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Systems Engineering Processes and Requirements

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Systems Engineering Processes and Requirements

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Preface

P.1 Purpose

P.1.1 This document establishes the processes and requirements for performing systems engineering on NASA programs and projects. It provides a consistent basis for achieving identified technical products and for developing the technical information required to support the management and decision processes of NPG 7120.4, Program /Project Management, and NPG7120.5, Program and Project Management Processes and Requirements.

P.2 Applicability and Scope

P.2.1 This NASA Procedures and Guidelines (NPG) document is applicable to NASA Headquarters and NASA Centers, including component facilities, and to the Jet Propulsion Laboratory to the extent specified in the contract.

P.2.2 This document defines the basic processes for systems engineering applicable to all PAPAC programs and projects. Its expected use is specifically for programs/projects that provide aerospace products or capabilities, i.e., provide space and aeronautics, flight and ground systems, technologies and operations. It is not required but may be used for other projects, such as non-flight infrastructure, Construction of Facilities (C of F), Small Business Innovation Research (SBIR), or Research & Analysis projects.

P2.3 While the requirements are to be addressed, they may be tailored to the specific needs of the program/project consistent with size, complexity, criticality, and acceptable risk. Tailoring is a method to encourage innovation while meeting customer needs. Approved Project Plans and/or Systems Engineering Management Plans (SEMP) will document the tailoring decisions. All programs and projects will comply with requirements established by law, regulations, Executive Orders, and Agency Directives.

P.2.4 The NASA Strategic Management Handbook, the NPD for Program/Project Development, the NPG for Program and Project Management Processes and Requirements, and the present document rank first, second, third, and fourth in order of precedence for managing all NASA programs and projects except if in conflict with statutory or regulatory requirements. Each Center is responsible for developing and implementing Center-level policies, processes, procedures and requirements necessary to ensure successful execution of the processes and activities according to this document.

Note: NASA contractors and/or partners should be aware of the systems engineering concepts and processes of this NPG.

P.3 Authority

42 U.S.C. 2473(c)(1), Section 203(c)(1) of the National Aeronautics and Space Act of 1958, as amended.

P.4 References

NPG1000.2	NASA Strategic Management Handbook
NPG2820.1	NASA Software Guidelines and Requirements
NPD7120.4	Program/Project Management
NPG7120.5	Program and Project Management Processes and Requirements

NPG8705.x	Risk Management Procedures and Guidelines
NASA SP-6105	NASA Systems Engineering Handbook
ANSI/EIA-632-1999	Processes for Engineering a System
ISO/IEC 15288	System Engineering-System Life Cycle Processes

Note: References are for informative purposes only. Applicability of these references to any NASA program or project is governed by the contents of the individual documents.

P.5 Cancellation

P5.1 This document is a new issuance.

CHAPTER 1. OVERVIEW

This chapter provides an introduction to the overall document, describes the Systems Engineering Framework and explains the document's relationship to NPG 7120.5, identifies key attributes of the systems engineering processes and requirements within the document, describes the structure of the document, and specifies the force of the requirements in the document.
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1.1 Introduction

1.1.1 NASA defines programs as major activities within an Enterprise that have defined goals, objectives, requirements, and funding levels, and consist of one or more projects. Projects are defined as significant activities designated by a program and characterized as having defined goals, objectives, requirements, life-cycle costs, a beginning, and an end. Systems engineering is a disciplined approach to the development of a system, which focuses on the technical decisions that address the system performance, safety, mission criticality, and operation across all aspects of the project.

1.1.2 As NASA strives for greater collaboration, integration, and sharing of expertise among Centers, external partners and customers in collaborative environments, there is synergistic value in having a common framework for systems engineering. This document provides the basic concepts, processes, activities, and requirements for executing the systems engineering associated with programs and projects. The content of this document intends to communicate a work focus (what has to be done), rather than a role focus (who has to do it). When the terminology "systems engineering" is used it will be for the purpose of communicating what processes are required to be performed and not to specify a responsibility or organization within NASA.

1.2 Framework

1.2.1 The Office of the Chief Engineer, NASA, has established a systems engineering framework to provide a structure for the continuous improvement of technical processes and requirements. Of particular focus are those for the engineering community to use to formulate concepts and to provide aerospace products and capabilities to satisfy NASA customers. NASA is developing this Agency-wide common framework to support and manage a robust, efficient, interoperable and consistent technical capability. The framework includes efforts for a) Process and Concepts Improvements, b) Tools and Methods Development, and, c) Enhancement of the Knowledge and Skill of the workforce. This NPG addresses the first of the three efforts.

The need for a framework resulted from the growth of complexities of NASA systems. Both the complexity of systems and complexity of the engineering of these systems have grown with the advent of international partnerships, increased technical risks and technologies, and the increased demands of hardware and software integration.

The purpose of this framework is to provide an Agency-wide approach for strengthening the systems engineering capability within NASA with focus on the technical and engineering aspects of NASA PAPAC programs and projects in support of NPG 7120.5. The framework is intended to guide the following:

1) The production and oversight of aerospace products, capabilities and services from a technical/systems engineering perspective.
2) Capability assessments as a basis for continuous measurable improvement.
3) Professional development of a strong technical workforce focused on utilizing a systems approach.

1.2.2 NASA document NPG 7120.5 "NASA Program and Project Management Processes and Requirements" details the management system that governs the formulation, approval, implementation, and evaluation of all agency programs and projects established to Provide Aerospace Products and Capabilities (PAPAC). This document describes herein the complementary procedures and requirements for executing the systems engineering aspects of a project.

1.3 Key Attributes

1.3.1 Method of Application. The processes, activities, and requirements of Chapter 3 are applicable at each system level from the top down and from the bottom up in an iterative or repetitive manner to add value to the system being engineered. Each level is considered to consist of one or more unique "systems of interest" that are engineered by the application of the processes and activities of Chapter 3.

1.3.2 Degree of Applicability. The processes, activities, and requirements of Chapter 3 are equally applicable to the engineering of hardware, software, facilities, or services. Each product or capability is considered to be a "system of interest. The intent is to encourage a systems thinking vantage point among all members of the NASA engineering community.

1.4 Document Structure

1.4.1 Chapter 2 explains the fundamental concepts adapted from non-government and international standards and Agency best practices for use in this document. The concept of the "System of Interest" is presented as the scope of interest to the principally assigned engineering team. The concept is meant to be equally applicable whether working on the "part", "assembly", or "subsystem" (terminologies of NASA SP-6105; or system element as described in ISO/IEC 15288). The "Enabling Systems" are those entities that while not a functioning part of the intended operational system are nevertheless required for the proper achievement of the system of interest. This implies a hierarchical relationship among systems of interest and their respective enabling systems. The "Systems Life Cycle " concept is discussed in relationship to the NPG 7120.5 program/project lifecycle.

Chapter 3 provides explanation for the systems engineering processes and activities prescribed by this document. The relationships among the crosscutting processes (Technical Management and Evaluation) and the sequential technical processes (Definition, Design, and Realization) of a system of interest are explained. The requirements for compliance with this NPG are contained in this Chapter. The requirements are expressed in the form of "shall" statements.

1.4.2 Appendices are included to provide instructions for tailoring (Appendix A), a brief set of definitions and terminology that are meant to be used in common across the NASA community (Appendix B), a brief discussion of the relationships between this document and informative national and international standards for systems engineering (Appendix C), and sample outlines for necessary or suggested documents (Appendix D).

1.4.3 Note: There are a number of references throughout this document to NASA Policy Directives (NPD)'s and NASA Procedures and Guidelines (NPG)'s documents that relate to other processes and requirements in support of PAPAC activities. Overlap with these documents is maintained at a minimum with only complementary information presented. Other references listed in Section P.4 provide additional helpful information.

1.4.4 Note: Centers are expected to implement appropriate Center-level policies, processes, procedures and requirements to ensure successful systems engineering execution of their specific programs and projects in compliance with the requirements of this NPG.

1.5 **Force of Requirements**.

1.5.1 In this document a requirement is identified by a “shall” statement, a good practice is identified by “should”, a permission is identified by “may”, and an expectation is identified by “will”. All else is descriptive material. Tailoring of a “shall” statement requires approval. All else is discretionary.

CHAPTER 2. NASA SYSTEMS ENGINEERING

The chapter explains the NASA model for systems engineering. Concepts for the 'system of interest' and the 'enabling systems' are adapted from the ISO/IEC 15288 System Engineering-System Life Cycle Processes. The explanation of the systems life cycle provides guidance and the basis for applying the processes and requirements of Chapter 3 to the stages of the systems life cycle.

