal counsel, and corporate expenses).

4.3.2 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 Project Manager's performance will be measured on how successfully he or she uses these two resources to accomplish project objectives within the project requirements baseline for funding and schedule. The Center civil service manpower provides the management and technical expertise to manage the contracted effort and in-house tasks.

The Project Manager's task is to successfully accomplish the technical performance and required hardware and software deliverables to a cost plan that can be accommodated within approved project funding. The fundamental challenge in this process is to manage the project to achieve technical, schedule, and cost objectives to the established baseline. The Project Manager must maintain knowledge of project status, and identify and scope problems early that can be solved by trade-offs within the capabilities of the baseline or, where this is not possible, identify necessary technical, schedule, and cost requirements to change the baseline in a timely manner that will support the Agency budget requests to Office of Management and Budget (OMB) and the Congress. Cost problems that result from underestimation or unforeseen technical or schedule problems must be identified and scoped early by the project office before they become unmanageable and result in project overrun elsewhere or termination. The functions and activities described in 4.3, along with the funding, costs, and manpower planning and status systems described, provide the necessary tools to the Project Manager.

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4.3.2.1 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 a successful cost planning and control effort 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.
- **Work Breakdown Structure:** Work planning and accounting, performance measurement, 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.

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- **Management of Changes:** Proposed changes must be thoroughly understood and questioned. Potential impacts on performance, cost, and schedule must be defined. Possible future changes are submitted utilizing NASA Form 533. Work planning and scheduling and performance and cost reporting procedures should also be employed in tracking the progress of major changes.

Other techniques and procedures for cost management exist and can certainly be viewed as belonging in the category of the above four. One technique that should be mentioned again is the management of changes. Proposed changes must be thoroughly understood and questioned. Potential impacts on performance, cost, and schedule must be defined. Possible future changes are submitted utilizing NASA Form 533. Work planning and scheduling and performance and cost reporting procedures should also be employed in tracking the progress of major changes.

4.3.2.2 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, resulting in a project operating plan. NASA uses this approach to plan, balance, and allocate funds. The Program/Project Operating Plan (POP) process begins with a request, Fiscal Year (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 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 Project's fiscal year operating plan. 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, fiscal year 2001 authority must be obligated no later than September 30, 2002.)

4.3.2.3 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.

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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.

4.3.2.4 Internal Reporting.

4.3.2.4.1 Center Resource Planning System. The CRPS is the official system for presenting and determining workforce planning numbers. It is an integral part of MSFC's budget execution process in that it 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 CWC's; which essentially are task agreements agreed to by Center requesting and 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). Until the system is fully operational, the Center currently uses the Workforce Information System (WIS) database for tracking actual civil service workforce data. Center offices use the WIS for workforce queries and for imports to planning documents on Excel spreadsheets.

4.3.2.4.2 Marshall Accounting and Resource Tracking System. The MARTS is the primary financial computerized system used internally by MSFC. System output is considered as the official MSFC position regarding actual charges to MSFC programs to be reported externally in Financial Accounting and Tracking System, POPs, budget estimates, and miscellaneous reports. The MARTS labor system is the input source for

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labor hours to the WIS. Likewise the project offices use the MARTS labor dollars for importing to their internal systems, and/or ad hoc requests are performed by the CFO.

4.3.2.5 Earned Value Management. 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 Earned Value System (EVS).

The requirements of MWI 5116.1, *Evaluation of Contractor Performance Under Contracts with Award Fee Provisions*, 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.

To express schedule in dollars, it is necessary to convert contract tasks, which were expressed heretofore in time, to a budget by estimating the resources (man-hours, materials, services, etc.) required for that task, and then time-phasing that budget over the length of its schedule duration. Now it is possible to determine how much of the schedule should have been accomplished (baseline) in dollars, how much was actually accomplished (performance) in dollars, and what were actual costs in accomplishing the work. The comparison of these three factors gives an accurate posture of that task, and if all contractual tasks are measured the same way, the total contract posture.

For the criteria to be effective, it is imperative that the contractor in question has a management system containing certain basic desirable features that, if operated in a systematic manner, will be capable of providing credible management information to both contractor and NASA Project Managers. Today, a basic objective of the NASA is to use the contractor's operating internal system to avoid duplication of systems, eliminate the need for transposition of data solely for NASA's use, and assure that the data received is valid, reliable, and from the same data base that the contractor uses to manage. While no two contractors' management systems are alike, all must contain formalized procedures for (1) defining the work to be done; (2) identifying each element

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of work (WBS) and the logical sequence of performance for each element (precedence network); (3) assigning responsibility for the work to individuals or organizations; (4) authorizing, scheduling, and budgeting the work to be performed; (5) determining the value and actual cost of work completed; (6) estimating the time and cost of completing remaining work; and (7) providing a means of showing progress toward meeting the contract. These functions are carried out within the framework of the contract, which establishes limits or targets in terms of cost, schedule, and technical goals. 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 systems 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 6). 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. It provides a point at which actual costs can be accumulated and compared to budget costs for work performed before summarization to higher reporting levels.

Once the tasks have been defined and organizational responsibilities have been determined, the work can be scheduled and budgeted. Each organization receives a separate budget for each WBS element that it must support. These budgets form the contract baseline for the entire scope of contractual or in-house effort. Since all the work must be scheduled, the entire contract budget is time-phased accordingly.

Each organization further subdivides the work into short span units of work (usually called work packages) that can be accomplished by individual operating organizations. (It should be noted that work packages may be further subdivided into individual job

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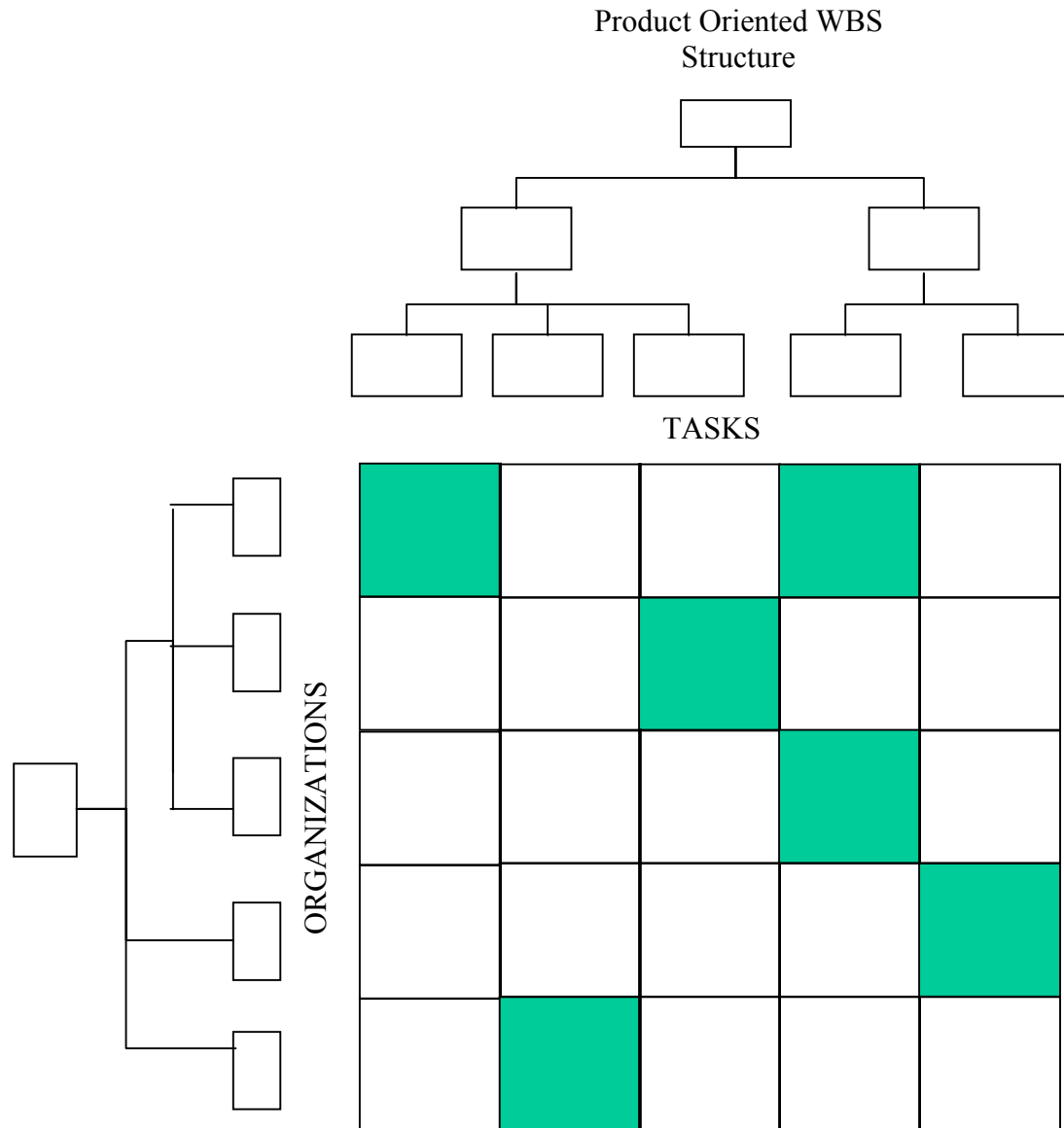


Figure 6. WBS Element/Functional Organization

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;

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- 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, to start over, thereby losing visibility of undesirable trends. Rebaselining should, as a rule, occur no more frequently than once per year. In the interim, the progress of the large majority of cost accounts which are not affected by project changes can be judged via the EVS with that of affected ("rebaselined") cost accounts judged on the Project Manager's overall understanding and feel for the situation.

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.

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.

It is intended that this requirement be made known to a potential contractor as early as possible during Formulation with actual implementation and demonstration of validation occurring during the first few months of Implementation. This will allow the contractor to formulate his management system in time for bidding and for smooth implementation of the system during early Implementation.

4.3.3 Requirements Management. Requirements Management is the process of establishing the project baseline 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 4.1.3.1

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discussed the process for establishing the baseline requirements through project requirements reviews, i.e., PRR and SRR.

Once projects have been through the formal PRR and/or SRR and the project baseline requirements are formally established, 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. Project management must be aware of proposed requirement changes to improve the system, or performance, if the system based on present requirements is adequate.

4.3.4 Configuration Management. Configuration Management (CM) is a formal and disciplined systems approach for the establishment and control of the requirements and configuration of hardware/software developed for NASA.

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 CM 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 CM support personnel are provided to projects, and direct CM 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*; and MWI 8040.5, *Floor Engineering Orders and Floor Engineering Parts Lists (FEOs/FEPLs)*, establish the basic policy and assigns responsibility for implementation of CM at MSFC.

Configuration management is basically composed of the following four major areas:

- Configuration identification

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- Configuration control
- Configuration accounting
- Configuration verification

4.3.4.1 Configuration Identification. Configuration identification is the definition and establishment of the total technical requirements 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, etc.). Configuration identification is established incrementally and is a product of the various project reviews as discussed in 4.3.6. The evolution of the configuration identification is depicted in Figure 7.

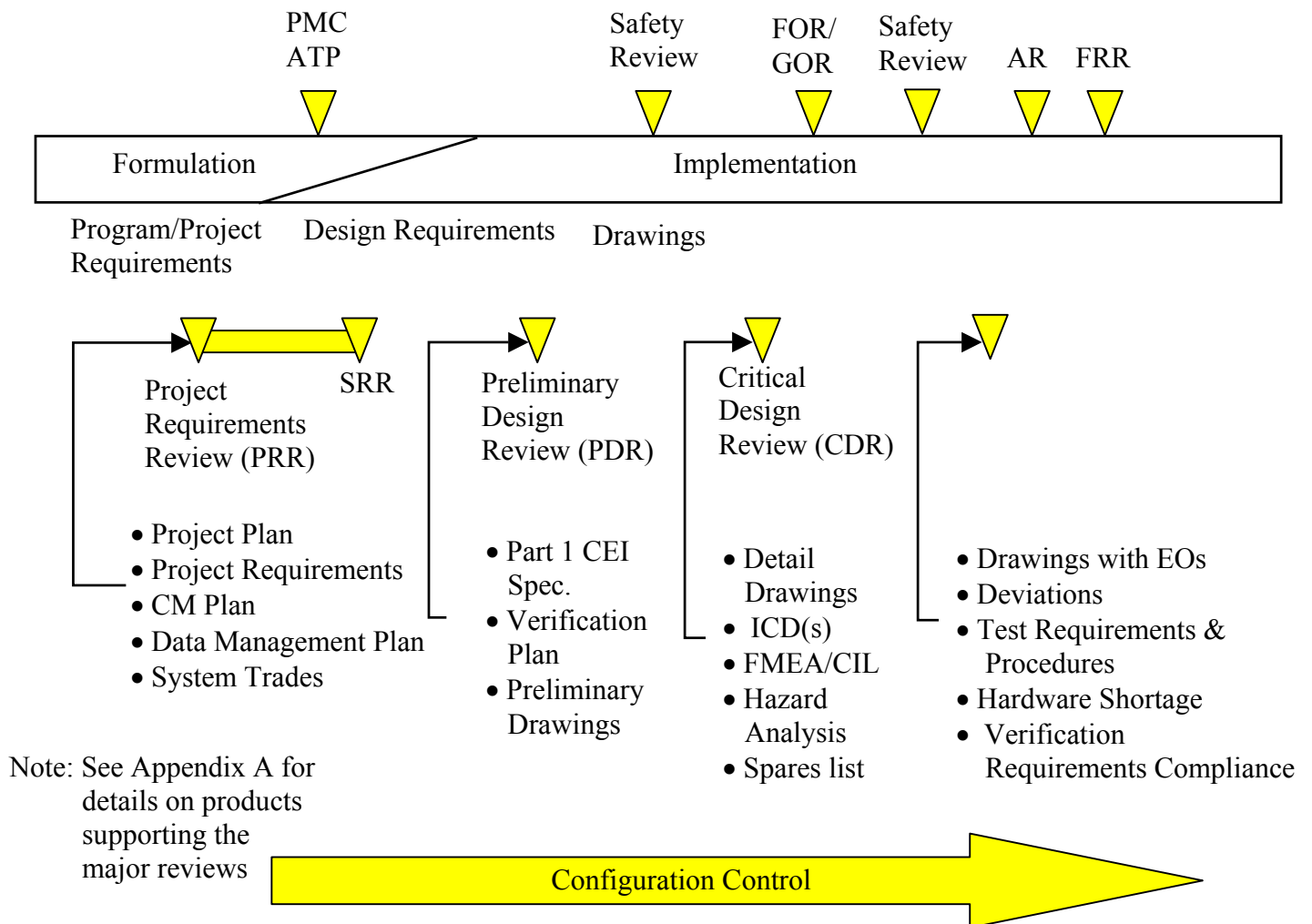


Figure 7. Evolution of Configuration Identification

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The Project Manager is required to develop and document management requirements as early in a project as possible. A Configuration Management Plan depicting the project's overall configuration management policies, requirements and procedures, must be a contractual requirement, classified as a Type 1 document. This plan then becomes the configuration management "contract" between MSFC and the contractor/design organization. A product of each plan is a procedures manual that defines specific policies, responsibilities, and functions, as well as detailed procedures.

Figure 8 depicts the various levels of plans and identifies the guidance documents and minimum operating plans and manuals.

4.3.4.2 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. 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 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.

The CCB membership includes the major organizations of the project, i.e., engineering, logistics, S&MA, program control, procurement, facilities, and others as deemed necessary by the manager. It is the responsibility of each CCB member to assure that all proposed changes are evaluated by the respective discipline/functional organization, and that the organizations provide a disposition recommendation and identified associated impacts. The CCB ensures that each proposed change is properly staffed and coordinated in order to provide the chairman with sufficient data concerning the detailed proposal and associated impacts (technical, cost, schedule, etc.) to properly determine the correct disposition of the change. The Project Manager, as Level III CCB chairman, is the final authority on the disposition of proposed level III changes. It is in

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the configuration control process that the Project Manager will devote a substantial portion of time and energy.

