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2nd Edition

SYSTEM ENGINEERING HANDBOOK

Volume 2 - TOOLS, TECHNIQUES, AND LESSONS LEARNED

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Systems Analysis and Integration Laboratory
Systems Definition Division

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LIST OF ACRONYMS AND ABBREVIATIONS

AFE	Aeroassist Flight Experiment
AR	Acceptance Review
ASE	Airborne Support Equipment
ATP	Authority to proceed
AXAF	Advanced X-Ray Astrophysics Facility
C^2	Command and Control
CCB	Configuration Control Board
CCBD	Configuration Control Board Directive
CDMS	Command and Data Management System
CDR	Critical Design Review
CEI	Contract End Item
CGF	Crystal Growth Furnace
CI	Configuration Inspection
CIL	Critical Items List
CM	Configuration Management
COCC	Certificate of Configuration Compliance
COFW	Certificate of Flight Worthiness
COQ	Certifications of Quality
CPU	Central Processor Unit
DCR	Design Certification Review
DN	Discrepancy Notice
DoD	Department of Defense
DR	Data Requirement
DRM	Design Reference Mission
EB	Electronics and Information Laboratory
ECP	Engineering Change Proposal
ECR	Engineering Change Request
EGSE	Electrical GSE
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO	Mission Operations Laboratory organization symbol/Engineering Order
EPED	Experiment Payload Element Developer
EPEMR	Electrical Power and Energy Management Report
ERD	Experiment Requirements Document
FCI	Functional Configuration Inspection
FMEA	Failure Modes and Effects Analysis
FOSP	Flight Operations Support Personnel
FRR	Flight Readiness Review
GFE	Government Furnished Equipment
GIRD	Ground Integration Requirements Document
GN&C	Guidance, Navigation, And Control
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

HOSC	Huntsville Operations Support Center
HST	Hubble Space Telescope
I/F	Interface
ICD	Interface Control Document
IIA	Instrument Interface Agreements
IOC	Initial Operational Capability
IPCL	Instrumentation Program & Command List
IPL	Integrated Payload
IRD	Interface Requirements Document
IRN	Interface Revision Notice
IRR	IPL Requirements Review/Integration Readiness Review
IV&V	Independent Verification and Validation
IWG	Interface Working Group
JSC	Johnson Space Center
KHB	Kennedy Handbook
KSC	Kennedy Space Center
LSSP	Launch Site Support Plan
MCC	Mission Control Center
MCT	Mission Control Team
MGSE	Mechanical GSE
MM	Marshall Manual
MMI	Marshall Management Instruction
MPE	Mission Peculiar Equipment
MRA	Mission Requirements Analysis
MRB	Materials Review Board
MROFIE	Mission Requirements On Facilities/Instruments/Experiments
MSFC	Marshall Space Flight Center
MSOE	Mission Sequence of Events
MUA	Materials Usage Agreement
MUL	Materials Utilization List
NAR	Non-Advocate Review
NASA	National Aeronautics and Space Administration
NHB	NASA Handbook
NMI	NASA Management Instruction
NSTS	National Space Transportation System
O&IA	Operations and Integration Agreement
OMRSD	Operation and Maintenance Requirements and Specification Document

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

PD	Program Development Directorate
PDR	Preliminary Design Review
PED	Payload Element Developer
PERT	Program Evaluation Review Technique
PI	Principal Investigator
PIA	Project Initiation Agreement
PIP	Payload Integration Plan
PMM	Payload Mission Manager
POCC	Payload Operations Control Center
PRD	Project Requirements Document
PRR	Program/Project Requirements Review
PRSD	Preliminary Requirements Specification Document
QA	Quality Assurance
R&T	Research and Technology Office
RFP	Request for Proposal
RID	Review Item Discrepancy
ROM	Read-only Memory
S&E	Science and Engineering Directorate
S&MA	Safety and Mission Assurance
S/C	Spacecraft
SA&I	Systems Analysis and Integration
SAIL	Systems Analysis and Integration Laboratory
SOW	Statement of Work
SRD	System (Science) Requirements Document
SSF	Space Station Freedom
STS	Space Transportation System
SWCDR	Software Critical Design Review
SWPDR	Software Preliminary Design Review
SWPRR	Software Preliminary Requirements Review
SWRR	Software Requirements Review
TBD	To-Be-Determined
TCRSD	Test and Checkout Requirements and Specifications Document
TDR	Test Discrepancy Report
TDRSS	Tracking and Data Relay Satellite System
TPS	Thermal Protection System
USAF	United States Air Force
VDC	Volts Direct Current (DC)
VRCD	Verification Requirements Compliance Document
VRSD	Verification Requirements and Specifications Document
WBS	Work Breakdown Structure

1.0 INTRODUCTION

Throughout this volume and its companion Volume 1, we have tried to describe the system engineering process used for both large and small experiments/payloads, both Spacelab and non-Spacelab missions, and both in-house projects and those which are contracted out. The process for Spacelab and other attached payloads is covered well as there exists prescribed procedures and documentation for these missions. Larger payloads, such as the International Space Station Alpha Program, on the other hand, are handled almost uniquely for each program. The approach here has been to try and provide generic examples of analyses and documentation which, hopefully, can be tailored to a specific program. The reader is referred to MSFC-HDBK-2221, Verification Handbook, for details in the verification area.

1.1 Purpose

The purpose of this volume of the System Engineering Handbook is to provide descriptions of the specific documentation and analyses performed by the System Engineering organizations at NASA/MSFC. These fact sheets include descriptions of tools, techniques, analyses, and documentation formats.

The reader is reminded that Volume 1 of this handbook describes the overall system engineering process and how the various pieces interrelate. Please refer to that volume to see where in the process the specific products, tools and analyses, described here, are used.

1.2 Document Organization

This document is organized into seven sections. Section 1 is this introduction. Section 2 contains templates for each of the documents regularly prepared by the SAIL, as well as sample schematics and diagrams. Section 3 contains references to applicable specifications and standards. Section 4 is a section containing tutorials on the specific system engineering analyses performed within the SAIL. Section 5 contains formal review checklists and various process descriptions. Section 6 is a summary listing of system engineering computer tools in use at MSFC. Section 7 contains lessons learned from previous programs and projects.

1.2.1 Documentation

Section 2.0 of this volume contains generic outlines of typical system engineering documents produced by SAIL. In addition, some examples of schematics and flow diagrams are included. These documents are divided into five categories: (1) Engineering Management, (2) Requirements, (3) Interfaces, (4) Verification, and (5) Design Support.

For consistency, each of these fact sheets contains five sections as follows:

I. OPR - Contains the organization code of the office of primary responsibility (OPR) for each document. This is to provide the reader with a starting place should additional information about a particular document be desired.

II. PURPOSE - Defines the purpose of the document.

III. DESCRIPTION - This is a detailed description of the document, including what it is, who uses it, when it is used, and what are the inputs and outputs.

IV. REFERENCES - Identifies other sources the reader may reference to get a better understanding of the document.

V. OUTLINE or FIGURE - Contains an annotated template for a typical document of this type, or an example if the subject is a drawing or schematic.

VI. LESSONS LEARNED - Contains applicable lessons learned extracted from Section 7.0.

1.2.2 Applicable Specifications and Standards

Section 3.0 of this volume contains lists of specs and standards for easy reference. Document number and title is listed for each entry.

1.2.3 Analyses

Section 4.0 contains brief technical discussions of system engineering analyses performed in SAIL. Each "fact sheet" or write-up is organized as follows:

I. OPR - Contains the organization code of the office of primary responsibility (OPR) for this analysis. This is to provide the reader with a starting place for additional information.

II. PURPOSE - Defines the purpose of the analysis.

III. DESCRIPTION - This is a detailed description of the analysis, including what it is, who uses it, when it is used, and what are the inputs and outputs. An example may also be given.

IV. REFERENCES - Identifies other sources the reader may reference to get a better understanding of the analysis or technique.

V. LESSONS LEARNED - Contains applicable lessons learned extracted from Section 7.0.

1.2.4 Processes and Checklists

Section 5.0 contains brief discussions of system engineering processes and design review checklists. Each "fact sheet" or write-up is organized as follows:

I. OPR - Contains the organization code of the office of primary responsibility (OPR) for this process or checklist. This is to provide the reader with a starting place for additional information.

II. PURPOSE - Defines the purpose of the process or review.

III. DESCRIPTION - This is a detailed description of the process or review, including what it is, who uses it, when it is used, and what are the inputs and outputs.

IV. REFERENCES - Identifies other sources the reader may reference to get a better understanding of the process or review.

1.2.5 Summary of System Engineering Tools

Section 6.0 contains brief summaries of system engineering computer tools used at MSFC. This is an output report from a database available from EL55.

1.2.6 Lessons Learned

Section 7.0 contains short (2-3 sentences) descriptions of system engineering lessons learned from previous programs and projects.

2. DOCUMENTATION

2.1 ENGINEERING MANAGEMENT DOCUMENTS

2.1 ENGINEERING MANAGEMENT DOCUMENTS

In Volume 1, the importance of early planning in the system engineering process is stressed. In this section of Volume 2, key documentation used in planning and managing the system engineering effort is discussed and generic outlines or examples are given.

2.1.1 TASK/DOCUMENTATION TREE

I. OPR

EL51

II. PURPOSE

The Project Task/Documentation Tree is an output of the initial planning process that the SAIL Lab Lead System Engineer performs. It serves to identify the hierarchy of tasks and associated documents to be produced for the project and the organizational level responsible for the document.

III. DESCRIPTION

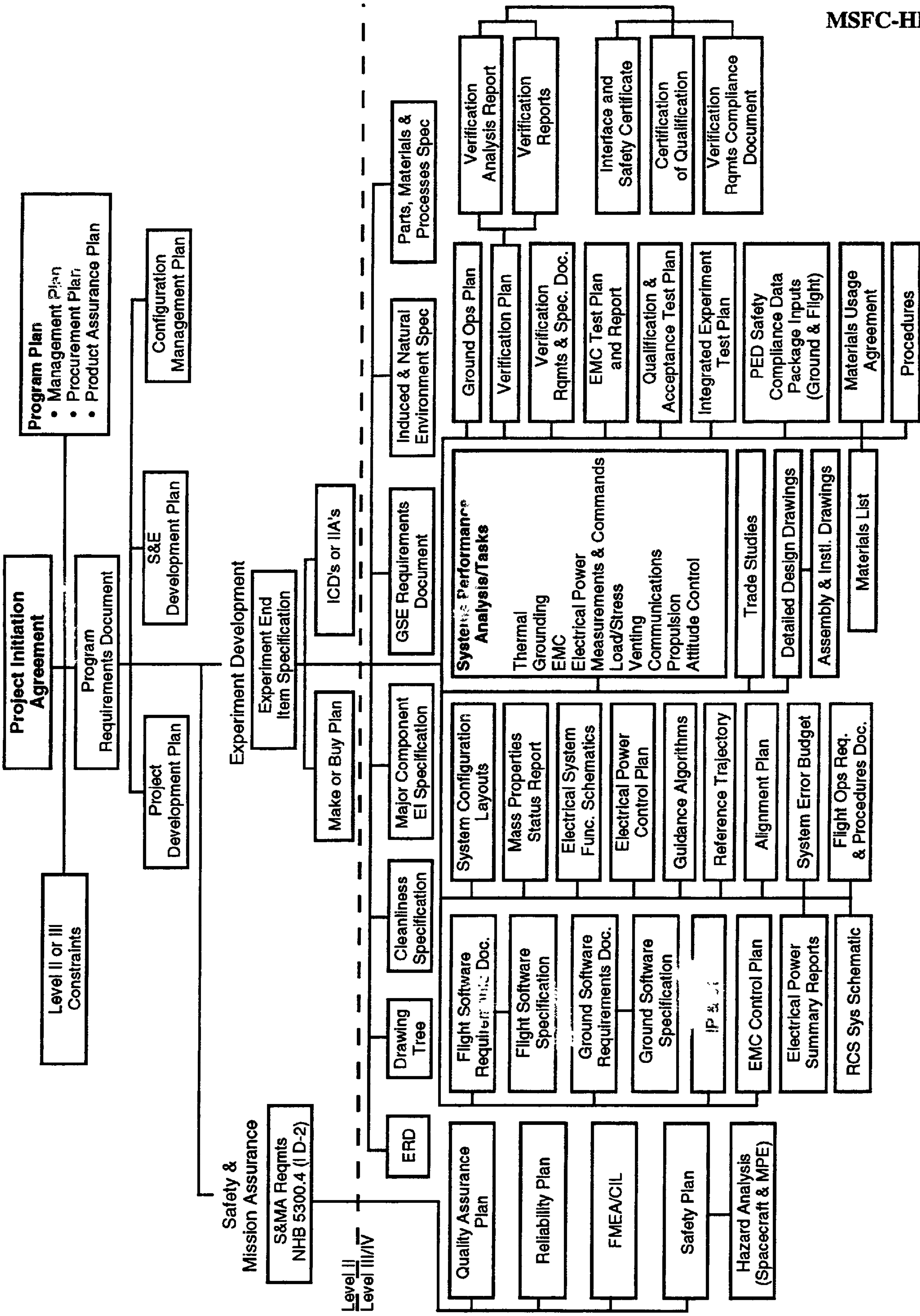
Although every project will be somewhat unique, there is a core-set of tasks and documents which every project will require. This set includes the top-level project requirements documents and the hierarchy of subordinate system and subsystem specifications. Note that certain documents are program dependent. That is to say, they are not required for every program/project. The nature of the program mission, requirements, and constraints should help the SAIL Lab Lead System Engineer decide which documents will be required.

IV. REFERENCES

None.

V. FIGURES

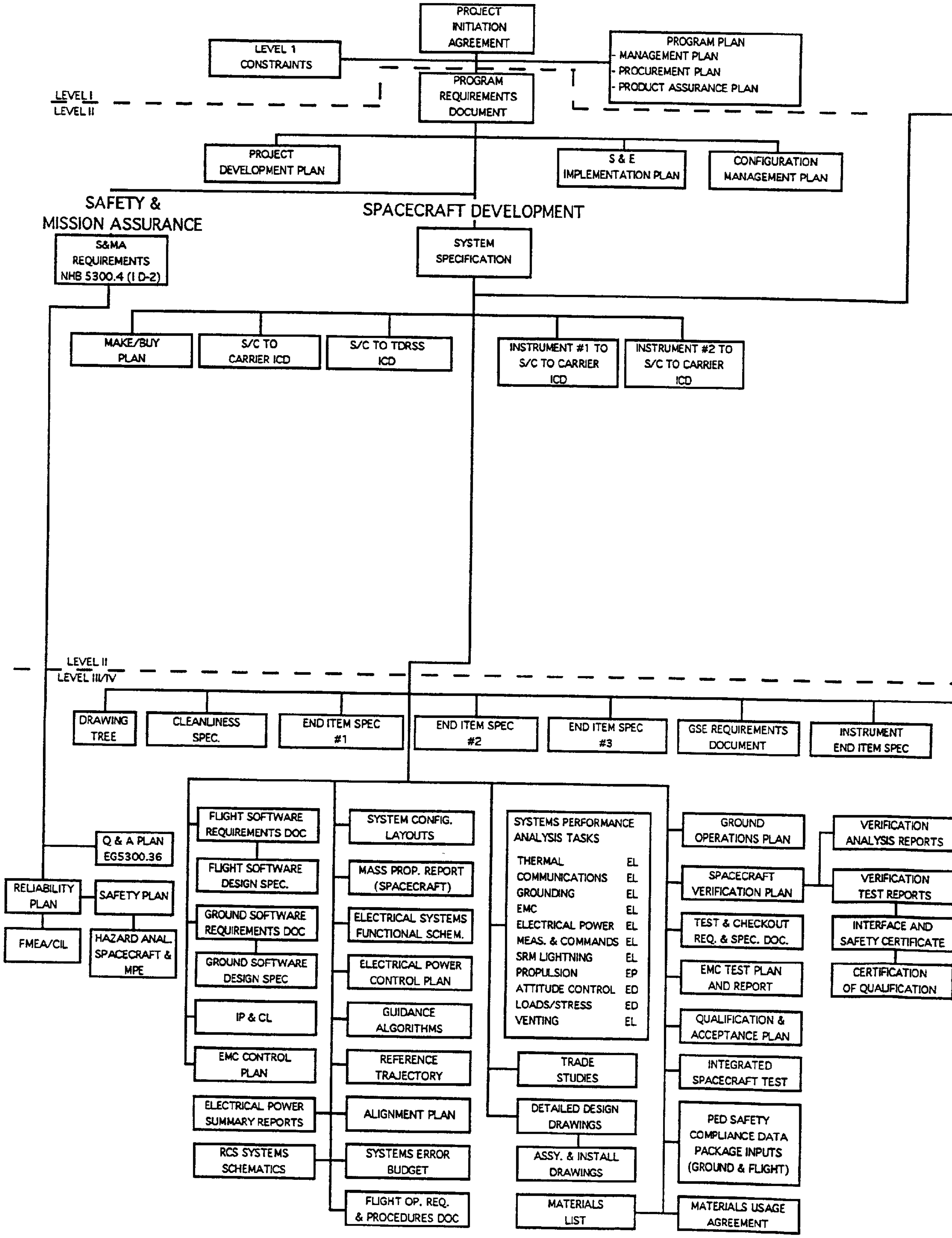
Figure 2.1.1-1 is an example of an MSFC-Developed Experiment Task/Documentation Tree and Figure 2.1.1-2 is an example of a typical spacecraft task/documentation tree.



Note: Not all tasks/documents listed will be needed on every experiment

Figure 2.1.1-1 Typical Experiment Task/Product Tree

TYPICAL SPACECRAFT



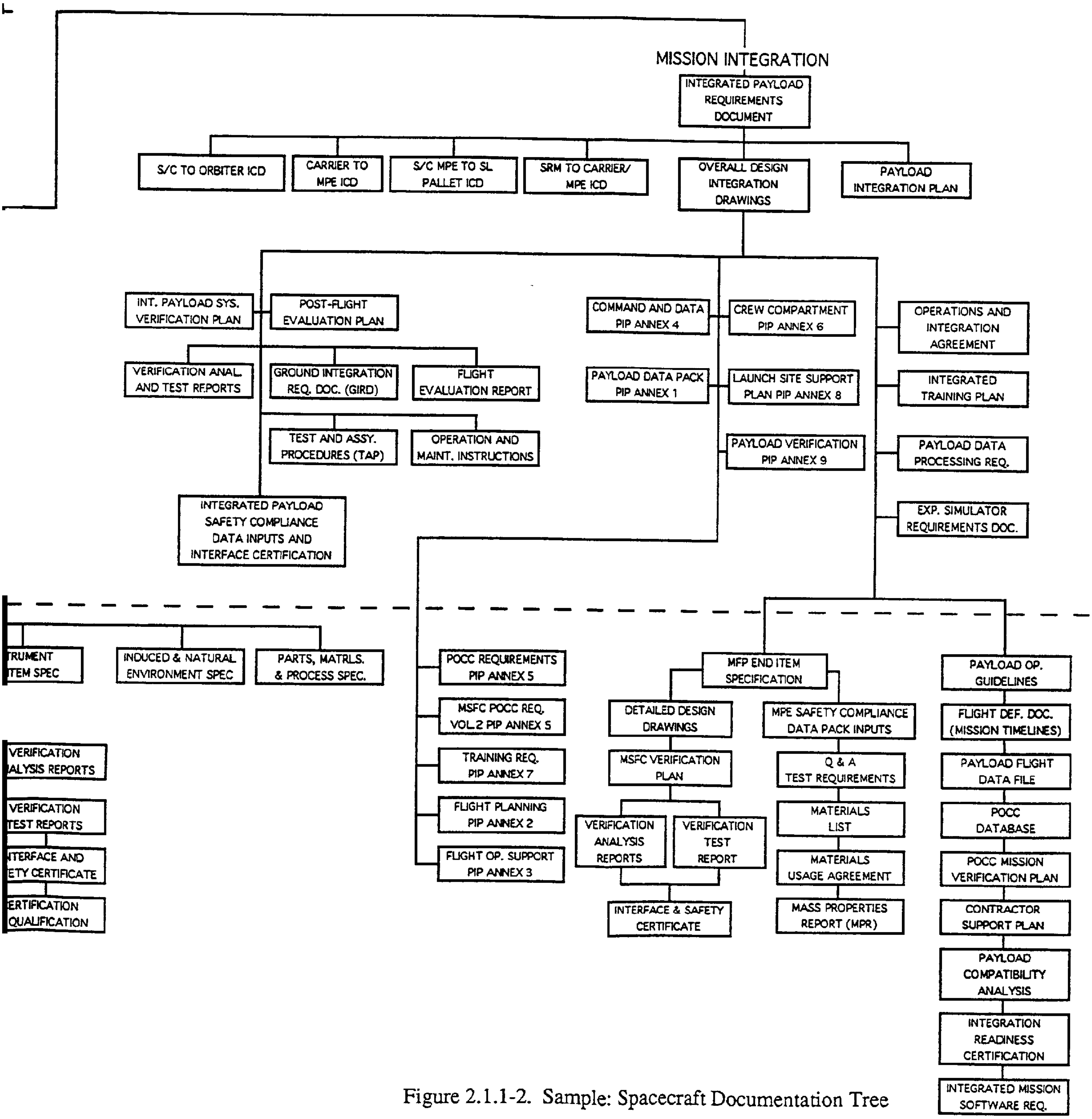


Figure 2.1.1-2. Sample: Spacecraft Documentation Tree

2.1.2 SYSTEM ENGINEERING DATA REQUIREMENTS (DRs)

I. OPR

EL31

II. PURPOSE

Data Requirements (DRs) specify format and content requirements for data and documentation to be delivered to MSFC. The following list of DRs is provided as a ready reference for preparing Requests for Proposals and other contract documentation.

III. DESCRIPTION

DR NUMBER	TITLE	CONTACT
STD/CM-ADP	Acceptance Data Package	EL32
STD/CM-CASR	Configuration Accounting and Status Reports	EL32
STD/CM-CMP	Configuration Management Plan	EL32
STD/CM-DWAR	Deviations/Waiver Approval Requests	EL32
STD/CM-ECP	Engineering/Project Change Proposals	EL32
STD/CM-EDAL	Engineering Drawings and Associated Lists	EL32
STD/CM-MINC	Modification Instructions and Installation Notice Cards	EL32
STD/CM-MRD	Major Review Documentation	EL32
STD/CM-SDT	Specification and Drawing Tree	EL32
STD/CM-SPEC	Specifications	EL32
STD/MA-DMP	Data Management Plan	EL32
STD/OP-GOP	Ground Operations Plan	EL43
STD/OP-GSER	Ground Support Equipment Requirements Document	EL43
STD/OP-OMM	Operations and Maintenance Manuals	EL43
STD/OP-OMRD	Operations and Maintenance Requirements and Specifications Document	EL45
STD/OP-PDH	Payload Description Handbook	EL44
STD/SE-AP	Alignment Plan	EL55
STD/SE-ASFD	Avionics Systems Functional Decomposition	EL56

STD/SE-CDFS	System Connectivity Diagrams and Functional Schematics	EL56
STD/SE-CSAS	Radio Frequency Communication Systems Analysis and Studies	EL56
STD/SE-CSM	Communications Subsystems Measurements	EL56
STD/SE-DHSA	Data Handling and Software Systems Analysis	EL56
STD/SE-EIA	Electromagnetic Compatibility Intrasystem Analysis Report	EL54
STD/SE-EMP	Electromagnetic Effects Control Plan	EL54
STD/SE-EPCP	Electrical Power Control Plan	EL56
STD/SE-EPMR	Electrical Power and Energy Management Report	EL56
STD/SE-ESA	Electrical System Analysis	EL 5
STD/SE-ESRD	Engineering Support Center Requirements Document	EL44
STD/SE-ESTP	Engineering Support Team Plan	EL44
STD/SE-ESTR	Engineering Support Team Training Requirements	EL44
STD/SE-FEP	Flight Evaluation Plan	EL44
STD/SE-FER	Flight Evaluation Report	EL44
STD/SE-GNSD	Guidance and Navigation System Design Document	EL58
STD/SE-ICD	Interface Control Documents (ICDs)	EL42
STD/SE-IPCL	Instrumentation Program and Command List Specification	EL56
STD/SE-IRD	Interface Requirements Documents (IRDs)	EL
STD/SE-MAFD	Mission Analysis and Flight Design Document	EL58
STD/SE-MPCP	Mass Properties Control Plan	EL42
STD/SE-MPR	Mass Properties Report	EL42
STD/SE-NSED	Natural Space Environment Definition and Requirements Document	EL54
STD/SE-PDPI	Payload Data Package Annex Inputs	EL44
STD/SE-RFM	Requirement Flowdown Matrix	EL55
STD/SE-RSTR	Range Safety Trajectory Analysis Report	EL58

STD/SE-SDH	Systems Description Handbook	EL55
STD/SE-SEB	System Error Budget	EL55
STD/SE-SEIP	Systems Engineering & Integration Plan	EL55
STD/SE-SRD	Systems Requirements Document	EL55
STD/SE-SS	System Specification	EL55
STD/SE-SSDD	System/Segment Design Definition Document	EL56
STD/SE-SSRD	System Software Functional Requirements Document	EL56
STD/VR-VP	Verification Plan	EL45
STD/VR-VR	Verification Reports	EL45
STD/VR-VRCD	Verification Requirements Compliance Document	EL45
STD/VR-VRSD	Verification Requirements and Specifications Document	EL45

IV. REFERENCES

A. MMI 2314.6, "MSFC Data Requirements Management System."

B. MSFC-PROC-1969, "Data Requirements Management Procedure."

V. LESSONS LEARNED

A. Take the time to identify and tailor RFP data requirements to be consistent with the project, S&E's role in that project, and MSFC's needs for contractor data to fulfill its role.

B. Integrated hardware and end-to-end functional schematics have been shown to be an important aid in problem detection and identification. Be sure the RFP calls for these as data requirements, consistent with the size and complexity of the system under development.

2.1.3 S&E IMPLEMENTATION PLAN

I. OPR

EE/EJ

II. PURPOSE

The S&E Implementation Plan documents the agreement/commitment between S&E and the Project Manager on the conduct of an in-house project.

III. DESCRIPTION

The S&E Implementation Plan defines the guidelines, tasks, products, manpower, approach, activities, responsibilities, and schedules for all technical support required of S&E and its laboratories. Also included are the activities and responsibilities of the Safety and Mission Assurance office, as applicable. The document should be written and approved soon after project approval and start of Phase C/D. Inputs include the Project Plan. After approval of the S&E Implementation Plan, an annual Task Agreement is written which translates this plan into specific requirements and activities for the coming fiscal year.

This document must be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

* Document Developer: Project Chief Engineer
* Director, S&E
* Project Manager
* Director, S&MA (if applicable)

IV. REFERENCES

A. MM 7120.2, "Project Management Handbook."

B. MMI 8200.1, "Task Agreements Between the Program/Project Offices and the Science and Engineering Directorate."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific program being documented.

VI. LESSONS LEARNED

One of the most over-looked and neglected aspects of system engineering is the importance of early planning and task identification and scheduling required to accomplish the total job.

OUTLINE
S&E IMPLEMENTATION PLAN

2.1.4 CONFIGURATION MANAGEMENT PLAN

I. OPR

EL31

II. PURPOSE

The Configuration Management Plan defines the contractor's intended implementation of configuration management (CM) to meet program/project requirements.

III. DESCRIPTION

The CM Plan is normally prepared by the Phase C contractor as specified in the RFP and contract. If the plan is required to be delivered to the government, it establishes a formal agreement between MSFC and the contractor on the CM policy and methods to be used by the contractor. The plan is maintained by the contractor with all changes and revisions submitted to MSFC for review and concurrence.

IV. REFERENCES

A. MM 8040.12, "Standard Contractor Configuration Management Requirements MSFC Programs."

B. DR STD/CM-CMP, "Configuration Management Plan."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific project being documented.

OUTLINE
CONFIGURATION MANAGEMENT PLAN

1.0 INTRODUCTION
1.1 Purpose
1.2 Scope
1.3 Objectives

2.0 ORGANIZATION

> Describe the organizational relationship of CM to project management. Use an organization chart and accompanying text to illustrate the authority/responsibility of the key organizational elements in the company charged with meeting CM contractual requirements. Include discussion on policy and procedures for CM and change control to include specification preparation, drawing preparation, engineering release, manufacturing, quality control, test and checkout, preparation for delivery, delivery, ECP preparation and control, CM audits and configuration indexing and accounting.

3.0 CONFIGURATION IDENTIFICATION
3.1 Specifications

> Define CEI and critical component specs the contractor will prepare and use. Show a specification tree to show the hierarchical relationships among specifications.

3.2 Drawings

> Define the drawing practices to be used and discuss any deviations or limitations for contractor-prepared drawings.

4.0 CONFIGURATION CONTROL

> Define policies and procedures for control of established configuration baselines, processing engineering changes, and deviations and waivers to configuration baselines. Discuss the control of technical interfaces.

5.0 CONFIGURATION ACCOUNTING

> Describe plans for application of the configuration identification index and modification status reports. Describe internal system for accounting for all approved Class I and Class II engineering changes, deviations, waivers, and contract noncompliances.

6.0 SUBCONTRACTOR/VENDOR CONFIGURATION MANAGEMENT CONTROL

> State proposed methods for control over subcontractors and vendors. Explain what methods will be used to determine their capability and monitor their ability to meet CM requirements.

7.0 PROGRAM PHASING

Propose major CM milestones including establishment of change boards, phasing of specific program implementation, establishment of configuration baselines, and establishment of interface control agreements with associate contractors.

8.0 MANAGEMENT INTEGRATION OF CONFIGURATION MANAGEMENT

Discuss management integration activities between CM and project management. Specify the relationship between critical CM events and sequencing of design reviews, release of engineering, production, test, logistic support events, audits, preparation for delivery, and turnover reviews, to name a few.

9.0 CONFIGURATION MANAGEMENT REVIEWS

Discuss plans for conducting or supporting appropriate CM reviews as required by the contract.

2.1.5 TASK FLOW CHART

I. OPR

EL51

II. PURPOSE

The task flow chart, or network chart as it is sometimes called, is used to ensure task integration. It identifies inputs and outputs for each task, shows task interrelationships, and assists in identifying the critical paths.

III. DESCRIPTION

The Program Evaluation and Review Technique (PERT) is one method used in constructing flow charts. When starting a flow chart, begin at the end of the process and work backwards. Identify each event in the process and the necessary inputs and outputs. Check to ensure all activities are in proper time-sequence. There should be only one starting and one ending event. Also, networks of varying levels of detail can be constructed to provide the required visibility into project progress.

Flow charts should be a key system engineering management tool for both small and large projects, whether performed in-house or contracted out. Their utility can be enhanced by including activity time estimates and associated probabilities of occurrence, as well as activity costs. This additional complexity allows better identification of problems and assessment of progress and estimated date of task completion. There are many computer programs which can be used in producing these diagrams.

IV. REFERENCES

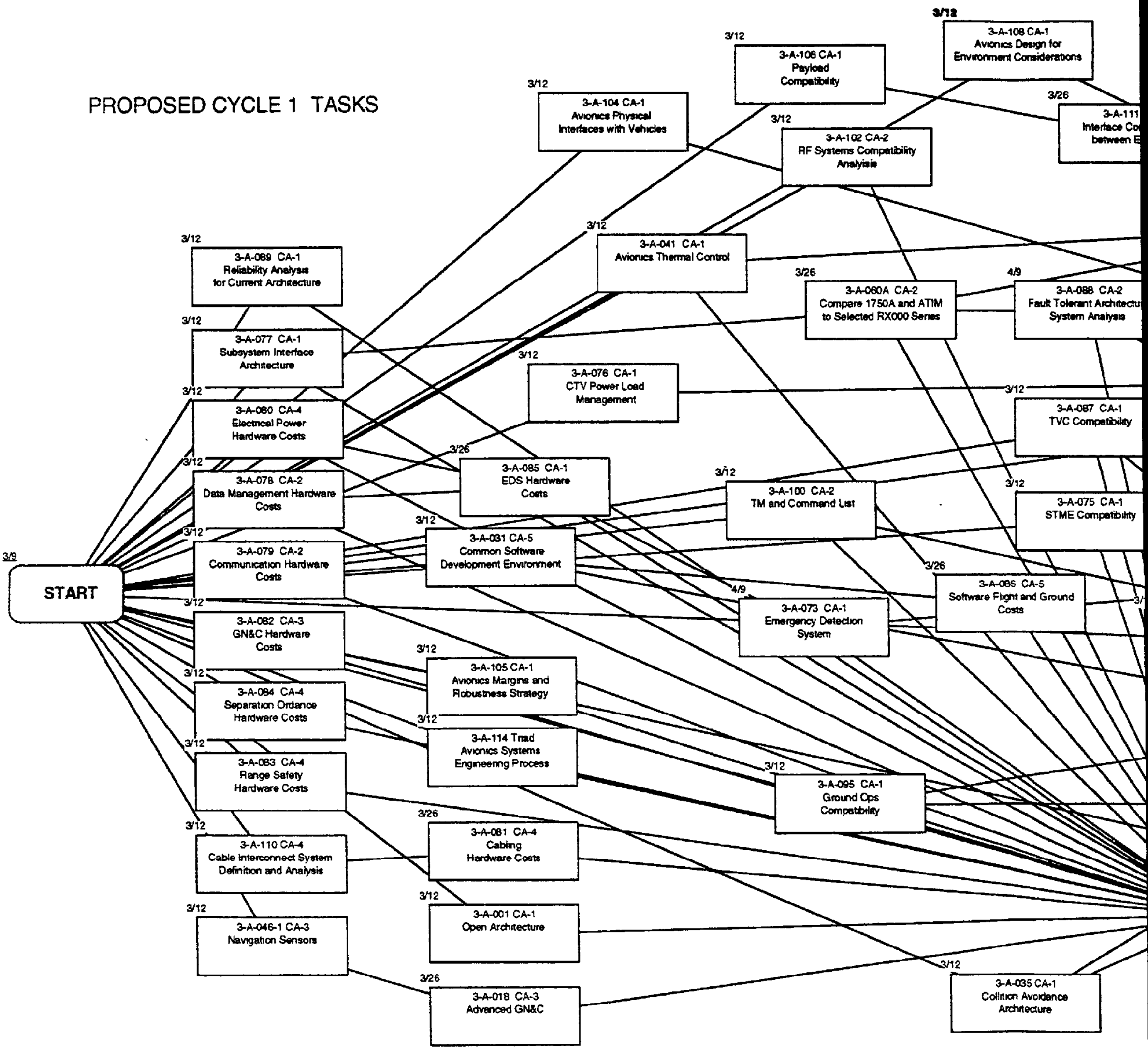
Blanchard, Benjamin S. and Fabrycky, Wolter J., Systems Engineering and Analysis, Prentice Hall, Inc., 1990, pp. 552-554.

V. FIGURE

Figure 2.1.5-1 is an example of a Flow Chart.