2.1 Systems Engineering Relationships and Characteristics

This NPG for systems engineering provides guidance and requirements for the processes and concepts dimension of the framework of Section 1.2. Figure 2-1 illustrates the relationship of this NPG with other NASA directives and guides. It also illustrates its intended relationship with Center directives and guides as well as a NASA Body of Knowledge for systems engineering. This Body of Knowledge is an accumulation of lessons learned, best practices, informational references to useful standards and handbooks, including the NASA Systems Engineering handbook, SP6105.

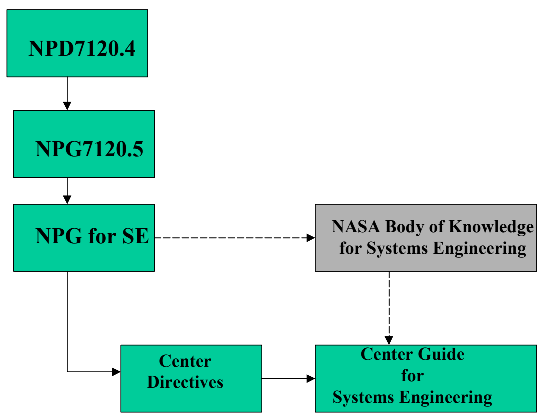


Figure 2-1. Hierarchical Relationship for the NPG for Systems Engineering

The intent of this NPG is to provide standardized systems engineering processes and requirements to be used across all the Agency programs and projects. More detailed requirements may be levied by Center Directives and project plans, depending upon the particular type of program or project.

From a general perspective, characteristics of sound systems engineering are viewed to be as follows:

1) The use of common systems engineering processes, terminology and definitions to enhance communication and collaboration among engineering teams across the Agency, and with external partners and customers.
2) The documentation of appropriate levels of technical planning throughout a systems life cycle.
3) The ability to view a system under development as a structure that is a sum of multiple hierarchical levels, each of which is a system of interest (previously referred to as "systems", "subsystems", "assemblies", and so on, down to the "part" level, from SP6105)

4) The use of an engineering model that comprises a decomposition and definition of requirements sequence followed by an integration and verification sequence of systems of interest and their enabling systems that validate the customers' desired objectives.
5) A systems life cycle model that addresses the system of interest's requirements during each stage of the life cycle from the Concept Stage through the Operational Stage, addressing the contribution of all engineering and scientific disciplines (mechanical, electrical, software engineering, reliability, logistics, safety, environmental, operators and customers) with a stake in the system of interest.
6) An interdisciplinary team approach throughout the system's Concept, Development and Production Stages to ensure that all system requirements are met within an acceptable level of risk, are technically feasible, and are met in a cost effective manner. This in particular applies to large scale, multi-disciplinary programs and projects with significant integration complexities.
7) A verification process that traces every requirement to a specific verification method (did we build it right?) at all levels of the system hierarchy and a careful validation of each end product at each level (did we build the right thing?).
8) A controlled technical resource budget allocation involving resource margins and periodic tracking with appropriate metrics.

2.2 Systems Engineering Definitions

Numerous definitions of systems engineering exist. The systems engineering community has no consensus for a single definition. Definitions employed depend on the industry perspective, organization and personal preference. Literature searches for a definition of system engineering produce varied results. Nevertheless, it is useful to review a few of the definitions that are accepted both within the Agency and by the Industry.

2.2.1 The International Council on Systems Engineering (INCOSE) definition of systems engineering:

System engineering is an interdisciplinary approach and means to enable the realization of successful systems.

2.2.2 The NASA Systems Engineering Handbook (SP6105) definition of system engineering:

Systems engineering is a robust approach to the design, creation, and operation, of systems. In simple terms the approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is the properly built and integrated, and post implementation assessment of how well the system meets (or met) the goals. The approach is usually applied repeatedly and recursively, with several increases in the resolution of the system baselines.

2.2.3 For the purpose of this NPG the following definition of systems engineering is used:

Systems Engineering is a disciplined approach for the definition, implementation, integration and operations of a system (product or service) with emphasis on the satisfaction of stakeholder functional, physical and operational performance requirements in the intended use environments over its planned life within cost and schedule constraints. Systems engineering includes the engineering activities and technical management activities related to the above definition considering the interface relationships across all elements of the system, other systems or as a part of a larger system

2.3 Key Concepts

For NASA, a 'system' is the combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, and the processes and procedures needed for this purpose.

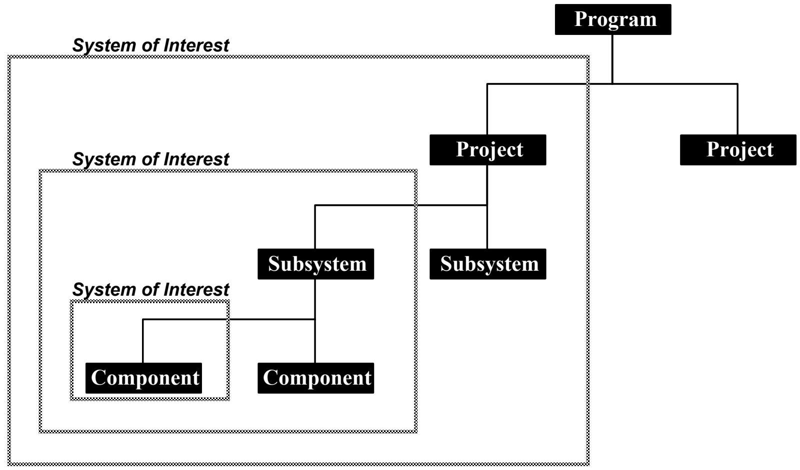
The engineering process involves breaking a complex system into smaller more manageable pieces, then bringing those pieces back together in the final solution. And this is repeated at each stage of the system life cycle. The engineering process is best visualized by using the engineering ("Vee") model that was developed by Forsberg and Mooz and appears in NASA SP-6105. This descriptive model shows how systems engineering activities flow both hierarchically and chronologically with respect to each other. It describes how the technical work flows in order to develop the system of interest, no matter what stage it is in the systems life cycle.

2.3.1 System of Interest

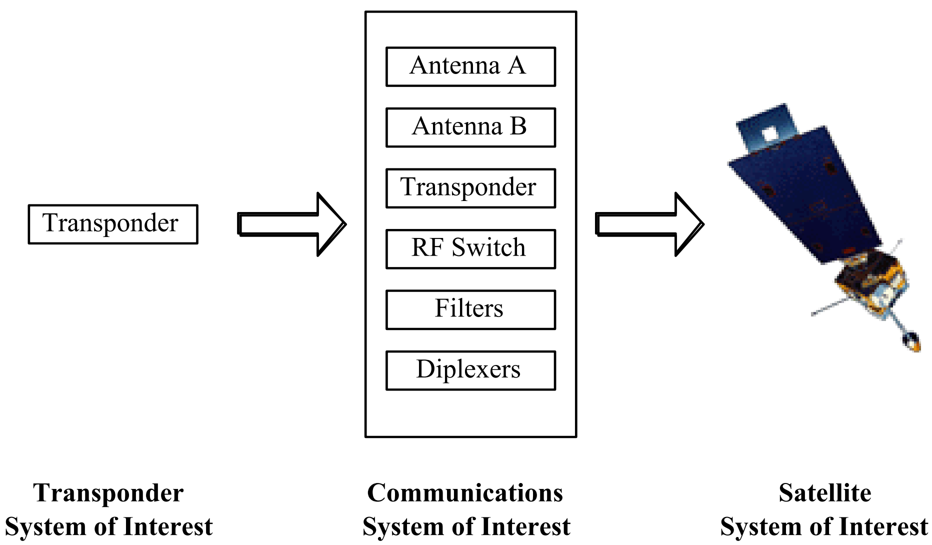
The processes and activities described in this document are intended to be applicable to all system development efforts across the Agency. The processes for engineering and producing quality systems are meant to apply to any object (hardware or software) with well-defined boundaries and end-points, and composed of interrelated and interacting elements.

This is characterized in the concept of the "system of interest". Understanding this concept is fundamental to establishing a common approach that can be applied to systems at all levels. The definition of a particular system to be engineered depends on the practitioner's responsibilities, scope of assignment, and interest. One person's system of interest may be viewed as a lower level system of interest in another person's system of interest.

It is instructive to think of these as forming multiple levels, or a hierarchy of systems. Figure 2-2 illustrates such a relationship. Each box formed with dashed lines in the Figure 2-2 is a system of interest for the application of the processes of chapter 3. As illustrated in the figure, each box has other boxes below it that make it up, until the one(s)are reached that can be realized by being bought, built, reused, or coded.



Hierarchical Relationships for Systems of Interest



Example for Three Levels of Systems of Interest

Figure 2-2. System of Interest

As an example of a system of interest and its levels, consider a satellite system containing a transponder, shown in Figure 2-2, which is being designed, manufactured, integrated and tested for delivery.