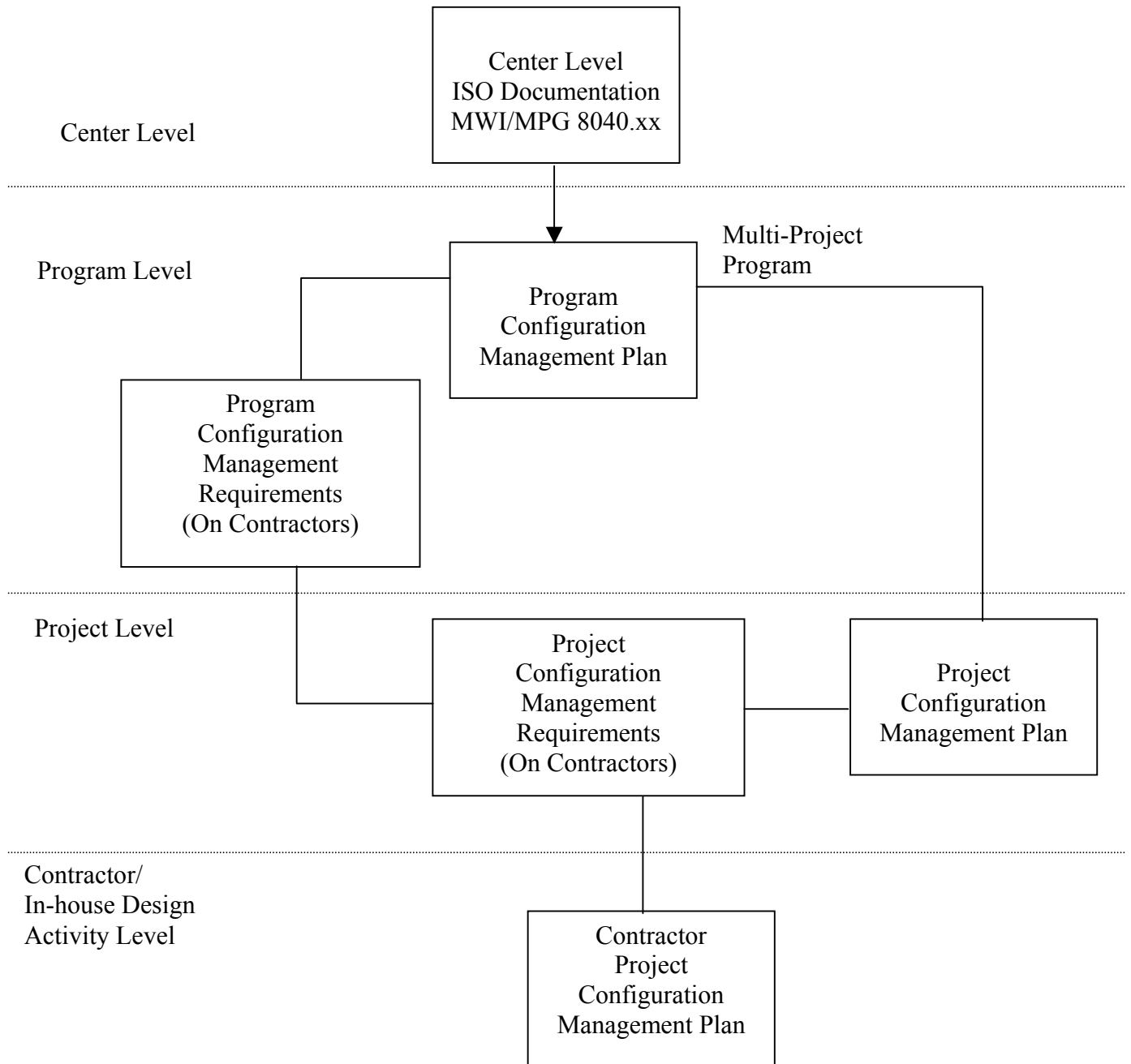


Figure 8. Configuration Management Documentation Tree

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In the process of assessing a proposed change, the Project Manager should assume a non-advocate position and delve deeply to assure that the change will both accomplish its intended purpose and not cause problems with interfacing elements. Organizations affected should be contacted to obtain all schedule impacts prior to issuing the formal CCB documentation. Care must be exercised to assure that a CCB does not authorize a change beyond its authority. Total impact definition/identification of effected elements are key factors to assure that changes are authorized by the proper CCB.

Change integration is a supporting function to configuration control that attempts to package all of the documentation pertaining to a given change in such a manner that the total effort is identified, all impacts are known prior to disposition, and the implementation status is accurately and currently defined. Proper change integration is a major contributor in assuring change disposition by the appropriate CCB.

A major tool in change integration is the Program Control Number (PCN). The PCN is the identifier assigned to the change package. It is not the change proposal identifier. Once a specific problem is identified and a change proposal is developed as a resolution for the problem, a PCN is obtained and assigned to the proposal in addition to the proposal's identification number. Upon receipt of the proposal, a change package is created. Likewise, proposals from other interfacing elements involved in the resolution of the problem will carry the same PCN as that assigned to the initiating proposal, and incorporated into the common change package. All of the associated documentation pertaining to this specific change will carry the same PCN.

Each proposal is tracked and ultimately dispositioned by the CCB unless the originator formally withdraws it. Likewise, all actions associated with the change are tracked until, as a minimum, contractual implementation of the proposal.

Change documentation is standardized to ensure that the required configuration management data, as well as engineering and program control data, are in compliance with MPG 8040.1. Additional change documentation may be used when directed by NASA Headquarters, or a lead Center. Classically, changes to the NASA baseline (performance requirements) are categorized as Class I, and required the Project Manager's approval. Changes that the contractor is authorized to make without NASA approval are categorized as Class II. The establishment of the classification of changes and approval authority is the responsibility of the Project Manager. Effective processing of changes requires timely and proper coordination and evaluation by all applicable organizations commensurate with program/project schedules. The configuration management control system must establish processing time spans and controls to meet this need. PCN packages (see above) serve to identify the various organizations, hardware/software, need dates, etc., affected by a given change. Figure 9 is a generalized representation of a flow for a typical change.

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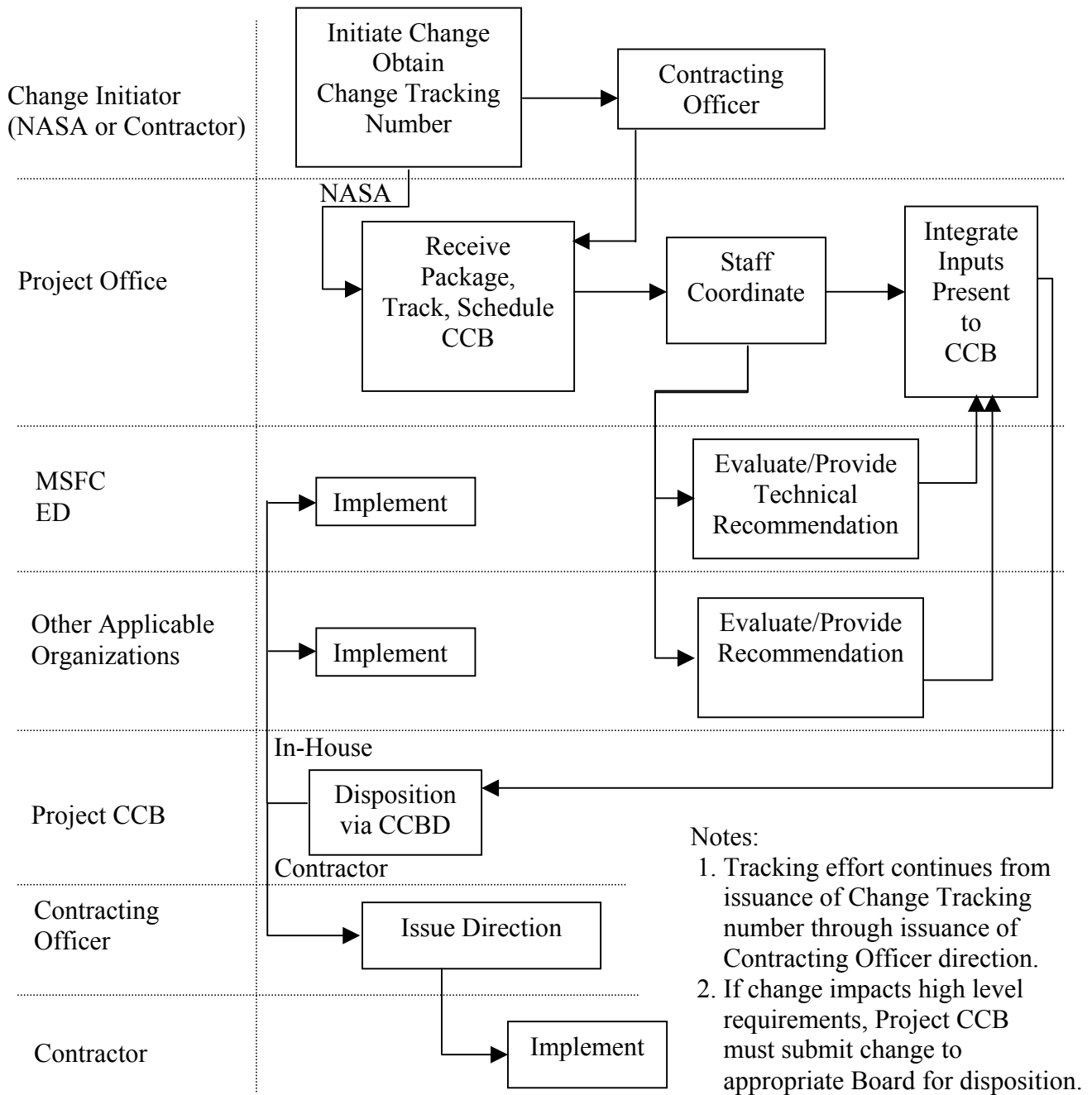


Figure 9. Change Process Flow

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4.3.4.3 Configuration Accounting. Once the NASA 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.

The NASA accounting system is used and recognized by NASA and the contractor(s) as the single authoritative source for the baseline definition. The types of data included in the system must be commensurate with the level of detail to which the project is managed. If the project is managed at the Engineering Change Proposal (ECP) level, then the accounting would track no lower than the ECP level.

MSFC uses an Integrated Configuration Management System for configuration control. The system helps Program and Project Managers maintain configuration control over their development, design and delivery/turnover activities.

4.3.4.4 Configuration Verification. Configuration verification is the task of ensuring that established baselines and subsequent changes to them have been incorporated into the contract and that resulting contract end 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 4.3.6.

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 contractually 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 contractually 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.

4.3.4.5 Data Management. Data management operates at all levels of project activity and is functional throughout the life cycle. At MSFC, data management for the early formulation phase of a project is performed by the organizations (or task teams)

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involved in that phase. Upon the Agency's initiation of a formal project and the establishment of the MSFC Project Office, the responsibility is transferred to the project organization managing the remaining phases of the project. The management of data within a project is assigned to the individual designated as the ODM. Under this focal point, further activity is organized and structured within the Project Office and the required data management functions to be performed at subordinate levels is defined, established, and implemented in accordance with MPG 7120.3, *Data Management, Programs/Projects*, and MWI 7120.5, *Data Management Plans, Programs/Projects*.

Data requirements will be levied on MSFC contractors and in-house development activities through the use of DPDs, Data Requirements Lists (DRLs), and Data Requirement Descriptions (DRDs). Data requirements management will be conducted with the maximum amount of uniformity consistent with the ability to satisfy the data needs, at the lowest possible costs, and with minimal staffing of the cognizant Center and contractor data management functions. A list of DRDs, their descriptions and definitions are defined in MWI 7120.2, *Data Requirements Identification/Definition*.

The ED's CDM organization is responsible for implementation and administration of Center-wide project data requirements. Detailed responsibilities for project data requirements management are contained in MPG 7120.3. The ED will serve as the Center Data Requirements Manager (CDRM) for data requirements common to both project and non-project activities. A Data Requirements Management System that includes descriptions of DRDs has been established at the following location:

<http://masterlist.msfc.nasa.gov/drm/>.

The ODM assists the Project Manager in structuring and developing the data requirements and collecting information consistent with project and institutional needs. The ODM assures that requirements are met, that documents are properly approved and released when required, and provides required direction to other involved project or support organizations. The ED provides the principal data management support described below to the project. The CDRM is the MSFC control point for institutional data management coordination and as such provides guidance and assistance to the project in complying with Agency and Center requirements. The CDRM is responsible for maintaining the DPD log, supplying the forms used, and assigning MSFC document numbers except for those technical documents released through the ED Engineering Release function to the MSFC Documentation Repository. Documentation Repository receives, indexes, catalogs, retrieves, and distributes documents for all Center elements, including those prepared by contractors for MSFC, and maintains the document records. The repository assists the project in formulating project media, quality, and delivery requirements, furnishes copies of filed data, and processes those documents received from project sources. The Procurement Office assists in defining contracted requirements, and assures these requirements, most of which are in the DPD, are included in appropriate procurement documents. It negotiates the requirements and, afterward, administers the procurement. Some other organizations

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also support the project by furnishing data used by the project, and provide reproduction, mail, shipping, and records retirement services.

The data management function, its organization, and the documentation approach are often described in the Project Plan. The project's generic document structure can be included in the plan or as part of the Configuration Management Plan in a form similar to and developed from Figure 10, Project Baseline Documentation. A project may elect to have a stand-alone Data Management Plan.

The structure is generally uniform for all projects except for that portion controlled by Center and project management. This portion must be specific for the project to reflect decisions regarding the numbers and types of documents required for project operation, the implementation of requirements, and the extent of project control or use of data prepared by performing activities. Based on the Project Plan, data requirements and operations are further defined, existing documents obtained and distributed, and plans made to procure documents needed in the future. The data to be procured is specified in individual DPDs prepared for each source.

4.3.5 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, and risk mitigation. MWI 7120.6, *Program/Project Risk Management*, 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 program due to technology considerations (i.e., new designs, materials, processes, operating environments), availability of vendors, failure modes, schedule optimism, margin allocation, and requirement stringency. System engineering is heavily involved in assisting the Project Manager 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.

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 Technical Interchange Meetings) using existing risk management tools (e.g., FMEA Critical Items List (CIL), Fault Tree Analysis, and Probabilistic Risk Assessments). Project events such as development testing, schedule deliveries, and cost expenditures

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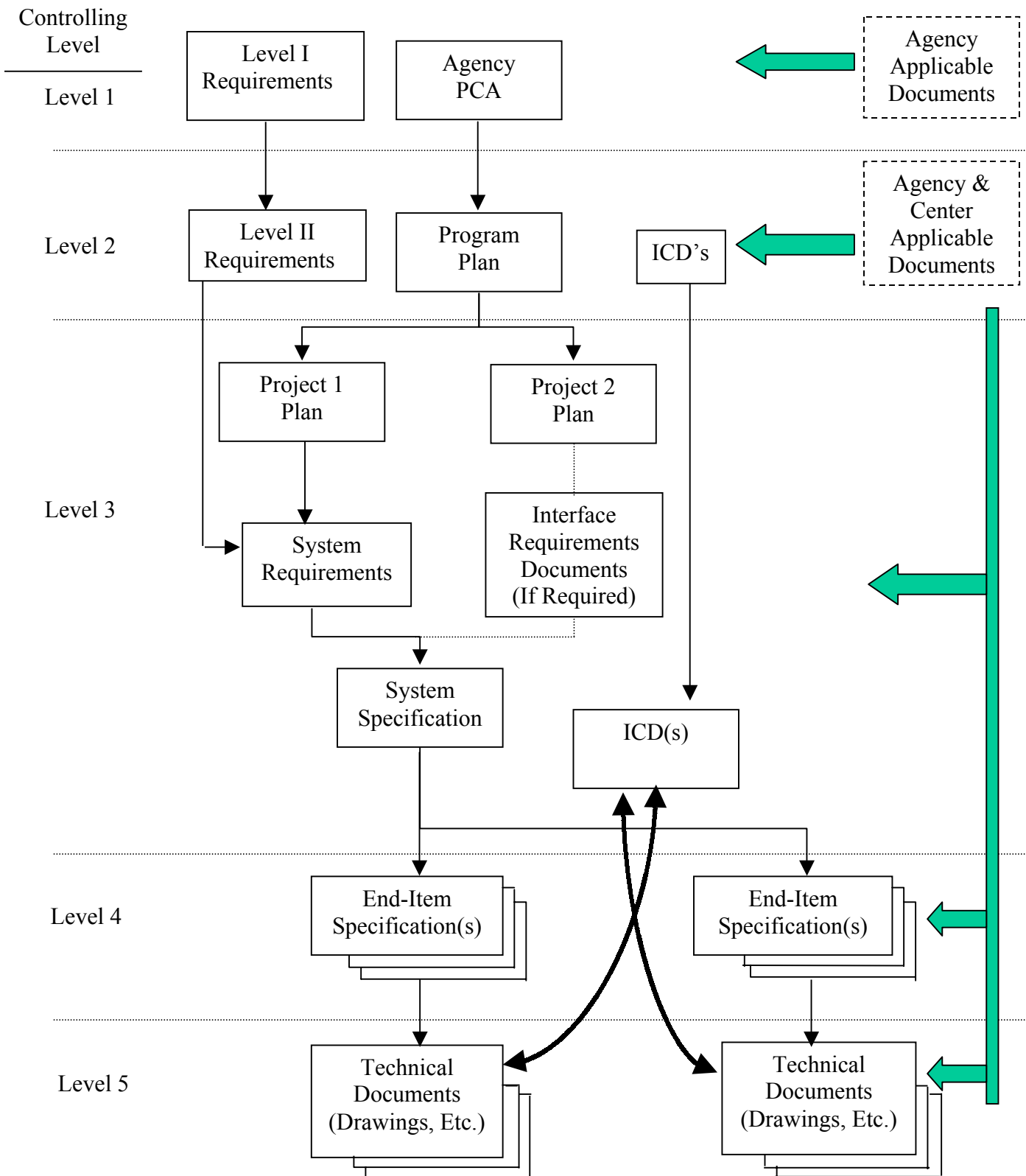


Figure 10. Project Baseline Documentation

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are also monitored. Any deviation from expected results will trigger alternate implementation actions if the proper identification and mitigation planning has been accomplished.