NLS LEVEL III AVIONICS T
MARSHALL SPACE FLIGH

PROPOSED CYCLE 1 TASKS



NICS TASKS NETWORK
FLIGHT CENTER (MSFC)

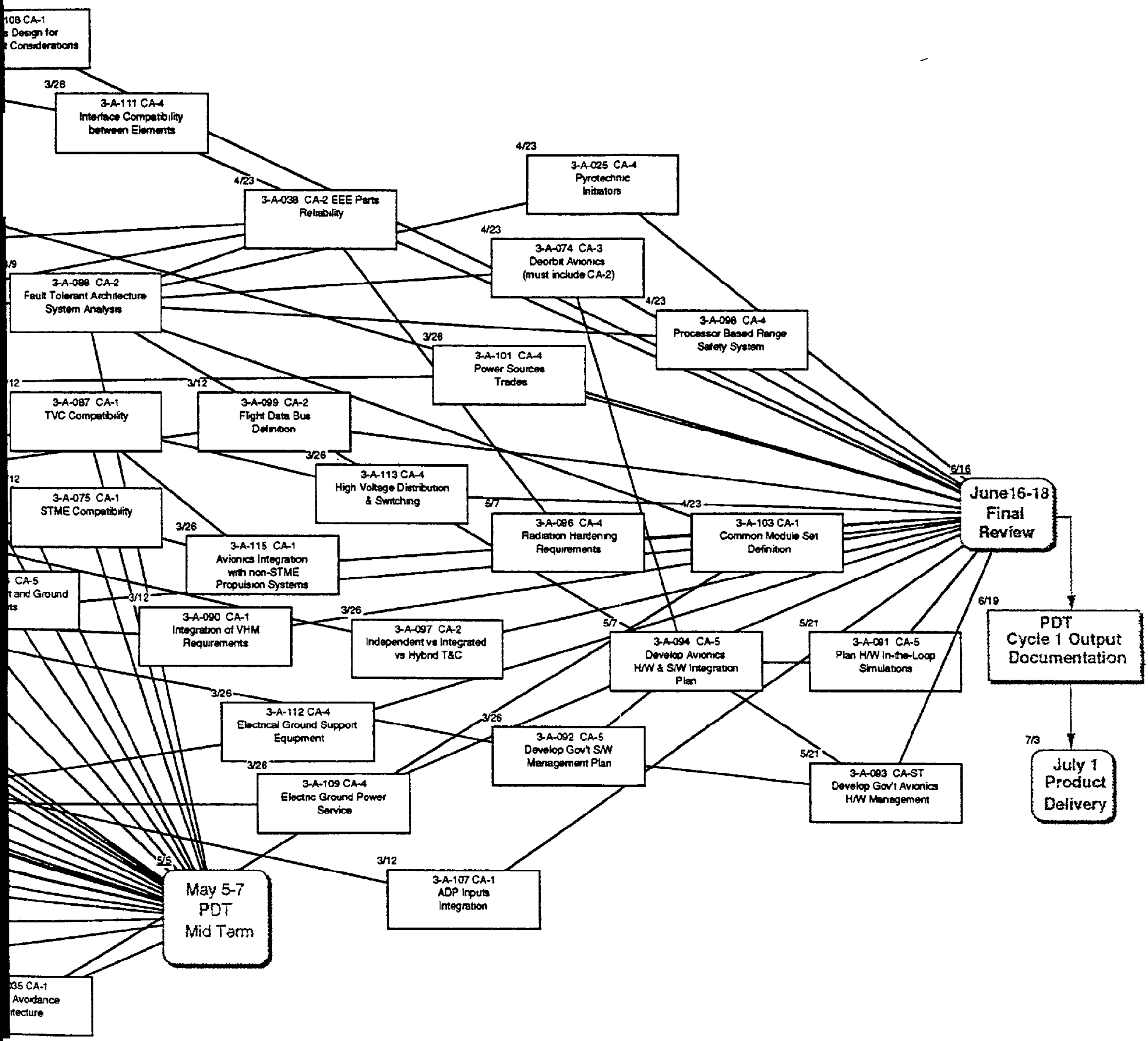


Figure 2.1.5-1. Flow Chart Example

2.1.6 SA&I LAB MANPOWER ESTIMATES

I. OPR

SA&I Lab Lead System Engineer (LLSE)

II. PURPOSE

This is developed to document system engineering manpower support to the Project Office for budgeting purposes.

III. DESCRIPTION

One of the first responsibilities of the LLSE on a new project will be to prepare a manpower estimate for the SAIL. This is usually done in conjunction with developing the S&E Implementation Plan (see Section 2.1.3 in this volume).

The first step in developing this estimate is to construct a Gantt Chart showing the project milestones. Specific system engineering tasks/ documents for which the SAIL is responsible should then be overlaid on the Gantt Chart. These tasks/document timelines should show interim milestones such as draft document releases, as well as estimated man-loading throughout the task duration. Do not forget to include level-of-effort type of system engineering support such as that provided by the Configuration Management and System Test Divisions. The LLSE should also be sure to include his own time in the overall manpower estimate. Support contractor man-loading should also be identified.

The specific man-loading estimate for each task is usually obtained from the responsible organization. The LLSE should review these inputs to ensure they are reasonable and that the task milestones support the project milestones and formal reviews.

Note that these estimates may be either a "planning estimate" or a "commitment from the Lab." Obviously, a planning estimate is just that, and does not represent a commitment from the Lab to provide that level of manpower support. If subsequent to a planning estimate, the Project Office should come back to the Lab to implement the scope of work identified in the planning estimate, a new estimate representing a Lab commitment would have to be made. Manpower planning estimates should go through the Lab Director. Commitments must go through the Lab Director. The LLSE should ensure that all applicable assumptions, caveats, and programmatic impact statements are included with each manpower estimate submitted.

IV. REFERENCES

"SA&I Lab Lead System Engineer Orientation Course", handout, September 1993.

V. FIGURE

Figure 2.1.6-1 is an example of a SA&I Lab manpower estimate.

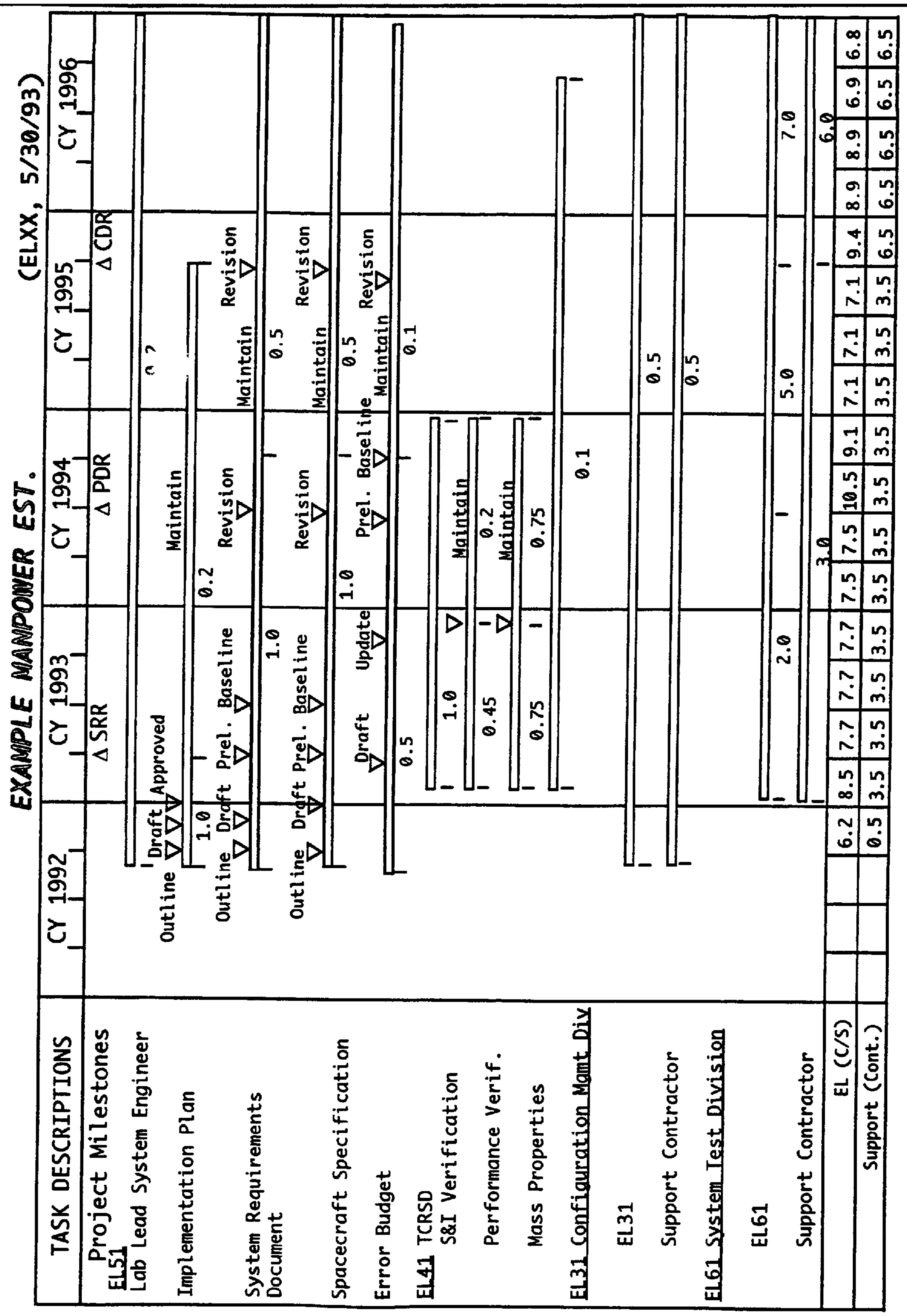


Figure 2.1.6-1. Manpower Estimate Example

2.2 REQUIREMENT DOCUMENTS

2.2.1 SYSTEM SPECIFICATION (SS)

I. OPR

EL55

II. PURPOSE

The System Specification (SS) is used to define the system level requirements for a project. These requirements should be top-level, providing guidelines and restrictions for the project, without providing design solutions. This type of specification states the technical and mission requirements for a system as an entity, allocates requirements to functional areas, documents design constraints, and defines the interfaces between or among the functional areas. Normally, the initial SS would be based on parameters developed during Phase A and will be further refined during Phase B.

Other top-level requirements documents are the Program Requirements Document and the Contract End Item (CEI) Specifications (Section 2.2.2 in this Volume).

III. DESCRIPTION

* Initial Release at SRR

* Baseline upon closure of PRR actions

This document must be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

If the document will be controlled at Level II, the following should sign:

* Specification Developer
* Branch Chief
* Division Chief
* Lab Director
* Chief Engineer
* Program Manager
* Stress
* Materials
* S&MA

If the document will be controlled at Level III, the following should sign:

* Specification Developer
* Branch Chief
* Division Chief
* Chief Engineer
* Stress
* Materials
* S&MA

IV. REFERENCES

A. MIL-STD-490A, "Specification Practices", 4 Jun 85

B. DR STD/SE-SS, "System Specification."

C. MSFC-STD-555, "MSFC Engineering Documentation Standard."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to tailor the outline to the specific system being documented. Also, note that, depending on the size of the system under development, the SS might not be necessary. In the case of a small experiment, for example, a CEI spec may suffice.

VI. LESSONS LEARNED

A. Assure that all applicable requirements and process documents are defined at the time of system and CEI specifications baselining.

B. Assure documents are baselined based upon their having reached the appropriate level of completeness and maturity and not solely because the project schedule says they should be baselined by a certain date.

C. Where design reference missions (DRMs) are used to bound program requirements, strive to replace DRM parameters with specific performance requirements as early as practical.

D. A hard weight limit is necessary to cap weight growth. This may require funds to be spent to reduce weight during the design process. In one case, the load-carrying capability of the trunnion pins used to mount the vehicle in the STS payload bay proved to be the practical weight limit.

E. Requirements definition and allocation should include sufficient margins to assure a robust design with inherent growth c ·ability. An example might be to requi 3.0 db communication link m..rgin at launch, 3.5 db margin at CDR, and 4.5 db margin at PDR.

F. Plan, identify, and perform n· ssary analyses to support systems requiren s and design. Document and review requ...ments **before** initiating design.

G. Continually assess systems requ··ments to assure they are, in fact, requiren. s and not desires or design implementation. **Requirements which cannot be verified are not valid requirements.**

H. All concepts, requirements, and designs should give primary consideration to safety. Performance requirements can be negotiated; safety requirements cannot.

I. Ensure that requirements in a document are traceable both to its precedent and antecedent documents. That is, that there exists a source document for each valid requirement and that all lower level requirements documents flowdown higher-level requirements.

J. Should ensure a minimum of two review iterations or tabletop reviews prior t submitting a requirements document for . formal requirements review.

K. Strive to develop and allocate the least complex interfaces possible between program elements (i.e., keep it simple).

L. Ensure all functional areas and disciplines are involved ·n developing the initial system requirements

M. Requirements for long-term projects such as launch vehicles, space observatories, or space static · should emphasize low operations cos.

N. Once the system requirements have been documented, review them from the perspective of a designer. Do they have enough information to design the system? Do they impose design solutions or unnecessary constraints?

O. Use of computer tools for requirements management and traceability is strongly recommended. Use of such tools will be facilitated if only a single requirement statement is included in each sentence/ paragraph. This structure also facilitates the writing of clear, concise, unique, and unambiguous requirements.

OUTLINE
SYSTEM SPECIFICATION

COVER
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

> Figures are numbered sequentially from 1 using Arabic numerals (1,2,3). Figure numbers and titles should be centered below each figure.

LIST OF TABLES

> Tables are numbered sequentially from I using Roman numerals (I,II,III). Table numbers and titles should be centered above each table.

1.0 SCOPE
1.1 Scope

> Define the contents of the document.

1.2 System Overview

2.0 APPLICABLE DOCUMENTS

> This section must contain a list of every document referenced in the text. Also, every document listed here must be in the text. A standard paragraph is usually included as follows: "The following documents, latest revision unless otherwise specified, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced herein and the contents of this specification, this specification shall apply, except for safety-related items and issues."

2.1 Reference Documents

> List documents which contain general background information. These could include documents identified as applicable to documents that are applicable to this SS. A standard paragraph is usually included, like this one: "The following documents are for reference only. As such, they do not constitute a part of this document, but may be of interest to the reader."

3.0 REQUIREMENTS

> All of the design and performance requirements for the system are specified in this section. This section is divided into subsections as follows:

3.1 System Definition

Identify major factors that affect the system design. Describe the system and identify the major physical parts and functional areas.

3.1.1 Missions

Describe the missions of the system to the extent the missions affect design requirements. Include operational information such as system deployment concepts, operating locations, and facilities.

3.1.2 System Description

Briefly describe the system and include a system diagram. In subparagraphs, identify each majoy functional element of the system and define the critical, top-level requirements that must be achieved by that element. Address pertinent operational and logistical considerations and concepts.

3.1.3 Interface Requirements

Describe interface requirements between/among system elements and interfaces with other systems. Detailed quantitative interface requirements may be defined in separate specifications or interface control documents and merely referenced here. All referenced documentation will be considered part of this specification. *NOTE: Interfaces should only be specified when essential. Excessive specification of interfaces in the SS may prematurely "lock-in" inappropriate design solutions.*

3.1.4 Government-furnished Property (GFP)

List and identify by nomenclature, spec number, and/or part number, all major items of GFP to be incorporated into the system. Software provided by the Government for incorporation into the system should be treated as GFP. If the GFP list is extensive, it can be included as an appendix to this SS and an appropriate reference made here.

3.2 Characteristics

Define the performance characteristics, physical characteristics, and "ility" requirements.

3.2.1 Performance Characteristics
3.2.2 Physical Constraints

Establish the boundary conditions not define [illegible] where. These include weight (mass), volume, and dimensional limits necessary to assure ph [illegible] al compatibility.

3.2.3 Reliability

State quantitative reliability requirements (with confidence levels, if appropriate) in terms of mission success or hardware mean-time-between-failures (MTBF). Initially, reliability may be stated as a goal and a lower minimum acceptable requirement.

3.2.4 Maintainability

> State quantitative maintainability requirements such as mean-time-to-repair (MTTR) or maintenance man-hours per flight/operational hour. Initially, maintainability may be stated as a goal and a higher maximum acceptable requirement.

3.2.5 Availability

> Specify the degree to which the system shall be in an operable and committable state at the start of the mission(s), where the mission(s) is called for at an unknown (random) point in time.

3.2.6 Environmental Conditions

> Specify environments the system is expected to experience in shipment, storage, service, and use. Where applicable, specify whether the system will be required to withstand, or be protected against specified environmental conditions. Subparagraphs should be included as necessary to cover environmental conditions such as climate, shock, vibration, noise, noxious gases, etc.

3.2.7 Transportability

> Include requirements for transportability which are common to all components. All major functional elements that, due to operational characteristics, will be unsuitable for normal transportation methods shall be identified.

3.3 Design and Construction

> This section generally is a standard section. It includes all of the specifications and standards that must be used in designing the entire system or segment in areas such as electrical, mechanical, materials, contamination, human engineering, and identification and marking. These different areas should be covered by their own subsection numbers.

3.3.1 Materials, Processes, and Parts
3.3.1.1 Toxic Products and Formulations
3.3.1.2 Volatile Organic Compounds (VOCs)
3.3.1.3 Protective Coatings
3.3.2 Electromagnetic Radiation
3.3.3 Nameplates or Product Markings
3.3.4 Workmanship
3.3.5 Interchangeability
3.3.6 Safety
3.3.7 Human Factors Engineering
3.3.8 Producibility
3.3.9 System Security

3.4 Computer Resource Requirements
3.4.1 Computer Hardware Design Considerations
3.4.2 Flexibility and Expansion
3.4.3 Software Portability
3.4.4 Software Supportability

3.5 Logistics
3.5.1 Maintenance

3.5.2 Supply
3.5.3 Facilities and Facility Equipment

3.6 Personnel and Training
3.6.1 Personnel
3.6.2 Training

3.7 Precedence

4.0 QUALITY ASSURANCE PROVISIONS
a. Analysis
b. Demonstration
c. Examination
d. T t
4.1 Contract Responsibilitv
4.1.1 Respo ibility for Ins ction
4.1.2 Responsibility for Compliance
4.1.3 Responsibility for Product Quality
4.2 Verification Inspections
4.2.1 Verification of Toxicological Product Formulations
4.2.2.1 Detailed Inspection Element X
4.2.2.1.1 Methods of Inspection
4.2.2.1.2 Inspection Conditions
4.2.2.1.3 Inspection Equipment
4.3 Special Tests and Examinations
4.4 Verification Requirements Matrix

Include a description of the VRM and reference to Appendix A where the VRM can be found.

5.0 PACKAGING

6.0 NOTES
a. Glossary of system terms
b. List of acronyms

All abbreviations and acronyms used in the document should be included here in an alphal tical list. Each acronym should be defined the first time it is used. After that, either the acronym or the complete name should be used, not both. Paragraphs should not begin with acronyms, write out the entire name.

6.1 Intended Use
6.2 Government-Furnished Property (GFP)
6.3 International Standardization Agreements

7.0 APPENDICES

Large, multi-page data tables, a specification tree, interface drawings/diagrams, cla d information, other needed information that because of its bulk or content would tend to degr e usefulness of the specification

APPENDIX A - Verification Requirements Matrix

Details for preparing a VRM can be found in Volume II of MSFC-HDBK-2221.

GENERAL NOTES

- Major paragraphs (i.e., 1.0, 2.0, etc.) should be as identified in the outline. Subsections may vary with each project.
- Specification should define only system requirements (**what** capability is to be provided, not **how** to implement).
- Include only requirements not "desirements."
- Obtain specific detail requirements from the different discipline engineers as inputs.
- Definition of all the interfaces for the system functional areas is important.
- Don't be hesitant to put out a review draft with TBDs. In fact, several drafts may be required to ensure the SS is complete and accurate. You're much more likely to get inputs as a result of a document review cycle than from a straight request for inputs.
- Try to look at/review the SS from the perspective of a designer. Does the specification have enough information to design the system?
- Applicable documents section should contain only specifications, standards, and other documents required for the specific program/project. The extent of specification/standard applicability must be stated in the text of the SS.
- Specifications or documents listed for reference or guidelines only should be listed separately from applicable documents.
- Several computer programs are available which can be used in managing requirements (e.g., System Engineering Data Base (SEDB)™, Document Director™). Use of these tools will be facilitated if the requirements are written such that only one requirement is included in each sentence/paragraph. The use of compound sentences containing many requirements makes it more difficult to automate requirements management and traceability using available tools.

2.2.2 CONTRACT END ITEM SPECIFICATION

I. OPR

EL31

II. PURPOSE

The Contract End Item (CEI) specifications are subordinate to Program/Project Specifications and the System Specification. The CEI specs flow-down the higher-level requirements to each end item.

III. DESCRIPTION

The CEI specs are composed of two distinct parts (I and II). The Part I CEI spec is used to specify technical requirements peculiar to the performance, design, and verification of the CEI. "Part I is a product of early design effort; and, when completed and approved, establishes the Design Requirements Baseline for the CEI." (Ref. B)

The Part II CEI spec is used, "...to specify exact configuration requirements peculiar to the production, quality control, acceptance verification, and preparation for delivery of the CEI. It is a product of development and operations; and, when completed and approved, establishes the Product Configuration Baseline." (Ref. B)

If the document will be controlled at Level II, the following should sign:

* Specification Developer
* Branch Chief
* Division Chief
* Lab Director
* Chief Engineer
* Program Manager
* Stress
* Materials
* S&MA

If the document will be controlled at Level III, the following should sign:

* Specification Developer
* Branch Chief
* Division Chief
* Chief Engineer
* Stress
* Materials
* S&MA

IV. REFERENCES

A. DR STD/CM-SPEC, "Specifications."

B. MM 8040.12, "Standard Contractor Configuration Management Requirements MSFC Programs."

V. OUTLINE

The following page is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific end item being documented.

VI. LESSONS LEARNED

A. Assure that all applicable requirements and process documents are defined at the time of system and CEI specifications baselining.

B. Assure documents are baselined based upon their having reached the appropriate level of completeness and maturity and not solely because the project schedule says they should be baselined by a certain date.

C. Where design reference missions (DRMs) are used to bound program requirements, strive to replace DRM parameters with specific performance requirements as early as practical.

D. A hard weight limit is necessary to cap weight growth. This may require funds to be spent to reduce weight during the design process. In one case, the load-carrying capability of the trunnion pins used to mount the vehicle in the STS payload bay proved to be the practical weight limit.

E. Requirements definition and allocation should include sufficient margins to assure a robust design with inherent growth capability. An example might be to require 3.0 db communication link margin at launch, 3.5 db margin at CDR, and 4.5 db margin at PDR.

F. Plan, identify, and perform necessary analyses to support systems requirements and design. Docum nt and review requirements **before** initiatin sign.

G. Continuall ss systems requirements to assure they n fact, requirements and not desires or design implementation. **Requirements which cannot be verified are not valid requirements.**

H. All concepts, requirements, and designs should give primary consideration to safety. Performance requirements can be negotiated; safety requirements cannot.

I. Ensure that requirements in a document are traceable both to its precedent and antecedent documents. That is, that there exists a source document for each valid requirement and that all lower level requirements documents flow-down higher-level requirements.

J. Should ensure a minimum of two review iterations or tabletop reviews prior to submitting a requirements document for a formal requirements review.

K. Strive to develop and allocate the least complex interfaces possible between program elements (i.e., keep it simple).

L. Use of computer tools for requirements management and traceability is strongly recommended. Use of such tools will be facilitated if only a single requirement statement is included in each sentence/ paragraph. This structure o facilitates the writing of clear, concise, unique, and unambiguous requirements.

OUTLINE
CONTRACT END ITEM SPECIFICATION

COVER
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

> All abbreviations and acronyms used in the document should be included here in an alphabetical list. Each acronym should be defined the first time it is used. After that, either the acronym or the complete name should be used, not both. Paragraphs should not begin with acronyms, write out the entire name.

1.0 INTRODUCTION

> This section should include the document scope along with any other introductory material, such as the key participants, historical background, or experiment objectives.

2.0 APPLICABLE DOCUMENTS

> This section must contain a list of every document referenced in the text. Also, every document listed here must be in the text. A standard paragraph is usually included as follows: "The following documents, latest revision unless otherwise specified, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced herein and the contents of this specification, this specification shall apply, except for safety-related items and issues."

2.1 Government Documents
2.2 Contractor Documents

3.0 REQUIREMENTS

> All of the design and performance requirements for the system are specified in this section. This paragraph is divided into subparagraphs as follows:

3.1 Mission Requirements
3.1.1 Experiment Requirements

3.18.5.1 STS Cargo Bay
3.18.5.2 Design Load Factors
3.18.5.2.1 Handling and Transportation Load Factors
3.18.5.2.2 Jet Aircraft Induced Vibration
3.18.5.2.3 Propeller Aircraft Induced Vibration
3.18.6 On-Orbit Autonomous

3.19 Transportability/Transportation

3.20 Storage

3.21 Design and Construction Requirements

> This paragraph generally is a standard paragraph. It includes all of the specifications and standard that must be used in designing the end item in areas such as electrical, mechanical, materials. contamination, human engineering, and identification and marking. These different areas should be covered by their own sub-paragraph numbers.

3.21.1 Selection of Specifications and Standards
3.21.2 General
3.21.3 Aeronautical
3.21.4 Civil
3.21.5 Electrical
3.21.5.1 Crimped Connectors
3.21.5.2 Soldering
3.21.5.3 Printed Circuits
3.21.5.4 Conformal Coating
3.21.5.5 Cable/Wiring Harnesses
3.21.5.6 Component Grounding
3.21.5.7 DC Power Converter
3.21.5.8 Orbiter to MDM Pallet Ground
3.21.5.9 Control and Signal Circuit Grounding
3.21.5.10 Electrical Bonding
3.21.5.11 Individual Circuit Shielding
3.21.5.12 Overall Shields
3.21.5.13 Electrical Fault Protection
3.21.5.14 Electromagnetic Compatibility (EMC)
3.21.5.15 Corona Suppression
3.21.5.16 Lightning Protection
3.21.5.17 Electrical, Electronic, and Electromechanical Parts
3.21.6 Mechanical
3.21.6.1 Fasteners
3.21.7 Materials
3.21.7.1 Materials and Processes
3.21.7.2 Outgassing/Offgassing of Materials
3.21.7.3 Corrosion of Metal Parts
3.21.7.4 Dissimilar Metals
3.21.7.5 Finish
3.21.7.6 Flammability
3.21.7.7 Brazing
3.21.8 Fracture Control
3.21.9 Coordinate System

Details for preparing a VRM can be found in Volume II of MSFC-HDBK-2221.

2.2.3 SYSTEM SOFTWARE FUNCTIONAL REQUIREMENTS DOCUMENT

I. OPR

EL56

II. PURPOSE

The System Software Functional Requirements Document (SSRD) defines the system requirements to be satisfied by the software.

III. DESCRIPTION

Initially prepared during the Preliminary Analysis Phase (Phase A), revised and expanded during the Definition Phase (Phase B), the SSRD is reviewed at the Preliminary Software Requirements Review (SWPRR). The SSRD is placed under configuration control following successful conclusion of the SWPRR.

Most inputs to the SSRD come from the System Specification (SS), but derived requirements are also used. These requirements are identified through analysis of the system functions, subsystem and payload requirements, and overall performance requirements. They are generally broad, high-level software requirements which require further expansion to the detail level for design purposes. Characteristics such as total data handling, throughput computer speed, mass storage, memory margins, and processor capabilities are identified in the SSRD.

Specific contents of the SSRD are as follows:

* identification of system software-related functions, interfaces, and error recovery requirements
* definition of system software performance requirements in measurable terms, and acceptance criteria for each requirement
* key assumptions and constraints used in defining interface (external and internal) requirements (e.g., sensor data inputs and outputs, data rates, computational frequencies).
* traceability of requirements by identifying the source of each requirement
* operations requirements that impact software design
* quality assurance requirements on the software design and testing

The following individuals should sign the document:

* Specification Developer
* Branch Chief
* Division Chief
* Chief Engineer

IV. REFERENCES

A. DR STD/SE-SSRD, "System Software Functional Requirements Document."

B. MM 8075.1, "MSFC Software Management and Development Requirements Manual."

C. DoD-STD-2167A, "Defense System Software Development."

V. OUTLINE

The following is a generic outline for this document since no specific format is specified in STD/SE-SSRD. Engineering judgment must be used to determine which parts are applicable to the specific project being documented.

OUTLINE
SYSTEM SOFTWARE FUNCTIONAL REQUIREMENTS DOCUMENT

COVER

CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET

TABLE OF CONTENTS

LIST OF FIGURES

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1.0 INTRODUCTION

1.1 Purpose

> State the purpose of this document; identify what the System Software Fur ..onal Requirements Document is documenting.

1.2 Scope

> Identify the CSCIs for which the System Software Functional Requirements Document provides requirements.

2.0 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

> This section must contain a list of every document referenced in the text. Also, every document listed here must be in the text. A standard paragraph is usually included as follows: "The following documents, latest revision unless otherwise specified, form a part of this docum to the extent specified herein. In the event of conflict between documents referenced herein and the contents of this document, this document shall apply, except for safety-related items and issues."

2.1.1 Government Documents

2.1.2 Contractor Documents

2.1.3 Reference Documents

List documents which contain general background information. These could include documents identified as applicable to documents that are applicable to this SSRD. A standard paragraph is usually included, like this one: "The following documents are for reference only. As such, they do not constitute a part of this document, but may be of interest to the reader."

3.0 MISSION DESCRIPTION

3.1 Operational Scenarios

Discuss operational modes, synchronization and timing, mission timeline, command and telemetry capabilities, system reliability and error recovery, safety requirements and any other critical activities or events.

3.2 System Configuration

Discuss and show diagrams of the data system configurations.

4.0 FLIGHT SOFTWARE REQUIREMENTS

4.1 Functional and Performance Requirements
4.2 Timing and Sizing Requirements
4.3 Design Standards
4.4 Interface Requirements
4.5 Programming Requirements
4.6 Adaptation Requirements
4.7 Database Requirements
4.8 Quality Factors
4.9 Qualification Requirements

5.0 GROUND SOFTWARE REQUIREMENTS

5.1 Functional and Performance Requirements
5.2 Timing and Sizing Requirements
5.3 Design Standards
5.4 Interface Requirements
5.5 Programming Requirements
5.6 Adaptation Requirements
5.7 Database Requirements
5.8 Quality Factors
5.9 Qualification Requirements

6.0 PREPARATION FOR DELIVERY

7.0 NOTES

APPENDIX A TRACEABILITY MATRICES

2.2.4 SOFTWARE REQUIREMENTS SPECIFICATION

I. OPR

EB41

II. PURPOSE

The Software Requirements Specification (SRS) defines the detailed requirements to be satisfied through the implementation of the software requirements contained in the System Software Functional Requirements Document (SSRD).

III. DESCRIPTION

Initially prepared during the Definition Phase (Phase B), it is placed under configuration control at the successful conclusion of the Software Requirements Review (SWRR).

The initial inputs come from the SSRD, but the SRS also contains derived requirements in the detail required to design and test the software. The SRS specifies in detail the requirements for the software Computer Software Configuration Items (CSCIs), including function and performance, interfaces, data, quality and qualification requirements, and security requirements.

Specific contents of the SRS are as follows:

* identification of all software-related functions, interfaces and error recovery requirements

* definition of software performance requirements in measurable terms and acceptance criteria for each requirement including memory and timing requirements

* key assumptions and constraints in defining the external software interface requirements (e.g., sensor data inputs and outputs, data rates, computational frequencies)

* traceability of requirements by identifying the source of each requirement

* operation requirements that impact software design

* software quality assurance requirements

IV. REFERENCES

A. DR STD/SW-RQS, "Software Requirements Specification."

B. MM 8075.1, "MSFC Software Management and Development Requirements Manual."

C. DoD-STD-2167A, "Defense System Software Development."

V. OUTLINE

The following is a generic outline for this document since no specific format is specified in DR STD/SW-RQS. Engineering judgment must be used to determine which parts are applicable to the specific project under development.

OUTLINE
SOFTWARE REQUIREMENTS SPECIFICATION

COVER
CHANGE RECORD

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SIGNATURE SHEET
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1.0 INTRODUCTION
1.1 Purpose

> State the purpose of this document; identify what the Software Requirements Specification is documenting.

1.2 Scope

> Identify the CSCIs for which the Software Requirements Document provides requirements.

2.0 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

> This section must contain a list of every document referenced in the text. Also, every document listed here must be in the text. A standard paragraph is usually included as follows: "The following documents, latest revision unless otherwise specified, form a part of this document to the extent specified herein. In the event of conflict between documents referenced herein and the contents of this document, this document shall apply, except for safety-related items and issues."

2.1.1 Government Documents

2.1.2 Contractor Documents

2.1.3 Reference Documents

List documents which contain general background information. These could include documents identified as applicable to documents that are applicable to this SRS. A standard paragraph is usually included, like this one: "The following documents are for reference only. As such, they do not constitute a part of this document, but may be of interest to the reader."

3.0 MISSION DESCRIPTION

3.1 Operational Scenarios

Discuss operational modes, synchronization and timing, mission timeline, command and telemetry capabilities, system reliability and error recovery, safety requirements and any other critical activities or events.

3.2 System Configuration

Discuss and show diagrams of the data system configurations.

4.0 REQUIREMENTS

4.1 Detail Requirements
4.2 Timing and Sizing Requirements
4.3 Design Standards and Constraints
4.4 Interface Requirements
4.5 Programming Requirements
4.6 Adaptation Requirements
4.7 Database Requirements
4.8 Quality Factors

5.0 QUALIFICATION REQUIREMENTS

6.0 PREPARATION FOR DELIVERY

7.0 NOTES (if applicable)

APPENDIX A COMMAND/TELEMETRY/STORAGE TABLES

APPENDIX B GUIDANCE AND NAVIGATION SYSTEM DETAILS AND EQUATIONS

APPENDIX C ATTITUDE CONTROL SYSTEM DETAILS AND EQUATIONS

APPENDIX D TRACEABILITY MATRICES

APPENDIX E VERIFICATION MATRICES

2.2.5 PAYLOAD INTEGRATION PLAN (PIP) AND ANNEX INPUTS

I. OPR

EL44, Operations Lab, JSC (NSTS Program Office)

II. PURPOSE

The PIP represents the payload-to-National Space Transportation System (NSTS) agreement on the responsibilities and tasks directly related to the integration of the payload into the Space Transportation System (STS) and defines NSTS standard and optional services. The PIP describes the management roles and responsibilities, definition of interfaces, and schedule requirements to accomplish the integration, launch, flight operations, and post-landing operations for the payload with the STS.

III. DESCRIPTION

The document consists of the basic PIP and annexes as follows:

1 - Payload Data Package Annex

2 - Flight Planning Annex

3 - Flight Operations Annex

4 - Command and Data Requirements Annex

5 - POCC Annex

6 - Orbiter Crew Compartment Annex

7 - Training Annex

8 - Launch Site Support Plan Annex

9 - Payload Verification Requirements Annex

10 - (Not Used)

11 - Extra-Vehicular Activities Annex

Responsibilities for the individual parties (NSTS Program Office at JSC and the Payload Projects Office at MSFC) are described. Payload and mission descriptions and operational requirements are also provided. The MSFC provides inputs for these documents to JSC.

IV. REFERENCES

A. DR STD/SE-PIDI, "Payload Integration Document Inputs."

B. DR STD/SE-PDPI, "Payload Data Package Annex Inputs."

C. NSTS-21000-A01, -A02, -A03, -A04, -A05, A07.

D. JSC-21000-A06, -A08, -A09, -A11.

V. OUTLINE

The following is a generic outline for the PIP.

OUTLINE
PAYLOAD INTEGRATION PLAN (PIP)

1.0 INTRODUCTION

2.0 MANAGEMENT RESPONSIBILITIES
2.1 Joint Responsibilities
2.1.1 Documentation
2.1.2 Reviews
2.2 NSTS Responsibilities
2.3 Customer Responsibilities
2.4 Authority and Responsibilities of the NASA STS Commander

3.0 PAYLOAD DESCRIPTION AND MISSION OVERVIEW
3.1 Payload Description
3.2 Mission Overview
3.2.1 Integrated Ground Operations
3.2.2 Flight Operations
3.2.3 Post-landing

4.0 MISSION OPERATIONS

Discuss orbital requirements, payload control parameters, operational and safety requirements and constraints.

5.0 PAYLOAD-TO-STS INTERFACES

Discuss all interfaces including structural, mechanical, cable, display, control, power, telemetry and data, command, fluid and software.

6.0 ENVIRONMENTAL ANALYSES AND INTERFACES

Include description of structural loads and deflections, thermal, EMI/EMC, contamination control, shock, vibration, acoustic, ground, materials, and off/outgassing environments.

7.0 INTEGRATION HARDWARE

Discuss NSTS-provided hardware, orbiter support hardware, payload integration hardware kits, customer-provided hardware, and Spacelab equipment, as required.

8.0 FLIGHT OPERATIONS

Provide details of flight design, flight activity planning, training, flight operations control, ground command and control, Spacelab input configuration/ formats and products, and in-flight maintenance.

9.0 LAUNCH AND LANDING SITE OVERVIEW

Discuss customer processing, payload and orbiter integration, launch delay/scrub turnaround processing, abort, landing, post-landing and ferry operations.

10.0 SAFETY

Include payload and GSE design, flight and ground operations, safety reviews, and biomedical payloads/ experiments.

11.0 INTERFACE VERIFICATION AND TESTING

12.0 POSTFLIGHT DATA REQUIREMENTS

13.0 SUMMARY OF OPTIONAL SERVICES

14.0 PIP ANNEXES

15.0 SCHEDULE

16.0 APPLICABLE DOCUMENTS

APPENDIX A - TO BE RESOLVED ITEMS

APPENDIX B - TO BE DETERMINED ITEMS

APPENDIX C - ACRONYMS AND ABBREVIATIONS

2.2.6 INSTRUMENTATION PROGRAM AND COMMAND LIST (IPCL)

I. OPR

EL56

II. PURPOSE

The IPCL is a compilation of all telemetry and command data which enter and exit a spacecraft, and as such shows the resource utilization of communication and telemetry systems. It is an overall listing of measurements and commands derived from several documents such as the Interface Requirements Document (IRD) and the Integrated Experiment IRD (IEIRD). The IPCL documents the design of the Data Management System (DMS).

III. DESCRIPTION

* Initial release 30 days prior to spacecraft PDR

* Pre-CDR 30 days prior to spacecraft CDR

* Baseline post-CDR; ECR required for changes once baselined

This document must be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

* IPCL Developer

* Branch Chief

* Division Chief

* Laboratory Director

* Chief Engineer

* Project Manager

IV. REFERENCES

A. DR STS/SE-IPCL, "Instrumentation Program and Command List."

B. MSFC-STD-1924, "Standard for Instrumentation Program and Command Lists (IP&CL), June 21, 1993.

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific IPCL being documented.

