Chapter 4

PROJECT LIFE CYCLE

SUMMARY

This Chapter describes the NASA project life cycle that uses a phased approach, defined goals, and measurable milestones to lead to the accomplishment of overall project goals.

4.1 INTRODUCTION

The NASA project life cycle is a phased approach that organizes project activities into a logical sequence of steps from initiation through completion. The project life cycle concept is a systematic method to organize a major effort into a series of progressive steps with well defined phased goals and measurable milestones leading to the satisfaction of overall goals of the project.

A summary of the project phases, objectives, and control gates are shown in Figure 4.1. The activities in Pre-Phase A, Phase A, and Phase B are termed the formulation phases of the project since the emphasis is on requirements analysis, project planning, concept definition, and feasibility demonstration. Phase C, Phase D, and Phase E are termed the implementation phases because operational hardware and software are designed, fabricated, integrated, and become operational. Typical phase durations are shown in the Project Phase column of Figure 4.1.

A time based schedule chart is shown in Figure 4.2, "Space Flight Project Life Cycle." Two charts are shown representing both a minor, short duration project and a major, long term effort for a sophisticated flight system. The chart displays typical phase durations, along with the associated timing of project reviews. Figure 4.2 shows the close relationship between the initiation of a major project and the NASA related funding activities shown in the Funding Activities Plans column. The funding activities require lead time; for example, Phase B funding plans must occur during Pre-Phase A activities.

4.1.1 Funding

Although the initial stages of concept development may proceed independently, an evolving project must very quickly become synchronized with the NASA budget cycle. If the project is part of a larger program, the project initiation may be keyed by response to an inter-center Announcement of Opportunity (AO). If so, the AO will usually describe the sequence of preliminary studies leading up to a project proposal which will be the basis of selection for a new start activity in a future fiscal year. When a project is accepted and funded to begin Phase C, it is commonly termed a "new start" or full authority to proceed (ATP). If the project is an independent activity, then the New Start Proposal may be incorporated in the Center Program Operating Plan (POP) for the new start year (NSY). The budget process may extend over a 3-year period leading up to the NSY.

PROJECT PHASE	OBJECTIVE	CONTROL GATES
Pre-Phase A: Advanced Studies (1 to 3 months)	Preliminary requirements and concepts analysis	Sponsoring Group Director's Review (SGDR)
Phase A: Preliminary Analysis (2 to 6 months)	Requirements definition and conceptual trade studies	Preliminary Systems Requirements Review (PSRR) SEIRC Review* Group Directors' Review (GDR) LaRC Center Director's Review NASA Headquarters' Review
Phase B: Definition (4 to 18 months)	(B1) Concept definition and preliminary design (B2) Source selection process (if required)	Systems Requirements Review (SRR)* [Conceptual Design Review (CoDR)] Software Concept Review (SCR) Software Requirements Review (SRR) Preliminary Design Review (PDR)* Software Preliminary Design Review (SPDR) Non-Advocate Review (NAR) Source Evaluation Board (SEB) Review
Phase C: Design (9 to 24 months)	Final design and engineering development	Critical Design Review (CDR)* Software Critical Design Review (SCDR)

Phase D: Development (9 to 24 months)	Fabrication, integration, test, and evaluation	Test Readiness Review (TRR) Software Test Readiness Review (STRR) Software Acceptance Review (SAR) System Acceptance Review (SAR)* [Pre-Shipment Readiness Review (PSRR)]
Phase E: Operations (3 to 12 months or longer)	Preflight and flight mission operations and disposal	Operational Readiness Review (ORR) Flight Readiness Review (FRR)* [Launch Readiness Review (LRR)] [Preflight Review] Operational Acceptance Review (OAR) [Post-flight Review] Lessons Learned Review*

*Formal reviews required per LAPD 7120.1.

Figure 4.1 - NASA Project Life Cycle.