4.3.6 Project Reviews. Project reviews generally fall into three categories: (1) those associated with discharging design, development, delivery, and operational responsibilities; (2) those associated with reviewing status, acquiring resources, reporting utilization, and reporting program status; (3) those 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. They provide the mechanism by which one assesses performance, acquires managerial confidence, enforces technical and programmatic discipline, and conveys requirements and progress. Technical reviews, in particular, must be thoroughly planned and interrelated from near program 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. As a rule PDRs are held when design is approximately 50% complete with 10% of the drawings available. The CDR is held when design and drawings are 90%-95% complete. These reviews are to establish technical baselines for the purpose of controlling requirements/configuration as the program evolves through the implementation phase. Precautions should be taken to ensure that these controls are not confused with, or take the place of, contract scope control.

While it is recognized that some of the following reviews may be properly categorized as either, they are listed below as technical or programmatic. 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 the review may be called by another name on any given project, and other reviews, principally operational oriented, will be required depending on the specific project.

Technical Reviews:

- Project Requirements Review (PRR)
- System Requirements Review (SRR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Functional Configuration Audit (FCA)/Physical Configuration Audit (PCA)
- Acceptance Review (AR)
- Test Readiness Review (TRR)
- Design Certification Review (DCR)
- Ground Operations Review (GOR)
- Flight Operations Review (FOR)

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- Flight Readiness Review (FRR)

Programmatic Reviews:

- 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 is prepared for each review that defines the details of the review. The Review Plan describes the conduct of the review, the data included in the review, 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 thoroughly and accurately closed out and their effect on the project properly implemented. Although there may be a climate after such a review of relief or let down, the follow-up work must be pursued aggressively. This 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 technical review; or specific, separate provisions must be made for such reviews. For the purposes of this section, it will be assumed that they are inherent in the listed 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.

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4.3.6.1 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, it is mandatory that summaries of the results be included in the overall, comprehensive reviews to assure that the incremental activity is compatible and satisfies project requirements.

The certification reviews (see 4.3.6.1.5 through 4.3.6.1.9) 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 they are conducted as identified in the following paragraphs. (See Appendix A for additional information and examples of data supporting many of these reviews).

4.3.6.1.1 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 quality assurance 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 Certification of Flight Readiness (COFR) and what level of technical penetration is required. Products from this review will support the SRR.

4.3.6.1.2 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 Systems Specifications are sufficient to meet project objectives and that systems engineering processes are in place. This review 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 management control. The SRR is chaired by the Project Manager.

4.3.6.1.3 Preliminary Design Review. The PDR is conducted when the basic design approach has been selected and the necessary documentation is available (usually when design maturity is approximately 50% and drawing release is 10% complete). PDRs may be conducted at the program level and/or the project level. This is a

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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; and
- Test and demonstration planning, safety, risk, reliability and maintainability assessment, and producibility should be addressed, as well as 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 of the Part I CEI Specification and its placement under configuration control. In the event a Part I CEI Specification has been previously placed under CCB 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 CCB control. As a minimum, the PDR should establish interface requirements and establish a basis for continuing the ICDs.

4.3.6.1.4 Critical Design Review. The CDR is the technical review of the detail design of the selected configuration. This review is generally held when the design and drawings are approximately 90 to 95% complete and provides assurance that the detail design is in accordance with the Part I CEI Specification prior to its release to manufacturing.

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 contract end item specifications.

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 ICDs, and the detail drawing control remains with the

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design contractor for contracted items. If not previously baselined, all ICDs should be baselined and placed under CCB 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.

4.3.6.1.5 Design Certification Review. The DCR (sometimes referred to as Functional Configuration Audit (FCA)) is conducted to evaluate the results and status of verification planning, testing, and analysis and basically to certify the design. Generally, the DCR is scheduled after CDR and prior to FRR; but depending on program structure, they 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. It should be noted that the ISS employs the Functional Configuration Audit in lieu of the DCR; however, it performs the same review function.

4.3.6.1.6 Configuration Inspection Review. The CIR (sometimes referred to as Physical Configuration Audit (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 basically accomplished by a comparison of the “as-built” configuration to the “as-designed” requirements. The CIR is a one-time review conducted for each family of CEIs.

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

The product of the CIR 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 CIR will be scheduled by the project management to be compatible with implementation of the Part II CEI Specification. It should always occur prior to turnover responsibility from one organization to another (e.g., prior to NASA acceptance).

It should be noted that the ISS employs the Physical Configuration Audit in lieu of the CIR; however, it performs the same review function.

4.3.6.1.7 Acceptance Review. The AR (or FCA/PCA) is the final review conducted for product delivery and NASA acceptance. It 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

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equipment, support software, etc. All aspects of qualification, verification/validation, and acceptance testing are addressed. The Acceptance Data Package (ADP) with supporting documentation, is examined for compliance with project requirements and that all open/deferred work identified and disposition plans 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.

4.3.6.1.8 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 safety assessment, including institutional, will be of highest priority during the review process, assuring safety of personnel, facility, and test article hardware. The TRR must be conducted prior to all hazardous testing. TRR's for other non-hazardous testing are conducted as required by the Project Manager and performing test organization.

4.3.6.1.9 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.

4.3.6.1.10 Flight Operations Review. The Flight Operations Review (FOR) ensures that the flight operations planning and flight support requirements have been defined and the necessary resources have been planned and allocated. 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).

4.3.6.1.11 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. Understanding early where to and how much penetration will be required to gain the proper level of insight/oversight is essential for successfully conducting the FRR. It includes review of the system verification process (both testing and analysis), system compatibility, operational planning, and team preparedness. The review will result in certification of flight readiness of the operational team, the acceptability of the system for flight, and the readiness of the system to achieve all flight objectives.

4.3.6.2. Programmatic Reviews. Programmatic reviews are less rigorously defined than technical reviews. Thus definition, frequency, content, and format will depend in large measure on the individual requirements of the project. There are, however, a

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number of typical programmatic reviews and review objectives associated with a MSFC-managed project. Those are elaborated briefly 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.

4.3.6.2.1 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, in essence, establishes the Project Manager's "contract" with Center management and Headquarters. It creates, as it were, 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.

4.3.6.2.2 Annual Manpower Review. Prior to the beginning of any given 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.

4.3.6.2.3 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 elements 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.

4.3.6.2.4 Project Management Council. Approximately twice per year, a comprehensive project review is held with the Center Director using the MSFC PMC and the GPMC. 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. Figure 11

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illustrates the various reviews and how they interface with the PMC while Figure 12 illustrates the MSFC PMC's interface with other GPMCs.

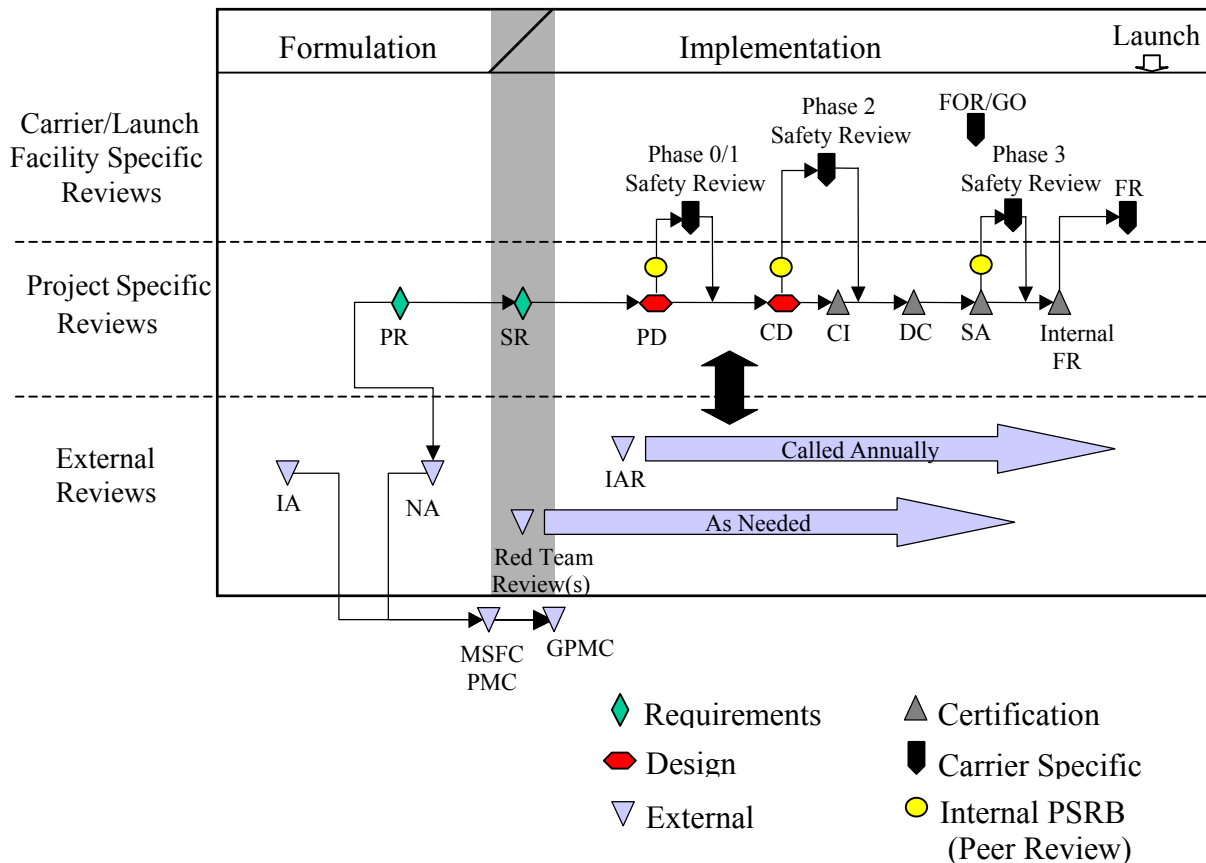


Figure 11. Milestone Reviews and MSFC PMC Interfaces

4.3.6.2.5 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, however that the Program Manager is provided all data required for effective direction and advocacy of the program.

4.3.6.2.6 Monthly Performance Evaluation and Reporting to Center Management. Project performance evaluations are conducted monthly throughout the life of the project and status reported to Center Management to keep them 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 alert both to

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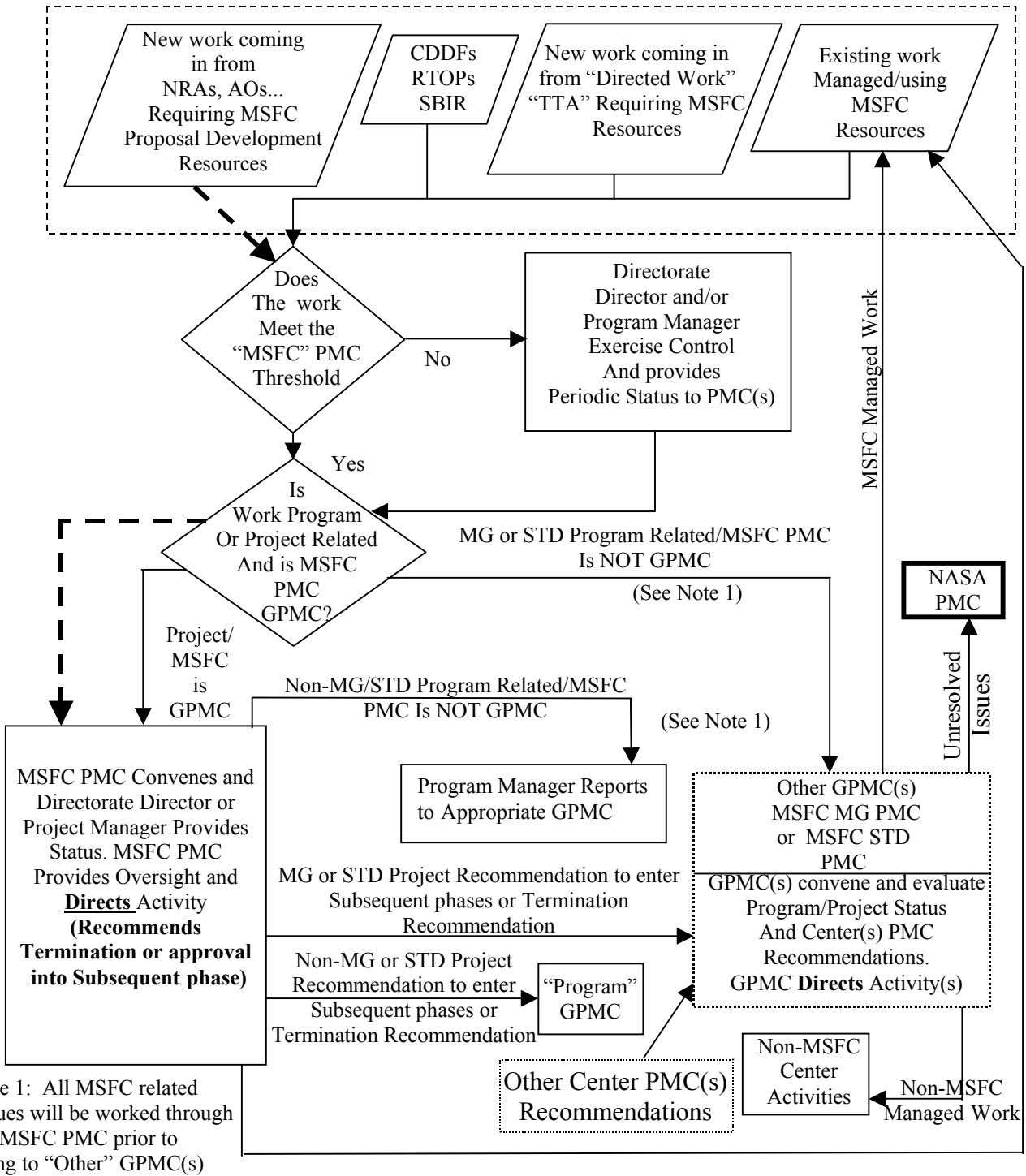


Figure 12. MSFC PMC Interface Description with Other Lead Center GPMCs

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potential problems. The “Stop Light” tool is provided by the SMO and provides a standard approach using standardized criteria.

4.3.6.3 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.

4.3.6.3.1 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, Life Cycle Cost (LCC), realism of schedule, risks and risks mitigation approaches, and technology issues.

4.3.6.3.2 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.

4.3.6.3.3 Independent Annual Review. The IAR is conducted annually throughout the implementation phase. The IAR is used to assess progress/milestone achievement against original baseline. The cost, schedule, and technical content of the activity is reviewed over its entire 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.