In the hierarchy of systems this satellite would be considered to consist of lower level systems of interest (one of which, for example, is the communications system of interest). At a level below the communications system of interest is the transponder system of interest.

The transponder itself is an identifiable, self-contained entity with its own defined functional and performance requirements, its own electrical and mechanical interfaces, development schedule, life cycle and cost constraints. It is an integrated whole composed of several lower level systems of interest (called parts in SP6105; for example, the case (or chassis), the printed circuit boards, the connectors, the harness, etc.).

The transponder is the system of interest for the engineering team responsible for designing, developing, integrating and testing the transponder and delivering it to the communications engineering team. The transponder engineer(s) will apply the systems engineering processes of chapter 3 to their system of interest in appropriate life cycle stages to ensure the delivery of a quality product. The transponder system of interest is viewed as being at a lower level from the next higher-level system of interest, which is the communications system. Again, the engineer(s) responsible for delivering the communications system to the satellite will apply the systems engineering processes of Chapter 3 to that system of interest.

It is essential to note here that this concept of the system of interest is applicable to any product or service. Hardware and software items can equally benefit through the application of the principles contained in this section.

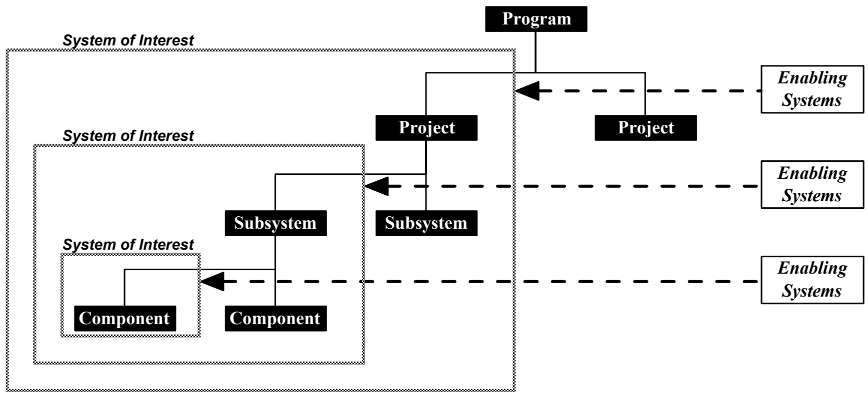
2.3.2 Enabling Systems

In designing and realizing the system of interest, essential services are often required from the NASA environments that are not directly a part of the functional environment of the system of interest. Typically, these essential services may already exist, are functioning and have been proven out, either during their own creation as a system of interest, or by their prior use on earlier systems of interest.

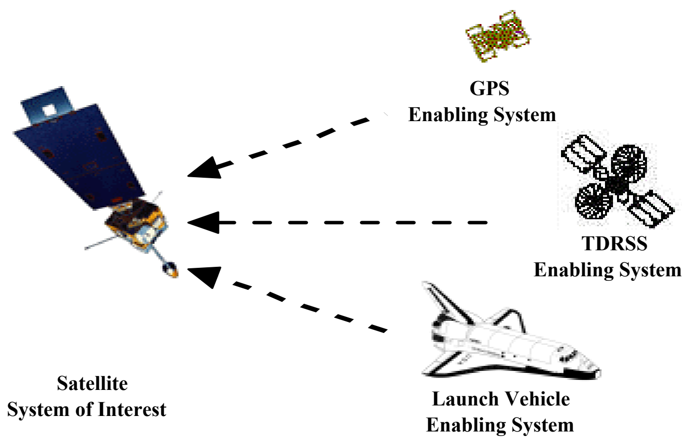
The systems that provide these essential services are called enabling systems. As indicated by Figure 2-3, an enabling system is a system that complements the system of interest but does not contribute directly to its functionality. Enabling systems operate separately or as an interacting group. Each system of interest has a set of enabling systems that allow the system of interest to perform its life cycle functions. When an enabling system has to be developed it is also considered to be a system of interest, and the processes of Chapter 3 are applied.

Examples of enabling systems are drawn from the previous example of the transponder and satellite. As shown in Figure 2-3 the satellite enabling systems are the launch vehicle to get the satellite into orbit, the TDRS communication system in space that the satellite uses to communicate, and the GPS satellite system that it uses for navigation.

The identification of a need for support from an enabling system that does not exist in NASA's environment may cause management to develop it as a new enabling system. From the perspective of this NPG, the new enabling system would be the system of interest and the processes of chapter 3 would apply.



Hierarchical Relationships for Enabling Systems



A Satellite with Three Enabling Systems.

Figure 2-3. Enabling Systems

2.3.3 The Engineering Model

To develop and realize a product, capability or service, the engineering team should take a top down/bottom up development approach that views the system of interest as a whole. The engineering process is best visualized by using the widely understood engineering ("Vee") model that was developed by Forsberg and Mooz and appears in NASA SP-6105. The model starts with the user needs and ends with a user-validated system. Initial effort starts with the development of the user or customer requirements and goes through a series of decomposition and definition activities to resolve the system architecture resulting in a completed design and documentation that meets the customer's user requirements. This initial effort can be considered a requirements-driven model of the system development process. Detailed design work can proceed early in the process to verify hardware and software models used to clarify customer needs. Time and project maturity flow throughout the model. This effort is then followed by the integration and verification sequences of the model. Integration and verification effort flows up the "Vee" vertically and validation occurs horizontally across the model.

2.4 Systems Life Cycle Model

This NPG has adapted the model of the "systems life cycle" from the ISO/IEC 15288 System Engineering-System Life Cycle Processes. The intent of ISO/ICE 15288 is to provide a common basis that covers the life cycle of systems. It is meant to promote communication and cooperation among the varied disciplines (hardware, software, etc.) that enable modern systems to be created, operated and managed in an integrated and coherent fashion. This international standard provides a valid model that is readily adaptable to Agency use. . Because long duration programs and projects may find that a majority of total life cycle costs are incurred within the Operational Stage, concern with the entire systems life cycle during the Concept and Development Stages should be paramount in creation of such new systems.

In this life cycle, systems engineering is performed to generate the information needed by the technical and project managers to decide whether or not to proceed the development of the system to the next stage. The processes and activities of chapter 3 are used throughout these stages to generate this information. It is important to understand that the concept of a systems life cycle is just as applicable to each individual system of interest as to the top-level system

The NASA systems life cycle model adapted from ISO/IEC 15288 consists of four stages. These stages include the Concept Stage, Development Stage, Production Stage and Operational Stage. The Operational Stage includes the three phases of Utilization, Support, and Retirement. Figure 2-4 illustrates these stages. Each NASA system progresses through the stages of this life cycle. These stages may overlap during typical systems development.

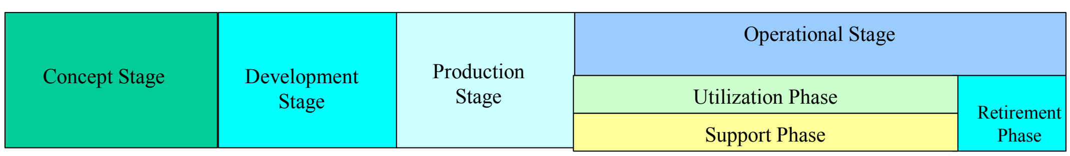


Figure 2-4. NASA Systems Life Cycle

2.4.1 Concept Stage

The Concept Stage begins with the identification of needs and/objectives. "Systems of interest" are identified for feasibility study. One or more concepts are developed through analysis, estimations, experiment, or reference to previous systems. This stage produces a feasible design solution. The needs for enabling systems are also identified and included in lists of alternate concepts.

The system engineering activities and requirements to be applied in the Concept Stage are included in the following processes:

1) Definition
2) Technical Management
3) Technical Evaluation

The expected products of this stage may include, but are not limited to the following

1) Functional requirements
2) Identification of feasible systems of interest and enabling systems required to meet the defined functional requirements
3) Operational concepts
4) Feasibility studies
5) System life cycle cost estimates
6) Systems Engineering Management Plan in support of Project Management Plan
7) Risk Management Plan
8) Preliminary safety plans
9) Metrics & reporting requirements
10) System cost/benefit analysis
11) System budget
12) System requirements
13) System budget
14) System architecture

The Concept Stage is executed as part of the program/project formulation phase of NPG 7120.5. It provides evaluated concepts with supporting information required to meet the requirements of the program/project formulation that leads to program/project approval. Appropriate Entrance Criteria and Exit Criteria, suitable for individual programs/projects should be prepared, approved and documented in Center Directives and program/project planning documents. The successful preparation or satisfaction of Exit Criteria enables the transition of activities on the system of interest into the next stage of the System Life Cycle.