OUTLINE
INSTRUMENTATION PROGRAM AND COMMAND LIST (IPCL)

COVER
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

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1.0 INTRODUCTION

> The introduction begins with a brief description of the spacecraft and its mission. This is followed by the purpose and a description of the document, as well as each of its appendices.

2.0 MEASUREMENT LIST FORMAT

> The Appendix C measurement fields are described in this section. The measurement number is described, followed by information contained in the other fields, such as the measurement name and other attributes of the measurements.

3.0 COMMAND LIST FORMAT

> The Appendix D command fields are described in this section. Similar to Appendix C, the command number is described, followed by information contained in the other fields, such as the command name and other attributes of the commands.

Appendix C List of Measurements

> *This and Appendix D are the main parts of the IPCL* Listed here are all the measurements which leave the spacecraft, along with extensive information about each measurement. This information includes sample rate, number of bits, accuracy, communication path, and range.

Appendix D List of Commands

The other main part of an IPCL, Appendix D includes all commands which enter the spacecraft, along with some information on each command. This information includes the communication path, bit configuration of command words, and measurement number to verify a command.

Other appendices may be added per requirements of individual missions.

2.2.7 NATURAL SPACE ENVIRONMENTS DEFINITION AND REQUIREMENTS DOCUMENT

I. OPR

EL54

II. PURPOSE

This document defines each of the expected natural space environments for a particular mission and establishes requirements which are derived directly from the definition analyses.

III. DESCRIPTION

This document provides all pertinent analyses results for each natural space environment: gravitational field, ionizing radiation, magnetic field, meteoroids/space debris, neutral thermosphere, plasma, solar environment, thermal environment. Analysis of the mesosphere is also provided if the mission altitudes are within this atmospheric region. Requirements are derived directly from the definition analyses results for each natural space environment.

This document should be prepared as early in the design cycle as possible. Finalizing this document before the Preliminary Design Review is optimum.

IV. REFERENCES

MSFC-DOC-2253, "Advanced X-ray Astrophysics Facility-Spectroscopy (AXAF-S) Natural Space Environment: Definition and Requirements", October 1993.

2.2.8 NATURAL TERRESTRIAL ENVIRONMENTS DEFINITION AND REQUIREMENTS DOCUMENT

I. OPR

EL54

II. PURPOSE

This document defines each of the pertinent natural terrestrial environments for a particular mission and establishes requirements which are derived directly from the definition analyses. Natural terrestrial environment information plays an integral role in designing, developing and operating launch vehicles. Natural terrestrial environment information is also used to develop safe, reliable methodologies for shipping, handling and transporting spacecraft and spacecraft systems/subsystems.

III. DESCRIPTION

This document provides all analyses results for each pertinent natural terrestrial environment. The natural terrestrial environments definition analyses should include but not be limited to the following parameters: atmospheric constituents (gases, sand, dust, sea salt ...), atmospheric electricity, clouds, fog, humidity, precipitation, sea states, severe weather, near-surface thermal radiation, temperature, pressure, density and winds. Requirements are derived directly from the definition analyses results for each natural terrestrial environment.

This document should be prepared as early in the design cycle as possible. Finalizing this document before the Preliminary Design Review is optimum.

2.3 INTERFACE DOCUMENTS

2.3.1 INTERFACE REQUIREMENTS DOCUMENT (IRD)

I. OPR

EL41

II. PURPOSE

The IRD establishes the specific functional and performance requirements for the design interface(s) (hardware and software) between systems or subsystems and enables the Government to assess whether the implementation of the interface(s) complies with those requirements.

III. DESCRIPTION

In developing interface definition and control, consideration should be given to whether an Interface Requirement Document (IRD), an Interface Control Document (ICD), or both will benefit the particular program. In general, an IRD contains much more information than is required for interface control. The IRD normally is a collection of data which includes interface characteristics and related information in addition to the interface definition.

The IRD is most useful during early systems definition to ensure both parties understand the interface and its functional characteristics. The IRD also provides traceability from requirements to the interface definition in the ICD. As the program definition matures, it is desirable to limit the formally controlled interface definition to only form, fit, and function information required for configuration control. This will greatly reduce change traffic and still retain required control.

Upon Government approval, the IRD becomes the joint configuration control device for the interface(s) and becomes part of the allocated baseline. The IRD may be used by the contractor as a basis for the development of the ICDs.

This document must be coordinated with and agreed to by parties from both sides of the interface. As a result, the review cycle can take a fairly long time. Recommend that at least a month be allotted for the review cycles. The document is baselined after agreement is reached by the parties.

If the IRD is controlled at Level II it should be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

* Document Developer
* Branch Chief
* Division Chief
* Lab Director
* Program Chief Engineer
* Program/Project Manager
* Stress
* Materials
* S&MA

IV. REFERENCES

A. DR STD/SE-IRD, "Interface Requirements Documents."

B. MIL-STD-483A, "Configuration Management Practices for Systems, Equipments, Munitions, and Computer Programs."

C. DR STD/SE-ASFD, "Avionics Systems Functional Decomposition."

D. DR STD/SE-SSDD, "System/Segment Design Definition Document."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific interface being documented.

OUTLINE
SYSTEM TO SYSTEM INTERFACE REQUIREMENTS DOCUMENT

COVER
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

> Figures are numbered sequentially from 1 using Arabic numerals (1,2,3). Figure numbers and titles should be centered below each figure.

LIST OF TABLES

> Tables are numbered sequentially from I using Roman numerals (I,II,III). Table numbers and titles should be centered above each table.

LIST OF ACRONYMS AND ABBREVIATIONS

> All abbreviations and acronyms used in the document should be included here in an alphabetical list. Each acronym should be defined the first time it is used. After that either the acronym or the complete name should be used, not both. Paragraphs should not begin with acronyms, write out the entire name.

1.0 SCOPE

1.1 Introduction

> This section identifies the extent and the systems/subsystems to which the ICD is applicable.

1.2 Program Description

> This section presents a brief description of the overall program and identifies each applicable interface. It will provide a general description of each interface and any other related systems.

1.3 Roles and Responsibilities

> This section will define the technical responsibilities for each organization involved in controlling the interface. It will specify who has prime and who has support responsibilities and will appropriately present a programmatic schedule.

1.4 Interface Configuration Management

> This section will specify how configuration control of the interface will be managed.

1.5 Contractor and Government/Customer Deliverables

This section will summarize any agreements that involve the interchange or delivery of hardware, software, or data between or among organizations. A clearly defined schedule will be provided and agreed to by all affected organizations.

2.0 APPLICABLE DOCUMENTS

This section must contain a list of every document referenced in the text. Also, every document listed here must be in the text. A standard paragraph is usually included as follows: "The following documents, latest revision unless otherwise specified, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced herein and the contents of this specification, this specification shall apply, except for safety-related items and issues."

2.1 Government Documents

Government documents shall be listed by the document number and title in the following order:

Specifications:
- Federal
- Military
- Other Government Agency

Standards:
- Federal
- Military
- Other Government Agency

Drawings:

Where detailed drawings referred to in a specification are listed on an assembly drawing, it is only necessary to list the assembly drawing.

Other Publications:
- Manuals
- Regulations
- Handbooks
- Bulletins
- etc.

2.2 Contractor Documents

Non-government documents shall be listed by the document number and title in the same order

3.0 INTERFACE DEFINITION AND DESCRIPTION

3.1 A to B Interface Characteristics and Functions

More detailed information on interface functional descriptions and unique interface properties will be provided here. The remaining paragraphs in this document will contain the detailed interface requirements. The sections specified in 3.2 thru 3.10 are provided as a checklist. Each of these topics listed, when applicable, will be accompanied by detailed interface drawings, schematics, wiring data, quantitative tables listing specific requirements (i.e. loads, environments), interface characteristics, etc. in order to specify exact parameters of the interface. The document will only contain those sections applicable to the interface.

3.2 Mechanical Interface Requirements
3.2.1 Envelopes
3.2.2 Coordinate Systems
3.2.3 Mounting/Installation
3.2.4 Stowage Provisions
3.2.5 Handling
3.2.6 Purge, Vent, Drain
3.2.7 Umbilicals and Appendages
3.2.8 Flight Crew
3.2.9 Personnel

3.3 Structural Interface Requirements
3.3.1 Loads
3.3.1.1 Acoustic
3.3.1.2 Transportation
3.3.1.3 Flight
3.3.1.4 Vibration
3.3.1.5 Ground Handling
3.3.1.6 Flight Crew
3.3.1.7 Personnel
3.3.2 Structural Characteristics
3.3.2.1 Flexibility
3.3.3 Mass Properties
3.3.3.1 Weight/Mass
3.3.3.2 Center of Gravity
3.3.3.3 Moments of Inertia

3.4 Environmental Interface Requirements
3.4.1 Thermal
3.4.2 Contamination
3.4.3 Humidity

3.5 Electrical Interface Requirements
3.5.1 Power
3.5.2 Switching
3.5.3 Fusing
3.5.4 Grounding
3.5.5 Electro-Explosive Devices
3.5.6 EMI/EMC/TEMPEST

3.6 Communications and Data Handling Interface Requirements
3.6.1 Communications
3.6.2 Telemetry
3.6.3 Tracking
3.6.4 Command

3.7 Performance Interface Requirements
3.7.1 Orbits
3.7.2 Delta V

3.8 Operations Interface Requirements
3.8.1 Flight Operations
3.8.1.1 Docking/Alignment
3.8.1.2 Rendezvous
3.8.1.3 Deployment/Retrieval
3.8.1.4 Flight Crew
3.8.2 Ground Operations
3.8.2.1 Checkout
3.8.2.2 Prelaunch
3.8.2.3 Post Landing
3.8.2.4 Personnel
3.8.3 Command/Control Center
3.8.3.1 Man-Machine Operations
3.8.3.2 Personnel

3.9 Safety Interface Requirements
3.9.1 Design Safety
3.9.2 Flight Operations
3.9.3 Ground Operations
3.9.4 Range Safety

3.10 Reliability Interface Requirements
3.10.1 Design Reliability

3.11 Maintainability Interface Requirements

4.0 INTERFACE REQUIREMENTS VERIFICATION

A Verification Requirements Matrix will be developed to provide traceability for the requirements of Section 3.0 (as is done with end item specifications). It will be updated and maintained until all requirements in the IRD are verified. See MSFC-HDBK-2221 for more details.

2.3.2 SYSTEM LEVEL INTERFACE CONTROL DOCUMENT (ICD)

I. OPR

EL41

II. PURPOSE

The system level ICD is the document used to control the interfaces (hardware and software) between major program elements. This document contains descriptions of the two systems, along with detailed plans for meeting the interface requirements as specified in the Interface Requirements Document (IRD).

III. DESCRIPTION

* Initial Release at PDR
* Baseline at CDR

This document must be coordinated with and agreed to by parties from both sides of the interface. As a result, the review cycle can take a fairly long time. It is recommended that at least a month be allotted for the review cycles.

If the ICD is controlled at Level II it should be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

* Document Developer
* Branch Chief
* Division Chief
* Lab Director
* Program Chief Engineer
* Program/Project Manager
* Stress
* Materials
* S&MA

IV. REFERENCES

A. DR STD/SE-ICD, "Interface Control Documents (ICDs)."

B. MIL-STD-483A, "Configuration Management Practices for Systems, Equipments, Munitions, and Computer Programs."

C. DR STD/SE-ASFD, "Avionics Systems Functional Decomposition."

D. DR STD/SE-SSDD, "System/Segment Design Definition Document."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific interface being documented.

OUTLINE
SYSTEM TO SYSTEM INTERFACE CONTROL DOCUMENT

COVER
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

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LIST OF ACRONYMS AND ABBREVIATIONS

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1.0 SCOPE
1.1 Introduction

> This section identifies the extent and the systems/subsystems to which the ICD is applicable.

1.2 Program Description

> This section presents a brief description of the overall program and identifies each applicable interface. It will provide a general description of each interface and any other related systems.

1.3 Roles and Responsibilities

> This section will define the technical responsibilities for each organization involved in controlling the interface. It will specify who has prime and who has support responsibilities and will appropriately present a programmatic schedule. The members and responsibilities of the Interface Control Working Group (ICWG) will also be identified.

1.4 Interface Configuration Management

> This section will specify how configuration control of the interface will be managed.

1.5 Contractor and Government/Customer Deliverables

> This section will summarize any agreements that involve the interchange or delivery of hardware, software, or data between or among organizations. A clearly defined schedule will be provided and agreed to by all affected organizations.

2.0 APPLICABLE DOCUMENTS

> This section must contain a list of every document referenced in the text. Also, every document listed here must be in the text. A standard paragraph is usually included as follows: "The following documents, latest revision unless otherwise specified, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced herein and the contents of this specification, this specification shall apply, except for safety-related items and issues."

2.1 Government Documents
2.2 Contractor Documents

3.0 INTERFACE DEFINITION AND DESCRIPTION
3.1 A to B Interface Characteristics and Functions

> More detailed information on interface functional descriptions and unique interface properties will be provided here. The remaining paragraphs in this document will contain the interface design details. The sections specified in 3.2 thru 3.10 are provided as a checklist. Each of these topics listed, when applicable, will be accompanied by detailed interface drawings, schematics, wiring data, quantitative tables listing specific requirements (i.e. loads, environments), interface characteristics, etc. in order to specify exact parameters of the interface. The document will only contain those sections applicable to the interface.

3.2 Mechanical Interfaces
3.2.1 Envelopes
3.2.2 Coordinate Systems
3.2.3 Mounting/Installation
3.2.4 Stowage Provisions
3.2.5 Handling
3.2.6 Purge, Vent, Drain
3.2.7 Umbilicals and Appendages
3.2.8 Flight Crew
3.2.9 Personnel

3.3 Structural Interfaces
3.3.1 Loads
3.3.1.1 Acoustic
3.3.1.2 Transportation
3.3.1.3 Flight
3.3.1.4 Vibration
3.3.1.5 Ground Handling
3.3.1.6 Flight Crew
3.3.1.7 Personnel
3.3.2 Structural Characteristics
3.3.2.1 Flexibility
3.3.3 Mass Properties

3.3.3.1	Weight/Mass
3.3.3.2	Center of Gravity
3.3.3.3	Moments of Inertia
3.4	Environmental Issues
3.5	Electrical Interfaces
3.5.1	Power
3.5.2	Switching
3.5.3	Fusing
3.5.4	Grounding
3.5.5	Electro-Explosive Devices
3.5.6	EMI/EMC
3.6	Communications and Data Handling Interfaces
3.6.1	Communications
3.6.2	Telemetry
3.6.3	Tracking
3.6.4	Command
3.7	Performance Interfaces
3.7.1	Orbits
3.7.2	Delta V
3.8	Operations Interfaces
3.8.1	Flight Operations
3.8.1.1	Docking/Alignment
3.8.1.2	Rendezvous
3.8.1.3	Deployment/Retrieval
3.8.1.4	Flight Crew
3.8.2	Ground Operations
3.8.2.1	Checkout
3.8.2.2	Prelaunch
3.8.2.3	Post Landing
3.8.2.4	Personnel
3.8.3	Command/Control Center
3.8.3.1	Man-Machine Operations
3.8.3.2	Personnel
3.9	Safety
3.9.1	Design Safety
3.9.2	Flight Operations
3.9.3	Ground Operations
3.9.4	Range Safety
3.10	Reliability
3.10.1	Reliability Design
3.11	Maintainability

4.0 INTERFACE REQUIREMENTS VERIFICATION

An abbreviated version of a Verification Requirements Matrix is included in this section. It addresses only those interface requirements in which it is necessary for multiple organizations to participate in verification activities. See MSFC-HDBK-2221 for more details.

5.0 APPENDICES

5.1 Interface Control Drawings

5.2 Supporting Data

2.4 VERIFICATION DOCUMENTS

2.4.1 VERIFICATION PLAN

I. OPR

EL45

II. PURPOSE

The purpose of the Verification Plan is to document the planning policies, activities, requirements, and organization necessary to define and execute the verification operations. It addresses both flight and ground support equipment at all test sites, launch site, on-orbit servicing, post-landing servicing, and the communication ground system.

III. DESCRIPTION

* Preliminary issue in SRR and PDR data packages.

* Baseline issue in CDR data package.

* Updates as required.

The plan contains,

A. A description of the Contractor's organization, methods, and controls to implement verification.

B. Descriptions of the verifications to be performed, including pre-requisites, constraints, and test objectives. The descriptions include verifications required to return a payload or module that has previously been flown to flight status.

C. A detailed time-correlated sequence of verification operations from component through subsystem, systems final acceptance, prelaunch, on-orbit, and post-landing servicing.

D. Definition of the method of verification for each item at the component, assembly, subsystem, system, element, and payload levels.

E. Description, planned usage, and scheduling of the support equipment, verification software, facilities, and tooling necessary to execute the verification activity.

F. Assessment Verification planning.

G. Requirements flow-down, traceability, and compliance.

Spacelab payload organizations and some other payload organizations use a document that is also titled, "Verification Plan." That plan defines the verification requirements, the method and process for verifying the requirements, and shows compliance to the requirements. The instructions for developing this type of Verification Plan are found in the following documents: JA-447, "MROFIE"; JA-061, "Payload Mission Manager Interface and Safety Verification Requirements for Instruments, Facilities, MPE, and ECE on STS Spacelab Payload Missions"; and JA-081, "Payload Mission Manager Interface and Safety Verification Requirements for Instruments, Facilities, MPE, and ECE on STS Partial Payload Missions."

IV. REFERENCES

A. DR STD/VR-VP, "Verification Plan."

B. MSFC-HDBK-2221, "Verification Handbook," section 2.1.1.4.

2.4.2 SAFETY AND INTERFACE VERIFICATION PLAN

I. OPR

EL43

II. PURPOSE

The purpose of this Plan is to outline the requirements for the Mission Manager Verification Program to ensure that the apparatus meets the mission requirements with regard to safety and interfaces as outlined in NSTS 1700.7, JA-081, JA-061, and JA-276.

III. DESCRIPTION

* Preliminary release one month prior to PDR.
* Update Issue at CDR.
* Baselined at CDR + 1 month.

This document should be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

* Document Developer
* Branch Chief
* Division Chief
* Laboratory Director
* Chief Engineer
* Project Manager
* Stress
* Materials

IV. REFERENCES

A. NSTS 1700.7, "Safety Policy and Requirements for Payloads Using the Space Transportation System," January, 1989.

B. JA-061, "Spacelab Payload Mission Manager Verification Requirements for Instruments, Facilities, MPE, and ECE."

C. JA-081, "Payload Mission Manager Interface and Safety Verification Requirements, Facilities, MPE, and ECE on STS Partial Payload Missions."

D. JA-276, "Orbiter Mid-deck Verification Requirements for Instruments, Facilities, MPE, ECE, and Integrated Payloads."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific plan being documented.

OUTLINE
SAFETY AND INTERFACE VERIFICATION PLAN

COVER
CHANGE RECORD

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SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

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1.0 INTRODUCTION
1.1 Purpose

> State the purpose of this document, identify what the Safety and Interface Verification Plan is documenting.

1.2 Scope

> Identify the system for which the Safety and Interface Verification Plan provides the test requirements.

1.3 Safety Verification Requirements

> The safety of the crew and the orbiter are mandatory considerations of the Verification Program. The prime safety verification requirements are generated in the hazard analysis reports. Verification that all hazards are closed must be provided to the satisfaction of the Flight and Ground Payload Safety Panels. Known and anticipated safety hazards have been analyzed and their verification is covered by the specific verification items selected and clarified from the applicable reference document(s). Any additional safety-peculiar verification requirements identified by the Payload Safety Panels will be added to this document and closeouts provided in the verification process.

2.0 APPLICABLE AND REFERENCE DOCUMENTS

This section must contain a list of every document referenced in the text. Also, every document listed here must be in the text.

2.1 DoD Documents
2.2 NASA Documents
2.3 Industry Documents

3.0 VERIFICATION PROGRAM

The basis for these verification requirements is the assurance that all Mission Manager-imposed design requirements for safety and interface compatibility are met. This includes all flight and ground support equipment (GSE and ECE) peculiar to the experiment.

3.1 Safety Verification

Safety and interface verification requirements will be developed from the data generated in the safety analyses as identified in the appropriate Hazard Reports. It is essential that the safety program provide the analyses and requirements in a timely manner supporting the phased safety reviews and the phased design and readiness reviews. The verification plan will be updated to provide specific safety verifications in addition to those covered in the applicable reference document(s).

3.2 Performance Verification

Verification that the flight article meets specific performance requirements related to accomplishing mission objectives is the responsibility of the Project Office. These specific performance requirements are documented separately.

4.0 VERIFICATION REQUIREMENTS

Table I lists the applicable verification requirements and the corresponding method and safety applicability. The verification data will be developed in accordance with the listing in the applicable reference document. The verification will be accomplished by the methods indicated, and the data will be provided in accordance with paragraph 4.2. The Verification Requirement Definition Sheets are contained in Appendix A.

4.1 Verification Method Selection

All project and experiment interfaces will be verified by the methods listed below, or a combination of these methods. Minimum criteria for use of these methods are defined below.

4.1.1 Test

Testing is the actual operation of equipment under simulated conditions or the exposure of equipment to specified environments to measure responses. Functional tests are one or more electrical or mechanical performance tests conducted on flight or flight-configured hardware at conditions equal to or less than design specifications. Environmental tests are one or more tests conducted on flight or flight-configured hardware to assure that the flight hardware performs satisfactorily in its flight environment.

4.1.2 Analysis

Analysis is a technical evaluation that relates equipment design and use parameters to prediction of actual design and operation. Analysis may be used to verify requirements when:

* Rigorous and accurate analysis is possible
* Testing is not cost-effective or practical
* Similarity is not applicable
* Verification by inspection is not adequate

Some examples of analysis are computer simulation, hardware simulation, analog modeling, and quantitative analysis.

4.1.3 Inspection

Inspection is a physical evaluation of equipment and associated documentation. Inspection may be used to verify construction features, drawing compliance, workmanship, and physical condition.

4.1.4 Demonstration

Demonstration is the acting out or displaying of techniques to verify compliance with a requirement. It is a special case of testing, and the closure information required usually takes the form of a test report. Some examples of requirements which may be verified by demonstration are service access, crew/hardware interfaces, maintainability, and transportability.

4.2 Reporting Verification Results

Results of each equipment verification test or analysis are documented per the applicable Data Requirement. Inspection verification is performed and recorded, and data submitted to the Project Manager. Detailed analysis and test data are made available. Data submittals by project and experiment apparatus developers are in addition to reports required to support program and design reviews.

Table I lists the applicable verification requirements and corresponding method and safety applicability. An example Table is shown below.

TABLE I. VERIFICATION REQUIREMENTS LIST

REQUIREMENTS		PAYLOAD ELEMENTS			
NUMBER	TITLE	CARRIER	AERO-BRAKE	SPACE-CRAFT	COMMENTS
4.1	STRUCTURAL AND MECHANICAL				
4.1.1	Mass Properties				
4.1.1.1	Weight	NA	NA	T	
4.1.1.2	Center of Gravity	NA	NA	A&T	
4.1.2	Mechanical				
4.1.2.1	Geometry	NA	NA	I	
4.1.2.2	Connection / Bolt Hole Location	I	NA	NA	
4.1.2.3	Attachment Hardware	I	NA	NA	
4.1.2.4	Surface Alignment and Finish	I	NA	NA	
4.1.2.5	Captive Parts	NA	NA	NA	
4.1.2.6	Sharp Edges	I	I	NA	
4.1.2.7	Equipment Adjustments	NA	NA	NA	
4.1.2.8	Mechanical Stops	NA	NA	NA	
4.1.2.9	Relatching	NA	NA	A & T	
4.1.2.10	Relief / Vent Valve Sizing	A & T	A & T	NA	
4.1.2.11	Equipment Jettison	A & T	NA	NA	
4.1.2.12	Equipment Deployment	NA	NA	A & T	
4.1.2.13	Mechanical Energy	A & T	NA	NA	
4.1.2.14	Time-Sensitive Items	NA	NA	A	
4.1.2.15	GSE Test Monitoring Cable	NA	NA	A & T	
4.1.2.16	Handling Clearances	NA	NA	A & T	
4.1.2.17	Non-Flight Equipment Removal	NA	NA	A & T	
4.1.2.20	Optical Alignment	NA	NA	NA	
4.1.2.21	Displays and Controls	NA	NA	NA	
4.1.2.22	Passive Thermal Protection Interfaces	NA	NA	NA	
4.1.2.24	Securing of Threaded Fasteners	NA	NA	I & T	
4.1.2.25	Coolant Loop Leakage	NA	NA	NA	
4.1.2.26	Coolant Loop Cleanliness	NA	NA	NA	

T = Test A = Analysis I = Inspection NA = Not Applicable

4.3 VERIFICATION ACTIVITY DESCRIPTIONS

Give a description of each verification activity to be performed. Includes as much information as needed to clarify methodology. Include only those methods below which are actually used in the verification program under discussion. The requirements to be verified in each activity described are shown in Table II. The matrix includes applicable requirements from the appropriate reference document(s) and the appropriate Hazard Report number.

4.3.1 Test
4.3.2 Analysis
4.3.3 Inspection
4.3.4 Demonstration
4.3.5 Validation of Records

TABLE II VERIFICATION ACTIVITY VERSUS REQUIREMENTS LIST

VERIFICATION ACTIVITY	JA-081	HAZARD REPORT NO.
ANALYSES		
4.3.1.1 Stress Analysis	4.1.3.1.1, 4.1.3.1.2, 4.1.3.1.3, 4.1.3.3, 4.1.3.5, 4.1.3.7, 4.1.4.8, 4.1.3.11, 4.5.4.1	CARR-1, CARR-2 AB-1, G-5, K-CARR-7, KG-2
4.3.1.2 Material Analysis	4.1.4.2, 4.1.4.3, 4.4.4	CARR-1, CARR-2 CARR-4, G-4, G-5
4.3.1.3 Electrical Analysis	4.1.2.15, 4.2.1.2.4, 4.2.1.5, 4.2.1.9, 4.2.1.10, 4.2.3.2, 4.2.3.3, 4.2.3.5, 4.5.2	CARR-7, CARR-8 G-1, G-2, MO-1 K-CARR-1, KG-1
4.3.1.4 Thermal Analysis	4.1.3.11, 4.1.4.5, 4.1.4.6, 4.4.3	CARR-1, CARR-2 CARR-4, CARR-7 AFE-3
4.3.1.5 Power Analysis	4.2.1.7, 4.2.3.6	
4.3.1.6 Mechanical Analysis	4.1.1.2, 4.1.2.9, 4.1.2.10, 4.1.2.11, 4.1.2.12, 4.1.2.13, 4.1.2.14, 4.1.2.16, 4.1.2.17, 4.1.3.5	MO-2, MO-3, AFE-3, AFE-4, AFE-5
4.3.1.7 Data Systems Analysis	4.3.1, 4.3.3, 4.3.5, 4.3.6, 4.3.8	
4.3.1.8 Modal Analysis	4.1.3.2	G-5

APPENDIX B VERIFICATION REQUIREMENT DEFINITION SHEETS

These verification sheets have no MSFC form number, but a blank form and an example are included as Figures 2.4.2-1 and 2.4.2-2, respectively.

MISSION	VERIFICATION REQUIREMENT DEFINITION SHEET	ELEMENT
REQUIREMENT NO.	REQUIREMENT TITLE	METHOD

VERIFICATION REQUIREMENT:

DESCRIPTION OF REQUIREMENT:

DATA REQUIRED:

APPLICABLE DOCUMENTS AND NOTES:

RESPONSIBLE PERSON: ____________________ ORG: ________________

PHONE NO: __________________ DATA SUBMITTAL DATE: ______________

Figure 2.4.2-1. Blank Verification Requirement Definition Sheet

MISSION	VERIFICATION REQUIREMENT DEFINITION SHEET	PAYLOAD ELEMENT
AFE		INT/SPACECRAFT
REQUIREMENT NO.	REQUIREMENT TITLE	METHOD
4.1.1.1	WEIGHT	T

VERIFICATION REQUIREMENT:

Verify the weight of the AFE spacecraft consisting of aerobrake, carrier, and SRM. Allowable tolerance of weighing equipment shall be ±0.3 percent. Also verify that the actual mass is no greater than the control mass.

DESCRIPTION OF REQUIREMENT:

Determine the actual weights of the SRM and the carrier, aerobrake both with and without propellants. All tare and missing flight items shall be accounted for, including loose equipment such as film and stowage items.

DATA REQUIRED:

1. Certified weight report for each item and integrated assembly. (See EX-D-01, JA-447.)
2. Weight and balance sheet in the acceptance data package (defined in MROFIE, JA-447, Table 4-2)

APPLICABLE DOCUMENTS AND NOTES:

RESPONSIBLE PERSON: ______________________ **ORG:** __________
(TECHNICAL RESPONSIBILITY)

PHONE NO: ______________ **DATA SUBMITTAL DATE:** ______________

Figure 2.4.2-2. Example Verification Requirement Definiti[on] Sheet

2.4.3 VERIFICATION REQUIREMENTS AND SPECIFICATIONS DOCUMENT (VRSD)

I. OPR

EL45

II. PURPOSE

The purpose of the VRSD is to document all requirements and specifications for verification of the payload, its subsystems, the ground system, orbital and post-orbital servicing, whether by assessment or test. These requirements are necessary for the preparation of verification procedures. Test and Checkout Requirements and Specifications Document (TCRSD) and Test Requirements Document (TRD) are also documents used by some programs to define verification requirements. The VRSD, TCRSD, and TRD, then, are different titles of verification requirements documents with the TCRSD usually found on smaller programs or projects.

III. DESCRIPTION

* Preliminary issues in SRR, PDR, and CDR data packages.
* Baseline issue 90 days prior to start of related verification phase (integration site, launch site, on-orbit, post-landing).
* Updates as required.

The VRSD will include verification requirements for test, analysis, assessment, demonstration, and inspection. The document will identify each requirement, specification, and constraint applicable to the various functional and environmental tests required for qualification and/or acceptance during the subsystem, system, and integrated systems verification activities. Specifications will include allowable tolerance for standards of judgment to be used in determining acceptable performance. Test types, levels, and durations will be included. Qualification test requirements will include test level margins and factors of safety. Verification requirements applicable to all test sites, integration sites, launch site, on-orbit, and post-landing will be identified.

IV. REFERENCES

A. MSFC-HDBK-2221, "Verification Handbook", section 2.1.1.10.

B. DR STD/VR-VRSD, "Verification Requirements and Specifications Document."

2.4.4 EMC TEST PLAN

I. OPR

EL54

II. PURPOSE

The purpose of the EMC Test Plan is to demonstrate systems level compatibility. The Electromagnetic Compatibility Test Plan describes the methods to be employed to demonstrate system/subsystem EMC in accordance with contractual EMC requirements. It provides the means for Government evaluation and judgment of the acceptability of the contractor's proposed EMC test program.

The EMC Test Plan is intended to provide the procuring activity with specific techniques by which the contractor will assure compliance with the appropriate EMC specifications and standards. As a minimum, the Test Plan should include the following:

* Methods to be used in selecting critical circuits to be monitored for compliance with the degradation criteria and safety margin
* Procedures used for developing failure criteria and limits
* Test conditions and procedures for all electronic and electrical equipment installed in, or associated with, the system and the sequence for operations during tests, including switching
* Implementation and application of test procedures which shall include modes of operation and monitoring points for each subsystem and equipment.

III. DESCRIPTION

The Test Plan is approved prior to the start of testing. The test itself cannot start until the individual subsystems that are installed in the system have been demonstrated to meet all functional requirements.

IV. REFERENCES

A. MIL-E-6051D, "System Electromagnetic Environmental Effects Control Requirements," September 1967.

B. SAE ARP 4242, "System Compatibility."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific test being planned.

OUTLINE
EMC TEST PLAN

COVER PAGE

CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET

TABLE OF CONTENTS

LIST OF FIGURES

> Figures are numbered sequentially from 1 using Arabic numerals (1,2,3). Figure numbers and titles should be centered **below** each figure.

LIST OF TABLES

> Tables are numbered sequentially from I using Roman numerals (I. II, III). Table numbers and titles should be centered **above** each table.

LIST OF ACRONYMS AND ABBREVIATIONS

> All abbreviations and acronyms used in the document should be included here in alphabetical order. Each acronym should be defined in the text the first time it is used. After that, either the acronym or the complete name should be used, but not both. Paragraphs should not begin with acronyms - write out the entire name.

SECTION A TEST PLANNING

1.0 Methods

> List methods to be used to select critical circuits to be monitored for compliance to the degradation criteria and/or safety margin.

2.0 Procedures

> Discuss procedures for development and methods for monitoring/evaluating failure/degradation criteria for each subsystem and equipment.

3.0 Test Conditions

> Include test conditions and operating modes/procedures for all electronic and electrical equipment installed in or associated with the system and the sequence of operation during tests, including all switch activations.

4.0 Demonstration Methods

> Discuss methods for demonstrating required safety margins for electro-explosive devices and for other subsystems/equipments whose degradation of performance could affect safety-of-flight or mission success.

5.0 Electrical Power Voltage Limits

List limits and methods for monitoring AC and DC power buses to assure that voltages are within proper limits.

6.0 Data Readout and Analyses

Discuss methods and procedures.

7.0 Test Locations and Simulations

List test locations and describe arrangements for simulating operational performance in cases where actual operation is impractical.

8.0 Control Settings

Describe adjustments and settings of variable controls such as audio gain, video gain, sensitivity, squelch, and any others.

9.0 Frequency Selections

Provide details concerning frequency ranges, channels, and combinations to be specifically tested, such as image frequencies, intermediate frequencies, local oscillators, and transmitter fundamental and harmonically-related frequencies. Include results of computer-aided analyses and laboratory testing used to make frequency selections.

10.0 Signal Input Simulations

Discuss means of simulating signal inputs such as Doppler, radar altimeter, and others.

11.0 Calibration

Provide calibration schedules and descriptions of unique EMC instrumentation for measuring electrical, video, and mechanical outputs of equipments and subsystems to be monitored during testing. Include applicable safety margins.

12.0 Personnel

List numbers and types of personnel required.

13.0 Schedule

Provide detailed schedules defining specific equipment/personnel availability requirements, as well as specific test sequence.

14.0 Bonding and Grounding

Discuss methods of measuring and demonstrating bonding and grounding requirements.

15.0 Test Site RF Profile

Describe test site and give RF profile.

16.0 Open Area Operation

Discuss considerations and regulations regarding the operation of test sample and measuring equipment in open areas.

SECTION B TEST PROCEDURES

This section is a detailed step-by-step test procedure suitable for use by test personnel. Each step shall show the purpose of the step, action taken by each participant, control settings, data to be recorded, and any other pertinent information.

2.4.5 EMC TEST REPORT

I. OPR

EL62

II. PURPOSE

The purpose of the EMC Test Report is to document the results of the EMC tests, that is, the degree of EMC achieved within the system between subsystems. As detailed below, it is a method by which the EMC program is brought to a satisfactory close.

The Test Report identifies potential sources and victims and the margin between the emission levels of the sources and the susceptibility level of the victims. In the case of a negative margin, a solution to the incompatibility must be included. Additional shielding, filtering, or time-lining may be used as a solution.

III. DESCRIPTION

This report is the proof that the system meets its EMC requirements. The report is customarily released 30-60 days after the completion of the test, as set by contractual requirements.

IV. REFERENCES

A. MIL-E-6051D, "System Electromagnetic Compatibility Requirements," September 1967.

B. MIL-STD-831, "Preparation of Test Reports," August 1983.

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific test being documented.

OUTLINE
EMC TEST REPORT

COVER PAGE
CHANGE RECORD

This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

Figures are numbered sequentially from 1 using Arabic numerals (1,2,3). Figure numbers and titles should be centered **below** each figure.

LIST OF TABLES

Tables are numbered sequentially from I using Roman numerals (I. II, III). Table numbers and titles should be centered **above** each table.

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BODY OF REPORT

> There is no specific outline for this report. In essence, any contractor format is acceptable. However, the following topics should be covered:
> * Description of the complete test program
> * An "as run" copy of the EMC Test Procedure(s) as an appendix
> * Summary of test results
> * Actual test data in Appendices
> * Descriptions of interferences (frequencies, mode of equipment operation, determination of coupling path)
> * Descriptions of fixes or operational work-arounds for all interferences

2.4.6 EMI TEST PLAN

I. OPR

EL54

II. PURPOSE

The purpose of the EMI Test Plan is to define the tests measuring the performance of the equipment while subjected to the electromagnetic environment, and to measure the EMI contributed to the ambient by the system. These tests serve as a validation of the analyses performed in conjunction with the EMI Control plan.

III. DESCRIPTION

The Test Plan is approved prior to the start of first article testing. The subsystem testing is normally completed before system integration.

IV. REFERENCES

A. MIL-STD-461C, "Electromagnetic Emission and Susceptibility Requirements for the Control of EMI," August 1986.

B. MIL-STD-462, "Measurement of Electromagnetic Interference Characteristics," Notice 2; May 1970.

C. DI-EMCS-80201, "Electromagnetic Interference Test Plan."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific test being planned.