4.3.6.3.4 Phased Safety Reviews. In addition to MSFC Safety policies and requirements, projects that will utilize the NSTS must meet the requirements of NSTS 1700.7, *Safety Policy and Requirements for Payloads Using the NSTS*. Payloads for the ISS must comply with the NSTS 1700.7, ISS Addendum. The ISS hardware systems must comply with handbook SSP50021, *Safety Requirements for the ISS Program*, and projects utilizing the Kennedy Space Center 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*.

NSTS and ISS safety requires that all payloads flying on the NSTS 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

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Phase 0 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 SRR and combined with other safety related data in an integrated payload safety package for review. The Phase 0 review will assist the payload organization in identifying hazards, hazard causes, and applicable safety requirements early in the development of the project. Phase 0 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 purpose of the Phase I safety review is to obtain safety panel approval of the updated safety analysis based upon the preliminary design of the project. Hazard reports are generated for each hazard identified and means of eliminating, reducing, or controlling the hazards will have been identified prior to the Phase I review. The SRP and/or the PSRP will either agree upon the safety analysis and controls, or will instruct the project in areas requiring further work.

The Phase II Safety review is scheduled to be after the project CDR that typically represents a level of design completion of 90 percent, or more. By Phase II, hazards assessments and methods for controlling hazards will be mature and reflect the knowledge of the final design on the hazard reports.

The Phase III Safety review is normally scheduled in the same time frame as the DCR for the project. The purpose of Phase III is to obtain safety panel approval of the completed safety analysis and of the safety certification data. The review package will be based upon actual tested hardware, and reflect the final configuration for the project.

4.3.6.3.5 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

4.3.6.3.6 Red Team Review. The purpose of a Red Team Review is to provide an objective, non-advocate review of the plans and processes in place that ensure mission success and safety are being considered and implemented. It 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 its objective. A red team review is typically organized and chaired by a Directorate Chief Engineer.

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4.3.6.3.7 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 and SMO organizes and chairs the review. Review findings are coordinated with the Project Office and the GPMC is briefed by the Project Office. 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.

4.3.7 Technical Management. Technical management of the project refers to the management functions associated with the actual transforming the project requirements into a full-scale system which functions as necessary to meet the project requirements. It 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 Managers 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. For the purpose of this document, technical management has been partitioned into the functions discussed in the following paragraphs.

4.3.7.1 Safety and Mission Assurance

4.3.7.1.1 System Safety. System Safety is concerned primarily with the safety aspects of aerospace flight systems, associated ground support equipment, facilities and software, as well as ground and flight personnel safety. 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. It is to be emphasized throughout the life cycle of program flight systems, from inception through project 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, *System Safety Program*.
- Prepare a detailed design hazard analysis and safety assessment.
- Prepare an operational hazard analysis including flight and ground activities.

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- Prepare an integration hazard analysis.
- Establish an accident/incident reporting system.
- Participate in project milestone reviews (i.e., PRR, SRR, PDR, CDR, Design Certification Review (DCR), Flight Readiness Review (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 National Space Transportation System (NSTS)/International Space Station (ISS) Safety Panel Reviews (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 (JSC) and the NSTS Ground Safety Review Panel (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.

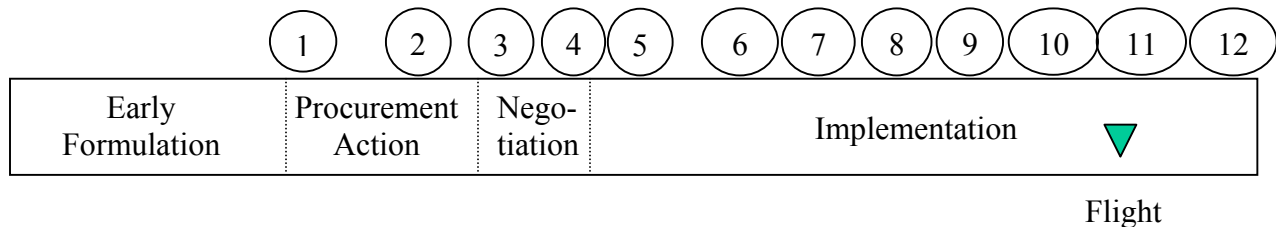
Assurance must be provided that RFPs include applicable programmatic system safety requirements adapted in compliance with NSTS 5300.4 (ID-2), *Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program Change No. 2*, and other S&MA requirement documents. NSTS payloads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

4.3.7.1.2 Mission Assurance. Mission Assurance functions for a project includes the quality, reliability, and maintainability activities described below. The total quality assurance activities that are to be utilized during any project phased planning activity at MSFC for major contracts are depicted in Figure 13. Smaller contracts are handled similarly.

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). This is accomplished by a complete review of these documents prior to release to ensure the incorporation of applicable portions of the NSTS 5300.4(1D-2) and/or ANSI/ASQ 9002, *Quality System-Model for Quality Assurance in Production, Installation and Services*, and other appropriate QA requirements. The project's Quality Plan

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and/or ANSI/ASQ 9001, Quality Management System Requirements govern the QA requirements for in-house projects at MSFC. Testing for in-house projects is governed by QS01-QA-004, *Quality Assurance Plan for In-House Manufacturing and Test*.



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|--|--|
| <ul style="list-style-type: none"> 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, Etc.) | <ul style="list-style-type: none"> 8. Progress Reports 9. Surveys 10. Problem Investigation 11. Reuse/Refurbishment Assessment 12. Production/Operations Surveillance |
|--|--|

(*) Prepare for In-house Projects

Figure 13. Quality Assurance Activities

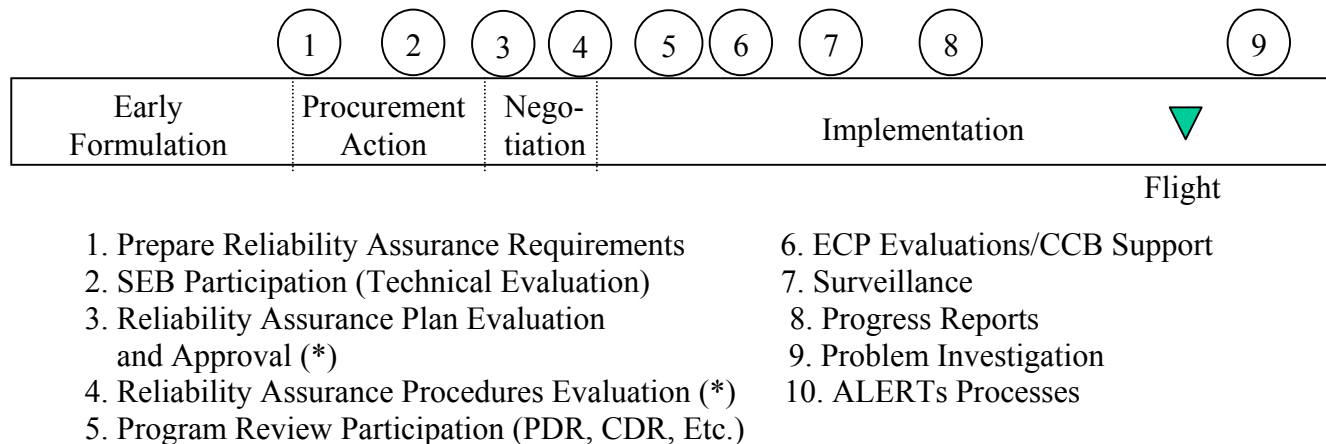
Contractor's QA hardware and software plans are evaluated during the SEB phase, and the recommendations to accept or revise the submitted plans are provided. QA hardware and software plans required of the contractor are Type 1 documents, i.e., requires MSFC approval.

When ATP has been authorized and the contract has been signed, a letter of delegation is prepared to other government agencies to perform quality assurance activities on the project. This delegation will include 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.

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.

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System reliability is also a function of project technical management. Reliability assurance requirements define the reliability tasks to be incorporated into RFPs, SOWs, and DRs. See Figure 14 for the reliability assurance activities.



(*) Prepare for In-house Projects

Figure 14. Reliability Assurance Activities

Source Evaluation Board/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 systems' 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.

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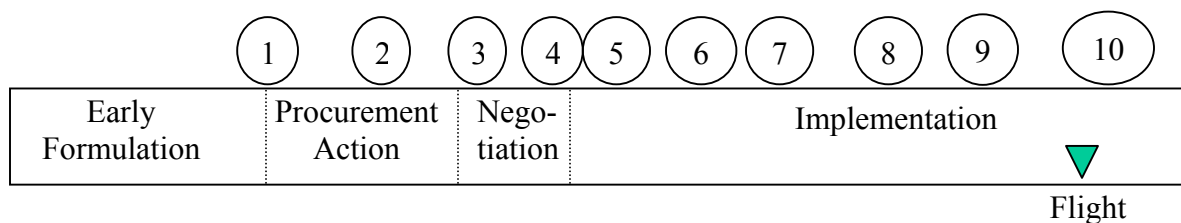
- e. Engineering Change Packages are assessed for the effect of the change on reliability. Changes that affect the FMEA/CIL will be reflected in change update sheets to the documents.
- f. Reliability Progress Reporting and Reviews are accomplished through periodic reports and meetings as a part of the 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 NMI 5350.1, *Maintainability and Maintenance Planning Policy*) that are to be utilized during any project-phased planning activity at MSFC for prime contractors are depicted in Figure 15. The maintainability requirements will be established and implemented into the contracts. These requirements define the maintainability tasks to be incorporated into RFPs, SOWs, and DRs.

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.

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|---|---|
| <ol style="list-style-type: none"> 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.) | <ol style="list-style-type: none"> 6. ECP Evaluations 7. Progress Reports 8. Maintainability Analyses 9. Surveys 10. Problem Investigation relative to Maintainability |
|---|---|

(*) Prepare for In-house Projects

Figure 15. Maintainability Activities

4.3.7.1.3 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 Implementation 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. Beginning with the Implementation phase the prime contractor will prepare and implement an Industrial Safety and Health

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Plan that meets the requirements of the contract safety and health provisions and MWI 1700.2.

- 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; and,
- (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.

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- (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.

4.3.7.2 System Engineering Management. A system engineering function is needed on every development and operational project. System engineering is responsible for ensuring the top project system requirements are ultimately met and the system performs as required. The system engineering function typically includes the following activities:

- Performing system level trade studies
- System requirements definition and flowdown
- Development of the SEMP
- System risk identification and assessments
- Operations concept development for integration into the system requirements and the flowdown of requirements
- Ensuring availability and proper execution of verification plans
- System performance analysis
- Error budget
- Resource allocation

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- Electrical and mechanical design integration at the system level (interface definition and control)
- Electromagnetic Interference (EMI), Electromagnetic Compatibility (EMC)
- Mass properties
- Design review coordination
- System Technical Performance Measurement parameters (e.g. power, weight, cooling bandwidth, etc.)
- Verification requirements, planning, and compliance assessments

4.3.7.3 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 the conduct of 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 issue resolution must be evaluated for system level impacts and any system issues resolved.

4.3.7.4 System Test Management. The system level testing is the key activity that verifies, to the extent possible, in the Earth environment, that the total system will fulfill its requirements and perform on-orbit as intended. The Project must ensure that all system level test activities and support are identified, planned, scheduled, and executed to support the overall project mission schedule. 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 the test readiness review, 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.

4.3.7.5 Mission Operations. All mission operations preparations must be regarded as essential parts of project responsibility, but where activities are performed by other

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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. NASA has by intent a limited number of launch sites, a limited number of operations control centers, 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 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 on any deviations from these criteria, major decisions must be concurred in where time allows. 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.

4.3.7.6 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 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. This decision is an

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educated one, 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 (see 4.2.2.3).

4.3.8 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. This database consists of lessons learned from past projects. The LLIS can be accessed at:

<http://standards.nasa.gov/>

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5. SYSTEM ENGINEERING

System engineering is simply defined 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. It is obvious from these definitions that 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.

5.1 System Engineering Overview. System engineering 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. A system consists of two or more functional items that must operate together to meet a common objective. The functions of system engineering activities also apply to the design activities of subsystems and components. The total system engineering effort is a series of processes. Figure 16 depicts the major system engineering activities, processes and feedbacks that support system development. Each process begins with an input (usually a requirement) and proceeds through a functional analysis of the requirement to decide what must be accomplished (requirements definition and allocation) 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 best solution then is designed in detail, manufactured, verified and deployed to perform the mission or met the original requirements (or the current version of the requirements). Throughout this series of processes there is provision for feedback to any previous stage and applying new knowledge gained to the refinement of the results and products of those stages.

If a project passes early control gates prematurely during the development process, it is likely to result in a need for significant iteration of requirements and designs late in the development process and in turn result in an increase in the development schedule and/or development cost. One way this happens is by failing to involve the appropriate technical experts at early stages, thereby resulting in the acceptance of requirements that cannot be complied with and the selection of design concepts that cannot be built, tested, maintained and/or operated. Implementation of concurrent engineering is an approach to eliminate these late impacts to project development.

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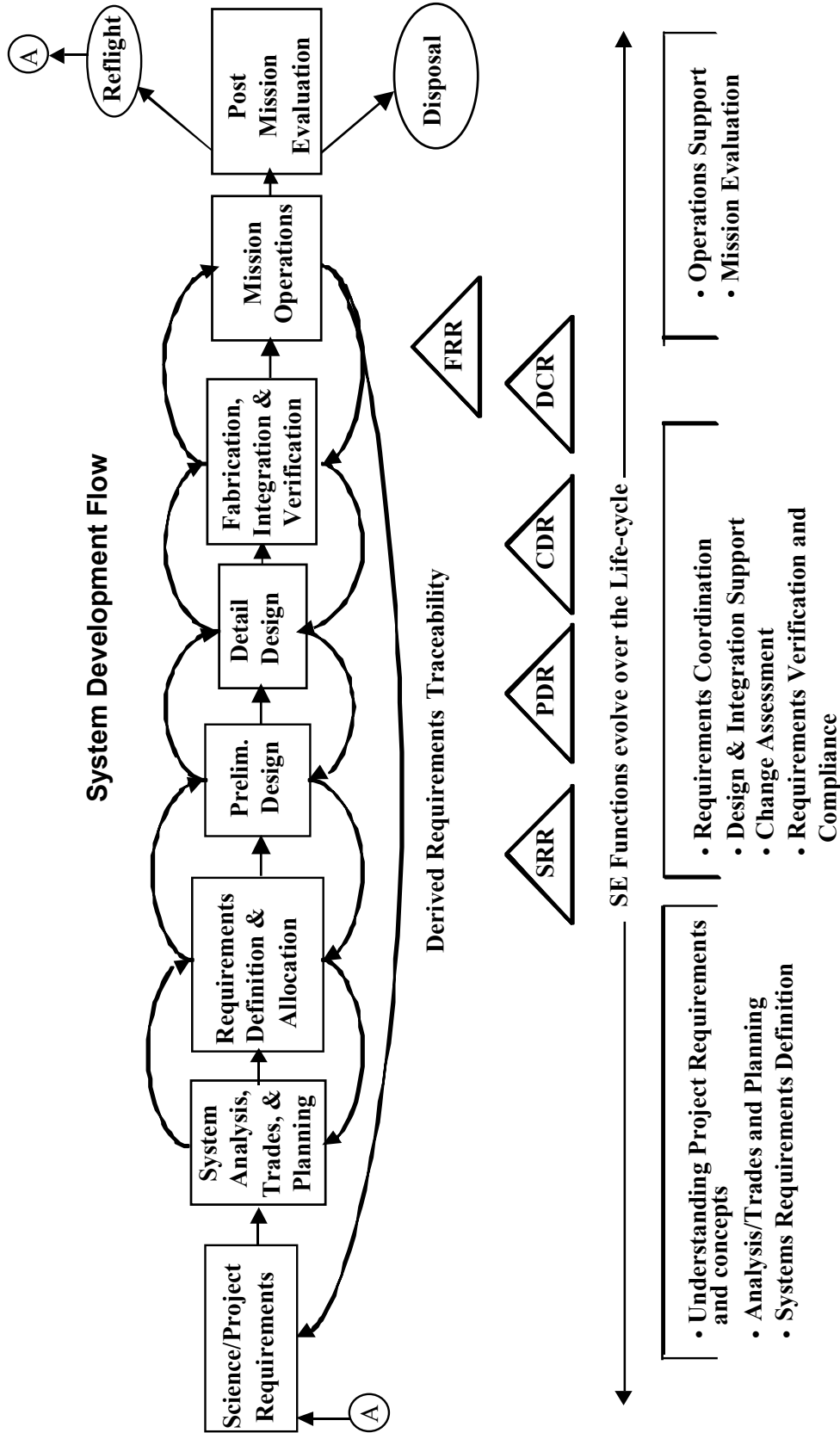


Figure 16. System Engineering Functional Overview

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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. The informational requirements of doing concurrent engineering are demanding. An automated environment can alleviate some of this burden. In such an environment, system engineering, design and analysis tools can easily exchange data, computing environments are interoperable, and product data are readily accessible and accurate.