2.4.2 Development Stage

The Development Stage begins with the governing PMC approval to move to implementation per NPG 7120.5. The primary objective of the Development Stage is to demonstrate that the identified needs or objectives of the customer can be achieved by the proposed system solution, and that the system can be produced, operated and de-commissioned within the technical and budget scope of the program/project plans. Planning for this Stage begins in the preceding Stage.

This stage involves taking the identified products of the Concept Stage and transforming them into the system definition required to move to the Production Stage. Any required enabling systems are included in this transformation.

The system engineering activities and requirements to be applied in the Development Stage are included in the following processes:

1) Design
2) Technical Management
3) Technical Evaluation

The expected products of this stage may include, but are not limited to the following:

1) System prototyping
2) Modeling/simulations
3) Refined lower level functional and performance requirements
4) Technical data package for system and enabling systems
    i) Detailed design/fabrication drawings & plans
    ii) ICD definition
    iii) Operational concept
    iv) Training documentation
5) Risk Management Plan refinement

6) Verification and Validation plans
7) SMA planning

Appropriate Entrance Criteria and Exit Criteria, suitable for individual programs/projects should be prepared, approved and documented in Center Directives and program/project planning documents. The successful preparation or satisfaction of Exit Criteria enables the transition of activities on the system of interest into the next stage of the System Life Cycle.

2.4.3 Production Stage

The Production Stage begins with the decision to proceed to produce the system of interest. During this stage the system of interest may be manufactured, assembled, integrated into other systems, and validation and verification plans executed. Individual system of interest testing, or end-to-end-testing of the top-level system, is performed as needed. The Enabling Systems also go through the same process. Planning for this Stage begins in the preceding stages.

The system engineering activities and requirements to be applied in the Production Stage are included in the following processes:

1) Technical Management
2) Technical Evaluation
3) Realization

The expected products of this stage may include, but are not limited to the following:
1) Qualification plan for production
2) Acquisition/logistics/procurement material and components required for system and enabling systems
3) Acquisition/procurement/manufacture of system of interest and it's enabling systems according to design packages
4) Verification and validation of system of interest and enabling systems
5) Operational Plans
6) Logistics Plans
7) Maintenance Plans

Appropriate Entrance Criteria and Exit Criteria, suitable for individual programs/projects should be prepared, approved and documented in Center Directives and program/project planning documents. The successful preparation or satisfaction of Exit Criteria enables the transition of activities on the system of interest into the next stage of the System Life Cycle.

2.4.4 Operational Stage

The Operational Stage is comprised of three concurrent phases: Utilization, Support and Retirement. Planning for these phases must start in the preceding Stages to achieve the most efficient and cost effective solutions for the requirements and objectives of the system of interest.

2.4.4.1 Utilization Phase

The Utilization phase of the Operations Stage is executed to operate and use the system products and services in their operational environments to satisfy the intended purpose of the system. During this phase the system of interest can evolve, giving rise to new requirements, for either modification or enhancement of the system of interest. Iterative applications of one or more Stages of the system life cycle and their associated systems engineering processes and activities may be necessary to achieve the modifications or enhancements.

The system engineering activities and requirements to be applied in the Utilization phase are included in the following processes:
1) Technical Management
2) Technical Evaluation
3) Definition
4) Design
5) Realization

2.4.4.2 Support Phase

Support begins with the provision of maintenance, logistics, support system, facility operations and other support required for the operations of the system of interest. Planning for Support, as with the Utilization, begins in the preceding stages. Utilization and Support generally occur in parallel as part of the Operations Stage. The Support phase ends when the decommissioning or Retirement phase of the operational system (and/or termination of the support services) begins.

Support includes all the enabling systems and processes required to operate the systems of interest to meet the planned objectives in the intended environment of operation. This phase includes the maintenance and support for all enabling systems. This includes the monitoring of performance, tracking and resolution of deficiencies in the enabling systems that support the operations of the system of interest. During this phase the enabling systems should evolve to support the most efficient and possibly changing requirements of the primary system of interest. In general, the enabling systems or the support infrastructure will be developed, procured and placed into operation in support of the objectives of the system of interest.

The system engineering activities and requirements to be applied in the Support phase are included in the following processes:

1) Technical Management Process
2) Technical Evaluation Process
3) Definition
4) Design
5) Realization Process

Support is executed to maintain and support the Utilization of the system of interest. The expected products of this phase may include, but are not limited to the following:

1) Launch services
2) Recovery services
3) Ground system operation in support the “system”
4) Training
5) Logistic Systems
6) Safety
7) Environmental

   a) Monitoring
   b) Data collection systems
8) Physical and IT security

The importance of understanding the functional requirements of the Utilization and Support phases should not be overlooked. In many cases, the success or the cost of success of the system is directly linked to the cost and complexity encountered by the system operators.

2.4.4.3 Retirement Phase

The Retirement phase is executed to provide for the removal of a system and/or a system's byproducts. Planning for the Retirement phase, as with the other phases of the Operations Stage begins in the preceding stages. This phase is applicable when the system of interest or its supporting enabling systems reach the end of the planned service life. Examples include replacement by a new system, catastrophic system failures, program termination, system is no longer useful to the operator or customer, system obsolescence, or system is no longer cost effective to operate.

The system engineering activities and requirements to be applied in the Retirement phase are included in the following processes:

1) Technical Management
2) Technical Evaluation
3) Definition
4) Design
5) Realization

The expected products of this phase may include, but are not limited to the following:

1) System decommissioning,
2) Disposal, refurbishing and/or recycling in accordance with applicable health, safety, security and environmental laws and regulations.
3) Data archival and disposition
4) Logistics plans
5) Agreement and contract terminations or closures
6) Enabling systems application to other programs

Appropriate Entrance Criteria and Exit Criteria, suitable for individual programs/projects should be prepared, approved and documented in Center Directives and program/project planning documents. The successful preparation or satisfaction of Exit Criteria activities signifies the conclusion of the system life cycle for the system of interest.

2.4.5 Systems Life Cycle Relationship to the Program/Project Life Cycle

NPG 7120.5 defines and controls the program/project life cycle of PAPAC programs and projects. The systems life cycle defined by this NPG fits within this program/project life cycle and provides greater definition to the life cycle for systems engineered in support of PAPAC programs and projects.

The intent of the systems life cycle is to institute a standardized set of stages for the development of systems of interest and their required enabling systems in support of PAPAC programs and projects within the Agency. The use of accepted life cycle concepts from the international standard ISO/ICE 15288 and the EIA 632 Processes for Engineering a System enable NASA to share a common framework with industry and international partners and foster agreements and understanding in the development of systems.

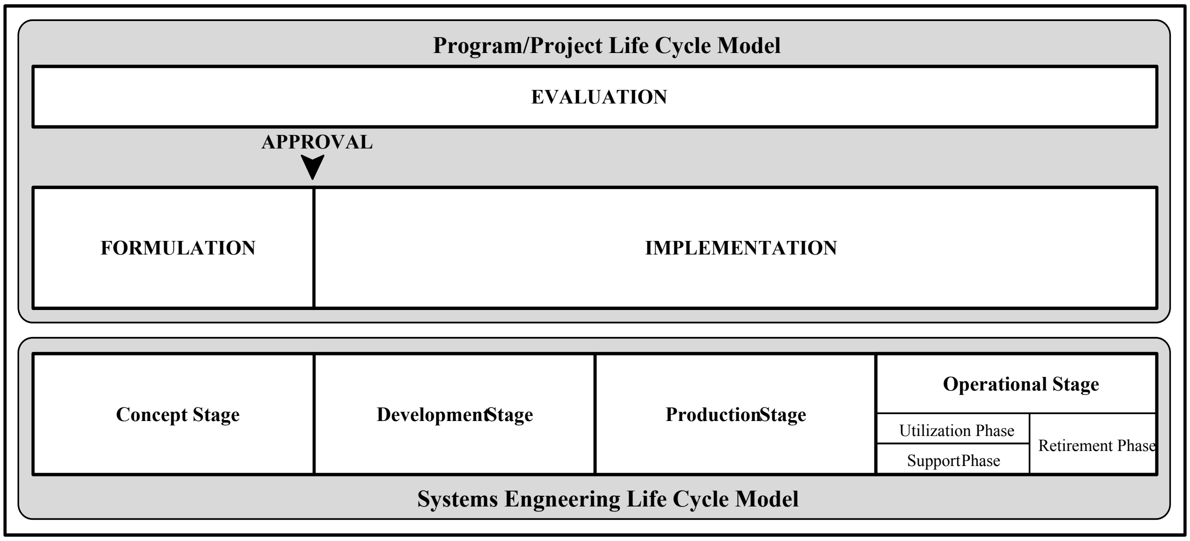


Figure 2-5. Relationship between the NPG 7120.5 program/project life cycle model and the stages of the Systems Life Cycle Model.