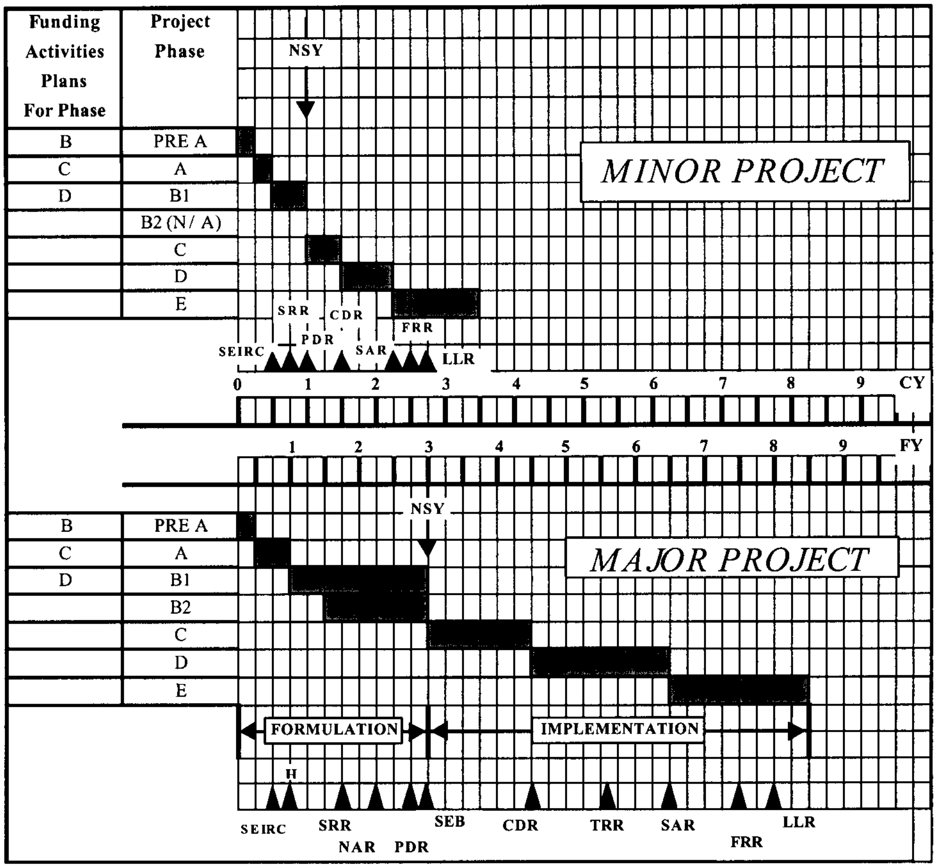

Figure 4.2 – Space Flight Project Life cycle

If the program is considered a major system acquisition as defined in NPG 7120.5A, NASA Program and Project Management Processes and Requirements, then the first key activity will be the submittal of a Mission Need Statement (MNS) approximately 3 years prior to the NSY. A smaller program may be initiated by means of a Project Initiation Agreement (PIA) between NASA Headquarters and LaRC. If approved, the program would typically be included in the POP for the NSY. The budget inputs are normally solicited in the spring of the second year prior to the NSY. The Center inputs are submitted to the NASA Program Office in the summer and the NASA budget recommendation is submitted to the Office of Management and Budget (OMB) in September about 1 year in advance of the NSY. The final budget is prepared by OMB and approved by the President for submittal to Congress in January. The Congressional budget process, including action on appropriation and revenue measures, begins 9 months prior to the fiscal year. The budget is scheduled for enactment and approval by October 1 of the NSY. Initial appropriated funds are apportioned to the Agency within a few weeks after the start of the fiscal year and the balance are received incrementally during the budget year.

Funding for the project formulation phases and for smaller projects is usually arranged on an ad hoc basis. The effort expended during Pre-Phase A is relatively minimal and personnel hours are usually funded by an ongoing, funded, research and development program. Similarly, Phase A activities are usually funded in-house from the related Research and Technology Operating Plan (RTOP) of the research and technology program or directly from the cognizant Program Associate Administrator (PAA) at NASA Headquarters.

Funding for Phase B activities must usually be obtained from a Program Office at NASA Headquarters. Phase B focuses the project planning and one of the outputs of Phase B is the Project Plan that will supersede the earlier PIA. One of the major challenges of the study/project team is to obtain and administer funding for the formulation phases so that the project goals can be addressed on a timely basis and the young project organization can be supported and held together until Phase B and/or Phase C funding is received.

It can be seen from the above general discussion that the project life cycle, for a large project, is driven by the NASA budget process. The Pre-Phase A effort must be completed as expeditiously as possible (usually within a 1- to 3-month period) to substantiate the beginning of the more detailed Phase A study. Phase A and Phase B for "complex" efforts must usually span the 2- to 3-year interval until the NSY. For example, Phase A for a complex project might last 6 months to a year from start to completion of the LaRC Center Director's and NASA Headquarters' Reviews. Phase B for concept definition might last a year until completion of the Systems Requirements Review (SRR), Non-Advocate Review (NAR), and the Preliminary Design Review (PDR). Another year might be required if a major acquisition activity with a Source Evaluation Board (SEB) is required.