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 discussed in 5.4. Certain tasks tend to overlap in practice by the parallel and iterative time phasing of many tasks. The phasing of system engineering functions across the life cycle is depicted in Figure 17.

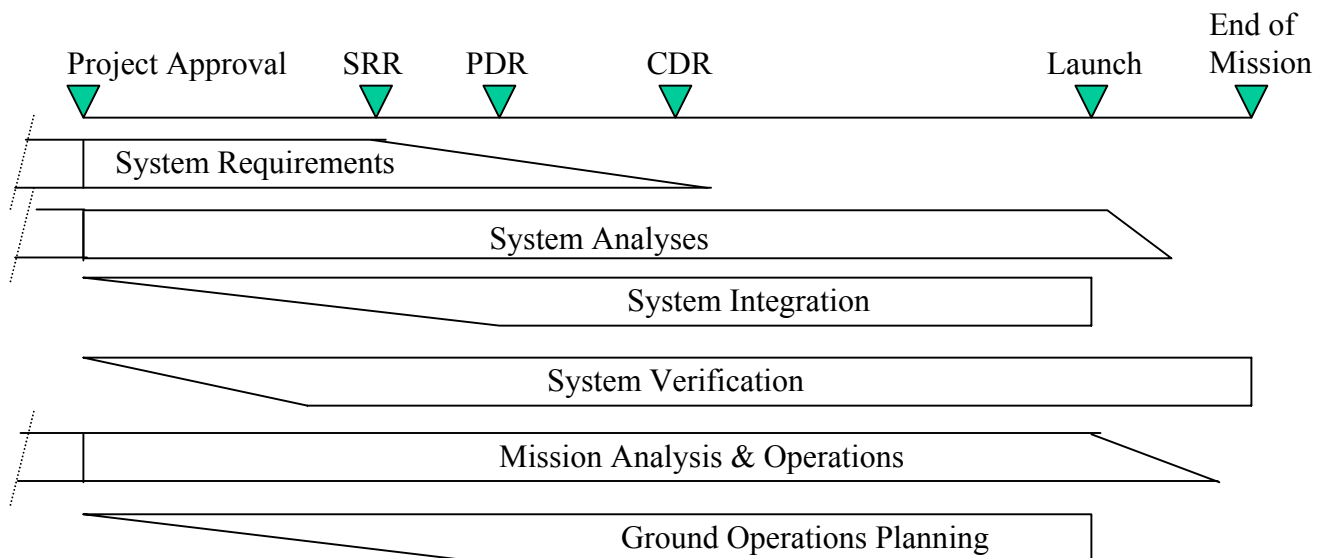


Figure 17. Phasing of System Engineering Functions Task

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It is important to observe that all of the system engineering tasks involve input from, coordination with, review by and, in most cases, approval by elements external to the system engineering organization. It should also be understood that these tasks apply to both hardware systems and software even though the software phasing is slightly different from the hardware development as shown in Figure 3. The ultimate approval and decision authority is the Project Manager. However, a cardinal measure of successful system engineering is the degree to which all parties accept that the systems engineering recommendation represents the best overall design solution, even though not necessarily the best for any single interest.

5.2 The System Engineering Process. System engineering is the key ingredient for ensuring that as project development and definition proceeds, all aspects of the project have been considered and optimized to the extent possible for the resources available. The system engineering process that complements the project development process (see 4.1) is described in the following paragraphs. The descriptions will describe in general the MSFC system engineering activities. It should be kept in mind that all projects are different and that system engineering must always be thinking of what is necessary for consideration on each individual project to ensure that every important aspect has been considered.

The general system engineering process for the formulation phase of a project is shown in Figure 18. A description of the major activities depicted in the figure follows in the paragraphs below. It must be remembered that system engineering is an iterative process that requires many system related assumptions, changes to assumptions, system impact definitions, analyses, and feedbacks to earlier definitions and analyses to eventually obtain the final system requirements.

5.2.1 System Concept Options Definition and Feasibility Studies. Once a project formulation study has been initiated, the system engineer assists in defining conceptual systems and their architectures to be further analyzed during the feasibility assessment phase. Concepts are defined by analyzing the top-level requirements, allocated resources, any other constraints, and by identifying methods that can be utilized for implementing a system that will accomplish the objectives. One method for beginning the initial system concept is to perform a functional decomposition analysis (see 5.4.2.1.1) which consists of defining the functions that have to occur at a high level and continues to break those functions down into lower levels, more detailed functions and allocating a conceptual method of implementing those functions. Eventually, a concept(s), subsystems, components, operations, and software will be defined to describe a system that will perform the functions necessary to satisfy the desired performance requirements.

For most projects there are probably several concepts and or architectures that will perform the functions required by the top-level requirements. Each concept and architecture must be considered and analyzed. The most promising initial system

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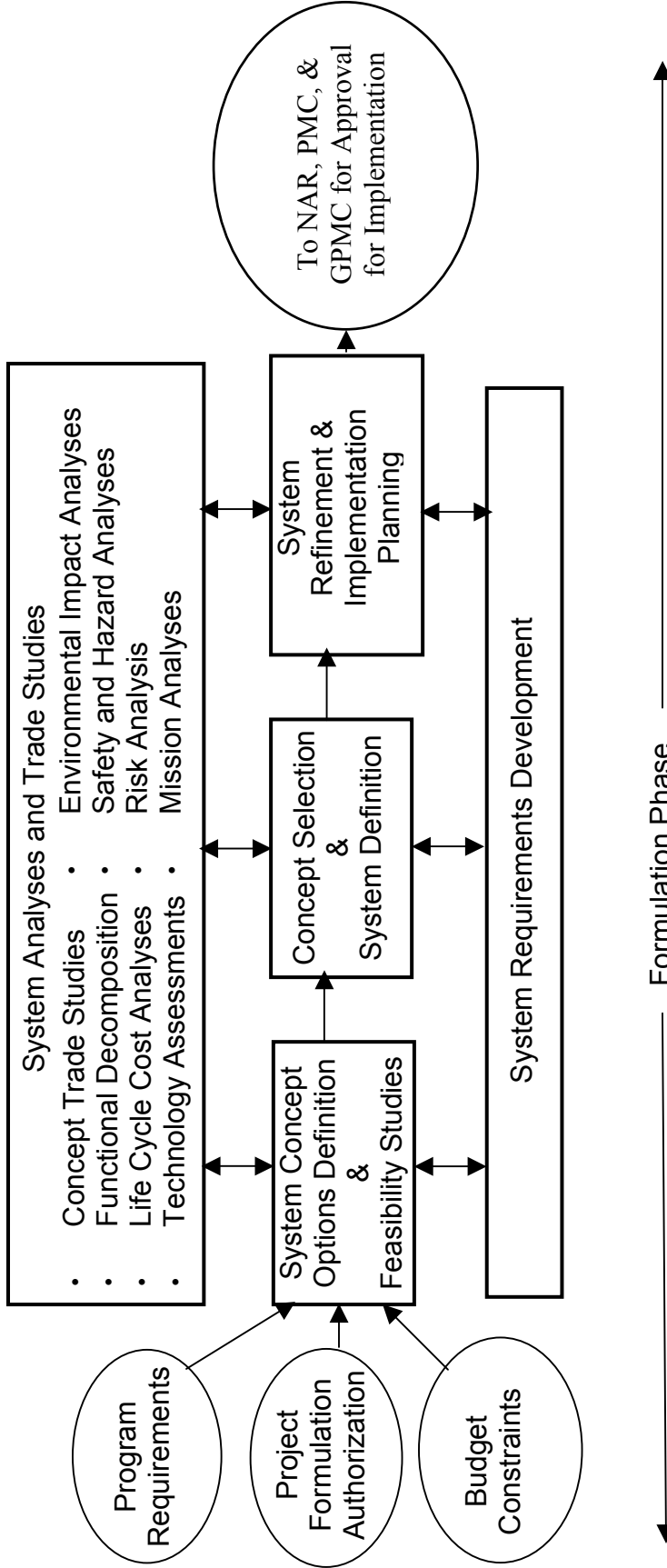


Figure 18. Formulation Phase System Engineering Process Flow

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concept will allow a basis for initial comparison analyses, and trade studies will begin to refine the concept definition, cost estimates, schedules, risk assessments, and begin the overall optimization of the system. The feasibility of the system is determined by comparing the data generated back to budget, schedule, and any other resource constraints. Risk and technology assessments are also part of determining feasibility.

5.2.2 System Analyses and Trade Studies - Formulation Phase. During the formulation phase, system analyses and trade studies are performed to compare the feasibility of concepts to meet top-level project requirements as well as budget and schedule constraints. A functional decomposition of the top-level requirements is performed, and various conceptual options, available technology, development risks, safety and hazards, environmental impacts and estimation of budget and schedule are identified and investigated. As part of this activity a detailed risk analysis and assessment is performed to establish a high level of confidence for the program cost. Other analyses performed as part of this activity include life cycle cost analyses, safety and hazard analyses, and environmental impact analyses. Also during this phase, mission analyses are performed and mission concepts and operations are formulated.

A utility analysis is performed to determine the value of a project. This analysis evaluates the potential benefits of the project system when considering the overall cost and risks. This analysis also includes comparison of life cycle costs and benefits with existing systems. As the formulation phase continues, all feasible concepts continue to be analyzed and trade studies performed for system refinement to determine the optimal concept and architecture for the project application.

5.2.3 Concept Selection and System Definition. The results of the system analyses and trade studies of the concept options provide the basis for concept selection and system definition. Each concept option is analyzed and evaluated for strengths and weaknesses. The iterative process eventually produces a comparison of all the concepts identified and data is generated to allow the project formulation team to recommend a concept selection for continued and more in-depth analysis. With approval from the Project Manager, a reference concept is selected and further detail of the system comprising the concept is defined.

5.2.4 System Requirements Development. As the more detailed system definition and analyses are conducted, the system level requirements are developed. The systems engineer supports the requirements development through the efforts of ensuring that all requirements defined are valid functional or performance requirements, are clearly defined, are not redundant or in conflict with other requirements, and can be verified. System engineering also ensures that all system aspects that must be accomplished are defined as system requirements.

5.2.5 System Refinement and Implementation Planning. As part of the formulation process, the system becomes better defined and understood as analyses are refined

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and updated system description data is incorporated into the analysis iterative process. As system studies continue, risks are continually assessed and risk mitigations are defined. Available technology is assessed and new technology requirements are identified. System costs and schedules are refined. System simulations and integrated system analyses are conducted to ensure system operability, and data is generated to both describe the system and convince non-advocates that the system is defined and understood enough to be able to ascertain performance, risks, and costs for implementation of the system. This process must also include the planning required for the implementation. System engineering supports the project planning in defining the system implementation processes and estimating resources and schedules. System engineering also assesses the safety and hazard aspects of the project system to ensure personnel safety in all project implementation planning.

5.2.6 System Requirements Refinement, Allocation and Flowdown-Implementation Phase. The requirements and concepts developed during formulation are refined and expanded throughout the formulation phase and into the early implementation phase. Figure 19 depicts the system general engineering process that comprises the implementation phase. The SRR is normally conducted early in the implementation phase to ensure that all system requirements have been identified and understood. Throughout the implementation phase, system engineers monitor system requirements implementation and update the System Performance Specification as necessary. Also occurring in the early implementation phase is the finalization of the verification planning.

The process of allocating and transferring system level functional and performance requirements to the lower level subsystem requirements is finalized during the early implementation phase. System resource allocations are also established. Each subsystem is assigned resources such as weight, volume, center of gravity envelope, and electrical power limits. Functions that have not been assigned to a subsystem are assigned. For example, temperature sensing could be allocated to command and data management, electrical power, avionics, or a separate thermal control subsystem. System engineering is responsible for ensuring that all such functions are allocated and in a manner that is advantageous for the overall system. While requiring engineering judgment and analysis, factors such as available technology, organizational expertise, and successful history may influence such allocations.

The flow-down of requirements from the system level to the subsystems is a team effort requiring as a minimum the LSE and the SLE's participation. However, it is system engineering's responsibility to ensure that all system requirements are allocated and as implementation progresses, that the system requirements are met.

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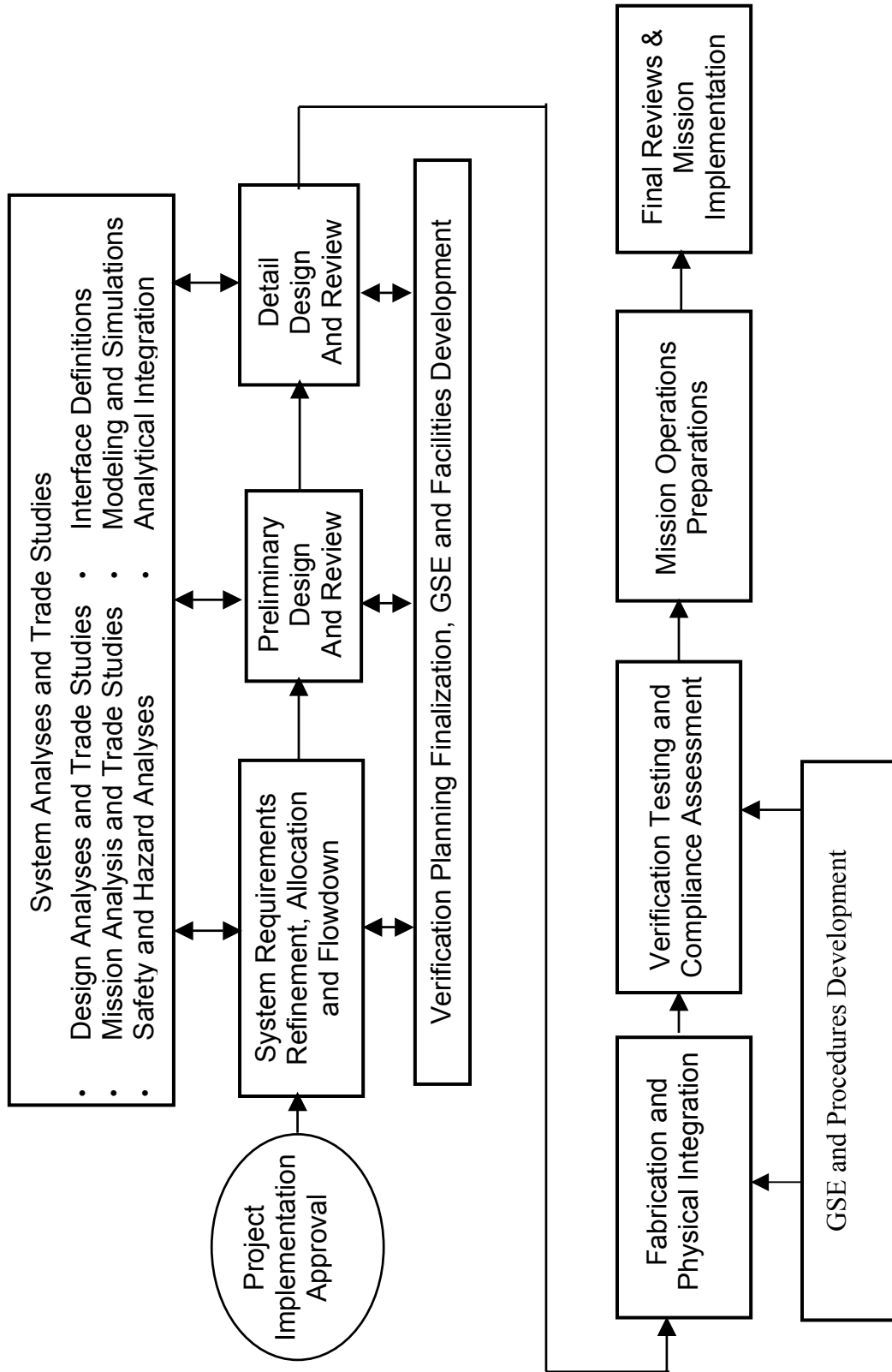


Figure 19. Implementation Phase System Engineering Process Flow

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5.2.7 Design Evolution. The design of a flight system evolves as architectural concepts are narrowed and refined by concept analyses and trade studies. This design evolution begins in the late formulation and continues into late implementation and is a continuing process as detailed system requirements are further identified and refined. The iterative design evolution cycle of a system is shown in Figure 20.