The Concepts Stage of the systems life cycle for the top-level system of interest coincides with the Formulation Phase of NPG 7120.5. Systems engineering is performed to generate the information needed by the technical and project managers to decide whether or not to proceed the development of the system to the next stage. The processes and activities of chapter 3 are used throughout these stages to generate this information. Figure 2-5 shows the Program/Project Approval control gate for transitioning from the Concept Stage to the Development Stage.

CHAPTER 3.0 SYSTEMS ENGINEERING PROCESSES

This chapter addresses the system engineering processes and associated activities that are applicable for NASA systems. The processes are divided into five different categories:

1. Definition,
2. Design,
3. Realization,
4. Technical Management, and
5. Evaluation

As depicted in Figure 3-1, the Definition, Design, and Realization processes occur sequentially with respect to each other with each individual process and associated activities taking the outputs of the preceding process and progressively transforming a set of needs into a product. Although occurring sequentially with respect to each other, do not consider the three processes as steps, that once completed, will not be revisited. Thus, the depiction in Figure 3-1, that the outputs of the processes must continuously and iteratively be assessed to make sure they are meeting the inputs of the processes. If necessary, the process (es) and any associated activity(s) will be refined. For example, once a solution is selected as a result of the Design process, that solution must be assessed to make sure it satisfies the requirements and the needs. If this is not true, the activities of the Design process or the Definition process must be reiterated.

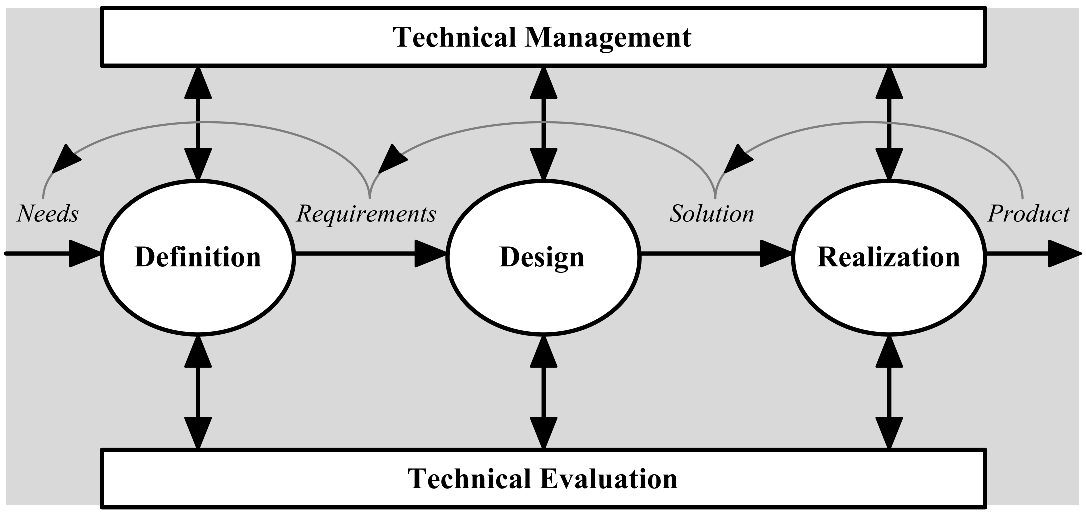


Figure 3-1. Systems Engineering Processes.

The Technical Management and Technical Evaluation processes and associated activities occur continuously throughout the systems engineering effort and are depicted, in Figure 3-1, as crosscutting processes to the Definition, Design, and Realization processes. For example, activities associated with the Technical Management process (e.g. Risk Management) and Technical Evaluation process (e.g. Reviews) are performed not only in the Definition process, but will continuously occur and mature in the Design process and Realization process.

As mentioned, there are essential activities associated with each of the processes that progressively transform the inputs of each process into an eventual product. In the paragraphs that follow, each process activity is described with a stated purpose and the minimum set of requirements to be implemented. The requirements listed establish “what” is to be implemented and not “how to” implement, which is the responsibility of each Center. The process activities are listed in Table 3.1.

Table 3-1. Process Activities

Definition	Design	Realization	Technical Management	Technical Evaluation
• Feasibility Study	• Design	• Attainment	• Acquisition Management	• Systems Analysis
• Technology Planning		• Integration	• Work & Resource Management	• Reviews
• Operational Concept Development			• Risk Management	• Verification
• Decomposition			• Configuration/Data Management	• Validation
• Requirements Development			• Safety	
			• Control	
			• Quality	

As discussed in Chapter 2, the processes and activities outlined in this chapter are applicable to every system of interest. The supporting enabling systems impact to that system of interest must be considered throughout the processes.

The processes and activities discussed in the chapter are to be described in detail for each program/project in a Systems Engineering Management Plan (SEMP). Appendix D provides a SEMP outline for reference. The SEMP outlines and defines in detail the systems engineering processes, activities, and requirements discussed in this chapter and is the primary planning document for the systems engineering effort on any program/project. The SEMP will be tailored to the program/project size and complexity and will work in concert with the program/project plan.

3.1 DEFINITION PROCESS

The activities listed within this process category are responsible for translating the customer and stakeholder needs into requirements.

3.1.1 Feasibility Study

3.1.1.1 Purpose:

The feasibility study activity iterates and evaluates the needs and potential concepts for establishing technical and programmatic feasibility. The outcome of the feasibility study activity establishes technical and resource feasibility and identifies the associated risks of meeting requirements within the given constraints.

3.1.1.2 Requirements of Activity:

The feasibility study activity shall establish the ranking and evaluation criteria for assessing the approaches.

The feasibility study shall establish one or more technically and programmatically feasible approaches for the system of interest under consideration.

Cost estimates shall be determined over the entire life cycle for each of the possible system of interest approaches.

3.1.2 Technology Planning

3.1.2.1 Purpose:

The technology planning activity ensures that the technologies critical for success are identified and the effort to advance the technologies is understood and feasible.

3.1.2.2 Requirements of Activity:

An initial technology assessment shall be performed and documented that identifies key enabling and enhancing technologies to be infused into the system of interest and identifies the existing Technology Readiness Level (TRL) for each.

The identified technologies shall be further assessed and documented to determine what is required (e.g. design, equipment, processes, tools, operation, risk, etc.) to advance those technologies to the level necessary for successful inclusion into the overall system of interest.

Technology maturation and insertion planning shall be developed and documented which identifies quantifiable milestones, decision gates, off-ramps and fallback positions for incorporating the technologies into the system of interest.

3.1.3 Operational Concept Development

3.1.3.1 Purpose:

The operational concept development activity establishes an operational scenario in which the system of interest will function or be used. This activity helps to focus the requirements development activity so that the systems operations and logistics/maintenance are considered during system definition.

3.1.3.2 Requirements of Activity:

The operational concept development activity shall develop a high level definition of the operating profile for the system of interest that covers the entire life cycle and defines timeline, functions, and interfaces.

3.1.4 Decomposition

3.1.4.1 Purpose:

The decomposition activity achieves an architectural breakdown of the system of interest into lower level components.

3.1.4.2 Requirements of Activity:

The decomposition activity shall develop physical and functional architectures that identify, as a minimum, the next lower level physical or functional components of the system of interest (e.g. System Block Diagrams).

The decomposition activity shall develop and maintain requirements traceability/flowdown to show the parent/child relationship of each requirement and the detailing or parsing of the requirement into requirements for functional or physical components of the system of interest.

The decomposition activity shall establish the system architecture for the system of interest that accounts for all requirements, including derived requirements.

The decomposition activity shall develop and maintain interface control or definition documentation that defines all physical and functional interfaces for the various levels of the system of interest.

3.1.5 Requirements Development

3.1.5.1 Purpose:

The requirements development activity gathers needs and constraints and transforms them into agreed to requirements for the system of interest. Requirements communicate the functions that a system of interest has to perform, how well it must perform these functions, and with what enabling systems the system of interest must interact.

3.1.5.2 Requirements of Activity:

The requirements development activity shall transform the customer and stakeholder needs into requirements for the system of interest and provide traceability of the requirements back to the customer and stakeholder needs to validate incorporation.

The requirements development activity shall establish and document system of interest requirements that can be verified and validated.

The requirements development activity shall establish and document all technical requirements including engineering standards, code/regulatory requirements, operational requirements, environmental requirements, safety requirements, interface requirements, human engineering requirements, logistics requirements, quality, reliability, maintainability, etc. in relation to the system of interest.

3.2 DESIGN PROCESS

The activities listed within this process category are responsible for transforming the requirements into qualitative and quantitative solutions.

3.2.1 Design

3.2.1.1 Purpose

The design activity is a methodical and iterative effort to transform the system of interest requirements into qualitative and quantitative solutions.

3.2.1.2 Requirements of Activity:

The design activity shall take the requirements from the Definition Process and further decompose and allocate functional performance to lower levels of the system of interest architecture.