OUTLINE
EMI TEST PLAN

COVER PAGE
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

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1.0 INTRODUCTION

> State the purpose of the plan and its relationship to the overall electromagnetic control program for the equipment or subsystem. Include a table listing the tests to be performed, the corresponding paragraph number in the plan, and the applicable test method. Describe the test sample including operating frequency, line current, and other parameters.

2.0 APPLICABLE DOCUMENTS

> List every document referenced in the text, but only those documents actually used in the text.
> List documents in the following order:
> * NASA
> * Company
> * Other Government or industry standards, specifications, or documents

3.0 TEST SITE

Describe the test facility, shielded enclosure or anechoic chamber (size, power availability, filters and attenuation, characteristics of room to electric, magnetic and plane waves. Describe ground plane (size and type) and methods of grounding or bonding the test sample to the ground plane to simulate actual equipment installation. Provide evidence of spot-check measurements of the ambient electromagnetic emission profile of the test facility, both radiated and conducted, to determine ambient suitability.

4.0 TEST EQUIPMENT

Describe the test equipment including nomenclature and bandwidth, scanning speed used to drive the measuring equipment, and characteristics of matching transformers and band rejection. Address antenna factors of specified antennas, transfer impedances of current probes, impedance of line impedance stabilization networks (LISN) and insertion losses and impedance curves of 10 microfarad capacitors.

5.0 TEST SAMPLE

Describe the test sample set-up and describe the actual physical layout of the equipment under test, the position of feedthrough capacitors or LISNs on the ground plane and the location of bond straps, loads and test sets. Notes should be used to indicate height above ground plane for leads. Include a description of the test sample's operation including:

* Modes of operation for each test and operating frequency
* Control settings on the test sample
* Control settings on any test sets employed or characteristics of input signals
* Test frequencies at which oscillators, clocks, and so on may be expected to approach requirements and limits
* Performance checks initiated to designate the equipment as meeting minimal working standard requirements
* Enumeration of circuits, outputs and displays to be monitored during susceptibility testing, as well as the criteria for monitoring for performance degradation
* Normal, malfunction, and performance degradation criteria for susceptibility testing

6.0 MEASUREMENTS

Discuss the measurements to be employed to demonstrate compliance with the contractual requirements. As a minimum, include the following for each test:

* Block diagram depicting the test set-up
* Test equipment used in performance of the test, and the methods of grounding, bonding or achieving isolation for the measurement instrumentation
* Procedure for probing the test sample, determining placement and orientation of probes and antennas, selecting measurement frequencies and detector functions, information to be recorded during the test including frequency and units of recorded information, sample data sheets, test logs and graphs. Graphs should include limits and the modulation characteristics of the susceptibility test signals, such as amplitude, waveform, type of modulation and so forth.

2.4.7 EMI TEST REPORT

I. OPR

EL62

II. PURPOSE

The purpose of the EMI Test Report is to document the results of the EMI tests performed on the system or subsystems. The report enables an evaluation of equipment or subsystem performance and the discussion of recommended corrective actions.

The Test Report discusses and summarizes the test methods, test set-up, and test results to demonstrate that the equipment or system being tested complies with the applicable EMC specifications. All data and any abnormalities or problems must be included.

III. DESCRIPTION

The EMI tests are performed as a part of first article testing (or acceptance testing). In the event that the system will be produced in large quantities, sample testing will continue throughout production.

IV. REFERENCES

None.

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific test being documented.

OUTLINE
EMI TEST REPORT

COVER PAGE
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

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1.0 INTRODUCTION

> List applicable documents such as requirements documents and test plans. Provide administrative information such as contract number, authentication and certification of test performance by qualified representatives of procuring activity, disposition of test specimens, description of test samples, list of tests performed and changes in limits or test frequencies previously authorized.

2.0 RECOMMENDATIONS AND CONCLUSIONS

> Include results of tests in brief narrative form, discussion of remedial actions already initiated and proposed corrective measures to be implemented to assure compliance of the equipment or subsystem with contractual EMI requirements. In addition, discuss any test sample characteristics which may influence the equipment's ability to meet the contractual EMI requirements. These characteristics may include power consumption, shock hazard, weight, watertightness, and utilization of non-ferrous materials.

APPENDICES

A separate appendix is prepared for each test. Each appendix should cover the applicable test procedure or reference to the approved EMI Test Plan (see Section 2.4.6 in this volume), data sheets, graphs, illustrations, and photographs. The log sheet should be the last appendix. Special terms or word usage should be defined in a separate appendix. Each appendix should contain the following information:

* Nomenclature and serial numbers of interference measuring equipment
* Date of last calibration of interference measuring equipment, procedures used and their traceability
* Photographs or diagrams of test set-up and test sample with identification
* Transfer impedance of current probes
* Antenna factors of specified antennas, impedance of line impedance stabilization networks, and insertion loss and impedance curve of 10 microfarad capacitors, as applicable
* Measured levels of emission at each frequency before and after the application of suppression devices
* Graphs or X-Y recordings of applicable limits and measured data in units as specified in the appropriate requirements document(s)
* Data to show compliance with susceptibility require- ments and thresholds of susceptibility or limitations of test equipment
* Identification, schematics, performance data and drawings of any suppression devices employed to meet the contractual requirements
* Sample calculations

2.4.8 VERIFICATION REQUIREMENTS COMPLIANCE DOCUMENT

I. OPR

EL45

II. PURPOSE

The purpose of the Verification Requirements Compliance Document is to provide evidence of compliance to each Verification Requirements and Specifications Document (VRSD) requirement and Level I to Level IV flow-down requirement to show traceability to compliance documentation, such as Assessment/Test/Inspection/Analysis Reports.

This document is generally developed in two volumes. Volume I usually contains the requirements flow-down matrix. This matrix details how a Level I requirement is met by a requirement at a lower level. Volume II contains requirements of the Verification Requirements and Specifications Document (see section 2.4.3). Alternatively, the engineer can develop one document with separate sections.

The preliminary documents are developed from the program IRDs, CEI specifications, and ICDs.

III. DESCRIPTION

* Outline and format included in PDR data package.

* Preliminary issue 30 days after CDR.

* Updates:

  - During integrated test
  - 3 weeks prior to CI/DCR
  - Pre-ship review
  - Flight Readiness Review

The compliance document includes the following:

A. Level I to Level IV flow-down requirements, verification methods, compliance data (test, verification procedure, automated test or sequence, verification report, analysis, or other reports), non-conformances and re-verifications, and a data statement.

B. Traceability of VRSD requirements to Level I to Level IV flow-down requirements (Project Requirements Document, Interface Requirement Document, Interface Control Document, and/or Contract End Item Requirements).

C. Separate sections documenting the compliance to VRSD requirements and to Level I to Level IV flow-down requirements.

IV. REFERENCES

A. DR STD/VR-VRCD, "Verification Requirements Compliance Document."

B. MSFC-HDBK-2221, "Verification Handbook," section 2.1.1.11.

2.4.9 OPERATIONS AND MAINTENANCE REQUIREMENTS AND SPECIFICATIONS DOCUMENT (OMRSD)

I. OPR

EL45

II. PURPOSE

The Operations and Maintenance Requirements and Specifications Document (OMRSD) defines the requirements and specifications for processing a payload and its associated hardware at the launch site.

III. DESCRIPTION

The OMRSD includes the verification requirements and specifications for processing a payload or flight hardware at the launch site. It covers prelaunch verification including integration into the launch vehicle, launch, and post-landing (including abort) operations. The document identifies each requirement, measurement stimuli, specification, and constraint applicable to the processing activity. Specifications include allowable tolerance for standards of judgment to be used in determining acceptable performance. Servicing requirements, safety considerations and hazardous operations, as well as crew participation will be addressed. Post-landing requirements (if applicable) for payload removal, deintegration, and disposition will also be defined.

IV. REFERENCES

A. DR STD/OP-OMRD, "Operations and Maintenance Requirements and Specifications Document."

B. MSFC-HDBK-2221, “Verification Handbook,” section 2.1.3.2.3.

2.4.10 VERIFICATION PROCEDURES

I. OPR

EL62

II. PURPOSE

Verification procedures document the sequence of steps or events in performing verification for all hardware, including flight, special test, and ground support equipment.

III. DESCRIPTION

Initial submission 30 days prior to the start of the related verification activity. Revisions and updates submitted as required.

Each procedure will be tailored to the verification phase and hardware level at which the activity is to take place. Each procedure will identify the verification requirements for the item from the related verification specification. Requirements will be fully referenced and will include the following information:

A. Nomenclature and identification of the test article or material, test configuration, and any differences from the flight configuration.

B. Identification of objectives and criteria established for test by the applicable verification specification.

C. Characteristics and design criteria to be inspected or tested, including values, with tolerances, for accept-ance or rejection.

D. Description, in sequence, of steps and operations to be taken.

E. Identification of computer software required.

F. Identification of measuring, test, and recording equipment to be used, specifying range, accuracy, and type.

G. Certification that required computer test programs/ support equipment and software have been verified prior to use with flight hardware.

H. Any special instructions for operating data recording equipment or other automated test equipment, as applicable.

I. Layouts, schematics, or diagrams showing identification, location, and inter-connection of test equipment, test articles, and measuring points.

J. Identification of hazardous situations or operations.

K. Precautions and safety instructions to ensure safety of personnel and prevent degradation of test articles and measuring equipment.

L. Environmental and/or other conditions to be maintained, with tolerances.

M. Constraints on inspection or testing.

N. Special instructions for nonconformances and anomalous occurrences or results.

O. Specifications for facility, equipment maintenance, housekeeping, Certification inspection, and safety and handling requirements which might occur before, during, and after the total verification activity.

IV. REFERENCES

MSFC-HDBK-2221, "Verification Handbook," section 2.1.1.15.

2.5 DESIGN SUPPORT DOCUMENTS

2.5.1 RESOURCE MARGINS AND CONTINGENCIES

I. OPR

EL41/EL51

II. PURPOSE

The assignment and allocation of margins are an important risk mitigation technique. Future payloads and launch vehicle programs likely will increasingly rely on robust margins to assure mission success.

III. DESCRIPTION

Proper identification and tracking of margins can greatly reduce the impact of unexpected changes in requirements, interfaces, and constraints. This can also reduce the ripple effect of a concept or design change from one portion of the mission or system to other portions. Margins and margin requirements must be determined carefully and take into account the maturity of the design, any development risks, risks associated with uncertainties in design parameters, interfaces, other ill-defined factors, and cost.

Mass Properties

The distinction between margin and contingency should be clearly understood. With regard to weight, contingency is defined as, "...an allowance added to a basic weight to account for deficiencies in detail of the current design, i.e., more contingency is added for estimated weights than for weights calculated from a released drawing."[B] Contingency is a resource category that will become smaller as design and hardware mature until evenually disappearing after actual weights are obtained (see Table II). Each project should develop tables similar to Tables I and II for the use of all program participants to ensure consistant application of margins and contingencies throughout the project. Margin refers to the difference between some allocated (or specification) weight or other parameter and the current estimate for that parameter plus contingency. Using a weight example, suppose the allocated weight for an item is 1000 kg and the current weight estimate is 800 kg with a 20 percent contingency. Then the weight margin for this item at this time in the project is 40 kg (1000 - (800+160)).

Electrical Power

The terms contingency and margin are used differently at MSFC in discussing electrical power resources. Contingency is defined as, "The margin between the actual vehicle power and energy requirements and the allocated power/energy minus any reserves or harness losses.[C] The power or energy margin is defined as the difference between the maximum power or energy available and the current estimate of power or energy utilization.[C]

For each performance parameter, there must be an associated margin. Development of margins starts during Pre-Phase A, is central to Phase A, and continues into Phases B and C. A fair and equitable distribution of margins to lower hierarchical levels must be implemented. Tracking the allocation of these margins is important, especially when requirements changes occur. Table I lists some suggested or commonly used margins for various classes of spacecraft, and for different phases in the development process. In general, margins are lowered as the design matures and are refined through continuing analyses and tests. As this occurs, a chief engineer or project manager may see fit to redistribute resource allocations between subsystems or elements if deemed necessary.

In order not to over- or under-allocate design margins and safety factors, the mission and system should be broken down into successively lower hierarchical levels until each portion has distinct levels of maturity and risk. For example, a new concept for a launch vehicle or a scientific spacecraft, should have relatively low margins assigned to portions of the system that are similar to ones previously designed and flown. A higher margin would be assigned to an instrument design that advances the state-of-the-art. Each project should develop a list of critical margins and parameters to be tracked. Explicitly relating the status of these items as a function of time and keying these to significant milestones, de-scope options and back-up options can be a critical risk reduction activity.

IV. REFERENCES

A. NASA Engineering Management Council Report, "The NASA Mission Design Resource Margins/Contingencies Process," December 22, 1992 (available from GSFC/Code 704).

B. MSFC-RPT-1553A, "Weight Control and Weight Histories Report, July 1991.

C. Vu-graph, "Electrical Power/Energy Margin & Contingency Application and Depletion Schedule," MSFC/EL56.

TABLE I. Typical resource margins
(Unmanned Spacecraft with Moderate Risk)

	PROJECT PHASE / PARAMETER	Phase A	Phase B PDR	Phase C CDR	Phase D FRR
Technical	Weight Margin (Note)	25-35%	15-25%	5-10%	0-5%
	Power (EOL)	35-50%	15-20%	5-10%	0-5%
	On-board data storage	40-50%	30-40%	5-10%	5%
	RF Link Margin (BOL)	6 dB	4 dB	3 dB	3 dB
	RCS Propellant	30-35%	10-15%	5-10%	5%
	Telemetry downlink utilization	30-40%	15-25%	5-10%	5%

Note: For weight contingencies see Table II.

TABLE II. Typical weight contingency application and depletion schedule [B]
(All entries in percent)

	Design Maturity					
	Conceptual Drawings	Layout Drawings	Pre-released Drawings	Released Drawings	Actual Weight	Vendor Specification
Structures	18	13	3	1	0	0
Mechanisms	18	13	3	1	0	0
Thermal	18	13	8	2	0	0
Batteries	18	13	13	2	0	0
Wire & Cable	33	18	8	2	0	0
Electronic Boxes & Components						
< 10 lbs.	18	13	8	8	0	0
10 to 30 lbs.	13	8	3	3	0	0
> 30 lbs.	8	3	3	3	0	0

2.5.1.1 MASS PROPERTIES REPORT

I. OPR

EL42

II. PURPOSE

The Mass Properties Report provides the current weight and other mass properties of an integrated payload or payload element. This document also provides the current status of mass properties controls and margins. This data may be used to verify integration requirements and as input to other analyses.

III. DESCRIPTION

* Initial release: 15th of the month after "Authority to Proceed" plus 60 days.

* Update quarterly and as part of any review package.

This document should be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

* Document Preparer

* Branch Chief

* Division Chief

* Program Chief Engineer

IV. REFERENCES

A. DR STD/SE-MPR, "Mass Properties Reports."

B. MSFC-RPT-1553A, "Weight Control and Weight Histories Report", July 1991.

C. MIL-M-38310B, "Mass Properties Control Requirements for Missile and Space Vehicles," July 1966.

V. OUTLINE

Although there is no specific format in use at MSFC, the following is a generic content outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific system being documented.

CONTENT OUTLINE
MASS PROPERTIES REPORT

TITLE PAGE
TABLE OF CONTENTS

INTRODUCTION

DEFINITIONS

WEIGHT SUMMARY

Include last submitted, current, CEI, maturity, and others.

COMPREHENSIVE REASONS FOR CHANGE

COMPREHENSIVE PENDING AND POTENTIAL CHANGES

CRITICAL MASS PROPERTIES STATUS

MASS PROPERTIES SUMMARY

Include subsystem, element, sequential, and others.

WEIGHT HISTORIES

ATUS AND PHILOSOPHY OF WEIGHT CONTINGENCY

STATUS OF CONTROL WEIGHTS (vs. current) AND CONTRACTOR RESERVE

COORDINATE SYSTEM(s) DESCRIPTION

DETAIL MASS PROPERTIES

Include sufficient detail to fully reflect all major items and subsystems.

SUMMARY OF PERFORMANCE MARGINS

UNCERTAINTY ANALYSES

REFERENCES

2.5.1.2 ELECTRICAL POWER AND ENERGY MANAGEMENT REPORT

I. OPR

EL56

II. PURPOSE

The Electrical Power and Energy Management Report (EPEMR) defines activities required to track and control electrical power and energy usage of spacecraft elements. The EPEMR periodically documents the status and trends on power and energy usage.

III. DESCRIPTION

The management portion of the report should identify an overall approach for implementation that depicts how electrical power and energy will be allocated, tracked, and controlled. The margin reporting portion of the report utilizes power load and timeline information to compile energy and power requirements. Commercial computer spreadsheet programs are often employed for performing report tabulations, but special-purpose computer programs may offer advantages. Tabulations, graphs, and bar charts are used to present individual equipment requirements as compared to the equipment allocations. Total power and energy consumption is also shown in comparison to the total system capacity.

This document should be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

* Document Developer
* Branch Chief
* Division Chief
* Program Chief Engineer

IV. REFERENCES

DR STD/SE-EPEM, "Electrical Power and Energy Management Report."

V. OUTLINE

The following is a generic outline for this document.

OUTLINE
ELECTRICAL POWER & ENERGY MANAGEMENT REPORT

COVER
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

> Figures are numbered sequentially from 1 using Arabic numerals (1,2,3). Figure numbers and titles should be centered below each figure.

LIST OF TABLES

> Tables are numbered sequentially from I using Roman numerals (I,II,III). Table .mbers and titles should be centered above each table.

LIST OF ACRONYMS AND ABBREVIATIONS

> All abbreviations and acronyms used in the document should be included here in an alphabetical list. Each acronym should be defined the first time it is used. After that, either the acronym or the complete name should be used, not both. Paragraphs should not begin with acronyms, write out the entire name.

1.0 INTRODUCTION

> This section should include the document scope along with any other introductory material, such as the key participants, historical background, or experiment objectives.

2.0 APPLICABLE DOCUMENTS

> This section must contain a list of every document referenced in the text. A o, every document listed here must be in the text.

2.1 Government Documents
2.2 Contractor Documents

3.0 SYSTEM DESCRIPTION

3.1 Overall System Description

> Include both a physical and a functional description of the entire system. The purpose of this section is to define the environment that the two components must interface within. Recommend a figure or schematic, illustrating the entire system, be included.

4.0 CONTROL PLAN

This section should contain a comprehensive plan on how electrical power and energy consumption of spacecraft elements will be tracked and controlled.

5.0 POWER & ENERGY REQUIREMENTS VERSUS ALLOCATIONS

This section consists of a series of tables or graphs showing the current actual or projected power and energy requirements for each experiment and subsystem element. Also shown is the power and energy allocated to that experiment or subsystem element and the resulting power and energy margin. The individual experiment and subsystem elements are summed to arrive at a total power and energy margin for the whole spacecraft or flight article.

2.5.2 FUNCTIONAL INTERCONNECT DIAGRAMS

I. OPR

EL56/EL42

II. PURPOSE

The functional interconnect diagram provides end-to-end functional definition of electrical and fluid systems for systems analyses and troubleshooting during design and operation.

III. DESCRIPTION

This diagram graphically depicts the arrangement of **external** plumbing/electrical cabling which interconnects assemblies/ enclosures/equipment. Diagrams for electrical and mechanical systems should be separately prepared with appropriate cross references.

IV. REFERENCES

EL51 Vugraph, "System Functional Schematics and Interconnect Diagrams."

V. FIGURE

Figure 2.5.2-1 shows an example of a functional interconnect diagram.

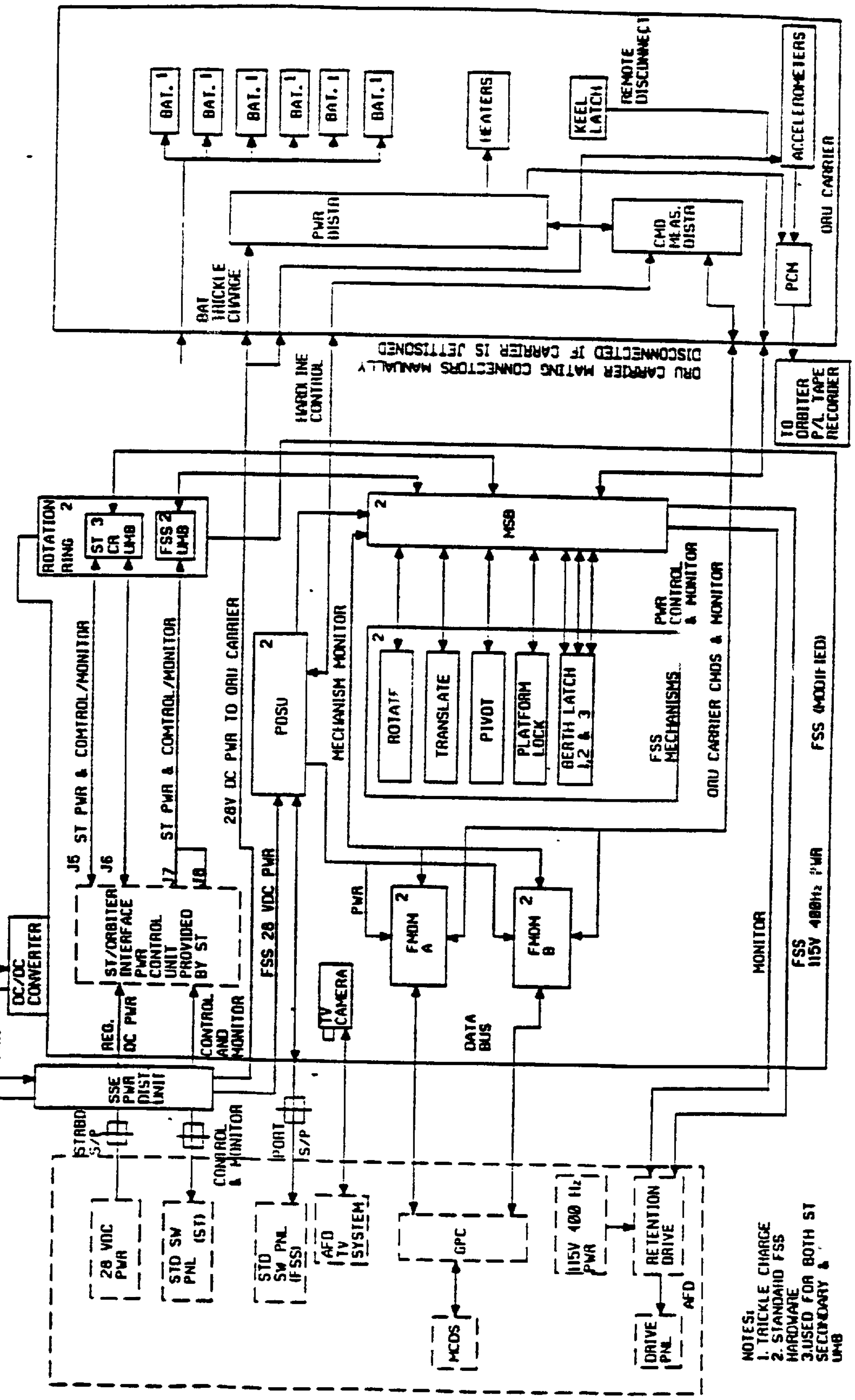


Figure 2.5.2-1. Functional Interconnect Diagram

2.5.3 END-TO-END SYSTEM FUNCTIONAL SCHEMATICS

I. OPR

EL56/EL42

II. PURPOSE

These schematics provide end-to-end functional definition of electrical and fluid systems for systems analysis and troubleshooting.

III. DESCRIPTION

Electrical - Provides end-to-end configuration definition of all power, control, and monitor functions/circuits. Primary element interfaces are shown down to the plug/pin level. Power sources, switches, controls, indicators, valves, motors, relays, and sensors are identified by symbol and reference numbers. Input/output channels for data and instrumentation systems are identified by name and identification number, and logic functions performed by the data management system are depicted. Internal component/box design drawings for distribution/configuration details are referenced.

Fluid - Provides integrated configuration definition of all fluid systems (vehicle, payload, or experiment) in one convenient reference. Schematics include all pertinent components (valves, regulators, pumps, filters) within the fluid system, as well as pertinent interfaces with other compatible fluid systems (STS, GSE, facilities, other projects). Schematics reference design drawings for configuration details and identify power and command and data interfaces by symbol and reference.

IV. REFERENCES

A. EL51 Vugraph, "System Functional Schematics and Interconnect Diagrams," November 1987.

B. DR STD/SE-CDFS, "System Connectivity Diagrams and End-to-End Functional Schematics."

V. FIGURES

Figure 2.5.3-1 shows an example Electrical End-to-End System Schematic, and Figure 2.5.3-2 shows a fluid schematic.

VI. LESSONS LEARNED

"Design error remained undetected due in part to lack of system engineering because the Super*ZIP end-to-end drawings were spread among several individual drawings and were never aggregated into a single end-to-end functional schematic."

STS-51 Super*ZIP/TOS Anomaly Investigation Report.

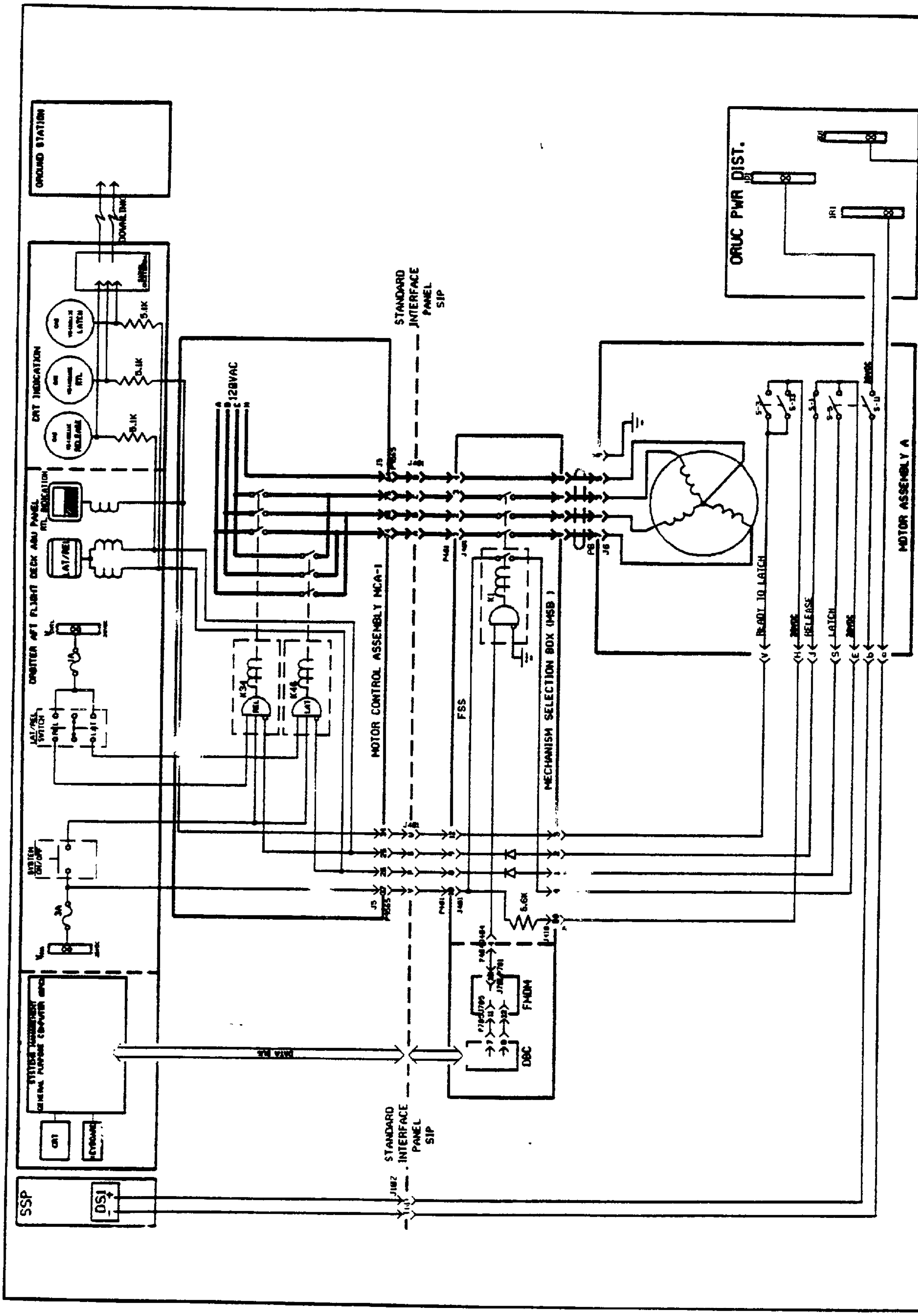
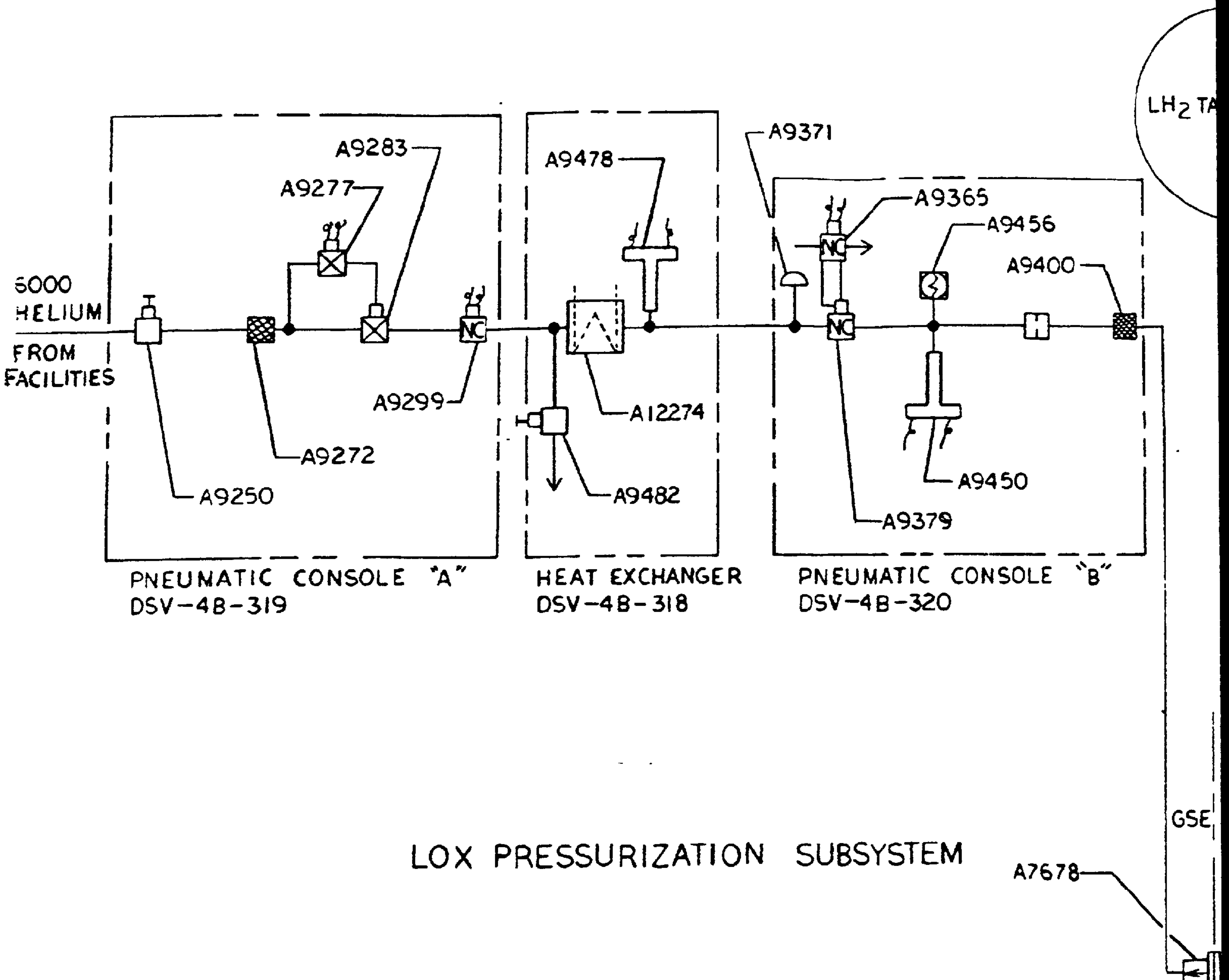


Figure 2.5.3-1 Electrical End-to-End System Schematic



LOX PRESSURIZATION SUBSYSTEM

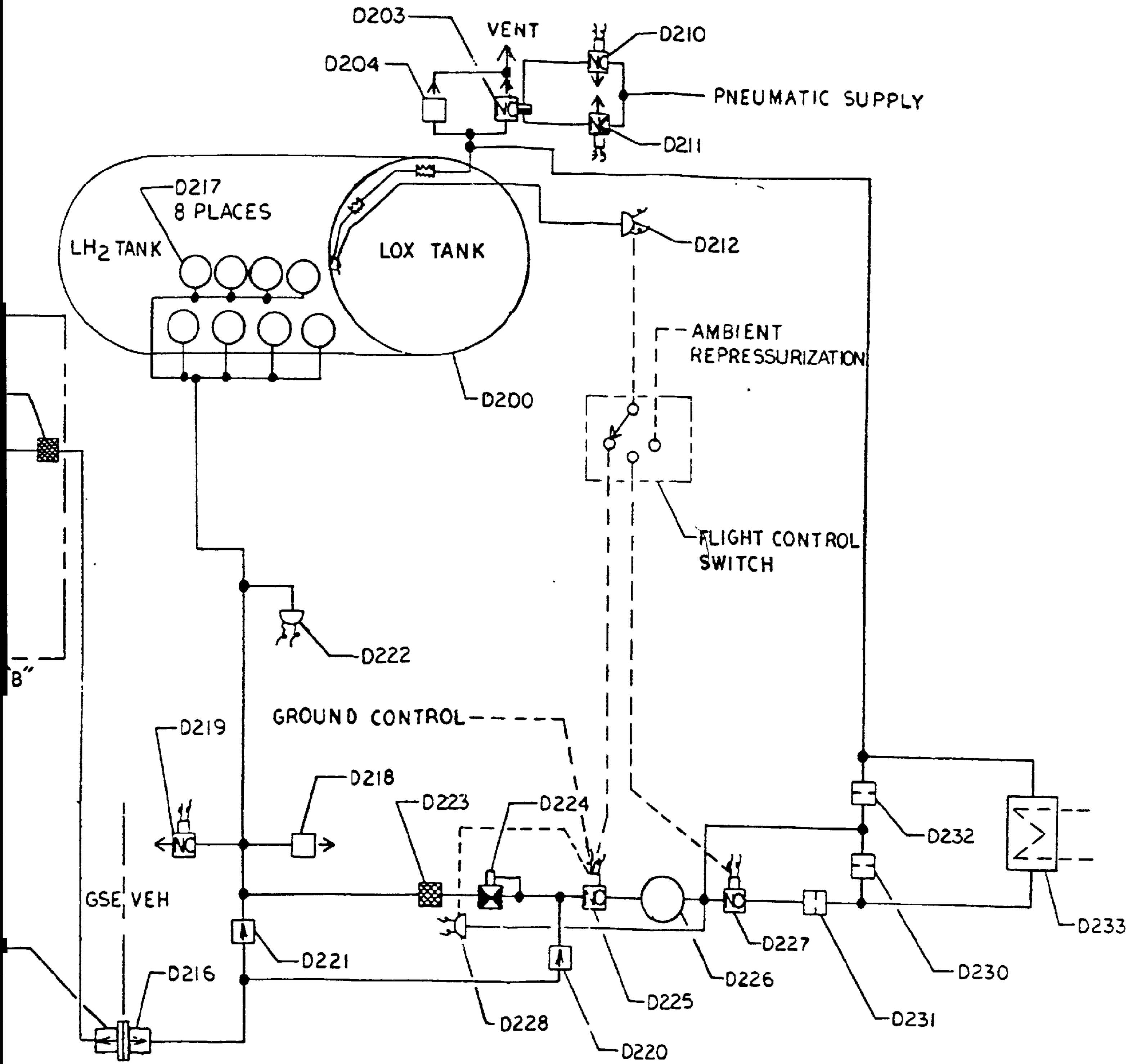


Figure 2.5.3-2 Fluid End-to-End System Schematic

2.5.4 EMC CONTROL PLAN

I. OPR

EL54

II. PURPOSE

The EMC Control plan is used to ensure that the system design and development will result in a product which is compatible with its environment.

III. DESCRIPTION

The EMC Control Plan is a formal document prepared early in a project, and revised throughout the project, to provide design guidelines, document design approaches, and document analyses and testing to demonstrate compliance with system EMC requirements. It should be recognized that for large systems composed of sufficiently complex sub-systems, separate EMC Control Plans will be used for the system and each subsystem.