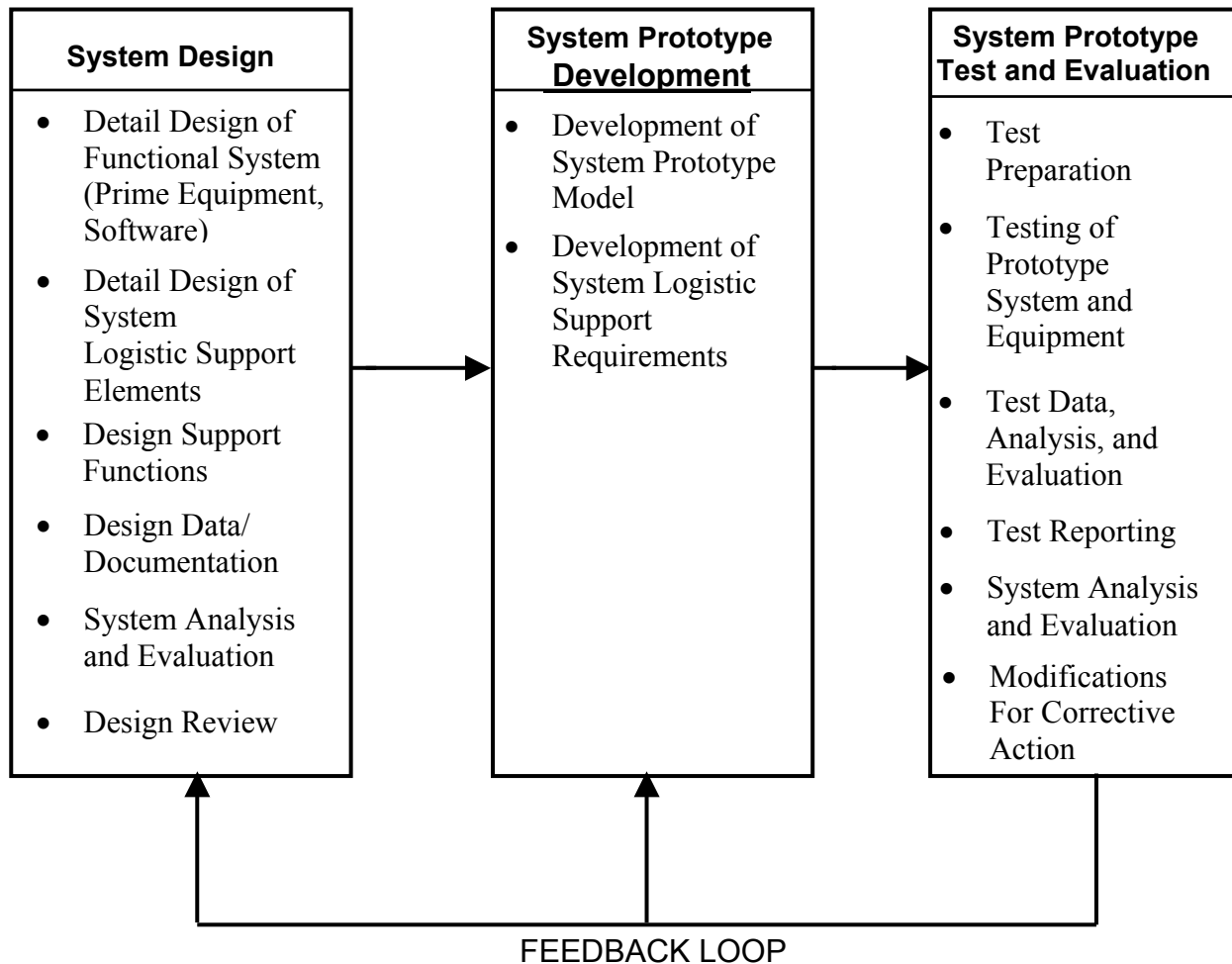


Figure 20. Design Evolution

5.2.7.1 Preliminary Design. Preliminary system design begins in the late formulation phase with the technical baseline for the system as defined in a feasibility analysis. It proceeds from the translation of established system-level requirements into detailed qualitative and quantitative design requirements. 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 as illustrated in Figure 21. Inherent in the activities identified in

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Figure 21 are the aspects of planning, implementing, and measuring with the necessary feedback provisions allowing for the incorporation of changes.

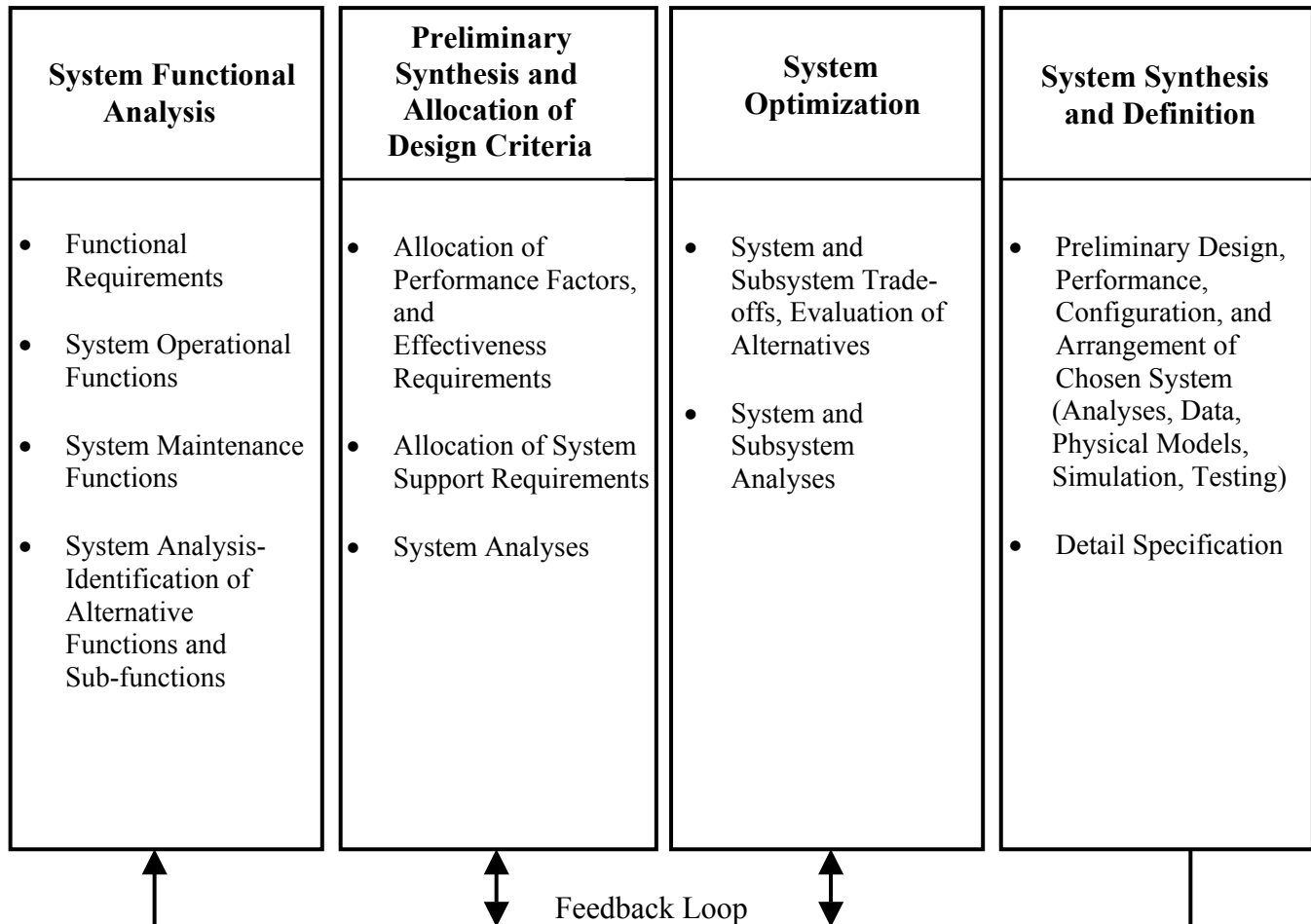


Figure 21. Preliminary System Design

Requirement changes will likely be needed as design implementation proceeds and additional definition is accomplished. These requirement changes may be the result of additional knowledge gained or the inability of the design to meet a specific requirement. Regardless of the reason for the change, it is essential to update the requirement specifications when required so as to reflect current design status and assure a reliable, cost effective product. The system requirement organizations work closely with the design engineering organizations to aid in understanding the requirements. The LSEs and SLEs also work closely with the Project Manager during

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the conclusion of the formulation phase to provide support rationale for project reserves required to mitigate necessary requirement changes that may occur during the design phase.

All the activities of the design evolution have the goal of meeting a specific set of requirements. The proper level of engineering effort must be applied to the system being developed. The steps of design evolution are considered as a thought process, with each step addressed to the extent and depth necessary to fulfill the requirements. Regardless of the system type and size, one commences with an identified need and a completed feasibility study for the purpose of establishing a set of requirements, constraints, and design criteria. Based on the results, functional analyses and allocations are generated to apportion the appropriate system level requirements down to the subsystem and lower levels of the system.

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.

A prototype of a flight system or a subsystem is 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.

When the basic design approach has been selected and the design is approximately 50% completed, the design is subjected to a PDR. The PDR is a technical review of the basic design approach to assure compliance with program requirements. The results of the review are assessed and input back to the design process (see 4.3.6.1.3).

5.2.7.2 System Analyses and Trade Studies – Implementation Phase. As the project proceeds into implementation more detailed analyses and trade studies are performed. These analyses and trade studies primarily support the development of design and performance requirements and specifications, the definition of interfaces and the assessment of the system configuration and performance. The objective of these analyses and trade studies is to optimize the total system design in meeting the system requirements and mission needs in the most cost effective way. 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. Analyses and trade studies performed during the implementation phase include; (1) system functional analyses to assess system capabilities to perform their mission and satisfy system requirements, (2) system synthesis to identify the preferred system configuration and feasible performance characteristics, (3) system performance and resource analyses for

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performance predictions and resource allocations, (4) system safety analyses to assure timely, effective design solutions that eliminate or properly control hazards, (5) risk analyses to describe and quantify risks and develop alternatives for risk mitigation or elimination, (6) cost analyses to monitor and track cost continuously through the implementation phase and (7) system analytical integration to ensure that the various elements of the total system are in accordance with the requirements, operate together as a system, and interface with the external environment as expected. (See section 5.4.2, System Analyses, for more detail definition of these analyses.)

5.2.7.3 Detail Design. 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.

The system designs become 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. Acquisition of long lead item components is started. The engineering drawings for component fabrication and acquisition are completed as designs are refined.

System engineering analyzes and documents solutions for all interfaces between hardware and software elements, the designs are firmed and the interfaces baselined, and the developers of both sides of the interface are bound by the baseline interface design. System engineering ensures that responsible personnel on each side of the interfaces are knowledgeable and comply with interface requirements and definitions.

When the detail design and drawings are approximately 90 to 95 % complete, the design configuration is subjected to a CDR (see 4.3.6.1.4). The CDR provides assurance that the detailed design is in accordance with end item specifications. Valid design discrepancies determined during the review are corrected and the design is baselined. Specific engineering documentation that will be authorized for use to manufacture the end item is formally identified.

5.2.8 Fabrication and Physical Integration. 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 as materials and

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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.

The fabrication and physical integration processes are the critical final steps during which hardware is acquired (either manufactured in-house, contracted out-of-house, or purchased off-the-shelf). The components or subsystems are assembled to produce the end item system. Make or buy decisions must be made for the parts that make up the components and subsystems. The make or buy decision activity must consider issues such as the number of items used, commonality, availability, material and reliability requirements, schedules, capabilities, and budgets. There are also trade-offs against the project requirements and constraints. The physical integration of all the various elements of a system is usually accomplished at multiple locations. This activity is the integration of all the discretely defined end items into a homogeneous system.

Another important function of the system engineer during the fabrication and integration phase is the system assessment that is required as a result of proposed design and/or requirement changes proposed to solve fabrication and/or assembly problems encountered during the process. When such situations occur, the system engineer must ensure that any proposed changes will not interfere with system hardware designs, software, or violate any system requirements. This process requires consideration of all system parameters to ensure that even a seemingly small change will not adversely affect other portions, or the operations of the system.

5.2.9 System Verification and Compliance Assessment. Early in the implementation phase, each of the system level design and performance requirements are assessed and decisions made on how requirements are to be verified. The methods used to verify requirements include testing, analysis, inspection, demonstration, similarity to other previously verified hardware/systems, and validation of records. The preferred method of ensuring that performance of the flight systems (hardware and software) is in compliance with the design and performance requirements is a test of the flight systems. The testing will generally fall into two major categories: functional testing and environment testing. Verification requirements and the corresponding acceptance criteria for each method of verification are developed based on the assessment of the system level design and performance requirements and other requirements that are derived. Testing procedures based on the verification requirements are generated for each test.

The data resulting from a test is assessed to ensure all criteria has been met. The results of the testing is documented in a test report that, along with the test data and as-run test procedure, become the compliance information that is documented as showing

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flight systems performance is in compliance with system level design and performance requirements and with verification requirements.

5.2.10 Mission Planning and Operations. Mission planning begins in the early formulation phase with an assessment of the mission objectives to determine the most effective and efficient methods of achieving the mission objectives. This assessment begins the definition of mission requirements. The mission requirements are further developed during the formulation phase as the design matures. Trade studies and analyses are performed to ensure system capabilities can accomplish mission objectives and are in compliance with mission requirements. Incompatibilities of system capabilities with mission objectives and requirements are input to the system design process. These activities lead to the development of the mission profile.

The planning for mission operations also begins in the early formulation phase to ensure that operations considerations are integrated into the system requirements definition. Early mission operations definitions, concepts, and sequences lead directly to a significant amount of flight and ground software requirements as the operations concept matures. Operations planning must consider the required operations, the resources and schedule for execution of these operations, and the interfaces between the operation facility and the flight systems. Trade studies and analyses of mission operations functions are performed and are continued through operations functions development. The operations functional requirements, the operations facility requirements, and the interface requirements are developed in the early system design process and provide a feedback into the design process. This iterative process continues throughout the system development phase. Operations requirements are updated as the system design and project matures.

5.2.11 Final Reviews and Mission Implementation. System engineering is intimately involved in the final reviews prior to mission implementation. System engineering's involvement ensures that all system design and performance requirements have been met and that supporting operations are prepared for mission implementation. Paragraph 4.3.6 describes several project reviews that are conducted as part of the final review process. The ARs are conducted to ensure that major end items have been properly designed and verified prior to acceptance by the NASA. A DCR ensures that the system meets the design requirements and verification planning, testing and analysis basically certifies the design. The GOR ensures that ground operations and equipment is ready to support the system physical integration and launch of the system. The FOR ensures that flight operations have been properly identified, planned, and implemented through training and flight preparations.

The final review prior to mission implementation is the FRR. The FRR ensures that the system has been certified for flight and that all operations and preparations have been accomplished. Any open items identified at the FRR are usually recognized as actions that will be accomplished as part of launch operations, or as actions that must be

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accomplished or will be a constraint for launch. System engineering assesses any open items to provide impacts and assist in ensuring all critical open items are accomplished.

5.3 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 Engineering Systems Department of the Engineering Directorate for specialized system engineering tasks (such as natural environments, supportability, mass properties analyses, and others) in support of the project, and operational support for configuration management activities, (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 systems engineering policies and processes.