The design activity shall determine alternative concepts and configurations that address the system of interest requirements.

The design activity shall conduct trade studies of the proposed concepts to provide an objective foundation for the selection of the solution(s). The trade studies shall encompass analytical and physical modeling and consider the feasibility and cost estimates of the proposed concepts.

The design activity shall recommend, select and document the solution.

3.3 REALIZATION PROCESS

The activities listed within this process category are responsible for transforming the solution into a product or final system of interest.

3.3.1 Attainment

3.3.1.1 Purpose:

The attainment activity transforms the solution into a product. Attainment actually begins at the point where the system of interests' design solution is considered fixed. The attainment activity, regardless of the system of interest, involves inventories, material acquisition and control provisions, tooling and test equipment, transportation and handling methods, facilities, personnel and data.

3.3.1.2 Requirements of Activity:

The attainment activity shall ensure the documented solution is available and can be communicated amongst those involved with transforming the solution into a product.

The attainment activity shall ensure procedures and work instructions are in place for transforming the solution into a product.

3.3.2 Integration

3.3.2.1 Purpose:

Integration is the activity by which distinct and separable products are interconnected to form a final product.

3.3.2.2 Requirements of Activity:

The integration activity shall plan for the needs (i.e., hardware, software, facility, personnel, etc.) to integrate the individual products into a higher-level product or system of interest.

The integration activity shall ensure procedures and work instructions are in place for integrating the products.

The integration activity shall ensure analytical integration is performed and representative of the configuration in which the system of interest will be used.

The integration activity shall ensure that within the verification planning that testing on both sides of the interface is performed.

The integration activity shall validate the configuration of the products being integrated as well as the integrated products as being representative of the configuration in which the system of interest will be used.

3.4 TECHNICAL MANAGEMENT PROCESS

The activities listed within this process category will plan, assess, and control the systems engineering effort.

3.4.1 Acquisition Management

3.4.1.1 Purpose

The acquisition management activity is responsible for obtaining products, materials, or services when it is not available. The requirements on the part of the systems engineering effort will be to provide technical inputs to the overall program/project acquisition planning established in NPG 7120.5.

3.4.1.2 Requirements of Activity

The acquisition management activity shall identify the technical requirements (e.g. detail specifications, cost, schedule/long lead, etc.) of the products, materials, or services being acquired.

The acquisition management activity shall strategize and provide recommendations on the acquisition approach (e.g. sole source, make/buy) and sources from which to obtain.

The acquisition management activity shall support and provide inputs on those acquisitions requiring performance evaluation or monitoring.

3.4.2 Work & Resource Management

3.4.2.1 Purpose:

The work and resource management activity plans how the work will be accomplished and the identification of resources necessary to accomplish the work. The requirements on the part of the systems engineering effort will be to provide technical inputs to the overall program/project work and resource planning established in NPG 7120.5.

3.4.2.2 Requirements of Activity:

The work and resource management activity shall define the technical content and technical products (e.g. documents, drawings) of the work to be accomplished.

The work and resource management activity shall define the detail technical schedule estimates necessary to accomplish the work

The work and resource management activity shall identify the technical skills and capabilities necessary to perform the work.

The work and resource management activity shall provide resource estimates (e.g. cost, manpower) to support the budget requests.

The work and resource management activity shall provide status relative to the cost, schedule, and technical progress of the work

3.4.3 Risk Management

3.4.3.1 Purpose:
The risk management activity is an organized, systematic decision making process that efficiently identifies, analyzes, plans, tracks, controls, communicates, and documents technical risk to increase the likelihood of achieving systems goals. The requirements on the part of the systems engineering effort will be to provide technical risk inputs to the overall program/project risk management planning established in NPG 7120.5. Refer to NPG 8705.x for a complete discussion of the Agency's procedures and guidelines for performing risk management.

3.4.3.2 Requirements of Activity:
The risk management activity shall identify the technical risks through such tools as FTA, PRA, FMCEA, etc.

The risk management activity shall conduct continuous and iterative risk analysis to describe and quantify the technical risk (i.e. likelihood vs. consequences)

The risk management activity shall identify controls and establish mitigation options for the technical risk.

The risk management activity shall track the technical risk.

3.4.4 Configuration/Data Management

3.4.4.1 Purpose:
The configuration/data management activity identifies and controls the products and processes of a system of interest configuration in a formal and orderly manner. The requirements on the part of the systems engineering effort will be to provide inputs to the overall program/project configuration management established in NPG 7120.5.

3.4.4.2 Requirements of Activity:
The configuration/data management activity shall identify requirements, processes, products, etc. to be placed under configuration control.

The configuration/data management activity shall develop and establish a baseline of configuration controlled items from which tracking of changes shall occur.

The configuration/data management activity shall collaborate and communicate changes to the baselined items.

The configuration/data management activity shall provide routine status accounting of configuration-controlled items.

The configuration/data management activity shall support configuration audits as needed.

3.4.5 Safety

3.4.5.1 Purpose:
The safety activity provides for the early identification, analysis, reduction, and/or elimination of hazards associated with the system. The requirements on the part of the systems engineering effort will be to provide inputs to the overall program/project safety and mission success established in NPG 7120.5.

3.4.5.2 Requirements of Activity:
The safety activity shall identify potential hazards.

The safety activity shall establish a method to control, eliminate or reduce the identified hazards.

The safety activity shall ensure hazard mitigation efforts are implemented as designed and perform the intended function.

3.4.6 Control

3.4.6.1 Purpose:
The control activity will identify, allocate, track, and control significant attributes of the system such as technical performance, technical resources, cost, schedule and interfaces.

3.4.6.2 Requirements of Activity:
The control activity shall allocate budgets and define margins for significant attributes (e.g. power, weight).

The control activity shall establish and track Technical Performance Measures (TPM).

The control activity shall establish tools for tracking metrics (e.g. cost, schedule, technical) and report status as needed.

The control activity shall establish, document, and maintain interface controls.

3.4.7 Quality

3.4.7.1 Purpose:
The quality activity assures the use and integration of high standards of quality within the systems engineering effort in order to reduce the technical risk.

3.4.7.2 Requirements of Activity:
The quality activity shall identify and establish the use of reliable and repetitive procedures and processes.

The quality activity shall incorporate the procedures and processes in the design of the system.

The quality activity shall ensure the system of interest meets the design (i.e. “as-built meets the as-design”) and maintain those records.

The quality activity shall incorporate continuous improvement and lessons learned within the procedures and processes.

3.5 TECHNICAL EVALUATION PROCESS

The activities listed within this process category will evaluate the systems engineering effort.

3.5.1 System Analysis

3.5.1.1 Purpose:

The system analysis activity is a specific, quantitative, engineering assessment used in making systematic, technical, and economic decisions to the systems alternatives and objectives.

3.5.1.2 Requirements of Activity:

The system analysis activity shall establish the evaluation criteria (e.g. environment, dimensions, life-cycle, weight, cost, etc.) to be applied during the assessment.

The system analysis activity shall perform analytical or physical modeling of the alternative concepts based on the established evaluation criteria to obtain a quantitative prediction.

The system analysis activity shall make a recommendation for the solution based on the quantitative outcome of the analytical or physical modeling.

3.5.2 Verification

3.5.2.1 Purpose:

Verification ensures the product complies with requirements. Those requirements will be contained in such documentation as specifications or drawings. Verification is accomplished at each level of the product's architectural hierarchy (e.g. component, subsystem, system).

3.5.2.2 Requirements of Activity:

The verification activity shall define the verification method(s) (e.g. test, analysis, inspection, etc.) that shall be performed to satisfy each requirement and the level at which the method(s) shall be performed.

The verification activity shall define the verification planning information that will describe the detail activities associated with performing the identified verification method(s).

The verification activity shall define the verification success criteria that will indicate successful completion of each verification activity.

The verification activity shall define the compliance program that identifies how the results of the verification activities will be submitted, reviewed, and tracked to demonstrate that the requirements are satisfied.

3.5.3 Validation

3.5.3.1 Purpose:

Validation ensures that the product is ready for a particular use, function, or mission. Although performed primarily at the deliverable product level, validation will continuously occur concurrently with verification and as the product matures throughout the life cycle. The "test as you fly/fly as you test" is a philosophy used in the validation activity to ensure that the configuration that is being tested is one that will represent the configuration in which the product will be used.

3.5.3.2 Requirements of Activity:

The validation activity shall define the validation method(s) (e.g. test, analysis, inspection, etc.) that shall be performed to ensure customer needs and use of the product will be met.

The validation activity shall define the validation planning information that will describe the detail activities associated with performing the identified validation method(s).

The validation activity shall define the validation success criteria that will indicate successful completion of each validation activity.