4.1.2 Concurrent Engineering

The importance of a well-integrated and informed team cannot be overstressed. Principles of concurrent engineering should be practiced from the onset of a project. Practically speaking, this means that the phase teams should be represented by members from all related functional fields such as hardware design, software development, manufacturing, project controls, testing, and so forth. The team should meet regularly for status updates and the exchange of ideas and viewpoints. This application of concurrent engineering is especially critical among subsystem managers with shared interfaces. One responsibility of the systems engineer is to ensure that these interactions occur among members of the project team.

4.1.3 Systems Engineering Analysis and Design in the Life Cycle

The application of systems engineering analysis in the project life cycle occurs at several levels. In the formulation phases of the life cycle the systems analysis process comprises the bulk of systems engineering activities. Early in the life cycle, systems engineering analysis is applied on the system level to analyze various approaches, and thus, support the selection of a baseline concept. The application of the systems engineering process, and related consideration of multiple conceptual options, is in sharp contrast to the "point design" approach. A point design occurs when the project team puts all efforts into a single alternative from the inception of the new project. While this approach may have been valid in the past, the increasing sophistication of advanced systems has rendered all but the simplest developments too complex for immediate design.

In formulation, the Systems Analysis and Design Procedure is guided by the systems engineer toward satisfaction of the principle customer goals. Thus, performance measures will be relative to overall project goals and typically related to the systems ability to perform a desired function. Examples of these functional performance measures may be: measurement accuracy, resolution, range, or data transfer rate. As a minimum, systems engineering analysis will be performed at this level for all projects.

Subsystem managers may wish to take advantage of systems engineering analysis for selection of subsystem configuration. In this case, the subsystem manager is usually designing within the engineering constraints and budgets allocated by the systems engineer. Weight, power, volume, heat flux, alignment, and other such parameters may be viewed as engineering constraints on a subsystem development. Variable performance measures for the subsystem engineering analysis, commonly referred to as trade studies, will likely take on other forms such as throughput, processing time, or material strength.

The Systems Analysis and Design Procedure is valid to the lowest level of hardware piece part selection and software unit development, but the value of the application will reach a point of diminishing return. At some point in the detail design, solutions become readily available based on experience, and details are captured in the form of drawings and specifications.

As the project progresses into the latter portion of Phase B and into Phase C, systems engineering analysis is used by subsystem managers, but other duties, such as hardware/software integration and verification, begin to dominate the attention of the systems engineer. These activities are outlined in detail in the following sections of Chapter 4 which present a general overview of the NASA project life cycle. A more detailed treatment with specific activities and products is given in Chapter 6 when the systems engineering process and the project life cycle are combined.

Each of the following phase descriptions contains a paragraph on team composition. The actual makeup of a phase team will be determined by the Project or Study Manager. The information presented here is meant to be indicative of the functional disciplines that typically participate in a given phase.

4.2 PRE-PHASE A - PRELIMINARY REQUIREMENTS AND CONCEPTS ANALYSIS

4.2.1 Pre-Phase A Team Composition

The Pre-Phase A team is established at the beginning of the phase and should, as a minimum, include the following functional representation:

* Science/Technology
* Study management
* Systems engineering
* Experts in the major hardware fields related to the project (that is, lasers, electronics, spacecraft, and so forth)

While the core team will probably consist of approximately seven members, contact with other experts, including software engineers, will be required on an as-needed basis for conceptual feasibility, cost, and schedule assessments.

One item of note in the above list is the presence of a Study Manager in place of a Project Manager. This distinction is made to emphasize the fact that the project is not yet mature enough to assume project status. A Project Manager is appointed in Phase A, and will ideally stay in that position for the balance of the project life cycle.

4.2.2 Pre-Phase A Implementation

The purpose of the Pre-Phase A study is to quickly assess the feasibility of a proposed project and develop a Go/No Go recommendation for Phase A. This first requires a thorough understanding of what is desired by the customer of the study. Given this information, concepts may be evaluated to determine what approaches, if any, are feasible. A critical question for resolution is the appropriateness of evolving the study into a project proposal. Sufficiency of work completed will be reviewed by the LaRC sponsoring Group Director at the end of Pre-Phase A to decide if progression into Phase A is warranted.

The advantage of applying a disciplined systems engineering process to the Pre-Phase A study is that the goals of the proposed project can be quickly focused, requirements defined, and the various system concepts can be developed and evaluated within a span of 1-3 months. Thus, promising ideas can be rapidly identified for further study to shorten the overall life cycle time from project initiation to completion.