IV. REFERENCES

A. MIL-E-6051D, "System Electromagnetic Environmental Effects Control Requirements," September 1967.

B. MIL-HDBK-237A, "Electromagnetic Compatibility Management Guide for Platforms, Systems, and Equipment," May 1981.

C. ARP 935, "Suggested EMI Control Plan Outline."

D. ARP 4242, "System Compatibility."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific system being documented.

OUTLINE
EMC CONTROL PLAN

1.0 MANAGEMENT

The EMI Control Plan will cover the specific organizational responsibilities, lines of authority and control, and the implementation planning, including milestones and schedules. In addition, the detailed EMI requirements to be imposed on subcontractors and a definition of responsibility for associated contractor equipment, GFE, and subcontractor vendor items will be discussed. A description of the equipment or subsystem, its characteristics, where known, and intended installation or platform will also be discussed.

2.0 SPECTRUM CONSERVATION

The plan will describe the program to be employed to minimize emission spectrum and receiver bandwidths and control oscillator frequencies, pulse rise times, harmonics, sidebands, and duty cycles within the constraints of the equipment or subsystem specified design parameters.

3.0 EMI MECHANICAL DESIGN

Describe the material and construction to be used to provide the inherent attenuation to electromagnetic emissions and susceptibilities while still meeting the contractual EMI requirements. Include the following:

a. Type of metals, castings, finishes, and hardware in the design;

b. Type of construction, such as compartmentization, filter mounting and isolation of other parts, type and characteristics of filtering used on openings, including ventilation parts, access hatches, windows, and metal gaskets used on all internal and external mating surfaces;

c. Shielding and design practices employed for determining shielding effectiveness;

d. Corrosion control procedures.

4.0 ELECTRICAL/ELECTRONIC WIRING DESIGN

Describe the wiring design, cable separation, and routing to minimize emission and susceptibilities. Ground philosophy and methods of shielding and routing of cables should be discussed. Include interconnect cabling diagrams for equipment and subsytems.

5.0 EMI CONTROL AND SUPPRESSION TECHNIQUES

Describe the EMI control and suppression techniques which will be applied to all parts and circuitry. Include the following:

a. Choice of parts and circuitry, criteria for use of standard parts and circuitry, and bonding and grounding techniques;
b. Justification of selected filter characteristics, including type and attenuation and technical reasons for selecting types of filters;
c. Part location and separation for reducing EMI;
d. Technical reasons for selection of pulse shape;
e. Location of critical circuits and decoupling techniques employed; and
f. Shielding and isolation of critical circuits.

6.0 ANALYSIS

Include details on prediction or analysis techniques and results employed to determine adequacy of contractor's conclusions.

7.0 R&D TESTING

Discuss the proposed testing program during development and breadboard construction stages.

8.0 PROBLEM AREAS

Discuss plans and procedures for identifying and resolving potential EMI problems. Also, discuss methods for testing and implementing solutions.

2.5.5 SYSTEM/SEGMENT DESIGN DOCUMENT (SSDD)

I. OPR

EL56

II. PURPOSE

The System/Segment Design Document (SSDD) describes the design of a system/ segment and its operational and support environments. It describes the organization of the system and allocates system requirements to hardware configuration items (HWCIs), computer software configuration items (CSCIs), and manual operations.

III. DESCRIPTION

* Initial Release at SRR
* Baseline prior to PDR

This document must be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

If the document will be controlled at Level II, the following should sign:

* Specification Developer
* Branch Chief
* Division Chief
* Lab Director
* Chief Engineer
* Program Manager
* Stress
* Materials
* S&MA

If the document will be controlled at Level III, the following should sign:

* Specification Developer
* Branch Chief
* Division Chief
* Chief Engineer
* Stress
* Materials
* S&MA

IV. REFERENCES

A. MIL-STD-490A, “Specification Practices”, 4 Jun 85

B. DR STD/SE-SSDD, "System/Segment Design Document."

C. MSFC-STD-555, "MSFC Engineering Documentation Standard."

D. DoD-STD-2167A, “Defense System Software Development”, paragraph 5.1.2.2.

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific system being documented.

OUTLINE
SYSTEM/SEGMENT DESIGN DOCUMENT

COVER
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

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LIST OF TABLES

> Tables are numbered sequentially from I using Roman numerals (I,II,III). Table numbers and titles should be centered above each table.

1.0 SCOPE

1.1 Identification

> Contains the approved identification number, title, and abbreviation, if applicable, of the system to which this SSDD applies. Also identifies the higher-level specifications containing the requirements from which the design was derived.

1.2 System Overview

> Briefly state the purpose of the system.

1.3 Document Overview

> Briefly state the purpose and contents of the SSDD.

2.0 APPLICABLE DOCUMENTS

> This section must contain a list of every document referenced in the text. Also, every document listed here must be in the text. A standard paragraph is usually included as follows: "The following documents, latest revision unless otherwise specified, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced herein and the contents of this specification, this specification shall apply, except for safety-related items and issues."

2.1 Reference Documents

> List documents which contain general background information. These could include documents identified as applicable to documents that are applicable to this SSDD. A standard paragraph is usually included, like this one: "The following documents are for reference only. As such, they do not constitute a part of this document, but may be of interest to the reader."

3.0 OPERATIONAL CONCEPTS

3.1 Mission
3.1.1 User Needs

Summarizes the user needs the system must meet and references the documents where these needs are stated.

3.1.2 Primary Mission(s)

Describe the primary system missions.

3.1.3 Secondary Mission(s)

Describe the secondary system missions.

3.2 Operational Environment

Describe the environment in which the system is intended to operate.

3.3 Support Environment

Describe the support environment for the system during the Operations Phase (Phase E).

3.3.1 Support Concept
3.3.1.1 Use of Multipurpose or Automated Test Equipment
3.3.1.2 Repair versus Replacement Criteria
3.3.1.3 Levels of Maintenance
3.3.1.4 Maintenance and Repair Cycles
3.3.1.5 Government and Contractor Support
3.3.1.6 Accessibility
3.3.1.7 Other

3.3.2 Support Facilities

Quantitatively describe existing facilities and equipment to be used during the Operations Phase (Phase E) so that availability may be verified. Describe new or modified facilities and equipment in enough detail that construction or procurement planning can be done.

3.3.3 Supply
3.3.3.1 Introduction of New Items into the Supply System
3.3.3.2 Re-supply Methods
3.3.3.3 Distribution and Location of System Stocks

3.3.4 Government Agencies

Identify Government organizations that will be development, support, and user agencies for the system.

3.4 System Architecture

Describe the internal structure of the system including identifying the segments, HWCIs, and CSCIs and their purposes. Describe the relationships among the segments, HWCIs, and CSCIs. Identify external interfaces and their purpose. A diagram should be used to illustrate the top-level system architecture.

3.5 Operational Scenarios

For each system state and mode, identify the configuration items that execute and the manual operations to be performed. Describe the general flow of execution control and data between configuration items while operating in the different states and modes. Flow diagrams should be used.

4.0 SYSTEM DESIGN

Identify prime item or critical item HWCIs, and describe the relationship of HWCIs, CSCIs, and manual operations within the system. Use specification tree diagrams to show the relationship between configuration items.

4.1 HWCI Identification

This section is divided into subsections, one for each HWCI, and identifying each requirement from the System Specification allocated to the HWCI.

4.2 CSCI Identification

This section is divided into subsections, one for each CSCI, and identifying each requirement from the System Specification allocated to the CSCI.

4.3 Manual Operations Identification

This section is divided into subsections, one for each manual operation, and identifying each requirement from the System Specification allocated to the manual operation.

4.4 Internal Interfaces

Describe the interfaces internal to the system.

4.4.1 HWCI-to-HWCI Interfaces

Identify each signal transmitted between HWCIs, the HWCI transmitting the signal, and the HWCI receiving the signal.

4.4.2 HWCI-to-CSCI Interfaces

Identify each signal transmitted between a HWCI and a CSCI, the HWCI or CSCI transmitting the signal, and the HWCI or CSCI receiving the signal.

4.4.3 CSCI-to-CSCI Interfaces

> Identify each data item transmitted between CSCIs, the CSCI transmitting the data, and the CSCI receiving the data.

5.0 PROCESSING RESOURCES

> Describe the system processing resources in separate subparagraph, one for each resource.

5.1 Processing Resource Name

> Identify the name of the processing resource and which configuration items use it. Each processing resource description should specify the hardware, programming, design, coding, and utilization characteristics. For each resource, the following characteristics should be discussed separately.

5.1.1 Memory Size
5.1.2 Word Size
5.1.3 Processing Speed
5.1.4 Character Set Standard
5.1.5 Instruction Set Standard
5.1.6 Interrupt Capabilities
5.1.7 Direct Memory Access
5.1.8 Channel Requirements
5.1.9 Auxiliary Storage
5.1.10 Growth Capabilities
5.1.11 Diagnostic Capabilities
5.1.12 Additional Computer Hardware Capabilities
5.1.13 Processing Resource Allocation

6.0 QUALITY FACTOR COMPLIANCE

> Specify the models and associated evaluation criteria to be used to measure compliance with quality factor requirements.

7.0 REQUIREMENTS TRACEABILITY

> Include a requirements traceability matrix to show how the requirements allocated to the HWCIs, CSCIs, and manual operations relate back to the requirements of the System Specification.

8.0 NOTES

> Include general information such as background information, glossary, formula derivations, acronyms, and abbreviations.

APPENDICES

2.5.6 ALIGNMENT PLAN

I. OPR

EL55

II. PURPOSE

The Alignment Plan describes the responsibilities, concepts, requirements, capabilities, and processes and functions to perform to assure the proper alignment of spacecraft systems, especially optical instruments.

III. DESCRIPTION

Depending upon the program, it may be beneficial to have a draft at SRR that captures the general alignment process sufficient to flush out design requirements.

* Initial Draft at SRR

* Updated prior to PDR, CDR

* Final in Acceptance Data Package

This document must be approved by the following individuals. In addition, other interested parties may need to sign the document. This must be determined on a case-by-case basis.

* Specification Developer

* Branch Chief

* Division Chief

* Chief Engineer

IV. REFERENCES

DR STD/SE-AP, "Alignment Plan."

V. OUTLINE

The following is a generic outline for this document. Engineering judgment must be used to determine which parts are applicable to the specific system being documented.

OUTLINE
ALIGNMENT PLAN

COVER
CHANGE RECORD

> This section contains the record of changes to the document.

SIGNATURE SHEET
TABLE OF CONTENTS
LIST OF FIGURES

> Figures are numbered sequentially from 1 using Arabic numerals (1,2,3). Figure numbers and titles should be centered below each figure.

LIST OF TABLES

> Tables are numbered sequentially from I using Roman numerals (I,II,III). Table numbers and titles should be centered above each table.

1.0 Purpose

> Briefly state the purpose of the plan.

2.0 Scope

> Briefly state the scope and applicability of the plan.

3.0 Introduction

> Provide and overview of the system/element being developed and the goals and objectives of the alignment effort.

4.0 Groundrules and Assumptions

> List all applicable groundrules and assumptions made in developing the Alignment Plan, as well as any and all requirements for alignment of the system/element.

5.0 Alignment Overview

> Provide a general overview of the alignment process.

6.0 Alignment Responsibilities

> Identify responsibilities for all the various alignment pieces including the particular branch within MSFC or the actual subcontractor(s) in a contracted program.

7.0 Alignment References and Setup

> Provide a description of all the alignment references/targets and the setups. Explain how they are to be used for the various alignment axes and directions. Figures should be included for clarity.

8.0 Hardware Design Requirements to Facilitate Alignment

Provide, based upon the alignment process, and and all derived flight hardware design requirements needed to perform the alignment.

9.0 Alignment Method/Process

Describe all the steps necessary to perform the alignments. These should be organized chronologically, and should indicate where these steps fit into the system/element integration and test process.

10.0 Notes

Include general information such as background information, glossary, formula derivations, acronyms, and abbreviations.

APPENDICES
A. Alignment Adjustment Ranges
B. Alignment Tolerances

3.0 APPLICABLE SPECIFICATIONS & STANDARDS

3.1 CLASS "C" PAYLOAD REFERENCE SPECIFICATION LIST

I. OPR

EL51

II. PURPOSE

The system engineer should spend time understanding requirements and intent of key specifications and standards - **they represent many years of experience**. The following list is intended to be used as a guide in defining the specifications to assure performance for Class "C" payloads and experiments. Safety specs and standards are listed in Section 3.2 and must be included to complete any list of specs and standards to be applied on a program/project.

III. DESCRIPTION

This list is a subset of specifications and standards listed in MM 2348, "MSFC Approved Baseline List of Specifications and Standards for Space Systems and Related Equipment," which should be consulted for completeness. In addition, for STS attached payloads, JA-447, "MROFIE," contains requirements for payload integration, safety, and operations which are in addition to this list. Engineering judgment must be applied to define the specifications for a particular project. System engineers should not place specifications and standards on contract unless they are applicable, and then they should be tailored to include only those portions which directly apply to the specific project.

NUMBER	TITLE
JSC-SL-E-0002	NSTS Specification Electromagnetic Interference Characteristics, Requirements for Equipment
MM 8075.1	MSFC Software Management and Development Requirements Manual
MIL-B-5087B(2)	Bonding, Electrical and Lightning Protection, for Aerospace Systems
MIL-E-6051D	Military Specification Electromagnetic Compatibility Requirements, Systems
MIL-HDBK-5D	Metallic Materials And Elements For Aerospace Vehicle Structures
MIL-STD-461A(6)	Notice 1,2,3 - Electromagnetic Interference Characteristics, Requirements for Equipment
MIL-STD-461B	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-889B	Dissimilar Metals
MIL-STD-975F	Standard Parts List for Flight and Mission Essential Ground Support Equipment, Military Standard

MSFC-HDBK-505A	Structural Strength Program Requirements
MSFC-HDBK-527E	Material Selection Guide for MSFC Spacelab Payloads
MSFC-HDBK-1453	Fracture Control Program Requirements
MSFC-RPT-653-A	MLI Design Guidelines
MSFC-SPEC-522A	Design Criteria for Controlling Stress Corrosion Cracking
MSFC-SPEC-250A	Protective Finishes for Space Vehicles Structures and Associated Flight Equipment, General Specification for
MSFC-SPEC-494A	Installation of Harness Assembly (Electrical Wiring), Space Vehicle, General Specification, for
MSFC-SPEC-521	EMC Requirements, on Spacelab Payload Equipment
MSFC-STD-506B	Materials and Processes Control
MSFC-STD-512A	Standard Man/System Design Criteria for Manned Orbiting Payloads
MSFC-STD-781	Standard for Electrical Contacts, Retention Criteria
MSFC-STD-1249	Standard, NDE Guidelines, and Requirements for Fracture Control Programs
NHB 5300.4(1A-1)	Reliability Program Provisions for Aeronautical and Space System Contractors
NHB 5300.4(1B)	Quality Program Provisions for Aeronautical and Space System Contractors
NHB 5300.4(1C)	Inspection System Provisions for Aeronautical and Space System Materials, Parts, Components, and Services
NHB 5300.4(1D-2)	Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program
NHB 5300.4(1E)	Maintainability Program Requirements for Space Systems
NHB 5300.4(3A-1)	Requirement for Soldered Electrical Connections
NHB 5300.4(3G)	Requires for Interconnecting Cables, Harnesses, and Wiring
NHB 5300.4(3H)	Requirements for Crimping and Wire Wrap
NHB 5300.4(3I)	Requirements for Printed Wiring Boards

NHB 5300.4(3J)	Requirements for Conformal Coating and Staking of Printed Wiring Boards and Electronic Assemblies
NHB 5300.4(3K)	Requirements for Rigid Printed Wiring Board Design
NSTS 07700	Vol. XIV, G/38, Attachment 1, ICD-2-19001 Space Shuttle Flight and Ground System Specification, Shuttle Orbiter/Cargo Standard Interfaces
SLP-2104	Spacelab Payload Accommodation Handbook

3.2 SAFETY SPECIFICATIONS AND STANDARDS

I. OPR

EL51

II. PURPOSE

The following list of safety specifications and standards is provided as a ready reference for preparing requests for proposals and other contract documentation. Selections from this list in conjunction with the list in Section 3.1 would be the basis for an initial set of specs and standards. Note that with regard to safety specs and standards, they should be considered non-negotiable.

NUMBER	TITLE
JA-061	Payload Mission Manager Interface and Safety Verification Requirements for Instruments, Facilities, MPE, and ECE on STS Spacelab Payload Missions.
JA-276	Payload Mission Manager Interface and Safety Verification Requirements for Instruments, Facilities, MPE, and ECE on STS Orbiter Mid-deck Payload Missions.
MIL-B-5087B(2)	Bonding, Electrical, and Lightning Protection for Aerospace Systems.
MJA-081	Payload Mission Manager Interface and Safety Verification Requirements for Instruments, Facilities, MPE, and ECE on STS Partial Payload Missions.
MIL-HDBK-5D	Metallic Materials and Elements for Aerospace Vehicle Structures.
MIL-STD-461A	Electromagnetic Interference Characteristics, Requirements for Equipment.
MSFC-HDBK-505A	Structural Strength Program Requirements.
MSFC-HDBK-1453	Fracture Control Program Requirements.
MSFC-SPEC-250A	General Specification for Protective Finishes for Space Vehicle Structures and Associated Flight Equipment.
MSFC-SPEC-521A	EMC Requirements on Spacelab Payload Equipment.
MSFC-SPEC-522A	Design Criteria for Controlling Stress Corrosion Cracking.
MSFC-STD-126E	Inspection, Maintenance, Proof Testing, and Certification of Handling Equipment.
MSFC-STD-506	Standard for Material and Process Control.

MSFC-STD-561	Threaded Fasteners, Securing of Safety Critical Flight Hardware Structures.
MSFC-STD-1249	NDE Guidelines and Requirements for Fracture Control Programs.
NHB 1700.7	NASA Headquarters, Safety Policy and Requirements for Payloads Using the STS.
NHB 8060.1	Flammability, Odor, and Offgassing Requirements and Test Requirements for Materials.

3.3 MARSHALL MANUALS/MANAGEMENT INSTRUCTIONS (MM/MMI)

I. OPR

EL51

II. PURPOSE

The following is a list of system engineering-related MMs and MMIs for ready reference.

NUMBER	TITLE
MM 2314.2	MSFC Data Management Operating Procedures
MM 2348	MSFC Approved Baseline List of Specifications and Standards for Space Systems and Related Equipment
MM 7120.2	Project Management Handbook
MM 8040.12	Standard Contractor Configuration Management Requirements, MSFC Programs
MM 8040.20	Configuration Management Manual, MSFC Programs (not yet released)
MM 8075.1	MSFC Software Management and Development Requirements Manual
MMI 1700.18A	MSFC System Safety Program
MMI 2314.6	MSFC Data Requirements Management System
MMI 2410.11	MSFC Software Management Requirements for Flight Projects
MMI 5330.4	Deviation/Waiver Approval Requirements Request
MMI 6400.2	Packaging, Handling, and Moving of Program Critical Hardware
MMI 8010.5	MSFC Baseline Design Reviews
MMI 8040.15	Configuration Management
MMI 8040.19	Engineering Change Requests
MMI 8070.3	Specifications and Standards for Space Systems and Related Equipment
MMI 8080.5	Policy for Certification/Qualification of Flight Hardware and Program Critical Ground Support Equipment

MMI 8200.1	Task Agreements Between Program/Project Offices and the Science and Engineering Directorate (S&E)

4.0 ANALYSES

4.1 ANALYSES CHECKLIST

4.1 ANALYSES CHECKLIST

I. OPR

EL51

II. PURPOSE

A large number of systems analyses will be required during a typical project. The following should be considered a "shopping list" of analyses which may need to be planned and performed depending on the nature of the project in question. This list is not complete, nor are all such analyses performed within the SAIL.

TITLE	PURPOSE
Aerodynamics	Analyses used to investigate the forces acting on bodies moving through the air or other gaseous fluids. Includes examination of lift, drag, heating, stability, loads, noise, and trajectory through the atmosphere.
Circuit Protection/Fusing	Examines adequacy of circuit protection scheme/ components to protect distribution wiring and hardware. Assess trip characteristics of circuit protection devices to ensure compatibility.
Communications	In Phases A and B, these analyses are used to define communication subsystem requirements such as operating frequency, bandwidth, and modulation technique. During Phase C these analyses monitor predicted communication subsystem performance as the design matures, and in Phase D they verify the completed design meets project requirements.
Computer CPU	This analysis models and assesses CPU throughput requirements, and results are used to maintain a CPU margins report. Shortages of processor capability can be identified.
Computer Memory Margins	Used to model and assess computer system storage requirements and maintain a memory margins report. Shortages in computer memory can be identified.
Computing Architecture	Analysis of program and system functional and detailed computing requirements to decide, for example, between central or distributed processing. Associated trades and risks will be identified for all alternatives.

Contamination	Used to determine and identify contamination-sensitive areas that influence the design and to specify contamination requirements.
Cost	Includes determination of total system life-cycle costs which include acquisition costs, operations and support costs, and disposal cost, if applicable. Also refers to estimates used to examine the cost effectiveness of various engineering design solutions. In general, three basic approaches to estimating cost are by parametric modeling, analogy, and grass-roots or "bottoms up."
Data Bus Traffic	Models data and command sources and sinks and determines the maximum and average bus rates to maintain a data bus margins report.
Docking/Berthing	These analyses are based on specific operational scenarios and are conducted to aid in the definition of requirements and specifications. Among the technical issues addressed are capture envelope, contact conditions, loads, positional placement accuracies, visual alignment aids, mechanical alignment aids, approach corridors, and ready-to-latch indicators.
Electrical Power/Energy	Conducted to determine if adequate power and energy margins exist.
Electromagnetic Compatibility (EMC)	Performed to predict system-level performance based on equipment-level EMC test data. Conducted emissions/ susceptibilities, and turn-on transients are examined and margins determined.
Environments	Performed to define the expected near-surface, launch/landing and on-orbit environments. These analyses serve to increase overall system reliability and performance.
Error Budget	Performed to identify sources of error in system performance and attempt to conservatively quantify the effect of each. Statistical or other methods are used to model how individual (subsystem) errors are combined into total (system) errors. These analyses serve to ensure subsystem requirements and specifications are realistic and compatible with system requirements.

Failure Modes and Effects	Performed especially in the early stages of preliminary design to identify possible problems that could develop as a result of system failures.
Field of View	Typically applicable in projects where there are optical sensors with apertures. Used to determine or identify potential interferences or violations of field of view requirements.
Grounding	Used to verify proper spacecraft to orbiter or ASE combined system electrical grounding scheme.
Hazards	Includes the examination of safety risk identification and characterization. Various techniques are used to determine fault tolerance, propagation, and reliability in large, interconnected systems.
High-Order Language (HOL)	Assess data handling system and program requirements and examine candidate HOLs and associated trades-offs.
Uplink/Downlink and On-board Data Storage	Analyze the IPCL database against a mission scenario to determine the real-time and data storage rate requirements. Used to assure that adequate measurement and command data handling capability exists.
Interface	Performed to determine where hardware and software articles must interact at a common boundary. Identifies the physical and functional characteristics which must exist at all of the interfaces to facilitate fit and function compatibility of all hardware and/or software modules.
Lightning	Performed to determine the effects on electrical circuits if a lightning strike occurs. Both direct and indirect effects are examined.
Loads	Examines the weight supported by a structure, as well as the forces that are applied to a system, especially during launch and landing phases.
Maintainability	Evaluation of alternative system/ product design configurations involving maintenance options, alternative repair policies, and alternative logistic support plans.

Mass Properties	Used to determine design/hardware mass properties and provide status of mass properties controls and margins.
Micrometeroid and Debris Impact	Performed to develop protection requirements for hardware or to evaluate the system's ability to meet such requirements.
Performance	Assess the capability of the system design to meet technical requirements.
Pointing/Attitude Control	Performed to determine if the hardware pointing requirements can be met by the spacecraft and whether the spacecraft can provide the required attitude control.
Redundancy	Examine options for increasing reliability through the use of operating or standby redundancy. Trades among reliability, weight, cost, and other factors are required.
Reliability	Examination of the probability that a system will perform satisfactorily for a given period of time under certain specified operating conditions. Includes the generation of block diagrams, mathematical models, worst-case analysis, and sneak circuit analysis, among other things.
Risk	An examination of risk areas or events to determine options and the probable consequences for each event.
Stress	Examination of the forces acting across a unit area in a solid material in resisting the separation, compacting, or sliding that tends to be induced by external forces.
Thermal	Performed to determine first, if the thermal control concept is adequate to meet design requirements and later, to verify the final design of the thermal control system.
Venting	Used to develop or evaluate venting requirements and performance for enclosures during launch, ascent, and descent.
Voltage Drop	Performed to determine if adequate voltage levels are present at specified power system locations given varying loads and power source capabilities.

4.2 SYSTEM ANALYSES

4.2.1 TRADE STUDIES: WEIGHTED FACTORS

I. OPR

EL51

II. PURPOSE

A trade study is a technique used for determining which is the "best" of a number of options. Weighted factors is one type of trade study, used when a lot of information is available about the options under consideration.

III. DESCRIPTION

Weighted factors trade studies are run when each of the options is well defined, and there is good definition of what is important to a specific program. The first thing done is identification of the factors that are important, then, a weighting factor is assigned to each. Next, a determination is made as to how well each of the options meets each of the factors. Finally, the weights are taken into account and the "scores" are totalled. The decision is then based on the final score.

1. Describe each of the options in as much detail as possible. Include sketches, data tables, documentation, and any other pertinent information.

2. Determine what factors, or criteria, are important to the decision. These factors could be weight, cost, complexity, technology availability, safety, maintainability, manufacturability, or anything else that is important to the program or project (See Figure 1).

FACTOR
Weight
Cost
Complexity
Safety
Maintainability
Manufacturability

Figure 1. Factors

3. Assign a weight to each factor. These weights should be a number between 0 and 1, where 0 implies that the factor is not important, and 1 implies that the factor is critically important (See Figure 2).

FACTOR	WEIGHT
Weight	0.8
Cost	0.9
Complexity	0.3
Safety	0.6
Maintainability	0.4
Manufacturability	0.4

Figure 2. Weights

4. For the first option, decide how well it "meets" each factor, again assigning a rating value between 0 and 1 (See Figure 3).

	Option 1	
FACTOR	WEIGHT	RATING
Weight	0.8	0.3
Cost	0.9	0.6
Complexity	0.3	0.9
Safety	0.6	0.9
Maintainability	0.4	0.9
Manufacturability	0.4	0.7

Figure 3. Assign Ratings

5. Score the values decided upon in step 4 by multiplying the weight by the rating factor, and then total the scores for this option (See Figure 4).

FACTOR	Option 1 WEIGHT	RATING	SCORE
Weight	0.8	0.3	0.24
Cost	0.9	0.6	0.54
Complexity	0.3	0.9	0.27
Safety	0.6	0.9	0.54
Maintainability	0.4	0.9	0.36
Manufacturability	0.4	0.7	0.28
			Total 2.23

Figure 4. Scoring

6. Repeat steps 4 and 5 for each option (See Figure 5). Based on the results shown, Option 2 would be the preferred option.

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I. MSFC System Engineering "Toolbox" for Design-oriented Engineers, Section 2.1.

V. EXAMPLE

A weighted factors methodology was used by MSFC to determine custodianship for each Interface Control Document (ICD) for the Space Station Freedom Program (SSFP). This methodology helped determine which NASA Center would prepare and maintain each ICD within the established SSFP inter-center configuration management procedures.

The steps taken in applying this methodology were exactly as listed above. Eight criteria were selected and assigned a relative weight based on the importance of each (with respect to each other) to determination of ICD sponsorship. The criteria and rationale were as follows:

1. Integration Center - Is one center accountable for integration of the interfaces controlled by this ICD? This criterion was considered relatively the most important, because the integration center will have final responsibility for certification of flight readiness of the interfaces controlled by the this ICD **Relative weight = 6**

2. US Center - Is the participant a US Center? This criterion was considered the next most important because of Agency experience and projected responsibility. **Relative weight = 5.**

3. Flight Hardware/Software - Is the interfacing article flight hardware/software (as opposed to support hardware/ software)? Flight hardware/ software

takes precedence. **Relative weight = 4.**

4. Flight Sequence - Does one side of the interfacing article fly on an earlier manifest than the other? An earlier flight sequence takes precedence over follow-on interfacing hard-ware. **Relative weight = 4.**

5. Host/user - Is the interfacing article a facility (as opposed to a user of the facility)? **Relative weight = 3.**

6. Complexity - How complex is the interfacing article (relative to each side)? The more complex half of the interface normally takes precedence. **Relative weight = 3.**

7. Behavior - How active is the interfacing article? The active side normally takes precedence over the passive side. **Relative weight = 1.**

8. Partitions - How are the partitions (Structural/ Mechanical, Electrical, Data/Software, Fluids) used by the interfacing articles. **Relative weight = 3.**

Scores were assigned to each interfacing article for each of the criteria. Discrete values were assigned to the first four criteria. A score of 1.0 was assigned is the interfacing article was unique in meeting the criterion, with the other article receiving a 0.0 score. Scores of 0.5 were assigned to both articles if both (or neither) of them met the criterion. Criteria 5 through 8 did not lend themselves to discrete values, so two methods of determining scores that were used were verbal consensus, and an unbiased survey.

The final results of this analysis are presented in Figure 6.

A variation of the weighted factors trade study is the Analytic Hierarchy Process (Ref. C,D) (AHP). The AHP provides a multi-criteria decision analysis methodology that allows subjective as well as objective factors to be considered in the trade study process.

The AHP employs a pairwise comparison process such that weights, or priorities, are not arbitrarily *assigned*, as in the preceding example, but are *derived* from the decision maker's verbal or numerical judgments. In addition to numerical weights, the AHP enables the user to perform a series of pairwise relative comparisons between each of the attributes using adjectives like *equal, moderate, strong, very strong*, and *extreme*.

		Option 1		Option 2	
FACTOR	WEIGHT	RATING	SCORE	RATING	SCORE
Weight	0.8	0.3	0.24	0.6	0.48
Cost	0.9	0.6	0.54	0.8	0.72
Complexity	0.3	0.8	0.24	0.6	0.18
Safety	0.6	0.9	0.54	0.7	0.42
Maintainability	0.4	0.9	0.36	0.6	0.24
Manufacturability	0.4	0.7	0.28	0.7	0.28
		Total	2.20		2.32

Figure 5. Completed Analysis

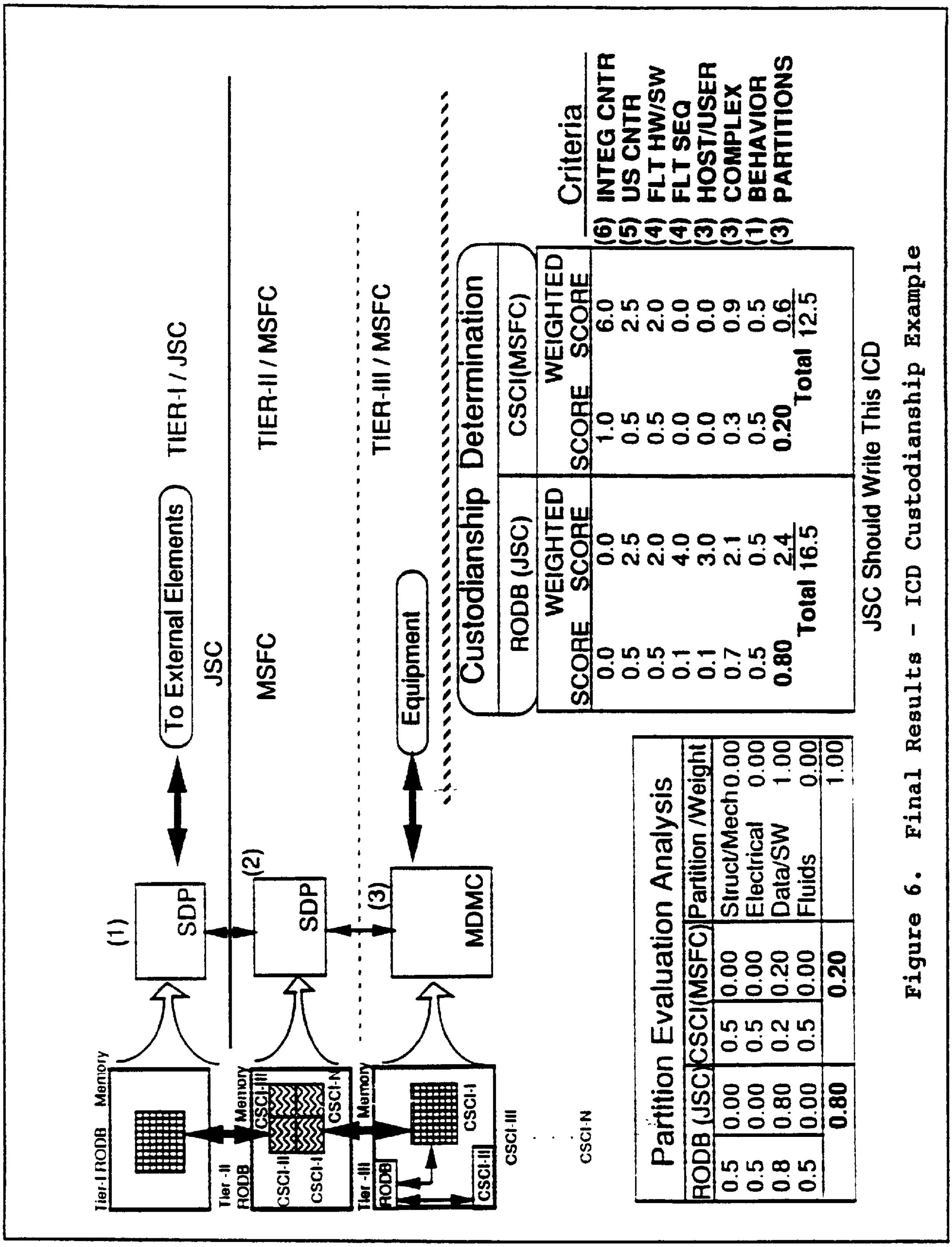
Validating verbal comparisons is important because almost every decision contains subjective or qualitative factors which do not readily lend themselves to numerical judgments. Words are often easier to justify than numbers, too. For example, if one proposes that cleaning up the air is three times more important than cleaning up the water, can the factor three be substantiated? Why not 2.5 or 4.0? On the other hand, if you said that clean air is *moderately* more important than clean water, this can be justified with a variety of arguments including some facts.Decision support software (Ref. E,F) has been developed which combines such verbal judgments and derives accurate priorities. The AHP method basically consists of three steps:

1. Structure the elements of the problem into a hierarchy.

2. Develop the relative weights of the various elements (again, these can be numerical values or adjectives as discussed above).

3. Synthesize and determine the likelihoods of each factor and sub-factor. These likelihoods are determined by aggregating their relative weights through the hierarchy (up to the highest level).

The use of decision support software makes structuring and modifying the hierarchy simple and quick, eliminating tedious calculations. For details on applications and the steps outlined above, see references G and H.



Partition Evaluation Analysis

	RODB (JSC)		CSCI(MSFC)	Partition /Weight
0.5	0.00	0.5	0.00	Struct/Mech 0.00
0.5	0.00	0.5	0.00	Electrical 0.00
0.8	0.80	0.2	0.20	Data/SW 1.00
0.5	0.00	0.5	0.00	Fluids 0.00
	0.80		0.20	1.00

Custodianship Determination

Criteria	RODB (JSC) SCORE	RODB (JSC) WEIGHTED SCORE	CSCI(MSFC) SCORE	CSCI(MSFC) WEIGHTED SCORE
(6) INTEG CNTR	0.0	0.0	1.0	6.0
(5) US CNTR	0.5	2.5	0.5	2.5
(4) FLT HW/SW	0.5	2.0	0.5	2.0
(4) FLT SEQ	0.1	4.0	0.0	0.0
(3) HOST/USER	0.1	3.0	0.0	0.0
(3) COMPLEX	0.7	2.1	0.3	0.9
(1) BEHAVIOR	0.5	0.5	0.5	0.5
(3) PARTITIONS	0.80	2.4	0.20	0.6
		Total 16.5		Total 12.5

JSC Should Write This ICD

Figure 6. Final Results - ICD Custodianship Example

4.2.2 TRADE STUDIES: ADVANTAGE/DISADVANTAGE

I. OPR

EL51

II. PURPOSE

A Trade study is a technique used for determining which is the "best" of a number of options. Advantage/Disadvantage is one type of trade study, used when there is not much information about the options under consideration, or when it is difficult to quantify how well each option satisfies the criteria selected.

III. DESCRIPTION

Each of the options is evaluated, identifying the advantages and disadvantages of each. These determinations can be made by a cognizant individual or group. The results are then presented to a decision-maker who makes a subjective decision, based on the information available, as to which is the "best" option.

IV. REFERENCES

MSFC System Engineering "Toolbox" for Design-oriented Engineers, Section 2.1, March 1994.