For projects supported by design and development contractors, it is equally essential to project success that the contractor(s) properly exercises 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 systems engineering and systems integration for a project. The Chief Engineer evaluates the Directorate's system engineering policy/processes and the Lead System Engineer 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.

5.3.1. 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. The Directorate

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also provides launch vehicle flight dynamics analyses, stabilization analyses for space tethers, attitude control system analyses and design guidance system algorithms development, and orbital mechanics analysis. The definition of launch vehicle aerodynamics is also provided.

5.3.2 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, verification, and testing of multi-user hardware 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.

5.3.3 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.

5.3.4 Engineering Directorate. The Engineering Directorate 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 provides is described in the following paragraphs.

5.3.4.1 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 systems 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, configuration management, data management, natural terrestrial environments definition and analysis, space environments and analysis, electromagnetic environments and effects, and spacecraft charging analysis.

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5.3.4.2 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.

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

5.3.4.4 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.

5.3.5 Safety & Mission Assurance Office. The S&MA Office provides the planning, establishment, and implementation of the assurance program. For each MSFC project, the S&MA Office performs surveillance of MSFC in-house and contracted design, manufacturing, and testing activities to ensure compliance with the project requirements and controls and provides special analyses such as the FMEA and hazard analyses. This is accomplished by providing a continuous review and evaluation of SRM&QA activities at all levels throughout the Center and its associated contractors. The S&MA Office provides overall flight and ground safety support for the project.

5.3.6 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 Center systems engineering functions related to space systems projects, including requirements development and flow-down, systems 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.

5.4 System Engineering Functions. This section focuses on the functions of the systems engineering activities, as implemented within MSFC and depicted in Figure 22. 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. At the project system level, the process 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 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,

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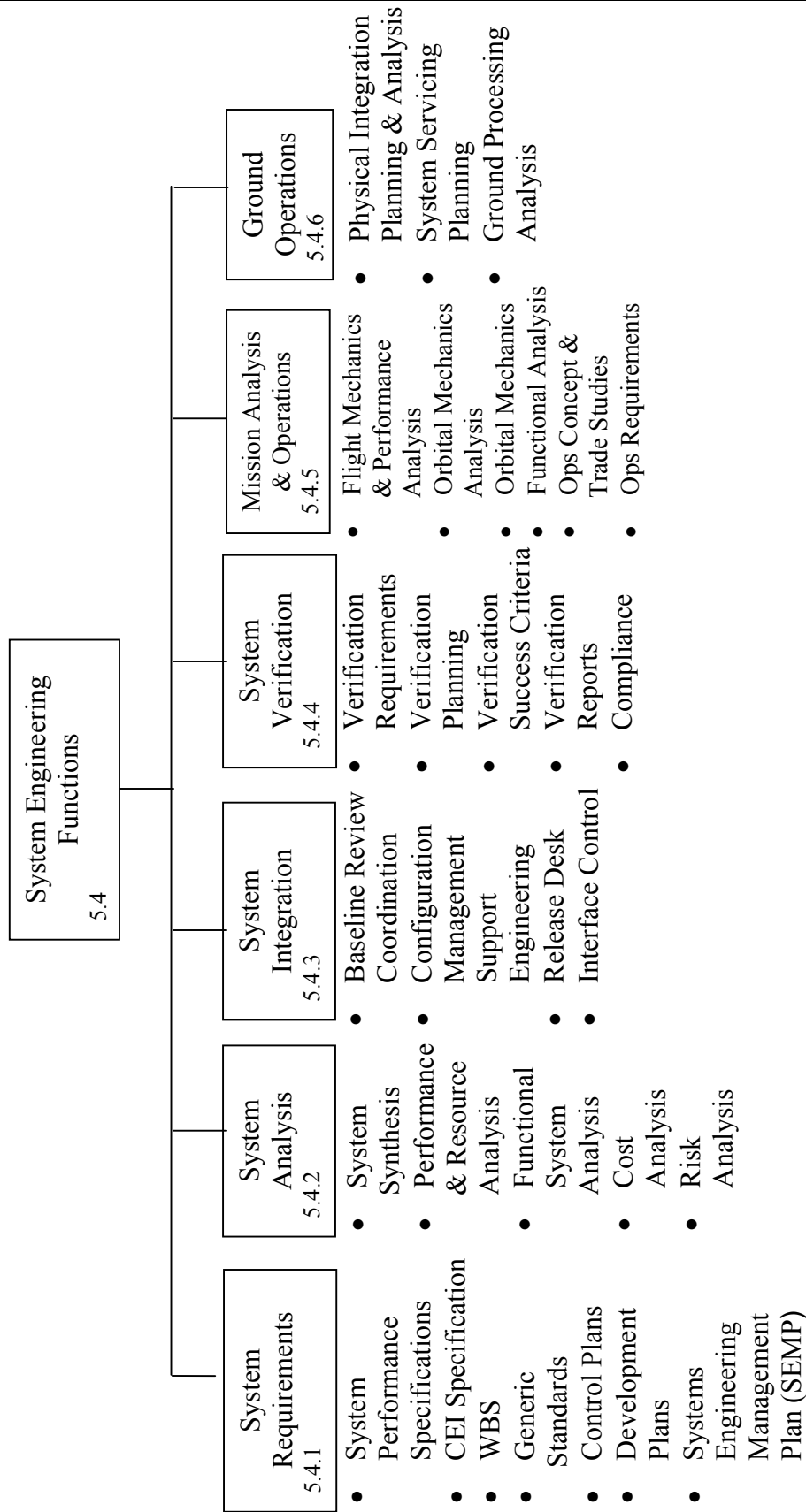


Figure 22. System Engineering Functional Task Breakdown

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manufactured, verified and deployed to perform the mission or meet the original requirements (or the current version of the requirements). Throughout this series of processes 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. This system engineering function and feedback process is depicted in Figure 16.

5.4.1 System Requirements. System requirements encompass 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 systems analysis, to define detailed performance requirements and a preferred system configuration. Typical products of the systems requirements activity include:

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

5.4.2 System Analyses. System analyses are a group of activities that supports both the definition of systems requirements and the conduct of systems 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 analysis activity maintains a close working relationship with the engineering discipline centers of expertise residing in the design organizations. This 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 synopsise typical system analyses.

5.4.2.1 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. They analytically confirm design performance in their application. Key analyses common to many projects include:

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5.4.2.1.1 Functional Decomposition Analysis. 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 how well it should do it.

5.4.2.1.2 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 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.

5.4.2.1.3 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: atmospheric constituents (gasses, sand, dust, sea salt), atmospheric electricity, sea states, severe weather, near-surface thermal radiation, temperature, pressure, density and winds. 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.

5.4.2.1.4 Human Engineering Analysis. Human engineering analysis is 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. The analysis includes man-systems integration associated with both ground operations and on-orbit operations of the system.

5.4.2.1.5 Life Support and Environmental Control Analysis. Life support and environmental control analysis is performed for manned systems requiring an environment to sustain life. This analysis supports the definition of system requirements and assesses the system design for meeting the requirements.

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5.4.2.1.6 Functional Instrumentation and Command Analysis. Functional instrumentation and command analysis are performed to support the development of the Instrumentation Program and Command List (IPCL) and assesses the capability of the system design to provide the defined instrumentation and commands. All telemetry and command data that enter and exit the system is compiled and the resource utilization of communication and telemetry systems are determined.

5.4.2.1.7 Electromagnetic Compatibility/Electromagnetic Interference Analysis. Electromagnetic compatibility/electromagnetic interference analysis is 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.

5.4.2.1.8 Spacecraft Charging Analysis. Spacecraft charging analysis is an assessment of a spacecraft's ability to cope with the electrical charge build up resulting from exposure to the ionizing radiation of space. The analysis combines 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. The results may result in a choice of different materials or protective coating for the spacecraft.

5.4.2.1.9 Induced Environments Analysis. An induced environments analysis is 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 environment results support the definition of the system requirements, and provide inputs to establishing induced test criteria.

5.4.2.1.10 Lightning Protection Analysis. Lightning protection analysis is performed to determine the effects on the system electrical circuits if a lightning strike occurs. Both direct and indirect strike effects are examined. The analysis assesses the system design to ensure proper lightning protection.

5.4.2.1.11 Contamination Control Analysis. A contamination analysis is 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.

5.4.2.1.12 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.

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5.4.2.1.13 System Communication Analyses. System communication analyses include radio frequency 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 spectral 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 communication requirements analysis supports the development of the system requirements. The 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.

5.4.2.1.14 Attitude Control Analysis. Attitude control is required on any launch vehicle, spacecraft, or experiments that require that stabilization of attitude as part of their mission. The analysis associated with the design and assessments of those systems requires knowledge and combination of the system mass properties, structural dynamics, attitude measuring, system disturbances, and control forces of the systems. The effects of local dynamics and/or vibrations are also necessary to be analyzed on many systems.

5.4.2.1.15 Dynamic Analysis. System structural dynamics analysis is required for ensuring understanding 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 analysis is also performed for projects utilizing tethers.

5.4.2.1.16 Guidance and Navigation Analysis. The normal missions of launch vehicles and spacecraft require that certain orbits are obtained. The ability of a system to be inserted in those orbits require 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. The analysis associated with designing and assessing the ability of a system to successfully achieve guidance and navigation requires the combining the characteristics of the navigation sensors, the system propulsion characteristics, and the attitude control system.

5.4.2.1.17 Supportability Analysis. Supportability analysis provides 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 analysis ensures

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that sufficient spares (flight hardware and GSE) are available to support a given system throughout its' operational life. The sparing philosophy results in an optimum mix of line replaceable units, shop replaceable units, orbital replaceable units and piece parts.

5.4.2.2 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. In this study, factors that are important are identified and then a weighing 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.

5.4.2.3 System Safety Analyses. System safety analyses activities are an integral part of the system analyses efforts. System engineering will closely coordinate with the systems safety engineering personnel 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.

5.4.2.4 Risk Analysis. Risk analysis is the process 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 this process, and these can be documented and tracked through 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. Also, it is necessary to identify any potential risks that arise as a result of design implementation and to incorporate risk mitigation.

5.4.2.5 Cost Analysis. 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

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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. This is a highly iterative process, and is essentially continuous throughout the project life cycle.

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

5.4.2.7 Performance and Resource Analyses. Performance and Resource Analyses support systems synthesis, as well as systems requirements and systems 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. Areas of analysis will be project-dependent, but key analyses include:

5.4.2.7.1 System Thermal Analysis. System thermal analysis is performed to support the definition of system requirements and to determine the capability of the thermal control system to meet the requirements. The system thermal analysis may also provide verification compliance of the thermal control requirements and are utilized to support thermal system thermal vacuum testing criteria.

5.4.2.7.2 Electrical Power Analysis. The electrical power analysis is 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 analysis includes 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.

5.4.2.7.3 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 level subsystems and piece parts with a reserve maintained. The mass properties analysis is a repetitive activity that occurs 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 analysis to refine the analysis results. Maintaining a comprehensive mass

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properties database allows the Project Manager and SLE to revise allocations as subsystems and piece part designs mature. The mass properties analysis will continue until the flight system is developed and a measure of total mass is performed.

5.4.2.7.4 Onboard Computer Timing and Memory Utilization Analysis. The onboard computer timing is a critical factor to ensure that onboard events that are controlled by the computer are properly implemented. Computer task analysis is 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.

5.4.2.7.5 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.

5.4.2.7.6 Pointing and Alignment Error Analysis. The pointing and alignment error analysis is 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.

5.4.2.7.7 Propulsion System Performance Analyses. Propulsion system performance analyses is the assessment 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.

5.4.2.7.8 Data Management Analysis. The data management analysis is performed to assess the IPCL database against a mission scenario to determine the real time and data storage requirements. This analysis provides assurance that adequate measurement and command data handling capability exists.

5.4.2.7.9 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. Such analyses also support mission timelines, define orbit pointing and

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attitude control requirements. Thermal analyses also utilize the results of orbital attitude analyses for generating sun angles, eclipses, and exposure times.

5.4.2.8 System Analytical Integration. System analytical integration is that analysis that takes place 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 system elements (e.g., spacecraft, payload, launch vehicle, ground systems, airborne support 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, design reviews and ensuring that the design is compatible with requirements are important tasks to be accomplished prior to drawings release.

5.4.2.8.1 Interface Analysis. An interface analysis is performed to determine and identify where hardware and/or software elements must interact at a common boundary. The analysis identifies 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 analysis also assesses the system design to ensure the interfaces (internal and external) are compatible with the applicable interface requirements.

5.4.2.8.2 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 of 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

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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, system, or a flight item. The breadboard is maintained current with the design and models as they are refined. A mockup to scale is 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.

5.4.2.9 Materials Analysis. A materials analysis is 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 analysis also includes assessment of the system design to ensure the use of approved materials.

5.4.3 System Integration.

5.4.3.1 System Reviews. System engineering's 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's participation in the SRR confirms that the requirements and allocations contained within the System Specifications 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's 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 GOR, 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.

5.4.3.2 System Configuration Control. 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

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changes, determining any impacts of the proposed change, and making recommendations based on analysis of the overall effect of the proposed changes. System engineering also supports project management in collecting, logging, and tracking all proposed configuration changes, and maintaining change control histories for the project.

Another function that system engineering supports is the operation of the documentation release system, or release desk. Formal documentation placed under configuration management control is reviewed to ensure that MSFC preparation and publishing standards have been met, the proper reviews were conducted and that the proper personnel and organizations approve the documentation prior to release.

5.4.3.3 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 systems to piece parts or operating systems to subroutines. 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.

5.4.4 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 will be discussed in subsequent paragraphs. For MSFC managed projects, MSFC Management System MWI 8050.1, *Verification of Hardware, Software, and Ground Support Equipment*, must be followed in the development of verification programs. Additionally, MSFC-HDBK-2221, *MSFC Verification Handbook*, provides guidance and examples in development verification programs. The information outlined

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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 the systems 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.

5.4.4.1 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.

5.4.4.2 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), made available for review during SRR, PDR, and CDR and placed under change control by the program/project following CDR.

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5.4.4.3 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), made available for review during PDR and CDR and placed under change control by the project prior to beginning of the verification activities.

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

5.4.4.5 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.

5.4.5 Mission Analysis and Operations.

5.4.5.1 Mission Analysis. Mission analysis is the system engineering discipline that develops, analyzes, and documents mission requirements leading to the definition of the most effective and efficient methods of satisfying mission objectives. Mission analysis 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 analysis are divided into three separate analyses as discussed in the following paragraphs:

a. Mission Requirements Analysis is an 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 analysis of those requirements, and finally, the development of finely detailed mission requirements and their allocation to individual system elements. These steps are summarized as follows:

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

b. Mission Planning and Profile Generation Analysis is the activity 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 Design Reference Mission (DRM). The process for mission planning and profile generation analysis is 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 systems
- 3) Develop trajectory design
 - (a) Trajectory analysis
 - (b) Guidance, navigation, and maneuver analysis
 - (c) Optimization analysis
 - (d) Range safety and reentry impact analysis
 - (e) Tracking/telemetry coverage study
 - (f) Performance capability analysis
- 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.

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c. Mission Performance Analysis is the process of assessing the capability of the system design to satisfy mission requirements. It defines and prioritizes specific mission performance parameters and performs 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, which 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.

5.4.5.2 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.

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- Providing status information to/from the science operations leads and management as appropriate.
- Flight Data Files

5.4.5.2.1 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 (i.e., the project office) 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. This process adds an element of realism to the overall development activity and helps fine tune the development process to achievable goals. The DRMs are also used to place bounds on the anticipated mission drivers for each subsystem.

As previously mentioned, 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 will be phased out.

5.4.5.2.2 Operations Planning. Operations planning is a critical function since it defines the functional requirements for operations, defines and baselines the interfaces between operations facilities and flight systems, 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

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- Software specification requirements for Flight Operations and Ground Control
- Training assessments/training plans
- Mockup Definition
- Human Factors Analysis
- Crew Procedures
- Crew Training Materials
- Crew Aids Definition (for manned flight programs)
- Ground Support Staff Definition and Requirements
- Ground Operator Workstation Definition

5.4.6 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 item 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 item 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 item de-integration and handling and transporting to a designated site.