4.3 PHASE A - REQUIREMENTS DEFINITION AND CONCEPTUAL TRADE STUDIES

4.3.1 Phase A Team Composition

The Phase A team may be somewhat larger and more specialized than the team from Pre-Phase A. Attempts should be made to retain those team members from Pre-Phase A with the best understanding of the concepts which were selected for further study. Additional support will be required from software engineers and product assurance support should begin. The following functional representation is typical:

* Science/Technology
* Project management
* Systems engineering
* Experts in the major hardware fields related to the concept options surviving Pre-Phase A
* Systems analysts (thermal, structural, control, others as required)
* Software development
* Product assurance engineering (may be delayed until Phase B at discretion of the Project Manager)

As in Pre-Phase A, contact with other experts will be required in support of concept design and analysis. The size of the Phase A team will be roughly the same as the Pre-Phase A, with extra disciplines added as required. Preliminary analysis of system thermal, structural, and control characteristics may be required. These team members are likely candidates to stay with the project into Phase B. A significant difference in the scope of the Phase A effort versus Pre-Phase A is the depth and duration of the analysis.

4.3.2 Phase A Implementation

The emphasis of Phase A is to do a more detailed definition of mission needs and requirements and to conduct more detailed trade studies and analyses of the best, feasible alternative system concepts identified in Pre-Phase A. To accomplish this, a Project Manager is appointed and the project staff is augmented for the 2- to 6-month effort. Most of the study will be done in-house, but contractor support may be utilized in specialized areas and other industry inputs may be sought to assure that the study results will be balanced.

The goal of Phase A is to establish which of the feasible system concepts under consideration are the most preferred. These concepts may be ranked in accordance with the various performance measures, but there is no action to select a single baseline conceptual design at this point. The results of Phase A studies are presented in a preliminary New Start Proposal; and when appropriate, a Mission Needs Statement to NASA Headquarters which can be used to justify funding for a Phase B effort.

Participation by technical hardware and software team members is required during the formulation phases to assure the proper allocation of system requirements to lower levels of assembly. Early partitioning of system functional requirements to software and hardware, if feasible, will greatly support timely system development. However, all pertinent system level studies should be completed before requirements are allocated. Actual software development activities will frequently be tied to risk reduction at this stage of the project. Often, software prototype models are required to serve as a simulator for a portion of the system that has yet to be developed. The purpose of the simulator is to interface with preliminary hardware which is built to increase confidence in the design approach. The results of these activities are maintained in the Systems Requirements Document and the Requirements Data Base.

Control gates during Phase A include a Preliminary Systems Requirements Review (PSRR) and a review by the LaRC Space-flight Experiment Initiatives Review Committee (SEIRC). The function of this committee is to review and critique proposed space flight experiments prior to presentation to upper management. These reviews are followed by briefings to the LaRC Group Directors and to the Center Director. Finally, the Phase B plan is presented to NASA Headquarters with a proposed PIA. The PIA outlines the new project's management and technical interfaces, schedules, resource estimates, and other ground rules and becomes the initial agreement between LaRC and the NASA Headquarters Program Associate Administrator (PAA) who will sponsor the project. At the completion of Phase A, a preliminary set of requirements and a rank ordered set of feasible system concepts are available. This is in contrast to the majority of past efforts which focused on a single concept early in the project formulation.

4.4 PHASE B - DEFINITION

4.4.1 Phase B Team Composition

In Phase B, the size of the project team will increase somewhat. The Project Manager will be responsible for selecting subsystem managers who will have responsibility for functional hardware and software segments of the system and for establishing the organizational structure of the project. After the baseline concept is selected, additional support will be required in new functional areas such as testing and quality control. A typical Phase B team consists of:

* Science/Technology
* Project management
* Systems engineering
* Subsystem management
* Experts in the major hardware fields related to the concept options surviving Phase A
* Systems analysts (thermal, structural, control, others as required)
* Software engineering
* Product assurance engineering
* Testing
* Project controls (costing, scheduling, and configuration management)
* Quality control
* Electronics manufacturing
* Hardware manufacturing

The team additions shown above will support risk reduction efforts, project planning, and the implementation of concurrent engineering.

4.4.2 Phase B(1) - Concept Definition and Preliminary Design

Phase B(1) is primarily concerned with the task of concept definition in order to establish the baseline system design and also the optional source selection process which will be discussed separately. The Phase B team will be staffed with personnel who are experienced in conceptual design studies and analyses.

The greatly expanded efforts in Phase B will result in a related increase in the size of the project team. Thus, initial Phase B activities will begin with bringing the new team members "up to speed." This emphasizes one of the important advantages of the structured systems engineering process. Since the process is cyclical in nature, new team members have the opportunity to review, verify, and refine work accomplished previously in the project.