V. EXAMPLE

NASA/MSFC is faced with a decision as to which way to proceed with evolution of the nation's space transportation system. Options to be considered include, but are not limited to:

1(a) Liquid propellant engines vs. Solid propellant motors

(b) Liquid Rocket Boosters vs. Solid Rocket Boosters

For Liquids only:

2) Pump-fed vs. Pressure-fed

1(a) Liquid Propellants -- ADVANTAGES--

Flight-proven effectiveness and reliability

High specific impulse

Good control for fine Delta-V adjustments

Entire propulsion system can be assembled and test-fired on the ground in near flight configuration

--DISADVANTAGES--

Complexity in operation--many components must work together properly

Require ancillary systems to support them:

- A propellant feed system
- A pressurization system for the tanks
- A chilldown system for cryogenic systems
- An accurately calibrated propellant loading system for both propellants, in order to minimize residuals

Engine mixture ratio must be controlled to a high degree

- tight mixture ratio constraints
- both propellants fully consumed to minimize residuals

1(a) Solid Propellants -- ADVANTAGES--

Flight-proven effectiveness and reliability

Relative simplicity in operation

Fewer parts and support systems required

Cheaper, more cost-effective, in general, for boost applications than liquid systems[1]

No inflight mixture ratio control is required

Propellant utilization always 100%, with no residuals remaining[2]

System is self-pressurizing[3]

--DISADVANTAGES--

Ignition system required

Exhaust products can be toxic and pollute the environment

Case walls/joints must be isolated from hot combustion gases

Cannot be acceptance tested before use

- First full-up flight configuration test occurs in the flight environment

1(b) LIQUID ROCKET BOOSTERS (LRBs) vs. SOLID ROCKET BOOSTERS (SRBs)

LRBs --ADVANTAGES--

Developing LRBs in consort with NLS/HLLV (National Launch System/Heavy Lift Launch Vehicle) propulsion needs could actually be a cost-effective path and could help evolve both the Shuttle and NLS programs.

Allow a variety of safe abort modes. Several engines could fail on ˋ off and still not cause a cata-strophic i.. .sion failure. If the engine monitoring systems indicate a problem, the engines can be shut down and the flight aborted on the pad.

The LRBs can be tightly monitored during flight and can be shut down if a problem arises. If an engine(s) must be shut down, the remaining engines can be throttled (unlike solids) to compensate for changed moments of force about the vehicle's center of gravity to reduce airframe stress and prevent cartwheeling.[4]

The LRB performance improvement for the Shuttle could be an additional 20,000 lbs. above the Shuttle using reusable solid rocket motors (RSRMs) and an additional 8,000-12,000 lbs. above the Shuttle using the advance solid rocket motors (ASRMs).[5]

Mission profile changes can be readily accommodated: throttling LRBs within reasonable thrust ranges is relatively easy and can be used to compensate for different payloads atmos-pheric conditions, desired trajectories or orbits, etc.

Liquid cryogenic fuels are well understood and have a good safety record.

Lighter structure of LRBs would allow horizontal assembly (empty LRB tanks are

1 This may be subject to change i: .uture -- see 1.b. below

2 Except for stages with submerged nozzles where some slag may remain onboard.

3 The gases produced by the burning propellants themselves pressurize the motor case

4 Complications induced by failure of more than one engine have not been thoroughly investigated.

5 U.S. Congress, Office of Technology Assessment, Round Trip to Orbit: Human Spaceflight Alternatives--Special Report (Appendix A), OTA-ISC-419 (Washington, D.C.: U.S. Government Printing Office, August 1979). This performance increase, which is nearly double that planned for the ASRMs, ·ould be possible in part because the LRBs would be ıonger and of greater diameter than the ASRMs. NASA held the diameter and length of the ASRM design to dimensions that would necessitate little or no alteration of the mobile launch platform. Because liquid eng· ·es would require fuel tanks that are larger than the AS . M dimensions to reach even 12,000 pound additional thrust, NASA relaxed the geometrical constraints in the LRB design.

lighter than assembled solid rocket motor segments, which have to be stacked vertically). Horizontal assembly and transport is much easier than vertical processing.

- Processing in the vehicle assembly building (VAB) would be faster and less dangerous with liquid boosters.

The LRBs are more environmentally sound - the exhaust of an LRB fueled by liquid hydrogen would consist solely of steam.[1]

--DISADVANTAGES--

Technical uncertainties -- the engine technology is known but the engines do not yet exist.

Long development times -- if an LRB program started today, liquid boosters might not be available for at least eight years.[2]

High initial cost -- NASA estimates that LRBs would cost $3 billion. Pad modifications would cost about $0.5 billion. A new flight dynamics data base would also have to be generated. If LRBs cost significantly more to develop than ASRMs, they could strain an already tight NASA budget.

NASA would need to dedicate a unique launching pad to LRBs because during the transition from solids to liquids, fuel handling, launch tower needs, component logistics, etc. would differ from those on the current Shuttle system.

1 Even if RP-1 (kerosene) or some other hydrocarbon fuel were used, the exhaust would be steam and carbon dioxide, along with small amounts of other gases.

2 This long time period results from the stringent development and testing requirements inherent for a new engine system, particularly one that must be "crew rated".

SRBs --ADVANTAGES--

Flight-proven effectiveness and reliability. Solid boosters have higher **density** specific impulse, are generally more compact than cryogenically-fueled boosters, and more reliable because they are simpler and have less moving parts. Infrastructure is in place for relatively inexpensive manufacture and production.

The ASRMs represent less development risk than do the LRBs.

--DISADVANTAGES--

A failure is generally catastrophic because solids cannot be turned off after they are ignited, but must burn through all of their fuel.

Once a solid is poured to a predetermined configuration, its burn and hence thrust characteristics are set, fixing the direction and speed of the Shuttle on ascent.

Solid booster thrust characteristics sometimes change unpredictably when the solids age.

The SRMs carry explosive fuel at all times and must be handled carefully.[3]

Environmental considerations -- the exhaust of a typical solid propellant rocket contains large amounts of hydrochloric acid.

2. PUMP-FED VS. PRESSURE-FED ENGINES

Pump-fed --ADVANTAGES--

Higher performance (by providing higher chamber pressure)

3 Safety considerations are a critical, and expensive, part of SRM use -- from manufacture, to transport, to launch vehicle mating, to liftoff.

Mature technology exists with a considerable experience base (especially for boost applications).

Turbopumps provide high chamber pressure (minimizing engine size) while permitting low stage weight by maintaining low tank pressure.

--DISADVANTAGES--

More complex because of the required turbomachinery that operates at high temperature and high rotational speed.[1]

Preburner design can dictate that very *high* operating temperatures be accommodated alongside *low* cryogenic temperatures.

Pressure-fed **--ADVANTAGES--**

Generally simpler and less expensive

- Reduced complexity and design for minimum cost increases attractiveness of completely expendable launch vehicles

--DISADVANTAGES--

Limited to relatively low chamber pressures -- propellant tanks must be pressurized to a level that will give satisfactory engine performance.[2]

Larger, heavier tanks require larger launch pads and facilities.

Design uncertainties persist related to the manufacture and demonstration of very large, pressure-fed engines.

- Unknowns associated with combustion performance and stability, and complexity of pressurization system.

Based upon study of the differing advantages and disadvantages of the above options as well as others not included here for brevity, the decision-making group could establish a preferred baseline concept for an NLS as follows:

A liquid-rocket propelled core stage vehicle, powered by SIX hydrogen-oxygen engines, four for boost mode and two for sustained mode thrust. This vehicle will use two large solid-propellant boosters for heavier payloads, advanced versions of the present Space Shuttle RSRMs, called ASRMs.

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1 A pump-fed engine may have 15,000 parts compared with fewer than 100 in a pressure-fed engine.

2 Usually limits pressure-fed engines to small upper stages where the required increased tank wall thickness does not impact system weight to such a high degree.

4.2.3 FUNCTIONAL FLOW ANALYSIS

I. OPR

EL56

II. PURPOSE

Functional Analysis (and the generation of functional flow diagrams) is intended to facilitate the design, development, and system definition process in a complete and logical manner, by structuring system requirements into functional terms.

III. DESCRIPTION

The Functional Analysis is based on the definition of the system operational requirements and the system maintenance concept, and is subsequently used as the basis for detail design. There are a number of interrelated detail design tools which must track the top-level functional analysis (e.g., operational and maintenance functional block diagrams). Objectives are to:

1. identify the system/sub-system functions,

2. identify the method for accomplishing the various functions (manually, automatically, or a combination thereof), and

3. identify the resources required to accomplish the function.

Both the operational and maintenance support aspects, as related to anticipated system life-cycle use in the consumer environment, must be addressed.

Functional flow diagrams are developed for the primary purpose of structuring system requirements into functional terms. They are developed to indicate basic system organization, and to identify functional interfaces. Functional blocks are concerned with what is to be accomplished, versus the realization of how something should be done. It is relatively easy to evolve prematurely into equipment block diagrams without having first established functional requirements. The decision concerning which functions should be performed by a piece of equipment, or by an element of software, or by a human being, or by a combination of each should not be made until the complete scope of requirements has been clearly defined. In other words, not one piece of equipment should be defined or acquired without first justifying its need through the functional requirements definition process.

Functional flow diagrams are employed as a mechanism for portraying system design requirements in a pictorial manner, illustrating series and parallel relationships, the hierarchy of system functions, and functional interfaces. Functional flow diagrams are designated as top level, first level, second level, and so on. The top level diagram shows gross operational functions. The first and second level diagrams represent progressive expansions of the individual functions of the preceding level.

Functional flow diagrams are prepared down to the level necessary to establish the needs (hardware, software, facilities, personnel, data) of the system. The indenture relationships of functions by level are illustrated in Figure 4.2.3-1.

Functional flow diagrams (or functional block diagrams) are developed to describe the system in functional terms. These are developed to reflect both operational and support activities as they occur throughout the system life cycle, and they are structured in a manner that illustrates the hierarchical aspects of a system (See Figure 4.2.3-1). Some key steps involved in the overall functional flow diagram process are noted as follows:

1. The functional block diagram approach should include coverage of **all** activities throughout the system life cycle, and the method of presentation should reflect proper activity sequences and interface interrelationships.

2. The information included within the functional blocks should be concerned with **what** is required before looking at **how** it should be accomplished.

3. The process should be flexible to allow for expansion if additional definition is required or reduction if too much detail is presented. The objective is to progressively and systematically work down to the level where resources can be identified with **how** a task should be accomplished.

The outputs associated with the generation of functional flows are many. First, the process enables the systems engineer to approach design from a logical and systematic standpoint. The proper sequences and design relationships are readily established. Second, the preparation of functional flows forces the integration of the numerous interfaces that exist in system development and operation. Both internal and external interface problems are quickly identified at an early stage in the life cycle. Sometimes these benefits are difficult to visualize unless one has actually had some experience in functional analysis. However, it has been shown that many operational problems which occur later in the life cycle could have been avoided had this approach been followed initially.

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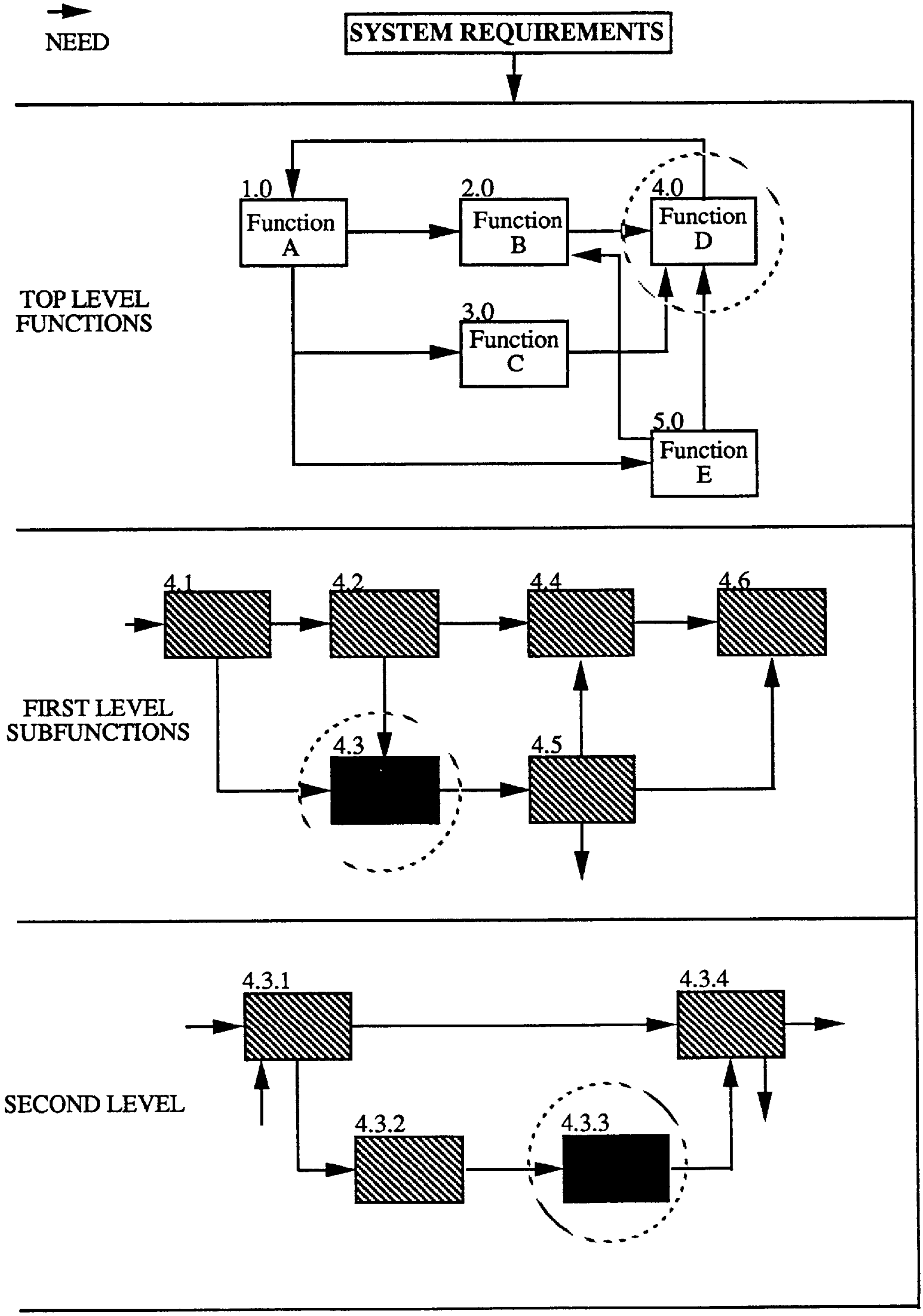

Figure 4.2.3-1. System Functional Indenture Levels

4.2.4 RESOURCE ALLOCATION

I. OPR

EL56

II. PURPOSE

Resource Allocation techniques allow the systems engineer to parcel out resources (crew-time, propellant, prime power, weight, volume, etc.) according to some predetermined set of criteria and objectives.

III. DESCRIPTION

Generally, resource allocation problems involve the problem of allocating limited resources among competing activities in the best possible way (i.e., optimal). This problem of allocation can arise whenever one must select the level of certain activities that compete for scarce resources necessary to perform those activities.

Many methods and techniques exist for solving resource allocation problems. These techniques include, but are not limited to, linear programming, goal programming, integer programming, and dynamic programming for linear problems; and geometric, quadratic and gradient methods for nonlinear problems. Nonlinear programming is used whenever nonlinear relationships appear in either the objective function or in one or more of the side constraints or both.

Most resource allocation techniques require two major inputs: (1) an objective function - this could be to optimize (maximize or minimize a specific resource (cost, tanks, etc.), in terms of known variables or parameters, and (2) a set of constraining functions in terms of the same variables. The goal is to find the values of the parameters or variables that optimize the objective function. Variations on these are problems that have multiple objectives (minimize cost, time and weight). These problems are referred to as multiple objective linear programming problems.

To give directions for each technique used in resource allocation problems would require much more space than is allocated for this handbook; therefore, we suggest the reader consult the references listed in Section IV.

The outputs of these tools are optimal values for the resources (time) at some maximized (merit) or minimized criteria. These tools are valuable in both early phase developments, during detail design phases especially when trade studies and cost-cutting measures are required.

Another asset of these tools is that they are, for the most part, available for personal computers and are easy to use. In dealing with two-variable type problems, the added feature of graphical output for management explanation is also available.

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4.3 TECHNICAL ANALYSES

4.3.1 MISSION ANALYSES

4.3.1.1 MISSION REQUIREMENT ANALYSIS

I. OPR

EL58

II. PURPOSE

The purpose of Mission Requirement Analysis (MRA) is to evaluate overall mission objectives leading to the definition of detailed mission requirements. These may be functional, performance, or operations in nature.

III. DESCRIPTION

Mission Requirement Analysis is the process which transforms overall program objectives into detailed mission requirements. It begins with the identification and extraction of mission objectives from higher level project documents (Level I/II). Mission objectives are then translated into mission requirements. The output or result of this analysis is the Mission Requirements Document (MRD) which is verified and accepted through the review process (PRR, PDR, etc., as described in Section 5.1). This document serves as the guideline in designing and developing the mission.

The mission requirements are then analyzed to determine the impact of these requirements on the system. Finally, the mission requirements are an input for both the other mission analyses and the systems requirements analysis. Any conflict between requirements and system capabalitites must be resolved before the requirements are included in the MRD.

IV. REFERENCES

None.

4.3.1.2 MISSION PLANNING AND PROFILE GENERATION

I. OPR

EL58

II. PURPOSE

The purpose of Mission Planning and Profile Generation (MPPG) is to develop the detailed mission plan, which consists of an optimum flight trajectory and/or mission profile (timed sequence of events).

III. DESCRIPTION

Mission Planning and Profile Generation is a major effort for mission analysts to ensure that the mission profile satisfies as many mission objectives as possible while not violating any system constraints or capabilities. In general, MPPG requires considerable interactions with other Systems Engineering disciplines. The goal of this effort is the trajectory design or orbit selection that maximizes accomplishment of mission objectives within the mission constraints. The trajectory/profile is then documented with a detailed sequence of events timeline called the mission profile. This serves as the baseline and the starting point for the detailed Mission Performance and System Analysis studies.

In addition, the outputs from the MPPG include preliminary descriptions of hardware and software systems (such as guidance and navigation systems) required to support the mission, preliminary parametric performance estimates, and a preliminary launch window evaluation. Finally, the mission profile can also be formally documented into a Design Reference Mission (DRM). However, DRMs are usually generated and used only in the earliest stages of program development.

A typical product may include a 30-Day Representative Timeline as a follow-on to a Design Reference Mission timeline for an on orbit science mission. The results may consist of a prescribed order for viewing a set of science targets along with viewing times and the required inertial attitude profile for each target so that communications, thermal, and solar power requirements are met while science viewing requirements are also satisfied.

Depending upon the type of mission being designed any or all of several computer programs (tools) may be used. Some are standard major software packages or simulators (such as ASEP, GRAVE, POST, QGAP, SCOOT, and SKYMAP) while others may be smaller analytic software developed and tailored for particular projects.

The tools used for both the mission planning and profile generation and mission performance analysis are summarized in Section 6.0 of this Volume.

IV. REFERENCES

None.

4.3.1.3 MISSION PERFORMANCE ANALYSIS

I. OPR

EL58

II. PURPOSE

The purpose of Mission Performance Analysis (MPA) is to assess the capability of the system design to perform the mission as defined by the requirements and specifications.

III. DESCRIPTION

The analysis examines a design for performance of the system itself or any of its pieces, i.e., elements and subsystems. The tasks which need to be accomplished in this analysis are highly mission dependent and the scope of MPA can range from relatively straight forward parametric studies to sophisticated models which simulate the system design end to end. MPA is an on-going task through the various phases of a program. MPA is a primary feedback mechanism to the program management as to the performance and capability of the evolving system design.

A variety of MPA tools can be applied to this analytic process. Most tools used for MPA are summarized in Section 6.0.

IV. REFERENCES

None.

4.3.2 COMMUNICATION ANALYSES

4.3.2.1 RADIO FREQUENCY LINK MARGIN ANALYSIS

I. OPR

EL56

II. PURPOSE

The link margin analysis is employed in the system design of a data link and examines the link margin to ensure that the link will maintain signal fidelity and synchronization.

III. DESCRIPTION

The link margin is highly analogous to the more familiar financial budget. Both are concerned with balancing assets and liabilities and use projected or predicted entries, at least in part. Both provide a preview of the new balance and suggest areas where adjustments may be made. The link margin balances gains and losses within a communications link to achieve the necessary net gain, or signal margin. Consequently, the link margin permits one to establish the feasibility and suitability of a desired communications link before proceeding with design and development.

The link margin is a systems design tool first exercised when the prospective communications link is in the conceptual or formative stage. This early application involves tentative data entries to establish feasibility. As planning matures, this tentative data becomes the link requirements. The link margin is maintained current throughout the development process, including verification testing. In this way, inevitable changes occurring to system parameters during development are assessed for impact on projected system performance.

Transferring information from one point in space to another by electromagnetic wave propagation requires a transfer of energy. One may express this energy transfer as an equation, where each communications link contributes a gain or loss. This equation, and the associated link margin, will quantify the essentials of communication link operation.

The operative communications link equation may be expressed as:

$$LM = EIRP - L_p + G_r - L_{ri} - L_n - E_b/N_o - L_i$$

where:

LM = Link Margin

EIRP $= P_t + G_t L_{ti}$ (Effective Isotropic Radiated Power)

P_t = Transmit Power (dBm)

G_t = Transmit Antenna Gain (dBi)

L_{ti} = Transmitter Implementation Losses
- Pointing Loss
- Component Line Loss

L_p = Propagation Losses (dB)
- Free Space Loss
- Atmospheric Absorption
- Precipitation Absorption

G_r = Receiving Antenna Gain (dBi)

L_{ri} = Receiver Implementation Losses (dB)
- Polarization Loss
- Pointing Loss
- Component Line Loss

L_n = Noise Floor (dBm)
- Thermal Noise Density (dBm/Hz)
- Receiver Noise Bandwidth (dBHz)
- Receiver Noise Figure (dB)

E_b/N_o = Signal to Noise Ratio required to achieve specified data quality.

L_i = Receiver Implementation Losses

The communication link equation expresses the "available" signal to noise ratio at the receiver in terms of link parameters. The parameters of this equation are expressed in decibels.

Given the definition of terms, the link equation may conveniently be expressed in tabular format as exhibited in Table I. Completing the individual entries is a systematic way of making data link implementation decisions. All such decisions are initially tentative. Ultimately, a proper balance between gains and losses must be achieved. Many parameters are available for adjustment to achieve a desired signal margin.

IV. REFERENCES

A. STDN 101.2, Appendix G; "SN User's Guide," Rev. 6, 1989.

B. Pratt, Timothy and Charles W. Bostian, Satellite Communications, John Wiley & Sons, New York, 1986.

C. DR STD/SE-CSAS, "Radio Frequency Communications System Analysis and Studies."

Table I. Example Link Margin for a Return Link

Item	Parameter	Entry, dB I	Entry, dB Q
1.	Transmitter (Tx) Power, P_t	7.0	7.0
2.	Tx Component Line Loss, L_{ti}	-2.6	-2.6
3.	Tx Antenna Gain, G_t	26.4	26.4
4.	Free Space Loss, L_p	-192.5	-192.5
5.	Available Signal-to-Noise Ratio (SNR)	-161.7	-161.7
6.	Required SNR, E_b/N_o	-182.0	-182.0
7.	Data Channel Power Ratio	-3.0	-3.0
8.	Link Margin, L_m	17.3	17.3
9.	Combined Link Margin (I + Q) 20.3		

4.3.2.2 FLUX DENSITY ANALYSIS

I. OPR

EL56

II. PURPOSE

The purpose of the Flux Density Analysis is to determine if the TDRSS return service spectral Power Flux Density (PFD) generated at the surface of the earth by user spacecraft is within the limits established by the Interdepartmental Radio Advisory Committee (IRAC).

III. DESCRIPTION

Spacecraft using the TDRSS return services, both S-band and K-band, impinge the surface of the earth with electromagnetic energy, stated as PFD. The IRAC has placed limits on the PFD that can be generated at the earth's surface, and these limits can be found in S-805-1, TDRSS Performance Specification, Rev. B. Conformance with these limits is necessary to preclude harmful interference to terrestrial systems operating in the same frequency band. Various methods of verifying conformance with these limits, calculation of the PFD, and example PFD calculations can be found in Appendix G, STDN 101.2 SN User's Guide, Rev. 6, 1989.

This analysis is performed by the communications systems engineer. Its outcome may impact the communication system design. Therefore, it should be done as soon as the communication system return link design is completed. If the design is affected and changes are made to the design, it should be repeated as often as the design changes to reflect the new design.

IV. REFERENCES

A. S-805-1, "TDRSS Performance Specification," Rev. B.

B. STDN 101.2, Appendix G; "SN User's Guide," Rev. 6, 1989.

C. DR STD/SE-CSAS, "Radio Frequency Communications System Analysis and Studies."

4.3.2.3 TDRSS COVERAGE ANALYSIS

I. OPR

EL56

II. PURPOSE

The purpose of the Tracking and Data Relay Satellite System (TDRSS) Coverage Analysis is to determine the amount of time for each orbit that a user spacecraft will be in the field of view of a Tracking and Data Relay Satellite (TDRS).

III. DESCRIPTION

An analysis of the TDRSS coverage determines the line of sight access to TDRSS in terms of orbit access time. Several factors contribute to this analysis which include TDRSS coverage, self-obscuration or shadowing of the Radio Frequency (RF) beam by the spacecraft's body, and sun pointing constraints.

The most severe limitation on orbit access time results from the obscuration by the earth's shadow. Because the TDRSS configuration consists of two TDRS's and one ground station, a Zone of Exclusion (ZOE) exists where communication with TDRSS is blocked by the earth's shadow as indicated in Figure 4.3.2.3-1. The TDRSS coverage is a function of altitude and inclination of the user spacecraft. Figure 4.3.2.3-2, from the Space Network (SN) User's Guide, STDN 101.2, gives the typical coverage for various altitudes and inclinations. The minimum coverage is 85 percent for lower altitude orbits, while above 1200 km and below 3000 km for Multiple Access(MA) service and below 10000 km for Single Access(SA) service results in 100 percent coverage. For example, a spacecraft with an altitude of 600 km and an inclination of 28.5 degrees would have an orbit access time of approximately 94 percent of each orbit.

Another condition which limits orbit access time is obscuration of the RF beam by the spacecraft's own body. Because of the spacecraft's design and the TDRSS configuration, the spacecraft itself may block the line of sight between its antenna and a TDRS. An analysis is performed, relating the position of the spacecraft and its orientation with respect to TDRSS, to determine if and when self- obscuration occurs.

Additional operational constraints affect the TDRSS coverage access time. These constraints are as follows:

* No MA forward link service will be scheduled when the TDRSS is in the earth's shadow (power constraint).

* No MA service is available when the center of the sun is either within 3 degrees of the TDRS MA return service antenna beam boresight or within 1 degree of the boresight of the WSGT antenna supporting that TDRS (sun outage).

* No SSA or KSA return service is available when the center of the sun is within 4 or 1 degrees of the TDRS SA antenna, SSA or KSA boresight, respectively or within 1 degree of the boresight of the WSGT antenna supporting that TDRS (sun outage).

Refer to the SN User's Guide, STDN 101.2, Rev. 6 for more detail and example coverage constraints.

IV. REFERENCES

STDN 101.2, "SN User's Guide," Rev. 6.

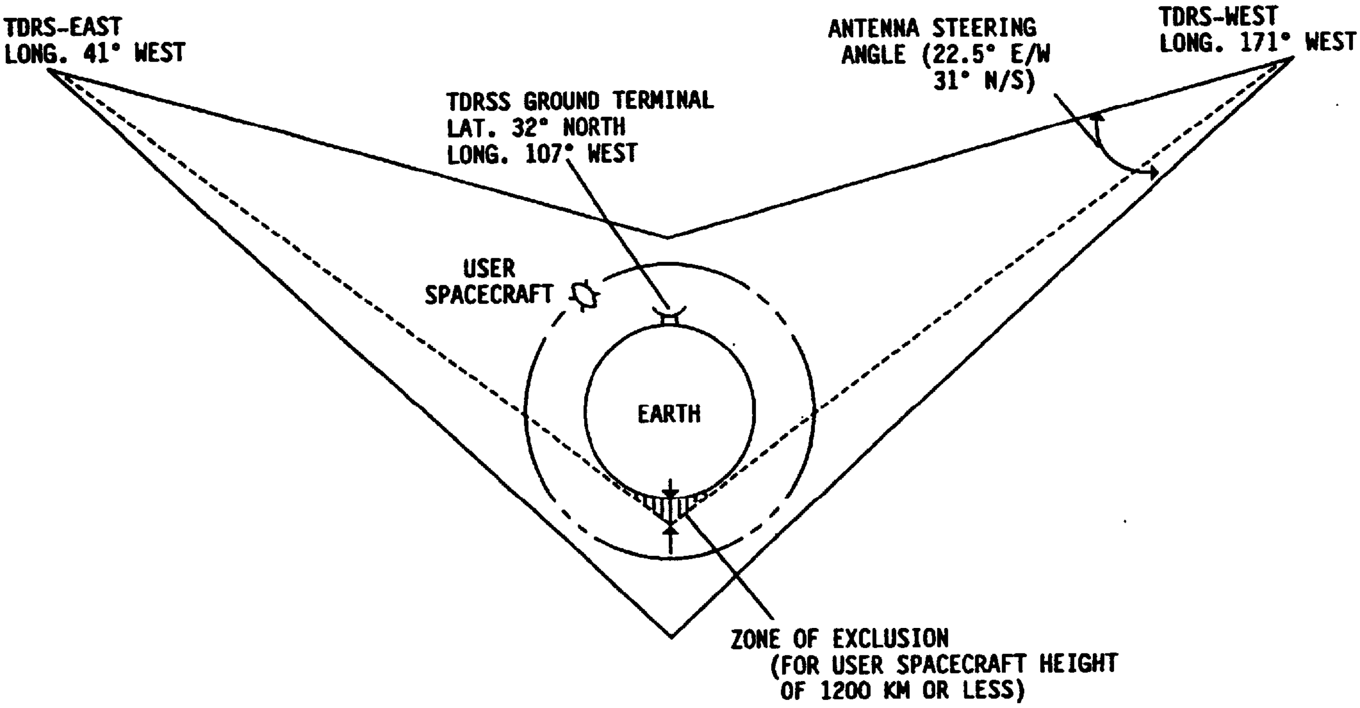


Figure 4.3.2.3-1. TDRSS Configuration and Coverage Limits

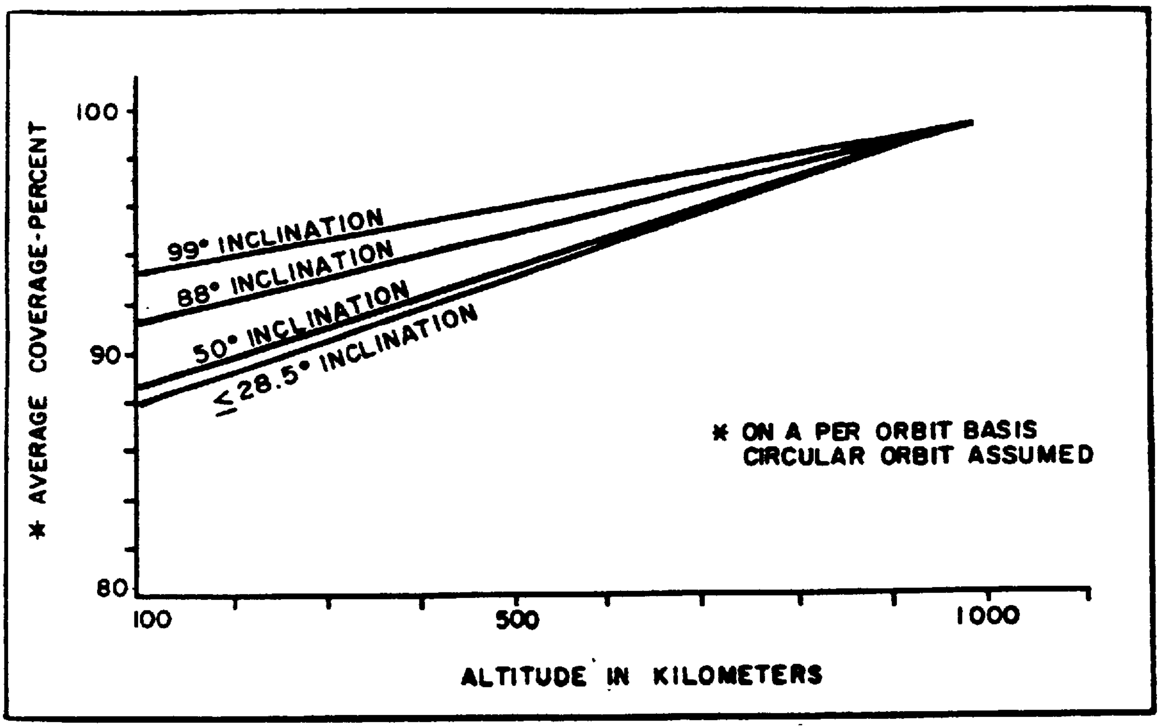


Figure 4.3.2.3-2. Average Geometric Coverage vs. User Spacecraft Altitudes at Various Inclinations

4.3.2.4 COMMUNICATIONS REQUIREMENTS ANALYSIS

I. OPR

EL56

II. PURPOSE

This analysis is used to develop a preliminary specification that describes the communication requirements at a high level. These requirements are used to develop a more detailed design.

III. DESCRIPTION

The requirements analysis begins with a mission analysis. This is a high level examination of the mission and functions that the project will perform. The analysis will examine the objective of the project, and the support required from other spacecraft or projects. It will identify the communication needs to support the mission, functions, and objectives.

TABLE I. MISSION ANALYSIS OUTPUTS.

ANALYSIS	- Requirement
MISSION DESCRIPTION	
	- Orbital Range
	- Inclination
	- Orbital Features
MISSION DATA	
	- Data Types
	- Data Rates
	- Communication Timeline
INTERFACE	
	- Intraprogram
	- Interprogram (TDRSS)
TELECOMMUNICATIONS	
	- Return
	- Forward
	- Tracking

The mission analysis consists of four basic parts. These are a mission description analysis, mission data analysis, interface analysis, and a telecommunications support analysis. These analyses and their respective outputs are given in Table I. The outputs from the mission analysis are used to drive and develop communication requirements. An additional output will be a connectivity diagram, which describes how the project relates to other programs.

Requirements Definition

To define the requirements for the project, a requirements analysis is performed. Two key elements in this analysis are a mission analysis and a TDRSS support analysis.

Mission Analysis

The mission analysis examines the mission description and mission objectives to derive high level communication requirements.

TDRSS Support Requirements Analysis

TDRSS support is typically the primary telecommunication service needed by most projects. Therefore, an analysis of TDRSS support is described in the following paragraphs.

TDRSS Services

The primary mode of spacecraft communications is through TDRSS. For a complete analysis of the TDRSS support requirements, it is necessary to know the type of services available from TDRSS. This information is contained in Table II. Multiple Access (MA) can support up to 20 simultaneous users on the return frequency and only one user at a time on the forward link. Single Access (SA) service can support only two simultaneous users on the return and forward frequency bands. However, SA service can support higher data rates.

TDRSS Support Requirements

The type of TDRSS service is determined by such factors as the data rate required, duration of service period, and user spacecraft telecommunication system design. These requirements were determined from the mission analysis and are used to define the TDRSS support requirements. The analysis to develop these requirements includes data rate, communication timeline, and TDRSS service options.

As an example, the data rate requirement helps to determine which TDRSS service can be used. A data rate above 50 Kbps requires SA service, while a lower rate can be supported by either MA service or SA service. The communication timeline takes into account orbital paths, orbit access time to TDRSS, and TDRSS loading to establish if data can be sent back real-time, or if it must be stored and transmitted as playback data. Real-time transmission of data may be required. The analysis of TDRSS service will also establish requirements for coverage, cost, antennas, and cross support. A summary of the TDRSS support requirements is contained in Table III.

Additionally, a guideline from the TDRSS project office is to minimize SA service and reduce its use to short periods.

IV. REFERENCES

STDN 101.2, "SN User's Guide," 1989.

TABLE II. TDRSS SERVICE.

SERVICE	TYPE	FREQUENCY	USERS	CHANNEL CAPACITY
MA	Return	2287.5 MHz	20	50 Kbps
	Forward	2106.4 MHz	1	10 Kbps
SA	Return	2200-2300 MHz	2	6 Mbps
	Forward	2025-2120 MHz	2	300 Kbps
	Return	15.003 GHz	2	300 Mbps
	Forward	13.775 GHz	4	25 Mbps

TABLE III. TDRSS SUPPORT ANALYSIS OUTPUTS.