Ground operations planning and analysis continues 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. A physical integration analysis of the interfaces and an assessment of interface requirements are performed to ensure the compatibility of all the ground interfaces and the compliance to the interface requirements. An assessment of launch site and launch vehicle (for payload launch) requirements is 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. A ground processing analysis is 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 complex, sophisticated, and quite varied elements of flight hardware. Certification of both supporting personnel and applicable support equipment is required to perform many of the activities associated with handling and transportation

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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 elements applicable to a project are a function of the ground processing flow for that project. The ground operations processing flow for a flight article is in turn dependent upon characteristics of that article.

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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.

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I. Project Requirements Review (PRR)

documents, with involvement to varying degrees by NASA/MSFC.

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

- Overall program/project plan, schedule and WBS
- Mission and requirements analysis (includes mission operations activities, feasibility and utility analysis)

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 quality assurance 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 Certification of Flight Readiness (COFR) and what level of technical penetration is required. Products from this review will support the SRR.

- Preliminary requirements definition and allocation, in the form of a Preliminary System Specification
- Functional flow analysis
- Systems analysis and models, including performance and requirements analysis, technology/risk assessments, cost risk analysis and assessment
- Systems trade studies (e.g., cost, schedule, lifetime and safety)
- Configuration Concepts
- Design analysis and trade studies
- Preliminary interface requirements
- Preliminary operations planning
- Synthesis activities
- Preliminary Quality Plan
- Logistics support analysis
- Specialty discipline studies (i.e., structures and dynamics, safety and reliability, or maintainability analyses; materials and processes considerations; electromagnetic compatibility/

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

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interference, inspection methods/techniques analysis, or environmental considerations)

- Preliminary data management plans
- Preliminary configuration management plans
- Preliminary System Safety Plan
- Human factors analysis
- Value engineering studies
- Life cycle cost analysis
- Manpower requirements/ personnel analysis
- For manufactured items: producibility analysis, preliminary manufacturing plans

The total system engineering management activity and its output shall be reviewed for responsiveness to the Statement of Work 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.

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I. System Requirements Review (SRR)

II. Purpose

The SRR confirms that the requirements and their allocations contained in the System Specifications 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 Space Shuttle, 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 analysis (includes mission operations activities, feasibility and utility analysis)
- Requirements definition and allocation, in the form of a System Specification including Requirements Flow Down
- Functional flow analysis
- Software systems requirements
- Systems analysis and models, including performance and requirements analysis, technology/risk assessments, cost risk analysis and assessment
- Systems trade studies (e.g., cost, schedule, lifetime and safety)
- Systems Engineering Process/Plan
- Design analysis and trade studies
- Preliminary interface requirements
- Payload Data Library Data (ISS Payloads)
- Verification Requirements and Verification Plan
- Flight and ground operations plan
- Synthesis activities
- Quality plan
- Logistics support analysis
- Specialty discipline studies (i.e., structures and dynamics, safety and reliability, maintainability, and hazard

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analyses; materials and processes considerations; electromagnetic compatibility/ interference, inspection methods/techniques analysis, or environmental considerations)

- Integrated test planning
- Data management plans
- Configuration management plans
- System safety reports
- Human factors analysis
- Value engineering studies
- Life cycle cost analysis
- Manpower requirements/ personnel analysis
- For manufactured items: producibility analysis, preliminary manufacturing plans

The total system engineering management activity and its output is reviewed for responsiveness to the Statement of Work 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:

- Baseline 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.

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I. Preliminary Design Review (PDR)

II. Purpose

The Preliminary Design Review (PDR) is held at the system, subsystem, and component levels to demonstrate 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 conducted when the basic design approach has been selected and the necessary documentation is available. As a rule it is held when the design is approx. 50% complete with 10% of the 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 analysis reports
- Preliminary Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL)

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- Verification/Validation plans including Verification Success Criteria
- Requirements Flow Down (update)
- Configuration management plans
- Interface Control Documents (ICDs)
- Systems description document
- Work Breakdown Structure and Dictionary
- Software documents,
- Spares philosophy
- Preliminary launch site requirements
- Preliminary GSE requirements
- Quality plan
- Part I Contract End Item (CEI) update
- Fracture control plan (updated)
- Preliminary strength and fracture mechanics analysis
- Proof of concept engineering analysis
- 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 interface requirements documents. 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 it lacking and are the resources (time, dollars) necessary for recovery affordable?"

In the event the Part I Contract End Item (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 Configuration Change Board (CCB) control
- Preliminary Interface Control Drawing update
- Preliminary design drawings
- Development plans
- Flow diagrams
- Safety analysis reports
- Preliminary Failure Modes and Effects Analysis
- Critical Items List
- Preliminary verification/validation plans
- Configuration management plans

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- Interface Control Documents (ICDs)
- Systems description document
- Work Breakdown Structure and Dictionary
- Software documents
- Spares philosophy
- Preliminary launch site requirements
- Preliminary GSE requirements
- Fracture control plan (updated)
- Preliminary strength and fracture mechanics analysis
- Proof of concept engineering analysis

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.

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I. Critical Design Review (CDR)

detail engineering drawings of the items to be manufactured.

II. Purpose

The objectives of the CDR are to assure that:

The Critical Design Review (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.

- 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.

III. Description

The CDR is the technical review of the detail design of the selected configuration. This review is generally held when the design and drawings have reached approx. 90%-95% complete. This review provides assurance that the detail design is in accordance with the Part I Contract End Item (CEI) Specification prior to its release to manufacturing. Configuration item and computer program configuration item critical design reviews are normally contractually required and are attended by the customer. Critical design reviews are normally conducted on the same items as preliminary design reviews, and as such warrant an in-house review prior to the formal critical design review.

Critical design reviews are normally conducted on the same items as preliminary design reviews, and as such may warrant an in-house review prior to the formal critical design review. Preliminary and final product specifications are not delivered/approved until the *as-built* items are delivered at acceptance.

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

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

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- Software definition
- Detail design/drawings
- ICDs
- Preliminary test results
- Failure Modes and Effects Analysis/Critical Items List
- Integration plans and procedures
- Subsystem description document
- Launch site requirements
- Detail design specifications
- Component, subsystem and system test plans
- Analyses reports
- Safety analysis/risk assessment
- Hazard analysis
- 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.

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- I. Ground Operations Review (GOR)
- Launch site support plan (Payloads)
- II. Purpose
- Baseline issue integrated payload safety compliance data.

The purpose of the Ground Operations Review (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/ Operations Flows
- Baselined Integrated System Verification Plan
- Verification Success Criteria
- Baselined Assembly and Installation Drawings
- Baselined Interface Schematics
- Preliminary Handling, Transportation, and Storage Plan
- Updated Payload Operations Control Center (POCC) data base

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I. Flight Operations Review (FOR)

II. Purpose

The purpose of the Flight Operations Review (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.

- Baseline issue Ground Data Systems data base
- Baseline issue Data Flow and Data Configuration Document
- Baseline issue Post-flight Evaluation Plan.

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:

- Baseline issue/baselined Operations and Integration Agreements/facility support agreements
- Baseline issue Flight Definition Document (ISS Payloads)
- Baseline issue Flight Supplement Payload Operations guidelines (ISS Payloads)
- Baseline issue flight planning
- Baseline issue flight operations support
- Baselined Integrated Training Plan
- Baseline issue payload/vehicle data processing requirements
- Preliminary Payload Flight Data File

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I. Design Certification Review (DCR)

II. Purpose

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

III. Description

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

The DCR 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, 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 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
- Manufacturing records
- Verification Reports
- Verification Procedures
- Verification Reports
- CDR RIDs and dispositions
- Engineering analyses
- FMEAs/CIL
- Open Work List
- Non-conformance Reports/Status
- Certification of Qualification (COQs)
- Hazard Analysis/Risk Assessment
- Waivers and Deviations
- Certificate of Configuration Compliance (COCC)
- Vendors Certificate of Flight Worthiness (COFW)
- Mission Constraints
- Materials Usage Agreement (MUA)
- Flight Data File
- All software development documentation
- Fracture Control Plan
- Strength and Fracture Mechanics for as-built hardware

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I. Configuration Inspection Review (CIR)

II. Purpose

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

The CIR will be scheduled by the Program/Project Office to be compatible with implementation of the Part II CEI Specification. It 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 Specification
- Release records
- Test requirements and procedures
- Drawings and engineering orders (EOs)
- Configuration Control Board Directives (CCBDs)
- System schematics

Required data for this review are listed below:

- Deviations
- Inspection tags
- Test log book
- Test Reports
- Certifications Of Quality
- 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 Certification Of Flight Worthiness (COFW)
- Non-conformance Report Status
- Hardware shortages
- Installed non-flight hardware list
- Safety Compliance Data
- Software
- Fracture Control Plan

Strength and fracture mechanics analysis for as-built hardware

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I. Functional Configuration Audit (FCA)/Physical Configuration Audit (PCA)

- Configuration Control Board Directives (CCBDs)
- System schematics

II. Purpose

The FCA/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. (See MWI 8040.6.)

Required data for this review are listed below:

- Deviations
- Inspection tags
- Test log book
- Test Reports
- Certification of Qualification (COQ)
- Materials certification
- Special handling procedures
- Contamination Control Records
- Software
- Fracture Control Plan
- Strength and fracture mechanics analysis for as-built hardware

III. Description

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

The FCA/PCA will be scheduled by the Program/Project Office to be compatible with implementation of the Part II CEI Specification. It 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 Specification
- Release records
- Test requirements and procedures
- Drawings and engineering orders (EOs)

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I. System Acceptance Review (SAR) / Integrated Readiness Review (IRR)

II. Purpose

Both the System Acceptance Review (SAR) and the Integrated Readiness Review (IRR) serve the same purpose: to transfer responsibility for a program from one organization to another. The SAR transfers responsibility from the contractor to MSFC. The IRR transfers responsibility from MSFC to 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 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. Acceptance data package (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.

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3. Open Work List must identify and describe any work planned for completion before shipment to the Launch Site but was actually not completed. It must also include any work or test previously planned to be performed at the Launch Site. These items must be categorized as follows:
- Open Review Item Discrepancies/ Discrepancy Notices (RIDs/DNs)
 - All ALERTs
5. Response to any MSFC design and operations issues, Open Items List and identification of additional items

- To be performed before shipment
- To be performed at the Launch Site:
- Off-line/After turnover to the Launch Site

4. Status and discussion of all:

- Waivers/Deviations/Engineering Change Requests
- Material Usage Agreements
- Hardware modifications (planned/proposed)
- Phase-down/phase-up plans

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
- Configuration at IRR versus Flight Configuration

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

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I. Test Readiness Review (TRR)

II. Purpose

The Test Readiness Review (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 TRR Board shall carry 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 Authority to Proceed 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

Board Membership:

- Chair - Manager from Test Organization/Facility (Independent from Project)
- Co-Chair - Directorate Chief Engineer or Program Manager
- S&MA
- Test Organization Representative
- Test Article Representative
- Engineering Directorate (Supporting Functions)
- Other MSFC Supporting Organizations
- Facilities Office
- Environmental Management

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I. Flight Readiness Review (FRR)

For Space Transportation Vehicles (Non-NSTS attached), the FRR is held at the successful completion of Vehicle/Launch Facility Integration requirements.

II. Purpose

The Flight Readiness Review (FRR) is the detailed review by which the system will be certified as flightworthy.

Successful completion of the FRR verifies:

III. Description

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

1. Recertification of interface requirements
2. Recertification of safety requirements
3. Vehicle Ground Integration requirements have been satisfied
4. Vehicle and Facility operations teams are ready for flight.

For NSTS attached 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. Recertification of safety requirements
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.

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APPENDIX B

ACRONYMS/DEFINITIONS

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
CDM	Configuration and Data Management
CDR	Critical Design Review
CDRM	Center Data Requirements Manager
CDDF	Center Director's Discretionary Fund
CEI	Contract End Item
CFO	Chief Financial Officer
CIL	Critical Items List
CM	Configuration Management
CMA	Configuration Management Accounting
COCC	Certification of Configuration Compliance
CofF	Construction of Facilities
COFR	Certification of Flight Readiness
COFW	Certification of Flight Worthiness
COQ	Certification of Quality
CPAF	Cost Plus Award Fee
CPFF	Cost Plus Fixed Fee
CPIF	Cost Plus Incentive Fee
CRPS	Center Resource Planning System
CWC	Collaborative Work Commitment
CY	Calendar Year
DCAA	Defense Contract Audit Agency
DCMA	Defense Contract Management Agency
DCR	Design Certification Review
DDT&E	Design, Development, Test, and Engineering/Evaluation
DN	Discrepancy Notice
DoD	Department of Defense
DPC	Data Processing Center
DPD	Data Procurement Document
DR	Data Requirements
DRD	Data Requirements Descriptions

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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
FAR	Federal Acquisition Regulation
FCA/PCA	Functional Configuration Audit/Physical 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 Operation Review
FPAF	Fixed Price Award Fee
FPI	Fixed Price Incentive
FRR	Flight Readiness Review
FY	Fiscal Year
G&A	General & Administrative
GOR	Ground Operation 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
IFMP	Integrated Financial Management Program
IPCL	Instrumentation Program and Command List
IRR	Integration Readiness Review
ISO	International Standards Organization
ISS	International Space Station
IV&V	Independent Verification & Validation
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LCC	Life Cycle Cost
LSE	Lead System Engineer

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MARTS	Marshall Accounting and Resource Tracking System
MG	Microgravity
MPD	Marshall Policy Directive
MPG	Marshall Procedures and Guidelines
MRD	Media Relations Department
MSFC	Marshall Space Flight Center
MUA	Material Usage Agreement
MWI	Marshall Work Instruction
NAR	Non-Advocate Review
NASA	National Aeronautics and Space Administration
NHB	NASA Handbook
NMI	NASA Management Instruction
NRA	NASA Research Announcement
NSTS	National Space Transportation System
OCC	Operations Control Center
ODM	Organizational Data Manager
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
PAS	Problem Assessment System
PCA	Program Commitment Agreement
PCN	Program Control Number
PDR	Preliminary Design Review
PED	Payload Element Developer
PFA	Project Formulation Authorization
PFD	Power Flux Density
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
RTOP	Research and Technology Operating Plan
RVC	Requirements, Verification, and Compliance
S&MA	Safety and Mission Assurance
SAR	System Acceptance Review
SBIR	Small Business Innovative Research
SCIT	Standard Change Integration and Tracking
SEB	Source Evaluation Board

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SEMP	System Engineering Management Plan
SLE	Subsystem Lead Engineer
SMO	Systems Management Office
SOW	Statement of Work
SRM&QA	Safety, Reliability, Maintainability, and Quality Assurance
SRP	Safety Review Panel
SRR	System Requirement Review
STD	Space Transportation Directorate
STDN	Space Tracking and Data Network
SW	Software
SWCDR	Software Critical Design Review
SWPDR	Software Preliminary Design Review
SWRR	Software Requirements Review
SWTRR	Software Test Readiness Review
TEB	Technical Evaluation Board
TDRSS	Tracking and Data Relay Satellite System
TIM	Technical Interchange Meeting
TRR	Test Readiness Review
TTA	Technical Task Agreement
V&V	Verification and Validation
VRSD	Verification Requirements and Specification Document
WBS	Work Breakdown Structure
WIS	Workforce Information System

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APPENDIX C

GLOSSARY

Agency: Term referring to the National Aeronautics and Space Administration

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 configuration control board before incorporation into the document, or drawing.

Classification of Contract Changes:

Class I: Changes that modify the latest approved baseline contract and have to be addressed by the Project Manager for resolution.

Class II: Changes that are editorial, or do not affect hard contract requirements such as cost and schedule.

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

Aerospace Technology: The mission of this Enterprise is to pioneer the identification, development, verification, transfer, application and commercialization of high-payoff aeronautics and space transportation technologies.

Earth Science: The mission of this Enterprise is to utilize space to provide information that is not obtainable in other ways, about Earth's environment.

Human Exploration and Development of Space: The mission of this Enterprise is to open the space frontier by exploring, using and enabling the development of space and to expand the human experience into the far reaches of space.

Space Science: The mission of the Space Science Enterprise is to solve mysteries of the universe, explore the solar system, discover planets around other stars, search for life beyond Earth from origins to destiny, chart the evolution of the universe and understand its galaxies, stars, planets, and life.

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

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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.

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.

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.