During Phase B, the project goals and requirements are reviewed and the Goals Analysis Document and Systems Requirements Document are finalized. A mature Performance Measures Statement is defined and more detailed verification and validation plans are developed. If required, the final systems engineering management plan covering in-house systems engineering activities should be issued.

At the beginning of Phase B, the candidate system concepts are reviewed and further tradeoff studies are performed, if necessary, leading to selection of one approach as the baseline concept for detailed study. This activity is required because of the significant increase in size and diversity of the project team. Detailed systems design studies are performed on the overall system and on the technical discipline subsystems such as electrical, thermal control, structural, electronics, software, and so forth. Of particular importance here is the development of the system architecture model that encompasses both hardware and software functions. This mathematical or systems simulation model must demonstrate that the predicted end-to-end system performance will meet the overall system requirements and satisfy the user needs and goals. This model or prototype should closely approximate the user interfaces but the internal hardware and software aspects will be very preliminary. This systems simulation model will be upgraded and maintained throughout the life of the project. The results of these studies are presented in the Baseline Design Concept Package and become part of the New Start Proposal.

Risk analyses and risk reduction activities are addressed to identify areas requiring further technology development. As further refinements are made to the conceptual design, the system Work Breakdown Structure (WBS) is expanded and the life cycle cost analysis is updated. The overall study effort is finalized and becomes more focused as the Systems Requirements Review (SRR) package is prepared and presented to an LaRC review team. This will address both hardware and software requirements as they have been allocated from the system level requirements.

One aspect of development which becomes important in Phase B is the allocation of system resources to subsystems. Such parameters as weight, power, volume, alignment tolerances, and heating/cooling capacities are vital commodities for space hardware and must be carefully controlled. The total amount available, or system budget, of a given resource must be divided among subsystems, carefully tracked, and reallocated as necessary. Each subsystem manager is responsible for assuring that their portion of the system stays within the guidelines provided by the systems engineer. Should it become apparent that an allocated budget is insufficient, as it usually will at some point, the systems engineer must either pull resources from another sub-system, determine the impact of decreased performance of the subsystem in question, or draw from resources held in reserve. Since the latter of these options is frequently the most attractive, it is very important for the systems engineer to hold a significant portion of system resources in reserve, especially in the earlier stages of development. (See Chapter 7, Section 7.5.)

Action items from the SRR are addressed and further studies are accomplished to enhance the baseline conceptual design. Subsequently, the team will present a formal Non-Advocate Review before a committee at NASA Headquarters or at a host field installation program office to obtain funding for Phase C and Phase D. At this time, the proposed Project Plan will also be reviewed. Release of funds for the implementation phases (Phase C and Phase D) is dependent upon project approval and authorization by NASA Headquarters and subsequent allotment authority for obligation of funds at the Center level.

The Preliminary Design Review (PDR) is also completed during Phase B. The PDR package is prepared and presented when the hardware and software designs are about 70 percent complete. Any PDR action items must be addressed prior to start of the final design phase. Following this review, the baseline concept will become the preliminary As-Designed Project Baseline under formal change control and Phase B(1) activities will be completed.

4.4.3 Phase B(2) - Source Selection Process

This phase is necessary if major portions of the system are to be contracted to industry. In the event of a major procurement, the project schedule may dictate that the acquisition process actually begins in Phase A or early in Phase B with the preparation of a Statement of Work (SOW) and preliminary technical interchanges with possible sources. It is also important that acquisition personnel be an active part of the Phase B team so that they can be informed about the scope and technical content of the proposed acquisition and have sufficient time for planning the procurement.

LaRC acquisition procedures are summarized in NPD 5101.32, Procurement. The project team or a group designated by the Project Manager will be responsible for preparing a procurement package technical specification or an SOW for the procurement. This group should contain representatives from hardware and software disciplines. When the contract is awarded, a project team member will be delegated by the Contracting Officer as the Contracting Officer's Technical Representative (COTR) who will be responsible for technical management of the procurement effort.

The procurement package should be submitted with sufficient time for completing the acquisition process. Lead times from submittal of the procurement package to contract award vary from 6 months to 1 year or more for competitive, negotiated contracts. Fixed-price contracts may be awarded within 2-3 months. The lead time is also influenced by the source evaluation methods used. For many competitive contracts requiring discussions with the offerors, a Source Evaluation Committee (SEC) may be used. An SEB is required for procurements in excess of $25 million. SEB policies and procedures are defined in the NASA FAR supplement 1815.300. The SEB process is concluded by an SEB review and report, followed by announcement of the decision by the Source Selection Official.