ANALYSIS	REQUIREMENT	
Data Rates	. < 50 KbpS:	MA SERVICE
		SA SERVICE
	. > 50 KBPS:	SA SERVICE
COMMUNICATION TIMELINE	. REAL-TIME DATA	
	. PLAYBACK DATA	
	. TDRS ACCESS	
SERVICE	. EQUIPMENT	
	. COVERAGE	
	. COST	
	. SIGNAL STRENGTH	
	. CROSS SUPPORT	
	. TIME SHARING	

4.3.3 ELECTRICAL/ELECTRONICS ANALYSES

4.3.3.1 LIGHTNING PROTECTION

I. OPR

EL54

II. PURPOSE

Launch vehicles require protection from the potential catastrophic effects of lightning. The vehicle may be designed to survive lightning or may only be launched under "blue skies". Launch vehicles require protection during shipping and while on the launch pad. Protection during manufacturing is a concern for solid propellant boosters.

Payloads are protected by launch shrouds or the payload bay of the Shuttle Orbiter. Design precautions are necessary because lightning current will flow through payload attach points and interconnecting cables and will couple sufficient energy to burn or damage cables and electronic circuits if the launch shroud or Shuttle Orbiter is struck by lightning.

III. DESCRIPTION

The process of lightning protection includes specifications, Technical Interface Meetings (TIMs), analysis, testing, design review, and change package or waiver review. Each of these processes will be explained in the subsequent discussion. The vast majority of the effort for the past 30 years has been for the Saturn and the Space Transportation System (STS) programs. An historical description of lightning protection for the Space Shuttle propulsion elements is provided in Reference A.

<u>Specifications</u>

Lightning protection requirements for the STS are specified by NSTS 07636. This specification has evolved over the course of the STS program to the current Revision E, which was approved in August 1990. Specifications are tailored to test equipment capabilities and to supporting analyses, and consist of several waveforms and series of pulses. The major component has a peak amplitude of 200 kA. Lightning is characterized by two major effects: namely, direct effects and indirect effects. Direct effects are characterized by blasting and burning. Indirect effects are characterized by induced voltages into critical electrical circuits.

The lightning protection specification for payloads launched by the STS is ICD2-19001. The specification for payloads launched on expendable launch vehicles is dependent on vehicle-particular specifications or may necessitate a new specification.

<u>Technical Interface Meetings</u>

Technical interchange of information and planning is achieved through Technical Interface Meetings (TIMs). Early phases of a program require extensive coordination between the contractor and NASA to transfer NASA experience acquired from previous programs and to gain a mutually cooperative understanding of design plans, and potential analyses and tests. Typically the TIMs continue throughout the life of a program with discussions of design options, test and analysis results, waivers, and forthcoming design or project office reviews.

<u>Analysis</u>

Lightning protection analyses are classified, for the purpose of discussion, as cable coupling, material temperature, circuit upset, circuit damage, test data, and complex. Cable coupling, material temperature calculations and a wealth of basic information necessary for lightning analysis can be found in Reference B.

Calculations involving material temperature require an understanding of material and bonding and detail structural layout.

Many useful analyses are performed with simple modeling and straightforward field strength equations that can be accomplished with hand calculators. Circuit upset and damage analyses can be also be performed with hand calculators (Reference C) or with the assistance of commercial computer programs such as MathCad™ or PSPICE™. Upset/ damage analyses requires an understanding of electrical circuit schematics for all electrical circuits on the Critical Items List (CIL).

Test data analysis (Reference D) requires scaling of test data from test site conditions to flight conditions. Commercial spreadsheet programs such as Lotus 1-2-3™ are often useful.

Complex analysis is occasionally performed for MSFC by Electro Magnetics Applications, Inc. (EMA) and by Lightning Technologies, Inc. (LTI). An example of how complex analysis is used to support lightning tests is contained in Reference E. This report is a noteworthy example of the analytical capability of EMA, and illustrates the numerical method of finite difference technique of solving Maxwell's equations. The method is implemented by establishing a grid, without undue computer memory requirements, to create a smaller simulated structure capable of representing the pertinent aspects of the SRM.

Testing

Lightning tests form an important role in evaluating or verifying designs. Analysis, by itself has limited usefulness in predicting the magnitude and variabilities of lightning strikes. The number of major lightning protection tests conducted on the Shuttle propulsion elements since the inception of the program probably exceeds 75 tests. Coupon testing uses small samples of material. These tests can be very inexpensive or can be quite complex. For example a coupon may be mounted on a test fixture to simulate cryogenic temperatures, pressures and material stresses experienced by the external tank (ET). Such tests are conducted by LTI in Pittsfield, MA (Reference F). Large scale testing was performed on the SRB at Wendover, Utah, as described in Reference D.

Lightning tests tend to last several weeks or even months and require active participation from many individuals. Test monitoring instruments must be installed and calibrated, high voltage test equipment must be reconfigured for each test series, and as the equipment frequently fails it must be repaired on-site. After normal working hours, test results are analyzed and plans are made for the following day.

Design Reviews

Lightning protection design reviews for the STS require an Element Electromagnetic Effects (EME) Control Plan, a Lightning Critical Items List (LCIL), establishment of system Transient Control Levels (TCLs), and establishment of Equipment Transient Design Levels (ETDLs) as specified by NSTS 07636.

A number of other documents are reviewed to understand and clarify design features necessary for adequate lightning protection. This might include suspect bonding, likely points where lightning may induce high electric fields through apertures, cable shielding plans and specifications, special attention to pyrotechnic devices, structural weak points susceptible to burn-through penetration, locations where insulation covers the skin, and in general an understanding of the main lightning path and structural features such as separation planes and flexible joints known to impede the flow of lightning current. Electrical cable diagrams, wire specifications, and mechanical drawings, however preliminary, are vital in order that reviewers, who are not imminently familiar with the design details, can contribute and support contractor lightning protection specialists toward an effective lightning-protected design.

Review Item Discrepancies (RIDs) are prepared when a discrepancy is found in preliminary documentation. Engineering Revisions (ERs) are required after the documentation has been released.

Payloads and satellites must also be protected against lightning. Lightning protection design reviews for payloads and satellites are much less complex than for launch vehicles, but the same principles are applied to payload design reviews for lightning protection.

Change Package and Waiver Reviews

Much of the lightning protection effort for the STS has been performed after the first flight in April 1981. A renewed surge of activity resulted from the three incidents: (1) a Pershing II missile ignited in West Germany as the result of Electrostatic Discharge (ESD) in January 1985, (2) the STS Challenger incident in January 1986, and (3) the destruction of the Atlas due to a direct lightning strike in March 1987.

Shortly after the Challenger accident, KSC established a committee called the Lightning Safety Assessment Committee to reassess lightning protection for the STS and launch sites. The analyses, design and testing for each of the questions raised by this committee took on individual importance. Early actions concerning lightning safety were conceived by the KSC committee and directed by the Systems Integration Review (SIR) Panel (Reference A). Review and response to Failure Modes and Effects Analysis/ Critical Item Lists (FMEA/CILs) followed in early 1987.

Considerable activity continues with the release of Revision E to the NSTS 07636 lightning protection specification and the ensuing waivers to the specification by the propulsion element contractors. Test and analysis reports from major lightning tests of the SRB and SSME during 1990 and 1991 are available, and a test of a composite nosecone for the ET was completed in October 1990.

Output products from this analysis include:

1. Lightning Protection Specification
2. Element Electromagnetic Effects (EME) Control Plan
3. Lightning Critical Items List (LCIL)
4. Transient Control Levels (TCLs)
5. Equipment Transient Design Levels (ETDLs)
6. Test and analysis reports
7. Participation in lightning tests
8. Damage and upset analysis reports
9. Support for project office actions: FMEA/CILs participation, waiver reviews, and Engineering Change Proposal (ECP) reviews.

IV. REFERENCES

A. Goodloe, C. C., "Lightning Protection for Shuttle Propulsion Elements," International Conference on Lightning and Static Electricity, April 1991.

B. Fisher, F. A. and Plumber, J. A. and the staff of Lightning Technologies Inc. and Rodney A. Perala, Electro Magnetic Application, Inc., Lightning Protection of Aircraft, Published by Lightning Technologies, Inc., 1990.

C. Gallaher, B. E., "Upset and Damage Analysis of SRB Criticality 1 Circuits", USBI-SYST-10-RPT-003, June 1988.

D. United Technologies USBI, C. O. 191, Lightning Test Final Test Report, USBI-SYST-10-RPT-010, December 1989.

E. Rigden, G. J., et al, Analysis of the Bonding Straps, the DFI Cables, and the Test Configuration for the Lightning Test Program, EMA-88-R-50, August 1988.

F. Plumber, F. A. and Crouch, K. E., Simulated Lightning Tests on ET Skin Panels, LT-88-480, August 1988.

G. ICD2-19001, "Shuttle Orbiter/Cargo Standard Interfaces."

4.3.3.2 SYSTEM LEVEL ELECTRICAL POWER ANALYSES

I. OPR

EL56

II. PURPOSE

System level electrical power analyses examine electrical power systems of spacecraft and propulsion vehicles and determine if requirements for a safe and reliable mission are met.

III. DESCRIPTION

Four basic analyses are required:

1. Electrical Power Analyses (general),
2. Voltage Drop Analysis,
3. Fusing & Fault Analysis, and
4. Grounding Analysis.

These analyses are customarily performed independently of each other, but a subset can conceptually be grouped under a common shell as envisioned in Figure 4.3.3.2-1. Here the master computer program shell is given engineering data such as wire size and length; power load lists and time lines; and electrical network definition. The program manipulates this input information through algorithms, models, tools, special programs and data bases and makes menu-selected input information available to the four subprograms.

Input Data

1. Wire Sizes and Length: Wiring detail is presently obtained from cable interconnect diagrams and wire lists but could conceivably be downloaded from other computers linked to a common network if the data was properly coded.

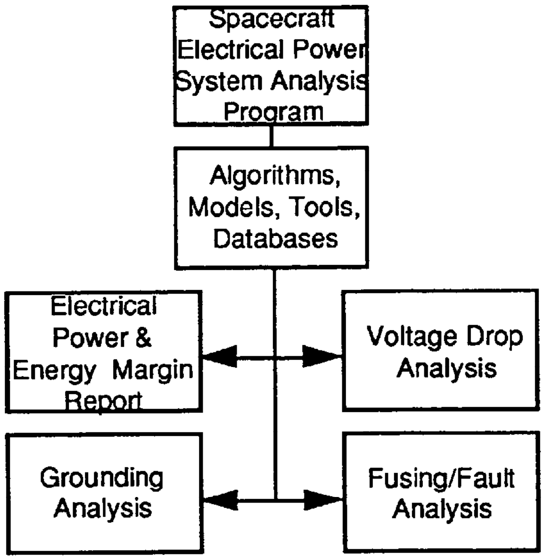


Figure 4.3.3.2-1. Spacecraft EPS Analysis

2. Circuit Elements: Resistance values for fuses, power switches and connectors are determined from specifications or measurements. Fuse sizing guidelines, for the fusing analysis, are obtained from system or wiring specifications.

3. Power Loads and Timelines: Power requirements are usually obtained through detailed discussion with engineers and scientists responsible for each equipment item. Timelines are usually generated by the Mission Operations Lab with inputs from the flight mechanics design groups. Space mission equipment normally has several operating modes ranging from all-up peak power transient to standby quiescent. These modes of operation must be fully understood in order to assign the correct power level to a given mission time period. Ideally, a common computer link with all engineering and science design groups participating in the spacecraft or vehicle design could automate this process.

4. Circuits: Circuits are obtained from electrical schematics and wiring diagrams,

but may require simplification to be usable for analysis.

5. Ambient Temperature: Ambient temperature is obtained from thermal control design groups. Wire resistance is a function of wire temperature which is in turn a function of ambient temperature and internal I^2R heating.

The electrical power system analyses use normal and worst-case subsystem and system interface conditions (voltage and bus transient and ripple) to evaluate the design for proper performance and compatibility. These analyses are also performed to evaluate power on/off switching transient generation for adverse or out-of-specification impacts to the interfacing bus. Power analyses should utilize thermal analyses data to define a coordinated thermal and electrical power consumption profile. Commercial computer programs are often employed to perform analyses, but special-purpose computer programs may offer advantages.

Voltage Drop Analysis

The voltage drop analysis utilizes the individual power requirements obtained from the EPEMR discussed in Section 2.5.1.2. Circuit resistance is determined by wire size (resistance per unit length), wire length, ambient plus internal wire heating temperature, and circuit element resistance.

A review of the electrical network or circuit indicates the approach for solving individual branch currents and voltages. Commercial computer programs such as PSPICE™ are useful for solving loop equations, but special computer programs are sometimes necessary. An example of a special computer program analysis is shown in Figure 4.3.3.2-2. The network diagram shows Space Shuttle Orbiter payload bay wiring and wiring for maintenance mission equipment for the Hubble Space Telescope (Reference A). The electrical network for the payload bay is quite complex but can be reduced to the equivalent circuit included in the Figure. The seemingly simple circuit presents two complications. First, the loads cannot be reduced to a Thevenin equivalent circuit, because one or both of the loads are fixed power loads, i.e., a constant power is drawn independent of input voltage (as is the case for DC to DC converters). Secondly, the power source is a fuel cell and the output voltage is known only as a function of total fuel cell current.

Fusing and Fault Analysis

The fusing analysis determines correct fuse size and response characteristics relative to normal and fault conditions. The fault analysis considers worst case faults from the standpoint of safety or mission compromise. The fusing and fault analysis relies on circuit solutions obtained from the voltage drop analysis and peak transient power requirements obtained from the EPEMR to calculate peak branch currents. Proper fuse sizing is verified by comparing peak branch current with wiring and fusing specification. The fault analysis reviews line-to-ground or line-to-line faults and power bus redundancy.

Grounding Analysis

Review of cable interconnect diagrams, wiring diagrams, electrical schematics, and/or grounding schematics is necessary to ensure that the system avoids ground loops and does not violate grounding philosophy. Often the spacecraft or propulsion vehicle must make an electrical power connection with another spacecraft or propulsion vehicle. An agreement must be reached between the two parties concerning a grounding scheme for the resulting combined system. For example, if both space systems have single point grounds, one of the space systems must open-circuit its ground to avoid ground loops that can upset sensitive electronic equipment.

These analyses verify proper operation of the spacecraft or propulsion vehicle. Discrepancies and misunderstandings are reviewed with the responsible engineer. This is usually an aerospace contractor. The formality of the review may vary from a

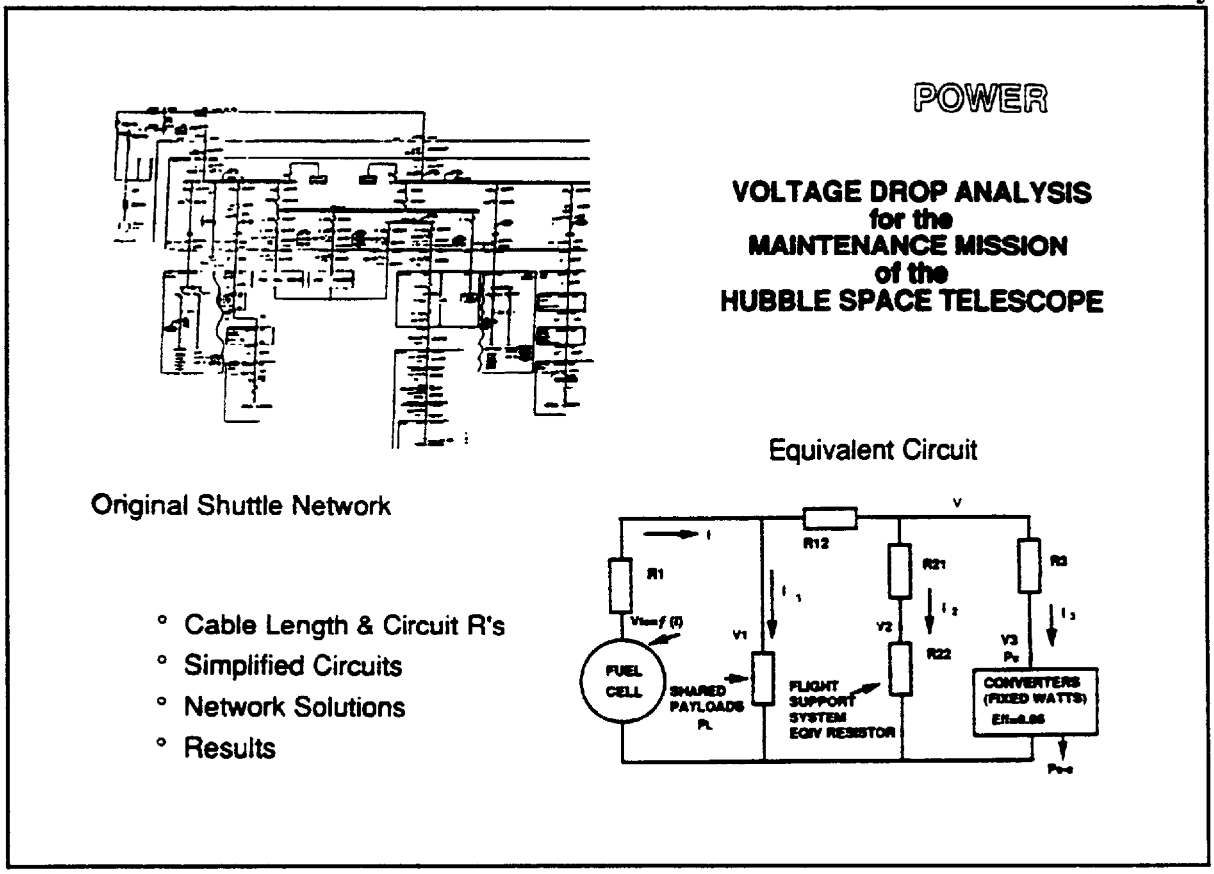


Figure 4.3.3.2-2. Voltage Drop Analysis

IV. REFERENCES

A. DR STD/SE-ESA, "Electrical System Analyses."

B. Giudici, R. J., Hulgan, W. W., and K. Hwang, "Voltage Drop Analysis for the Hubble Space Telescope Maintenance Mission", paper submitted for TABES '91 conference, Huntsville, AL.

4.3.3.3 ELECTRICAL POWER AND ENERGY MARGIN ANALYSIS

I. OPR

EL56

II. PURPOSE

The purpose of this analysis is to define the electrical power and energy requirements for spacecraft and propulsion vehicle elements and compare these requirements with power system capacity and the power and energy allocations assigned to individual equipment or elements. The difference between power source capability and user demand is termed the margin.

III. DESCRIPTION

The Electrical Power and Energy Management Report (EPEMR), as discussed in Section 2.5.1.2 of this Volume, utilizes power load and timeline information to compile power and energy requirements. Commercial computer spreadsheet programs are often employed, but special computer programs may offer advantages. Tabulations, graphs, and bar charts are used to summarize total and individual element power and energy and to compare these summed requirements against power system capacity and individual element power allocations.

Input Data

1. Power Loads and Timelines.- Power requirements are usually obtained by detailed discussion with engineers and scientists responsible for each equipment item. Timelines are generated by mission operations with inputs from the flight mechanics design groups. Equipment normally has several operating modes ranging from all-up peak power transient to standby quiescent. These modes of operation must be fully understood in order to assign the correct power level to a given mission time period.

2. Power Source Characteristics. - Power source characteristics must be understood in order to establish the capacity and determine whether the capacity is being exceeded. Chemical energy sources, batteries and fuel cells, are time-limited and sensitive to total mission energy demand. The capacity of photovoltaic power systems varies with mission duration, spacecraft orientation, and time of year.

Procedure

Power source capability is compared with total power and energy demands to establish margins. Power allocations assigned to individual equipment items are likewise compared with requirements to establish margins. Negative margins, indicating that demands exceed capacity, require resolution.

The margin reporting portion of the EPEMR will be described using an example[A]. There is no fixed format for margin reporting; rather, good judgment is relied on to account for the important aspects of the particular spacecraft or vehicle being analyzed. The analysis utilizes Lotus 1-2-3™ software for the spreadsheet and graphics. The spreadsheet automatically manipulates the equipment power and time values to obtain subtotals and totals of power and energy. Major topics of the report follow.

Introduction:

- Changes since the last report.

- Groundrules and assumptions: Information about the Orbiter and spacecraft power systems required to understand the technical data to be presented.

Mission Descriptions:

- Orbiter support power, e.g., predeployment power from the Orbiter is supplied by a single 1750 Watt power feeder.

- Spacecraft battery power, e.g., the electrical system contains three 250 ampere-hour (Ah) silver-zinc batteries that have been derated to 225 Ah due to a 90-day wet stand time requirement.

- Mission phases and time of transfer to spacecraft power.

Electrical Power Requirements: (See Figure 4.3.3.3-1).

- The Figure illustrates the basic spreadsheets used for the analysis. The first of four tables are shown in the Figure. Requirements are tabulated for the spacecraft, the experiments, and the Airborne Support Equipment (ASE).

- Spacecraft battery power and energy margins are tabulated in two tables. Two additional tables tabulate support power and energy margins.

Conclusions: (See Figure 4.3.3.3-2).

- Discussion of results.

- Required power and energy are compared with allocated power and energy in four bar charts: (1) Spacecraft System - Battery Power Margin, (2) Experiments - Battery Power Margin, (3) Total - Battery Power Margin, and (4) Total - Battery Energy Margin.

- A series of eight power versus time profiles for the separate flight experiments.

more sophisticated spreadsheet analysis was performed for the Orbital Maneuvering Vehicle (OMV) by TRW [B]. Spreadsheets are difficult to update to accommodate changes to time periods and mission sequences. The difficulty must either be accepted or the spreadsheet, or other analysis tool, must become more elaborate.

The margin reporting portion of the EPEMR is used by electrical power system designers and by thermal control designers to size their respective systems, i.e., electrical power and energy entering a spacecraft must be eventually rejected to space as waste heat energy. The EPEMR is useful to project managers to track and control spacecraft or propulsion vehicle growth. Finally all equipment designers utilize the document to verify that their equipment electrical power requirements fall within the power allocations.

The EPEMR is a Data Requirement (DR) for contracted projects and is typically submitted quarterly. Updated reports are usually required three weeks prior to PDR and CDR.

IV. REFERENCES

A. Woodruff, L.D., Hulgan, W.W., "Electrical Power Margin Report for the AFE Mission," MSFC-RPT-1728, October 1990.

B. Starritt, B., "Update to Electrical Subsystem Computer Model," Interoffice Correspondence, TRW Space & Technology Group, 22 July 1988. This elaborate spreadsheet analysis was performed for the Orbital Maneuvering Vehicle (OMV).

C. DR STD/SE-EPEMR, "Electrical Power and Energy Management Report.

POWER SOURCE	Spacecraft Battery (W)					
TIMELINE	Prelaunch					
PERIOD	Battery Test			System Verification		
DURATION	0.5			0.5		
Device/Requirement	Max Cont	Dty Cycle	Avg.	Max Cont	Dty Cycle	Avg.
Primary thrusters (8)	0	0.0%	0	0	0.0%	0
Vernier thrusters (8)	0	0.0%	0	0	0.0%	0
TCV Heaters (16)	29	1.0%	0.29	0	0.0%	0
Pri Cat Bed Htrs (8)	436	1.0%	4.36	0	0.0%	0
Ver Cat Bed Htrs (8)	262	1.0%	2.62	0	0.0%	0
Feedline/Tank Htrs	110	1.0%	1.1	0	0.0%	0
Avionics Heaters	0	0.0%	0	0	0.0%	0
Cold Gas Thrusters	0	0.0%	0	0	0.0%	0
Transponder	38	100%	38	18	100%	18
RF Power Amp	0	0.0%	0	0	0.0%	0
Exp Computer	104	100%	104	0	0.0%	0
Exp IOU	40	100%	40	0	0.0%	0
GN&C Computer	104	100%	104	104	100%	104
GN&C IOU	52	100%	52	52	100%	52
TCE	20	100%	20	0	0.0%	0
IMU	100	100%	100	0	0.0%	0
Power Dist.	92	100%	92	92	100%	92
Dist Losses (8%)	110.96		44.67	21.28		21.28
Max Cont. Power	1497.96			287.28		
Average Power			603.04			287.28

Figure 4.3.3.3-1. Example Power Margin Spreadsheet

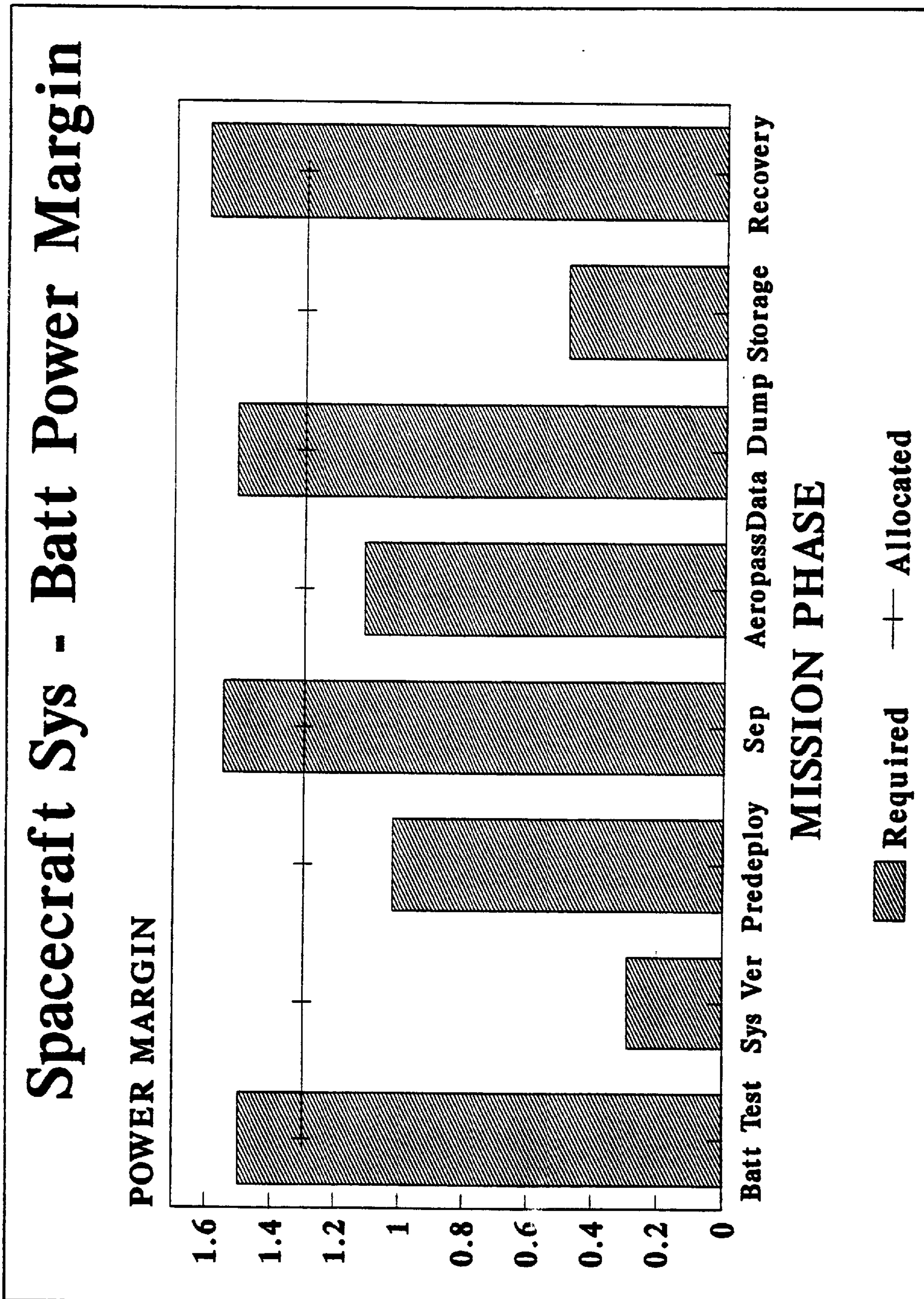


Figure 4.3.3.3-2. Presentation of Results

4.3.4 NATURAL ENVIRONMENTS ANALYSES

4.3.4.1 NATURAL SPACE ENVIRONMENT DEFINITION ANALYSES

I. OPR

EL54

II. PURPOSE

To develop natural space environment requirements for a particular mission, each natural space environment must first be defined using specific mission characteristics as inputs to the definition analyses.

III. DESCRIPTION

The natural space environment includes: gravitational field, ionizing radiation, magnetic field, meteoroids/space debris, neutral thermosphere, plasma, solar environment, thermal environment. Analysis of the mesosphere is also provided if the mission altitudes are within this atmospheric region. These analyses require the manipulation of computer models and databases particular to each space environment. The results are then documented in the natural space environment definition and requirements document.

IV. REFERENCES

MSFC-DOC-2253, "Advanced X-ray Astrophysics Facility-Spectroscopy (AXAF-S) Natural Space Environment: Definition and Requirements", October 1993.

4.3.4.2 NATURAL TERRESTRIAL ENVIRONMENT DEFINITION ANALYSES

I. OPR

EL54

II. PURPOSE

Natural terrestrial environment information plays an integral role in designing, developing and operating launch vehicles. Natural terrestrial environment information is also used to develop safe, reliable methodologies for shipping, handling and transporting spacecraft and spacecraft systems/sub-systems.

III. DESCRIPTION

The natural terrestial environment includes but is not limited to the following parameters: atmospheric constituents (gases, sand, dust, sea salt ...), atmospheric electricity, clouds, fog, humidity, precipitation, sea states, severe weather, near-surface thermal radiation, temperature, pressure, density and winds. These analyses require the manipulation of computer models and databases particular to each terrestrial environment. The results are then documented in the natural terrestrial environment definition and requirements document.

4.4 SYSTEM ENGINEERING MANAGEMENT

4.4.1 EFFECTIVE MEETING GUIDELINES

I. OPR

EL51

II. PURPOSE

These guidelines should be used to improve the quality of and satisfaction with your meetings.

III. DESCRIPTION

Applying the guidance below will help make your meetings more effective and efficient.

* All meetings should have advanced publication of:

  1. Objective

  2. Agenda

  3. Schedule

  4. List of required participants (if substitutes allowed, so state).

* For S&E Director's meetings give oral agenda to secretaries.

* Maximize use of electronic mail information exchange with copies to other interested parties.

* Attempt to minimize word chart viewgraphs.

* Use questionnaire to evaluate meetings (selected).

* When possible, distribute viewgraphs via electronic mail before the meeting in lieu of handouts.

* Question subordinates (and others as practical) about necessity for meeting, length of meeting, and agenda.

* Check who is attending meeting - question their attendance discreetly.

* Eliminate unnecessary introductory material.

* Minimize the time for meetings. Preparatory material distribution in advance will help.

* Document meeting results and actions.

* Follow-up to ensure actions are completed.

IV. REFERENCES

A. "Lead Engineer's Guide," Preliminary Design Office, Program Development Directorate, MSFC, April 1989.

4.4.2 DECISION MAKING

I. OPR

EL51

II. PURPOSE

The Decision-Style Model described below presents four decision styles which can be used depending on the nature of the problem confronted.

III. DESCRIPTION

Sooner or later the system engineer will need to make important decisions affecting the project or program under development. As engineers, we are trained in quantitative problem-solving techniques. This may explain the current interest in quantitative-oriented decision-making theory. The exciting fact about complex, esoteric mathematical models is that they become more meaningful as the number of unknowns decreases. The greater the information available, the fewer the unknowns, and the more realistic the mathematical model. However, the unhappy reality is that even after the computer has produced the numbers, someone, somewhere, has ultimately to assume responsibility for making the final decision.

Research has shown that two dimensions seem to be relevant in effective decision-making. One of these is the objective or impersonal quality of the decision. This aspect is the most common focus of mathematical models. The other has to do with its acceptance, or the way the persons who must execute the decision feel about it. This aspect is the most common focus of behavioral models.

Many individuals have a normal style of decision-making and tend to focus on quality or acceptance regardless of the nature of the problem situation. The Decision-Style Model was developed to make individuals more aware that their decision style should be flexible and should depend on the nature of the problem confronted.

Four decision styles are recognized in this model: Command, Consensus, Consultation, and Convenience. The Command style is characterized by the superior making the decision based on the information available, independent of others. Consensus is a group decision based on shared information and ideas. Consultation is the process whereby the superior makes the decision after soliciting subordinates' opinions. The final style, Convenience, involves the decision being made by the easient means available, like flipping a coin or drawing straws, for example.

Figure 4.4.2-1 illustrates the Decision-Style Model. There are two other factors besides quality and acceptance which may influence the choice of decision style. These are time and trust. Where time is of the essence, the command style is probably the only viable option. An example of this is a medical emergency. However, it is rare that time-critical situations occur in the multi-year development cycle of a typical project. On the other hand, trust is often important in international or multi-center cooperative project decisions. In such cases, the consensus decision style may be the most appropriate. Monitor your own decision style, and if you find yourself over-emphasizing one style consider it a warning sign that you may not be using the most effective decision-making technique. In the final analysis, the choice of decision style should be flexible and depend on the nature of the problem confronted.

IV. REFERENCES

Adapted from R. Roskin's "Decision Style Inventory," Annual Handbook for Group Facilitators, University Associates, San Diego, 1975.

PROBLEM TYPE	Suggests	DECISION STYLE
Quality / Acceptance	» Suggests »	COMMAND

Problem Type: Quality of the decision is more important than its acceptance.
Decision Style: The decision is made by the superior, using available information, independently of others.

PROBLEM TYPE	Suggests	DECISION STYLE
Acceptance / Quality	» Suggests »	CONSENSUS

Problem Type: Acceptance of the decision is more important than its quality.
Decision Style: The decision is a group decision evolving from shared information and ideas.

PROBLEM TYPE	Suggests	DECISION STYLE
Quality & Acceptance /	» Suggests »	CONSULTATION

Problem Type: The quality and acceptance of the decision are equally important.
Decision Style: The decision is made by the superior, using subordinate opinion but without bringing the subordinates together as a group

PROBLEM TYPE	Suggests	DECISION STYLE
/ Quality & Acceptance	» Suggests »	CONVENIENCE

Problem Type: The quality and acceptance of the decision are both unimportant.
Decision Style: The decision results from the easiest method at hand.

Note: Remember that two other factors (time and trust) besides quality and acceptance may influence the choice of decision style.

Figure 4.4.2-1. Decision-Style Theory Summary

4.4.3 CONCURRENT ENGINEERING

I. OPR

EL51

II. PURPOSE

Concurrent engineering (CE) is a philosophy and methodology for efficient and effective integration of the technical and business specialties needed to develop, produce and sustain today's complex hardware and software space systems. Significant reductions in cycle time can be expected through the application of CE. Concurrent engineering is required throughout the life cycle of a system, and can be viewed as one of the most important management tools available to a NASA program manager.

III. DESCRIPTION

Concurrent engineering is an integrated process involving all appropriate disciplines simultaneously. Throughout the definition and design phases, concurrent engineering draws on the various disciplines to trade off parameters such as producability, testability, and serviceability, along with the customary performance, size, weight, and cost. The concurrent engineering information flow shown in Figure 1 provides the necessary feedback loops of information needed to assure that adequate system requirements definition is given in the design stage, so that costly redesign and reverification are avoided before production and test. As shown in Figure 2, a longer conceptual design phase, with balanced or weighted treatment of performance, cost, producability and supportability is the ultimate goal of concurrent engineering. Multidisciplinary integration is associated with the traditional aerospace disciplines of aerodynamics, propulsion, structures, and controls--however, concurrent engineering adds the life cycle areas of manufacturability, supportability, and cost which require integration. A longer conceptual design process captures more knowledge and more design freedom. The detail design period is reduced based on the use of more upfront design, and a more evenly distributed effort of disciplines is provided in the conceptual and preliminary design phases. The dashed line projection from the "Knowledge about Design" curve reflects the need to retain more design freedom later into the process in order to act on the new knowledge gained by analysis, experimentation, and human reasoning. In sum, concurrent engineering allows better integration of multi- and interdisciplinary design, analysis, and optimization. The overall design time is shortened, or in a given development timeframe a broader selection of optimized alternative designs is obtained.

IV. REFERENCES

1. Rosenblatt, Alfred and Watson, George F., "Concurrent Engineering," *IEEE Spectrum*, July 1991 pp. 22-37.

2.Ulerich, Phillip L., "Tips for Concurrent Engineering," *Machine Design*, August 20, 1992 pp. 54-56.

3. Anon., "Current State of the Art on Multidisciplinary Design Optimization," AIAA White Paper, *AIAA Technical Activities Committee*, September 1991.

4. Snoderly, John R., "How to Organize for Concurrent Engineering," Program Manager, July-August 1992, pp. 2-13.

5. Winner, R.I., et. al.; "The Role of Concurrent Engineering in Weapons System Acquisition," IDA Report R-338, Institute for Defense Analysis, Alexandria, Virginia, December 1988.

6. Chamis, C.C. and Singhal, S.N.; "Computational Simulation of Concurrent Engineering for Aerospace Propulsion Systems," AIAA Technical Paper # 92-1144, 1992 Aerospace Design Conference, Feb. 3-6, 1992.

7. Phillips, Clifton B., and Peterson, Robert R.; "Integrating Reliability and Maintainability

into a Concurrent Engineering Environment," AIAA Technical Paper # 93-1021, AIAA/AHS/ASEE Aerospace Design Conference, Feb. 16-19, 1993.