The validation activity shall define the compliance program that identifies how the results of the validation activities will be submitted, reviewed, and tracked to demonstrate that the originally established needs are met.

3.5.4 Reviews

3.5.4.1 Purpose:

The reviews activity establishes a formal examination of the system of interest status. This status is then used to determine readiness to proceed through a progressive maturation of processes and activities to develop the final system of interest. The customer and stakeholders shall be a participant in these reviews.

3.5.4.2 Requirements of Activity:

The reviews activity shall include as applicable:

(1) Requirements Reviews (e.g. PRR, SRR) to establish a requirements baseline from which the design will occur

(2) Design Reviews (e.g. PDR, CDR) to evaluate the maturity of the design in meeting established requirements

(3) Acceptance/Readiness (e.g. AR, FRR, CoFR) reviews to determine system readiness or completeness

(4) Independent Reviews (e.g. Peer, NAR, IAR) to ensure the technical adequacy in meeting objectives within cost and schedule.

The reviews activity shall establish entry and exit criteria for conducting reviews and shall ensure the criteria are accomplished.

APPENDIX A TAILORING INSTRUCTIONS

This Appendix explains to the user how the PROCESS, ACTIVITY, and REQUIREMENT statements may be tailored for particular project environments, i.e., the principles but not the How's.

Use of Tailoring

Each project using the Processes, Activities and Requirements of this NPG has its own unique set of needs that cannot necessarily be anticipated by the NPG. Since each project has to consider and demonstrate the benefits of what it does to satisfy stakeholder requirements, there is a need to concentrate on the relevant processes and activities and requirements, including specific output documentation. This is especially true for small projects with limited budgets and staff and for mature projects and/or organizational efforts that already have much of the documentation completed.

Thus, it is expected that the Processes, Activities and Requirements of this NPG will be tailored to the characteristics of a particular project, life cycle stage, or agreement. Tailoring takes the form of deletion, alteration or addition. Care is to be taken to avoid unnecessary costs and consider dropping factors of the NPG that do not add value to a process, system-of-interest or system element.
When tailoring is done, it is important to ensure that each requirements tailored out is documented in the Systems Engineering Management Plan and rationale provided for such deletion.

Tailoring considerations

The objectives and requirements of an agreement can scope the depth and breadth of NPG use. To assist in defining the depth of application and the level of effort required for execution of some process, activity or requirement, the following inputs can be considered in tailoring.

a) The life cycle stage and the applicable exit criteria.

   Fewer levels of the physical system hierarchy could be needed to meet the requirements for the concept stage, especially if the project is dealing with a legacy system or with a system for which a valid simulation or virtual reality model exists. However, sufficient depth is needed to provide confidence in cost, performance and schedule objectives and related risk estimates, especially when a new technology is involved. Later in the life cycle, such as prior to production of the system-of-interest or system element, the systems engineering work has to be in sufficient depth to provide detailed drawings and other detailed configuration documentation related to a technical data package.

b) The mission profiles, operational scenarios, and/or operational concepts for each major functional requirement of the system-of-interest or individual system elements.

c) The set of measures of effectiveness, with relative importance, by which the acquirer typically determines success and satisfaction.

d) Constraints and risks that could affect the systems engineering work.

   This includes budget, resource, competition, and schedule and the existence of quantitative data relating to these constraints and risks.

e) The technology base and any limitations on the use of technologies.

General guidance

To further aid tailoring the following factors affecting the systems engineering work can be helpful:

a) Systems engineering requirements

Items such as the required systems engineering work, schedule and funding; and technical requirements (e.g., functional, performance and interface) can drive stage timing and the definition of the system-of-interest or system element under consideration. These can also drive the criticality of the system-of-interest or system element and its enabling systems.

b) Applicable processes and activities

Only the processes and activities of the NPG that apply to the Center/Enterprise, and type of organization (e.g., supplier, user, acquirer, or other stakeholder) should be included in technical plans. Other processes and activities that are not in the NPG can be required by an agreement or by the nature of the project, the applicable system-of-interest or system element, or the type of organization. These processes can be added, complete with their purpose, objectives and activities.

c) Activities for each applicable process and the requirements of each activity.

Depending on the size and scope of the project, the type of organization, and whether a precedented or unprecedented system-of-interest or system element is the object of the project, one or more of the NPG activities for a process could possibly not apply. Likewise, activities can be added to a process when needed to meet agreement requirements or to meet unique requirements for a system element or system-of-interest.

d) Tasks, methods and tools required for activity completion.

The applicable tasks, methods and available tools are not included in the NPG. These can be added by the project or organization during planning for an adopted process.

e) Reporting and technical review requirements.

The reporting and technical review requirements applicable to the life cycle stage or stipulated in the governing agreement or in project procedures should be considered.

f) Technical measurement requirements

Provisions can be included for the collection and reporting of key metrics by which systems engineering progress will be evaluated.

f) Requirements related to involving specialty engineering and functional disciplines.

For special or critical project and/or system requirements or life cycle stage exit criteria (e.g., safety, security, human factor engineering, design, software development, production, test, and logistics) related activities and tasks may be integrated in appropriate processes. Specialty and/or functional plans needed to ensure completion of project work may be included in work definition.

g) Applicable standards, policies and procedures, regulations and laws.

These can be the source of additional activity requirements to add to the systems engineering work definition, even though not included in the NPG requirements.

Tailoring documentation

The tailoring of the NPG requirements should be documented for the benefit of all who must execute the resulting set of activities. Some suggestions to follow in documenting the tailoring include:

a) Explicit process and activity descriptions and requirements can be documented in the systems engineering management plan or project management plan.

b) A line in/line out of the NPG can be used where tailoring does not need to be formally documented.

c) Templates or worksheets for each NPG process/activity and life cycle stage can be developed to prescribe the depth of detail required for particular documentation.

APPENDIX B DEFINITIONS

Acquisition Management		
Attainment		
Baseline	The technical performance and content, technology application, schedule milestones, and budget (including contingency and APA) that are documented in approved program and project plans. See also Performance Measurement Baseline.	NPG7120.5
Configuration Management	The identification, control, accounting, and verification of requirements and implementation documentation for formal orderly control of the program/project configuration.	NPG 7120.5
Decomposition		
Design Architecture	An arrangement of design elements that provides the design solutions for a product or life cycle processes intended to satisfy the functional architecture and the requirements baseline.	IEEE-1220-1998
Development Stage		
Enabling System	A system that complements the system of interest but does not contribute directly to its functionality. Each system of interest has a set of enabling systems that allow the system of interest to perform its life cycle functions.	
Feasibility Study		
Flowdown	The allocation of requirements down to successively lower level system elements.	INCOSE SE Handbook
Functional Analysis and Allocation	Examination of a defined function to identify all of the sub-functions necessary to the accomplishment of that function. The sub-functions are arrayed in a functional architecture to show their relationships and interfaces (internal and external). Upper-level performance requirements are flowed down and allocated to lower-level sub-functions.	INCOSE SE Handbook
Integration		
Interface		
Interface Requirements	Interface requirements define the internal and external physical interfaces the system must interface with to meet both functional and technical requirements	SP 6105
Life-cycle Cost	The total of the direct, indirect, recurring, nonrecurring, and other related expenses incurred, or estimated to be incurred, in the design, development, verification, production, operation, maintenance, support, and retirement of a system over its planned lifespan.	NPG7120.5
Logistics	The management, engineering activities, and analysis associated with design requirements, definition, material procurement and distribution, maintenance, supply replacement, transportation and disposal which are identified by flight and ground systems supportability objectives.	NPG7120.5
Maintainability	A system design characteristic associated with the ease and rapidity with which the system can be retained in operational status, or safely and economically restored to operational status following a failure	SP-6105
Metrics	A measurement, taken over a period of time that communicates vital information about a process or activity. A metric should drive appropriate leadership-management action. Physically, a metric package consists of three parts: (1) an operational definition, (2) measurement over time, and (3) a presentation package.	NPG7120.5