Funds must be properly authorized before a procurement process can be initiated, and the formal contract award cannot be completed until funds are obligated by an allotment authority. This will usually occur at the same time that implementation funds are released at the beginning of Phase C.

4.5 PHASE C - DESIGN

4.5.1 Phase C Team Composition

The size of the Phase C team may be easily double that of the Phase B team. As system designers produce detail hardware drawings and software specifications for the engineering or prototype model, more involved participation by fabrication, testing, and assembly personnel will be required. Represented functions are:

* Science/Technology
* Project management
* Systems engineering
* Subsystem management
* Experts in the major hardware fields related to the concept options surviving Phase A
* Systems analysts
* Software engineering
* Product assurance engineering
* Testing
* Project controls (costing, scheduling, and configuration management)
* Quality control
* Electronics manufacturing
* Hardware manufacturing
* Integration engineering
* Data management
* Design
* Operations

During Phase C and Phase D, the project team will reach its greatest size. Planning in the areas of data management and operations will begin as will the development of draft procedures for test and integration. Detail design activities are a large portion of the Phase C effort.

4.5.2 Phase C - Final Design and Engineering Development Implementation

This phase will produce final drawings for fabrication of the engineering model hardware and software. There may also be development and fabrication of flight hardware for long lead items.

The beginning of Phase C again requires a period of project planning. New project members must be briefed and contractors must be given a "period of understanding" time to staff their efforts and become familiar with the project. An important aspect of this is preparation of the contractor systems engineering management plan, which will define how the contractor's systems analysis will be conducted.

In-house systems engineering activities include a review and flow down of requirements in the form of design specifications for hardware configuration items (HWCI) and computer software configuration items (CSCI). Error budget refinements are ongoing and continual reallocation to subsystems will likely be necessary. Systems engineering also supports the preliminary design and analysis of subsystems and monitors the development of hardware and software for any long lead items. Continuing tradeoffs among cost, schedule, and expected system performance will be required. Plans for systems integration are developed and the end-to-end performance model is maintained and updated. Overall systems performance is monitored as more information becomes available through analysis and test.

Plans for manufacturing, testing, integration, and verification/validation are finalized. Systems engineering must closely monitor both hardware and software development and prototype testing, and upgrade the systems simulation model as subsystem design and performance characteristics become better defined. Software simulation models and mission simulation models should be completed during this phase.

More sophisticated breadboard and brassboard models of key subsystems and assemblies may be developed during this time. It is important that these models incorporate both hardware and software functions, although the actual hardware elements will not be of flight quality and the software implementation may use an informal pseudo-code rather than a higher order language. These models can demonstrate subsystem performance and verify the interfaces and performance assumptions of the systems simulation model.

An important task, which is continued in Phase C, is the performance of operational scenarios and mission anomaly simulations. These "what-if" analyses are completed by subjecting the overall systems simulation model to events and combinations of events which are off-nominal. The purpose is to develop contingency plans which will be available during mission operations, should the events actually occur. Note that these "what-if" analyses are performed early in the implementation phase to serve as an input to the system design.

As in earlier phases, the effect of a subsystem's inability to achieve required performance must be carefully examined. If a requirement at a low level cannot be met, the impact of this shortfall on overall system performance must be determined. The goals and requirements development process outlined in this handbook makes this analysis much easier. However, determination of appropriate corrective action will be the responsibility of the systems engineer. Suitable workarounds may be found through the trade study portion of the systems engineering process. Specifically, performance measures should be established for the trade study, options should be developed, and the performance of those options estimated on the performance measures. Subsystem level trade studies will form a major part of the Phase C systems engineering analysis effort.

The engineering, or prototype, model is built in Phase C from preliminary drawings. This model is built to the specifications expected for the final flight version, but without all the formal configuration and quality control. This model is produced to represent the best information on the final flight configuration anticipated. Software development efforts progress concurrently, leading to an initial version of the flight software. The engineering model provides an opportunity to identify and work around unforeseen problems with system fabrication and assembly. The model also allows an early indication of the expected performance of the final flight system. Shortcomings that are identified may be corrected and verified, with updates being input to the final Build-To Drawings. Configuration and change control will typically be the responsibility of the subsystem managers at this point. After CDR, software will be placed under configuration control with any changes reviewed internally by the software development organization. Any software changes, which are made due to a deficiency identified by team members not involved with soft-ware development, are reviewed by the project configuration control function.

The CDR should be scheduled when the detailed design and analysis of hard-ware and software is approximately 95 percent complete and when engineering model testing is complete. Following the CDR, any action items or changes are incorporated. Systems engineering must verify the effect of any changes on systems performance.

4.6 PHASE D - FABRICATION, INTEGRATION, TEST, AND EVALUATION

4.6.1 Phase D Team Composition

The functions represented in the Phase D team will closely resemble that of Phase C. The main difference is a shift in the focus of efforts from design into system production. Fabrication and procurement will assume a strong role as will configuration management and product assurance. Testing and integration will likewise come to the forefront as analysis activities decrease. The net result will be an effort that is roughly equivalent in magnitude to that of Phase C.

4.6.2 Phase D Implementation

This phase concentrates on proto-flight or flight hardware fabrication and on flight software implementation. Continual emphasis must be placed on verification of requirements at all levels. As parts are fabricated and assembled into subassemblies, assemblies, and subsystems, the integration plan must be implemented to impose appropriate test and verification requirements at each level. Error allocations should be verified and any Nonconformance-Failure Reports (NFR's) issued by quality assurance should be closely monitored to assess the effect on system tolerance and alignment budgets.

As subsystems are assembled into system elements and segments, increased emphasis is placed on the verification of external interfaces and the specification of test requirements to validate the system performance. A key aspect of the integration process is the integration of the computer software units at the appropriate stage of hardware assembly. Test procedures and system integration and operational procedures are prepared for verification testing at both subsystem and system levels.

Test Readiness Reviews (TRR's) are held to verify test readiness prior to critical tests. Systems acceptance is verified by a System Acceptance Review (SAR) prior to delivery of the system for integration at the next higher assembly level, or before integration to the launch vehicle.

4.7 PHASE E - OPERATIONS PHASE

4.7.1 Phase E - Pre-flight Team Composition

During Phase E, project emphasis shifts to preparation of the verified system for shipment and integration to the next higher level of assembly. Final data reduction and mission operations procedures are produced. By Phase E, the size of the project has begun to decrease, and many technical personnel may be relieved for other assignments. At this stage, the team may include:

* Science/Technology
* Project management
* Systems engineering
* Subsystem management
* Software engineering
* Product assurance engineering
* Project controls (costing, scheduling, and configuration management)
* Quality control
* Integration engineering
* Data management
* Operations

All activities required to allow for operation of the system in-orbit must be finalized and accomplished.

4.7.2 Phase E - Flight Mission Operations Team Composition

In the operational phase, control of the system is typically assumed by agents of the science or technology team representative. In some cases, LaRC personnel will be required to operate the systems from a ground station. In any event, the data gathered must be routed to the science/technology customer and processed into useful information. The project team is generally disbanded at this point with the exception of personnel to complete these activities.

4.7.3 Phase E - Preflight and Flight Mission Operations Implementation

The key systems engineering function during this phase is to monitor system performance during spacecraft/vehicle integration and pre-launch preparations. Additional systems engineering support may be needed to prepare for launch and flight operations. A key activity at this time is training of the flight operations team. All internal and external system interfaces are demonstrated during this phase using the Systems Integration Document (SID).

Control gates during this phase include the Operational Readiness Review (ORR) and the Flight Readiness Review (FRR). Systems engineering activities include the verification of the integrated system with the expected system performance as base-lined on the systems performance model.

Mission activities during this phase are focused on the initiation of flight operations and the validation of flight data. The first phase of this activity involves system performance checkout in-flight by the project team and initiation of routine flight operations. This is followed by routine flight operations by the flight operations team for as long as required, with only necessary involvement of the project team to address operational questions or flight anomalies. The crucial systems engineering activity is the consolidation of system records and the development of lessons learned information to support the systems engineering database. The concluding control gates for the project are the Operational Acceptance Review (OAR), or post-flight review which essentially summarizes the project activities and assesses mission success and the Lessons Learned Review (LRR). The purpose of the LRR is to collect and disseminate information on experiences gained during the project life time.

Chapter 5

SYSTEMS HARDWARE/SOFTWARE ENGINEERING

SUMMARY

This Chapter discusses the critical hardware/software systems interface, with emphasis on continuous communication and periodic formal briefings and reviews.

5.1 INTRODUCTION

The systems engineer must establish and maintain control of all systems interfaces throughout the project life cycle. This is especially true with the important hardware/software interface. Project schedule and flowcharts may show an initial definition of "system requirements" followed by an early division into "software requirements" and "hardware requirements." The software and hardware development processes must not be allowed to proceed on two separate and parallel paths until some point far downstream where the "hardware/software integration" occurs. Systems engineering should pay special attention to hardware/software questions and see that communication is initiated early and maintained between the system users, algorithm developers, hardware engineers, software engineers, and software development teams. It is important that the hardware/software interface be continually verified for consistency and completeness throughout the project life cycle.