Operational Scenarios	Operational scenarios are a step-by-step description of how the proposed system should operate and interact with its users and its external interfaces (e.g. other systems)	
Operational Stage	The stage is comprised of three concurrent phases: Utilization, Support and Retirement.	
Product		
Production Stage	The stage in which the system of interest may be manufactured, assembled, integrated into other systems, and validation and verification plans executed. Individual system of interest testing, or end-to-end-testing of the top-level system, is performed as needed.	
Program	An activity within an Enterprise having defined goals, objectives, requirements, funding, and consisting of one or more projects, reporting to the NASA PMC, unless delegated to a GPMC.	NPG7120.5
Program plan	The document that establishes the overall baseline for implementation as well as the agreements among the EAA, LCD, Center Director, and program manager	NPG7120.5
Project	An activity designated by a program and characterized as having defined goals, objectives, requirements, LCC's, a beginning, and an end.	
Project Plan	The document that establishes the overall baseline for implementation as well as the agreements among the LCD, program manager, and the involved NASA Center managers.	NPG7120.5
Quality		
Requirement	A statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability (by consumers, or internal quality assurance guidelines)	IEEE 1220-1998
Risk	The combination of both the likelihood of various outcomes and their distinct consequences.	6105
Risk Management	An organized, systematic decision making process that efficiently identifies, analyzes, plans, tracks, controls, communicates, and documents risk to increase the likelihood of achieving program/project goals.	NPG7120.5
Risk Management Plan	A document that provides a disciplined and documented approach to risk management throughout the project life cycle.	6105
Safety		
Support Phase	Phase for the provision of maintenance, logistics, support system, facility operations and other support required for the operations of the system of interest	
System	The combination of elements that shall function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel; and the processes and procedures needed for this purpose.	NPG7120.5
System of Interest	The entity for which the engineering team is responsible for designing, developing, integrating and testing	
Systems Engineering Management Plan (SEMP)	A comprehensive plan that describes how a fully integrated engineering effort will be managed and conducted.	6105
Technical Performance Measure	Key indicators or system performance that, if not met, put the project at cost, schedule and performance risk.	IEEE 1220-1998

Utilization Phase	The phase of the Operational Stage is executed to operate and use the system products and services in their operational environments to satisfy the intended purpose of the system. During this phase the system of interest can evolve, giving rise to new requirements, for either modification or enhancement of the system of interest	
Validation	Proof that the product accomplishes the intended purpose. May be determined by a combination of test, analysis, and demonstration.	7120
Verification	Proof of compliance with specs. May be determined by a combination of test, analysis, demonstration, and inspection.	7120

APPENDIX C RELATIONSHIP WITH STANDARDS

This NPG for SE attempts to present the minimum set of processes, activities, and requirements needed to produce a system. It presents these ideas in a context of key concepts whose primary intent is to encourage the NASA community to take a complete systems point of view in each and every program and project. In order to use the latest results of not only the NASA community but also the national and international communities, critical reviews of the extant systems engineering literature were conducted. Because many ideas were adopted, or adapted in some cases, from this literature, the following paragraphs present a summary of the primary documents, and a comparison and an indication of the origin of many of the concepts and principles used in this NPG for SE.

C.1 NPG7120.5

NPG7120.5 establishes the management system for processes, requirements, and responsibilities for implementing NPD7120.4. This NASA management system governs the formulation, approval, implementation, and evaluation of all PAPAC programs and projects. It is intended to support safe accomplishment of the NASA programs and projects, consistent with established Agency strategic planning, on schedule, and within budget, while satisfying the success criteria and requirements of multiple stakeholders and customers. In addition, NPG7120.5 defines the requirements for formulating, approving, implementing and evaluating programs and projects. It is intended to be flexible and adaptable to the many types of programs and projects that NASA manages.

This document establishes program/projects systems requirements in a number of areas. Included in these are the following areas that are also found in systems engineering discussions:

1) Resources management
2) Risk Management
3) Performance Management
4) Acquisition management
5) Safety and Mission Success Management

In addition, NPG7120.5 specifies basic content requirements for a number of program/project level documents. It also outlines basic content for program/project level reviews and independent evaluations.

C.2 NPG SE versus NPG7120.5

This NPG SE document provides the technically oriented processes and requirements for producing a system of interest. It is at a lower tier of precedence when determining applicability. Processes and requirements in this document are designed to accomplish the technical work of the project. The concept of the top level system of interest is matched directly to the NPG7120.5 program/project management life cycle so that the transition across the phases of the life cycle match the transition across the stages of the systems life cycle at the same Program Approval Control Gate.

Critical Reviews (PDR, CDR) called for in NPG for SE Overlap with the callout for these reviews that is being added to NPG7120.5, rev. B.

C.3 ISO/IEC 15288

The committee draft version of ISO/IEC 15288 System Engineering – System Life Cycle Processes proposes to establish a common framework for describing the life cycle of systems created by humans and a set of well-defined processes and associated terminology. It suggests that selected sets of these processes may be applied throughout the life cycle for managing and performing the stages of a system’s life cycle. This proposed standard also provides processes that support the definition, control, and improvement of the life cycle processes used within an organization or project. This proposed standard applies to the full life cycle of systems, including conception, development, production, utilization, support, and retirement of systems and to the acquisition and supply of systems.

The document utilizes the concepts of the system of interest, the enabling systems, and the hierarchy of levels of systems of interest. The document provides information on six examples of life cycle stages. These stages may be used to construct frameworks within which system life cycle processes are used to model life cycles. The proposed standard does not detail the life cycle processes in terms of methods or procedures required to meet requirements and outcomes. The document format provides Process purpose, outcomes, and activities.

C.4 NPG SE versus ISO/IEC 15288

This NPG has adopted the key concepts of the system of interest and enabling system from ISO/IEC 15288. The idea that each system of interest has its own life cycle is also adopted from this proposed standard. The system life cycle model also originated from this draft standard but its content has been adapted to NASA to show emphasis of the Operations Stage.

C.5 EIA 632

The existing standard EIA 632 Processes for Engineering a System provides an integrated set of fundamental processes to aid a developer in the engineering or reengineering of a system. The standard defines processes for engineering a system. There are thirteen processes organized into five groups. The relationships among the processes are presented in figure form. The intent of the special relationships in the figure implies sequencing of the processes and a degree of crosscutting among the processes. In all cases the ideas of iterative and recursive application are emphasized. The use of directional arrows and labels convey time relationships, inputs, and outputs. The point is made, however, that the processes are applicable at any point in the life cycle.

The standard does not specify the details of “how to” implement the process requirements for engineering a system. Nor does it specify the methods or tools a developer would use to implement the process requirements.

C.6 NPG SE versus EIA 632

This NPG groups the systems engineering requirements into five process categories, Definition, Design, Realization, Technical Management, and Evaluation. In a vein similar to the approach taken by EIA 632, this NPG provides a figure showing the relationships among the processes. This document also allows for the processes and requirements to be applied to the system of interest throughout the systems life cycle.

C.7 SP6105

The NASA Systems Engineering Handbook is based on a Phase A-E project life cycle. It provides extensive information on what to do and how to do systems engineering activities. The Handbook has extensive information regarding tools for performing systems engineering tasks. The concepts of the engineering “Vee” model and the spiral model are discussed. In addition it provides detailed information to assist the engineer in applying processes in various stages of the project life cycle process flow. The organization and terminology in the handbook is in need of an update.

C.8 NPG SE versus SP6105

This NPG retains the use of the engineering (“Vee”) model to describe the top-down development and the bottom-up realization of a system of interest. The Book of Knowledge cited in this NPG proposes to include the SP6105 as a valuable reference tool for educating practitioners OF SYSTEMS ENGINEERING.

APPENDIX D KEY DOCUMENTS

This appendix establishes the content for the following basic documents associated with the systems engineering process:

D.1 Systems Engineering Management Plan

D.1 Systems Engineering Management Plan

Title Page
1.0 Introduction
1.1 Purpose
1.2 Scope

2.0 Documents
2.1 Parent Documents
2.2 Applicable Documents
2.3 Reference Documents

3.0 Part I: Technical Program Planning and Control
3.1 Project Organization
3.2 Responsibilities and Authority
3.3 Standards, Procedures, and Training
3.4 Work Breakdown Structures
3.5 Technical Design Verification/Validation
3.5.1 Verification/Validation Testing
3.5.2 Discrepancy Reporting and Disposition
3.6 Change Control Procedures
3.6.1 Project Change Control Board (PCCB)
3.6.2 Project Change Approval Procedure
3.7 System Integration
3.8 Interface Control
3.9 Project Schedule and Milestones
3.10 Project Reviews
3.10.1 Technical Reviews
3.10.2 Technical Design Review
3.10.3 Technical Interchange Meeting (TIM)
3.11 Technical Performance Management
3.11.1 Parameters
3.11.2 Planning
3.11.3 Implementation
3.11.4 Cost and Schedule Performance Measurement
3.11.5 Status Reporting
3.11.6 Other Plans and Controls
3.12 Technical Communication
3.13 Configuration Control
3.14 Mission Assurance
3.15 Project Risk Analysis

4.0 Part II: Systems Engineering Process
4.1 Project Requirements Analysis and Definition
4.1.1 Functional Analysis
4.1.2 Requirements Allocation
4.2 Trade Studies
4.3 Design Optimization/Effectiveness Compatibility
4.4 Lessons Learned
4.5 Synthesis
4.6 Logistic Support
4.7 Produceability Analysis
4.8 Documentation
4.8.1 Project Documentation
4.8.2 Documentation Release Process