An important aspect of the overall system design is to avoid premature allocation of systems requirements into hardware and software requirements. Particularly in the early phases of a study, there is usually a need to prepare project cost estimates. Cost analysts desire to learn systems details such as the weights of hardware and the number of lines of software code. Such estimates should be based on comparative data base experience from other projects when possible rather than from a premature "freezing" of the system design. It is very important that systems tradeoffs and optimization be allowed to proceed until systems scope and overall feasibility are demonstrated before partitioning the system into hardware and software modules.

The systems engineer should be aware of the full scope of the project software influence including applications for ground support equipment (GSE), engineering models and simulations, data processing, embedded architecture, test data reduction, and mission operations, as well as prototype and flight hardware. Unless other factors are present, considerations of language commonality, maintainability, and reusability should be emphasized to assure the most cost-effective selections for the overall system.

5.2 SYSTEMS REQUIREMENTS DEFINITION

The emphasis during definition of systems requirements should be on both hardware and software aspects of the system. For example, a systems design with a hardware bias might over-emphasize parameters such as instrument transfer functions or signal throughputs with less emphasis on important systems control and data flow characteristics.

It is important that the Systems Requirements Document include functional requirements, as well as physical requirements. One aspect of this is to address user operational needs very early in the formulation phases. This will establish how the user intends to operate the system, what type of commands and responses are expected, what type of message flows are needed, and what timing allocations are necessary. A very useful technique at this stage is the use of rapid prototyping to develop an end-to-end model of the system. When the end-to-end message flows are demonstrated, the system can evolve into a more detailed requirements model with state transition diagrams and specific control and data flows. This leads to the system architecture model which will subsequently be decomposed into specific hardware and software requirements.

5.3 SYSTEMS REQUIREMENTS ALLOCATION

It is desirable that the allocation of requirements be the result of studied deliberation among the systems, hardware, and software engineers. When agreement is reached on the division of systems responsibilities, it is the responsibility of the systems engineer to document the results in the Systems Requirements Document. These requirements are further flowed down into more detailed design specifications and assigned to hardware and software configuration items.

The layout of the systems concept must assure that each systems entity represents a logical and contiguous portion of the system. Each Computer Software Unit (CSU) should be a stand-alone entity that can be verified and validated. At each system level, it is important that systems requirements maintain traceability to hardware and to software code. Also, in the event of changes, it is important that the changes be flowed down from the systems level rather than be inserted from the bottom up.

5.4 HARDWARE/SOFTWARE DEVELOPMENT PROCESS

Systems engineering should maintain control and cognizance of the system while the separate hardware and software development processes are proceeding. At the top level this is done through periodic status reports and formal design reviews. Schedules should identify the critical paths between hardware and software and show key verification points. The systems engineer must also stay intimately connected to the design process at all times. One method of doing this is by maintaining the system simulation model and upgrading it to incorporate all design refinements. The systems engineer should also closely monitor the software verification and validation program which should be in continuous operation. By reviewing the periodic software metrics which are generated, a gauge of development progress is obtained. Hardware activities should also be closely monitored with emphasis on any nonconformance or failure reports and results of analytical verification, breadboard, and brassboard tests.

An important aspect of the hardware/software development process is continual change control. Beginning in Phase C both hardware and software designs will be under configuration management and should be functionally correlated at all times. An example of this is the development of engineering models and prototypes. The performance capability of a prototype will initially be limited, perhaps to a few critical functions, and then become more sophisticated as the model is developed. The software version developed to support the respective hardware model must provide an appropriate functional capability to demonstrate the system performance. As the model evolves and develops more functionality, the compatibility between hardware and software must be maintained until the model eventually becomes a fully functional simulation of the flight system.

Close surveillance of all contract end item (CEI) hardware should also be maintained to assure that technical requirements will be met. The systems engineer should carefully maintain the system error allocation budget and make adjustments as the design is refined.

5.5 HARDWARE/SOFTWARE INTEGRATION

If the hardware and software development processes have been adequately controlled, there should be few surprises during systems integration. As the system was decomposed during the development process, so it is recombined for integration from the part level through subassemblies to assemblies, and so forth in an iterative process. The respective CSU's are incorporated and verified at each level before being integrated into the major elements or segments of the system. This assures requirements traceability and isolation of any hardware/software incompatibilities or anomalies.

Systems performance is verified against the systems model baseline during each phase of the integration process and further verified by performance and environmental tests. The culmination of the process is the end-to-end systems test with subsequent review of test results and systems validation and acceptance.

Continue to Next Section