V. IMPLEMENTATION AT MSFC

The process begins with the system engineer heading a requirements definition team which includes all appropriate discipline representatives. These requirements are allocated and flowed-down to lower-level design and performance specifications. Following this, in a conventional design environment, the designer creates an engineering database — drawings — to document the design, and product development occurs sequentially from there. In a concurrent engineering environment, designs are generated on a computer, where images are produced as they are conceived and drafting is mostly an auxiliary function. Drawings merely document designs like a final report, after the design teams have created engineering databases on computers. Databases transfer electronically to the drafting and analysis departments for design verification, stereolithography shop for prototyping, spray-metal mold manufacturer for short-run tools, and tooling vendors for quotes and permanent-tool design.

For any one design at MSFC, the engineering analysis tools can span multiple disciplines including thermal, stress, dynamics, design, computational fluid dynamics, aerodynamics, aeroheating, and pointing and control. A problem is that while common data must be shared by all the analytical software tools, the current existing software at MSFC will not allow for ease of data transportation to other software systems. Sometimes manual recreation of data has been necessary (a costly and redundant process). MSFC is conducting a formal evaluation of commercially available software products which will provide a single software solution to multiple engineering analysis tools. An inter-lab working group, the Integrated Engineering Environment (IEE) WG, is addressing this problem. [The commonality of this problem has been echoed by industry and the engineering community].

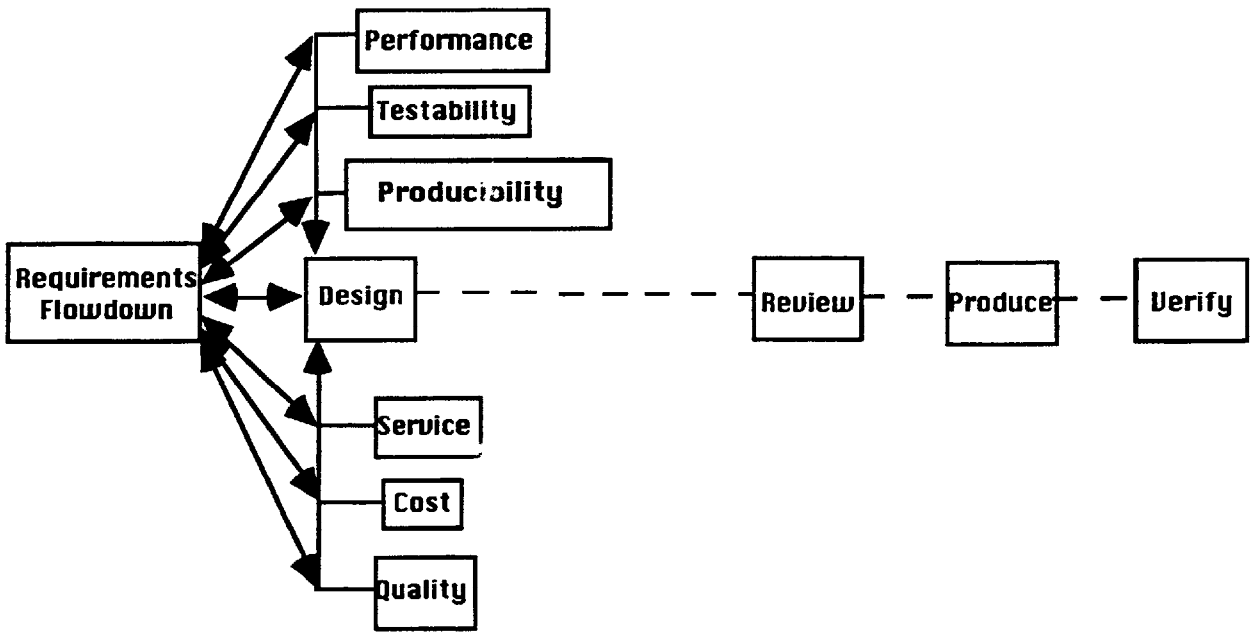


Figure 1. Concurrent Engineering

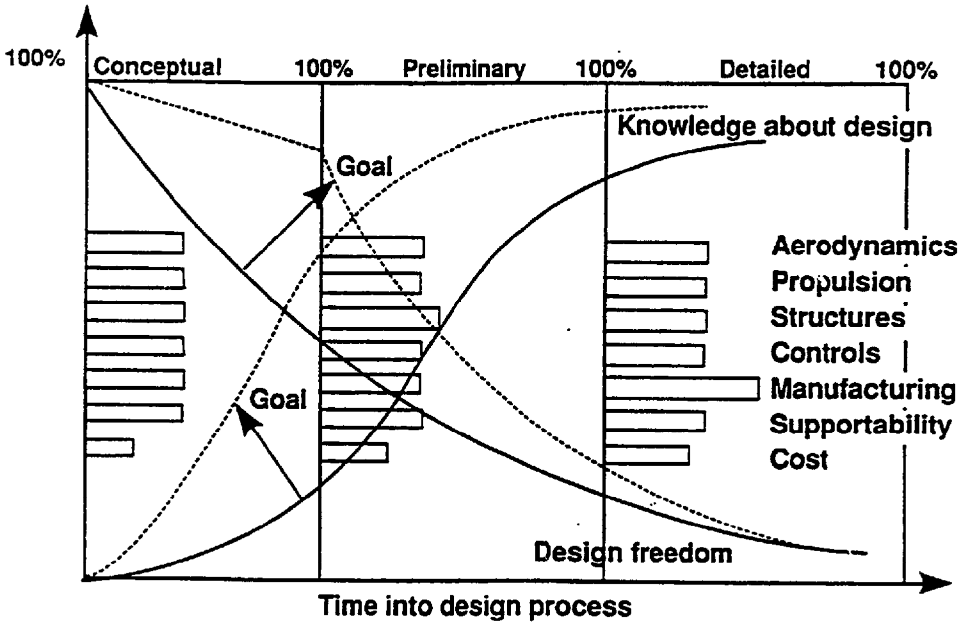


Figure 2. Concurrent Engineering Design Process Reorganized Gain Information Earlier and To Retain Design Freedom Longer

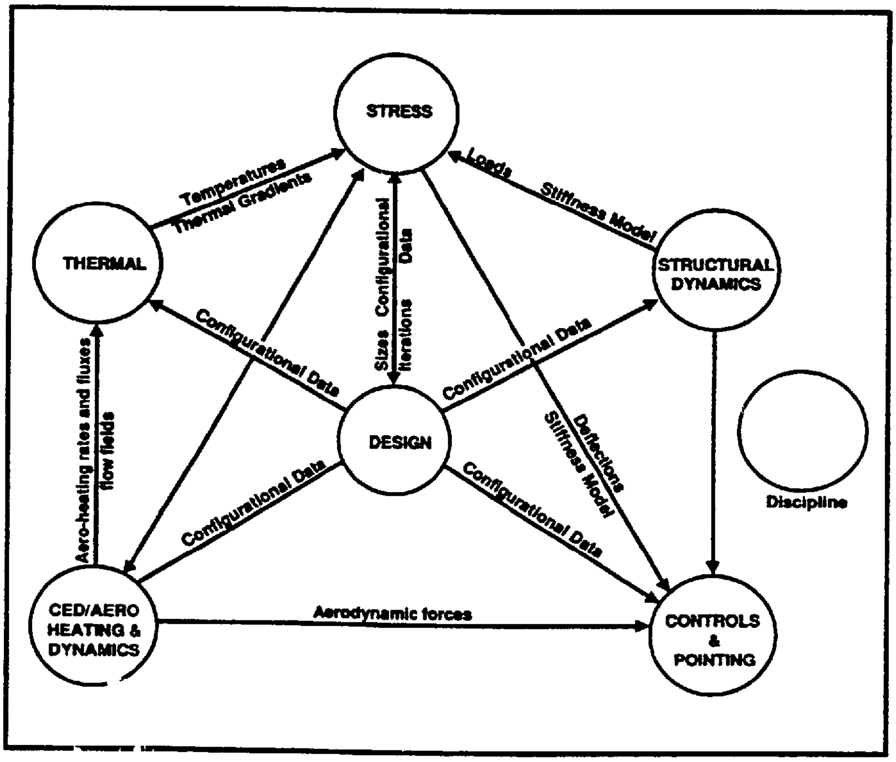


Figure 3. Interdisciplinary Analysis Improvement at MSFC

4.4.3.1 MULTI-DISCIPLINARY TEAMS

I. OPR

EL51

II. PURPOSE

Multi-disciplinary teaming ties in with concurrent engineering as a necessary condition for success of the total engineering effort. Teaming facilitates system engineering on a project. Multi-disciplinary teams, that have representatives from applicable disciplines for the design/development effort, not only improve communications but allow for simultaneous engineering of the products and associated processes of a system. The team concept maximizes communication between functional organizations so that adjustments to requirements, design, fabrication and test can be made, such that all project technical, schedule and cost goals are satisfied. Each team member represents his functional organization in the development of the product. The result is a flexible, participative organization that focusses the engineering efforts on a specific program. Such teaming has proven successful in the commercial arena by reducing cycle times, reducing engineering changes later in the program, and providing better product quality.

III. DESCRIPTION

The multi-disciplinary teams often have multi-functional (technical and business) members. Both technical and non-technical personnel are needed to ensure that issues such as producibility, reliability, verifiability, deployability, supportability, maintainability, trainability, and operability are all considered in the design. In addition, business representatives for such issues as marketing, contracting, legal implications, and cost accounting are added to the team as the need arises. Maintaining a consistent core membership (the role of the Core Product Development Team is described below) throughout the system life cycle will ensure effective project integration. Soundness of design and continuity from conceptual design through the operations/flight support phase is ensured. The system engineering discipline needs to be represented in the core membership throughout the system life cycle, although the team composition and leadership may change as the system matures from phase to phase.

The organization of the multi-disciplinary teams needs to be tailored to best support the project at hand. A multi-disciplinary team should:

- Accomplish engineering functions more effectively and in more timely manner
- Ensure early involvement of all disciplines
- Be essential for effective concurrent engineering
- Reduce/minimize costly engineering changes late in the life cycle
- Operate within the basic systems engineering functional process
- Produce products and services better, faster, and cheaper

As shown in Figure 1, the development teams can be at the ***system*** level (System Development Teams, or SDTs), the ***product*** level (Product Development Teams, or PDTs), or at the ***component*** level (Component Development Teams, or CDTs). These development teams of functional representatives have as their common purpose the concurrent development of a specific product or design. All Development Teams must be integrated and their outputs optimally time-phased to meet the needs of the project. Both PDTs and SDTs deal with the common goal of the design or development of a specific product. For MSFC as a Space Transportation System development center, PDTs and SDTs are responsible for the design of baseline vehicle elements; and are long-term, semi-permanent entities tied to the project. The difference is that SDTs in general deal with a larger subsystem or assembly of components/products than PDTs. The project office and SDTs have to grapple with integration and interface issues, and ensure that systems meet the cost, performance, reliability, safety and operability requirements of the project. Special Studies (ad hoc) teams are responsible for conducting short term design or trade studies. The Special Study team is typically disbanded when its task is complete.

At MSFC, for large space transportation programs, management authority is delegated to such teams to:

— Ensure effective integration of the product elements

— Develop product schedules and costs

— Approve or iteratively refine requirements

— Develop drawings and Requests For Procurement (RFP) inputs

— Draft development/ verification plans (including RFPs)

— Report progress

— Solve multi-functional problems

Development team members wear two hats: their FUNCTIONAL job (e.g., stress/thermal analysis, design, hardware, test, program administration) and their PROJECT job (as PDT member, to plan and manage the work, e.g., reviews, approvals, budgeting, progress reporting, multifunction problem solving). PDTs typically have the following responsibilities:

1. Review and accept all specifications, tasks and contract data items. Identify all requirements that do not add value to the product and take appropriate action to modify or delete them. Record all accepted requirements.

2. Develop Level IV and subservient product schedules and implement changes thereto.

3. Draft, review and approve development verification plans.

4. Review and approve all product drawings, associated documents and data items. Ensure that all requirements are fully incorporated in each design.

5. Review all Requests For Procurement (RFPs).

6. Participate in development, review and approval of the contract SOW, specifications and data requirements as well as in the source selection process.

7. Monitor subcontractor performance and report status to concerned functional organizations and the PDT Council.

8. Review and approve functional plans for fabrication, testing and delivery.

9. Measure and evaluate product development status. Develop integrated solutions to multi-functional problems as required to meet committed goals.

10. Report status to and interact with other teams, functional organizations and the PDT Council as required.

Each PDT meets on a regular basis. All core team members attend, agendas and minutes are required, and an action item log is kept. The PDT reports task status during program reviews. PDT task leaders can also have separate meetings, to exchange ideas on how teams are operating, and recommend changes to the project plan. As seen in Figure 1, the PDT reports to a PDT Engineering Council whose purpose is to review the status of products being developed. The Council is composed of project managers, chief engineers, S&E management and appropriate laboratory managers. It is chaired by the program manager, who may delegate to the chief engineer. The Council checks progress against schedule (upcoming events), progress against the requirements check list, makes key decisions, and addresses issues and concerns.

Why a Core PDT Is Needed

A mechanism is needed between the project or program office and the supporting functional organizations. A good approach to resolve this dilemma is through the use of a "**CORE**" **PDT** comprised of at most 12-14 members. It has been found that too many members (30-40) is inefficient. It is essential to establish a core PDT to plan, schedule, cost, and integrate the program's implementation of the product. The core PDT is responsible to ensure overall product development, integration, configuration, and compatibility with requirements.

How Core PDTs Should Work

The Chief Engineer chairs this PDT, with discipline membership from appropriate design and support organizations and/or the chief engineer's office. The core PDT membership is empowered to activate the supporting functional organizations, drawing upon their expertise as needed, to carry out design, development, test and evaluation activities. The core PDT establishes design PDTs and CDTs within the functional organizations to ensure an integrated design approach down to the component/subsystem level. The program implementation, detailed design, etc. is performed by the existing functional organizational elements. During product definition, the core PDT reviews any changes to "design control parameters" and ensures total impact assessment (upon the product) prior to implementation.

Figure 2 shows a generic multi-disciplinary teaming arrangement where SDTs, PDTs and CDTs are embedded in functional organizations, with manpower allocation and team composition tailored to suit specific program needs. The Core Product Development Team is shown as a dedicated cadre of some 10 to 14 key experienced personnel who embody the disciplinary functional expertise germane to the needs of the program. Personnel in a functional discipline usually support multiple projects, and at the end of the program the Core Product Development Team members can return to their functional 'home'.

It is essential that the PDT efficiently communicate, coordinate, and resolve conflicts among the participating tasks, peer PDTs, and panels. A panel can be thought of as a custom-tailored PDT to address the needs of a particular subsystem, such as the engine. Essential in this process is the role played by the PDT systems engineers. This group coordinates, interfaces and resolves issues among the PDTs on a daily working basis, with selected individuals within a PDT serving a dual role as both a functional specialist and a system engineer. These dual-hatted individuals form the cadre of the system engineering organization at the working level. A typical PDT working mechanism at MSFC (for communication, coordination, resource sharing and conflict resolution) is shown in Figure 3.

It must be emphasized that the specific composition, structure, and working mechanisms of multi-disciplinary PDTs will vary in accordance with the size, scope, and needs of individual projects.

IV. REFERENCES

A. MSFC/EL51 briefing, April 1992.

B. Shishko, Robert and Chamberlain, Robert G.; *NASA Systems Engineering Handbook* (Draft), September 1992, p.22.

PDT Lessons Learned

- Top management sponsorship and involvement is critical (includes program manager and functional managers)
- A Program Plan must establish rules for all to play by
- Delegation must be accompanied by real authority
- PDTs must have direct linkage to program management, through the PDT Engineering Council

• Good team members are essential, this works best if they do not have other management responsibilities

• Use small teams (4-14 people)

• System engineering as a discipline must be represented on each PDT, and communication/ coordination/resource issue resolution among PDTs facilitated by the system engineers

• Decisions must be made in real time--no messengers

• Training is essential, to learn the program role and team skills

• Meeting discipline needs to be enforced (adhere to agenda and time limits).

• PDTs must have direct involvement in functional processes

• Be patient and persistent

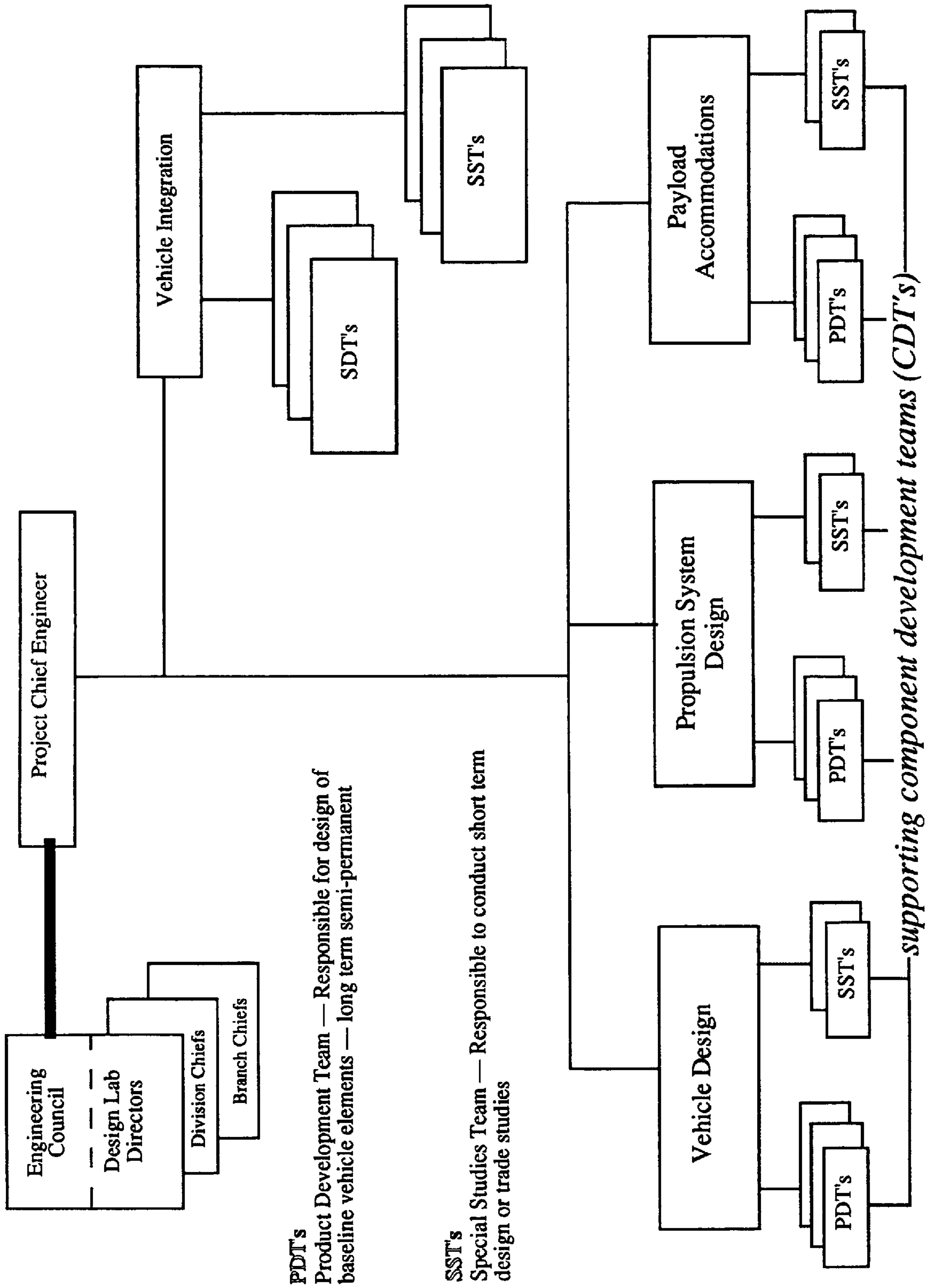


Figure 1. Multi-Disciplinary Teaming Arrangement (MSFC Typical)

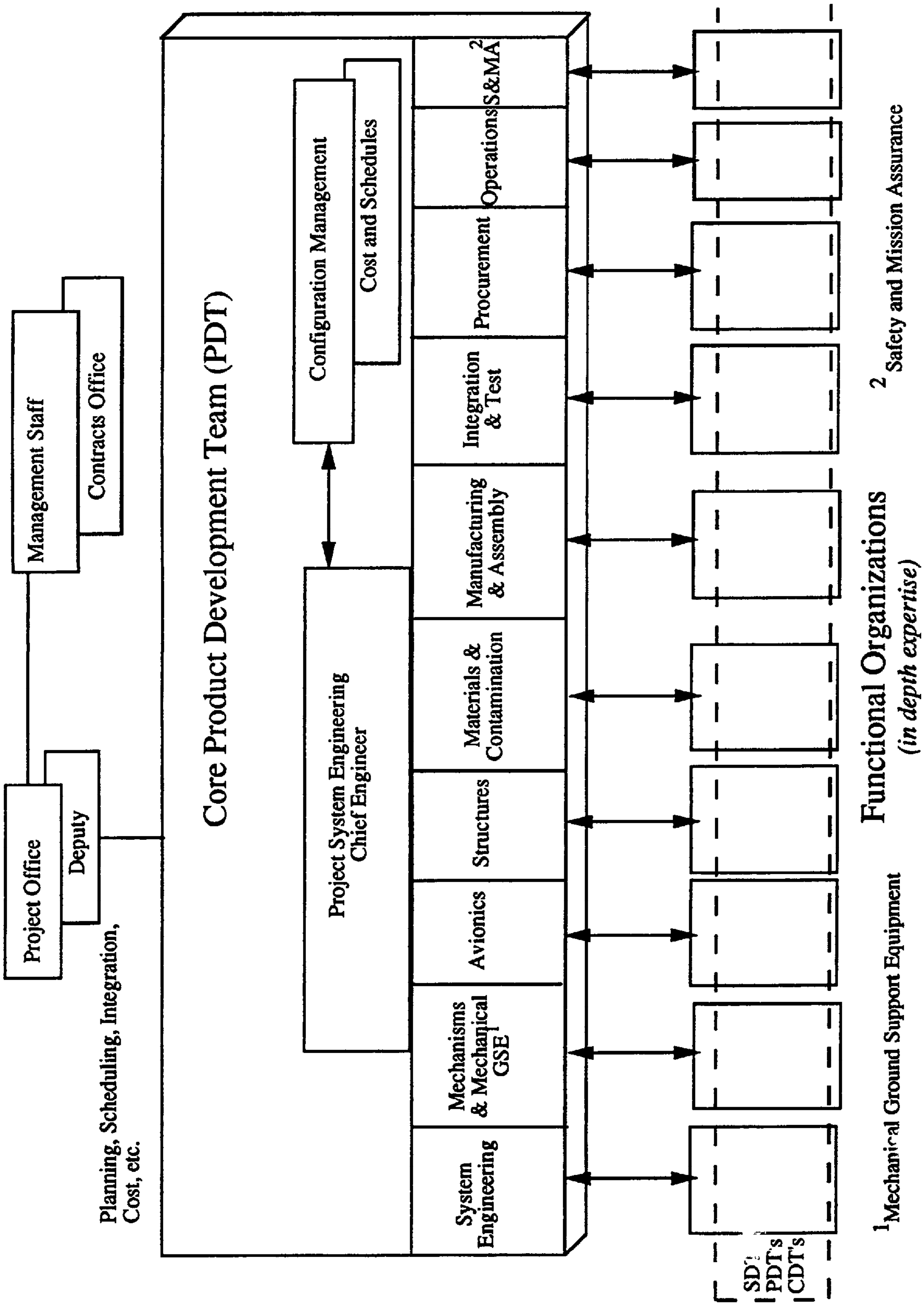


Figure 2. Multi-Disciplinary Teaming Functional Layout

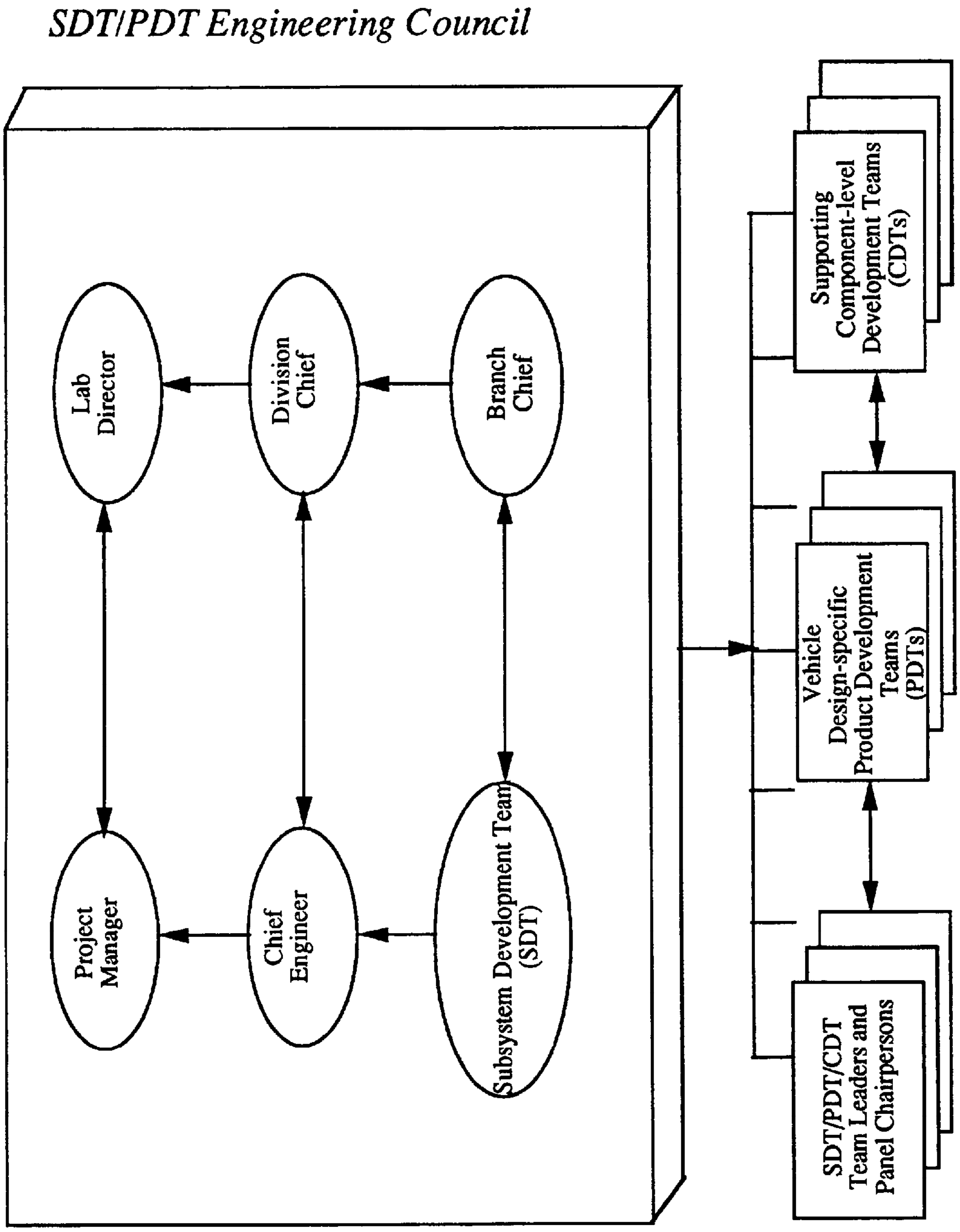


Figure 3. SDT/PDT/CDT Working Mechanism for Communication, Coordination, Resource Sharing and Issue Resolution

4.5 MISCELLANEOUS ANALYSES

4.5.1 MONTE-CARLO SIMULATIONS

I. OPR

EL58

II. PURPOSE

Monte-Carlo simulations are used to estimate solutions to problems that are too complicated to solve by analytic methods alone. A probabilistic approximation to the solution of the problem is obtained by using statistical sampling techniques. The many iterations required by the Monte-Carlo technique have been made possible through the capability of electronic computers to perform increasingly rapid numerical computations. Please note that model sampling is a Monte-Carlo method of numerical analysis.

III. DESCRIPTION

The Monte-Carlo method (named after the famous gambling casino in Monaco) applies random sampling techniques, often in conjunction with computer simulation, to obtain approximate solutions to mathematical or physical problems. The Monte-Carlo analysis technique can best be used in mathematical modeling situations where an exact solution is not attainable or for some reason is too difficult to obtain.

The solution x of a numerical mathematical problem is estimated by means of an artificial sampling experiment. The estimate is usually given as the *average* value, in a sample, of some statistic whose mathematical expectation is equal to x. In other words, a range of values for x is obtained, each of which has a calculated probability of being the solution.

The name "Monte-Carlo Methods" is given to all procedures that make use of the concept of randomness for the solution of deterministic problems. An artificial stochastic model of a physical or mathematical process is constructed. This stochastic process has distributions or parameters which satisfy the equations. The method applied is similar to the statistician's "*model sampling*" where drawings are taken from random numbers to observe the distribution of a statistic that is estimated empirically.

The analysis employed is that of first determining the standard deviations of each contributor to performance and then applying a deviate to provide a sample of each component. These samples are then combined to project parameter variations. Once a particular relationship is established between variables or they are deemed independent, and useful limits are established on each variable, a solution can be obtained by picking random numbers (within the range) and replacing the variables with them. By running numerous examples, a range of answers can be obtained.

This procedure has been used to simulate many real life problems, such as time to failure for a mechanical system or even a solid rocket motor. For example, there may be many independent variables that determine the service life of a solid rocket motor. If the lower limit of each variable is used for the estimate, an unrealistically low service life will be predicted. On the other hand, if each of the variables are allowed to be picked at random (similar to the real world situation), within the normal limits, some factors will be low while others will be average or high, thereby showing an increase in the service life. By letting a computer solve many different combinations of random input variables a more realistic distribution of service life will result.

First, one must determine the standard deviations of each contributor to the performance, and then apply a deviate to provide a statistical sample of each component. These samples are then combined to project parameter variations. In other words, once a particular relationship is established between variables or they are deemed independent, and useful limits are established on each variable, a solution can be obtained by picking random numbers (within the range) and replacing the variables with them. By running numerous examples on the computer, a range of answers can be obtained.

One of the first problems faced by anyone doing Monte-Carlo calculations is the generation of the sequences of random variables required by the problem. This generally breaks down, if the problem is to be run on a computer, into two problems:

[1] how to generate sequences of random numbers uniformly distributed on the interval (0,1); and

[2] how to transform the random numbers into random variables having specified probability distributions. Advances in this area with very high level computing power have reduced the problems in generating random numbers.

While Monte-Carlo is a fairly easy technique to apply, it does have some pitfalls. The most important consideration should be to make sure that the mathematical relationship is defined accurately. In other words, if one has made the assumption that the variables are independent where in reality they do have some correlation the results could turn out to be in error. In addition, the sampling techniques used can contribute greatly to reduce the cost and increase the accuracy of the solution.

The cost and accuracy of running an analysis is very dependent on the sampling technique used. Six sampling techniques commonly used in Monte-Carlo analysis include:

1. Importance Sampling
2. Russian Roulette and Splitting
3. Use of Expected Values (combination of analytic and probabilistic methods)
4. Correlation and Regression
5. Systematic Sampling
6. Stratified Sampling (Quota Sampling)

Judicious application of these sampling techniques can increase the accuracy and reduce the number of computations in running an analysis.

The first three seem to have found particular and specialized usefulness in Monte-Carlo applications as differentiated from the usual applications in ordinary sampling. This is mainly due to the fact that in Monte-Carlo problems the experimenter has complete control of his sampling procedure.

1. Importance Sampling - The general idea of Importance Sampling is to draw samples from a distribution other than the one suggested by the problem and then to carry along an appropriate weighting factor which, when multiplied into the final results, corrects for having used the wrong distribution.

2. Russian Roulette and Splitting - In an example using dice, if the first die is tossed and if it happens to come up three or greater, it will be impossible to get a total of three, no matter how the second die comes up. Under these circumstances, there is no point in making the second toss and we can simply record a zero for the experiment. This makes it unnecessary to toss the second die 2/3 of the time. Therefore on the average we will do 1/3 fewer tosses in an experiment.

3. Use of Expected Values - For the dice throwing example, one should notice that in some cases there is no point in tossing the second die; that is, once the first die is tossed, it is trivially easy to calculate the probability of obtaining a total of three. For example, when the first die comes up one, the only way we can get the three total is for the second die to come up two. This event obviously has a probability of 1/6. Similarly, if the first die comes up two, the only way to get three is for the second die to be one. This event has a probability of 1/6. Finally, all the other possibilities for the first die (three to six) have a zero probability of giving three. If

we record the probabilities rather than toss the second die, then it is a fact that the average of these probabilities is an estimate of p. This method of doing the problem simultaneously reduces the number of tosses we need by a factor of two and decreases the variance, so that the tosses we do make are more effective.

Experience has shown that the above three techniques can effectively reduce the variance in Monte-Carlo analysis by significant amounts. This in turn allows for much cheaper and more practical computer solutions.

4. Correlation and Regression - Assume that the proprietor of one of the gaming establishments in Las Vegas wishes to change the rules in force at his dice tables. Under the current rules, if a player tosses a 2,3, or 12 on the first throw of the dice, the player loses. If he tosses a 7 or 11 he wins, and if he tosses a 4, 5, 6, 8, 9 or 10, he will win or lose, depending on whether or not that number or a 7 comes up first in his subsequent throws.

Suppose that the proprietor wishes to interchange the roles of 3 and 4, and wishes to determine by sampling what the change in his revenue will be. The obvious way to do this is to run two sets of experiments, one with the old rules and one with the new rules, and then compare the two experimentally determined revenues. Under these circumstances, one is subtracting two relatively large, fluctuating quantities to determine a small quantity. In general, this yields a process with a large percent error.

There is a better way to do this problem. Instead of running two independent games, the proprietor could run only one game and apply both sets of rules simultaneously to this game. In fact, he can choose to estimate the difference in revenue directly rather than the revenue that would be achieved under each set of rules. It should be noticed that the specific game that is being played is quite different from the two games that are being compared. As usual, this causes a double saving of efficiency; first because only one set of games is played, and second because the number of kinds of chance fluctuations that can affect the results are greatly reduced.

This illustrates a substantial virtue of the Monte-Carlo method. In many complicated problems we are not actually interested in absolute values but only in comparisons. We may wish, for example, to know if Strategy A is better than Strategy B, or if Engineering Design A is better than Engineering Design B.

5. Systematic Sampling - If we are doing a multi-stage sampling problem, it often turns out to be very easy to do the first stage systematically. For example, in the dice problem, if we are going to toss the dice one at a time then there is really no point in actually tossing the first die. If, for example, we were planning on getting 600 samples, we would expect on the average that each die would come up one about 100 times, two another 100, and so on. It is easy to show that we do not bias the results if we assume that the first 100 tosses of the first die actually do come up one, the second 100 tosses of this die come up two, etc. and so we only need toss the second die. The main advantage in doing this is that we have eliminated the error caused by the fluctuation in the proportion of ones, twos, etc. which would result if the first toss was random.

6. Stratified Sampling - This last technique is a sort of combination of Importance Sampling and Systematic Sampling. For example, if we were only a little bit sophisticated and were doing the systematic sampling described above, we would soon notice that there is no point in considering the 400 tosses in which we have assigned the values three to six for the first toss of the die, since under these circumstances, we can never get a total of three. Therefore, we might systematically divide the sample into halves rather than sixths. In the first half we would say that the first die came up one, and in the second half that the first die came up two.

In theory, this method could be as powerful as Importance Sampling. In actual practice, the fact that you have to sample systematically turns out to decrease sharply the number of places in which it can be used. However, where it can be used, it is usually better than Importance Sampling and in any case never worse. Therefore whenever the costs of the two techniques are comparable, Stratified Sampling is preferable to Importance Sampling.

IV. REFERENCES

A. Woody, Donald, "Monte-Carlo Methods," notes from UAH Course ISE 790 (Dr. Mike Dorsett), Feb. 19, 1986.

B. Shreider, Yu. A., The Monte-Carlo Method, Pergamon Press, New York, 1966.

V. EXAMPLE

Flight Mechanics Application

Suppose one were interested in running a set of Monte-Carlo simulations to study the effect of initial atmospheric entry flight path errors on the required delta-V at atmospheric exit for the Aeroassist Flight Experiment (AFE). These errors could be caused by any of a number of error sources; such as GN&C hardware, software errors in state vector propagation, initial and updated position errors, and others.

First, a state vector error covariance matrix must be specified, developed, or calculated. This matrix, of dimension 9 X 9, includes three position and three velocity error components (downrange, crossrange, and radial), and three attitude error compon-ents.

Second, compute the 9x9 lower triangular matrix, L, using the state vector error covariance matrix, E, and the following algorithm (a variation of Cholesky decomposition) given in pseudo-code:

```
for i=1 to 9
    for j=1 to 9
        if i=j, do
            sum= Eii
            for k=1 to i-1
                sum=sum-Lik^2Ekk
            end for
            Lii=(sum/Eii)^1/2
        else if i<j, do
            Lij=0
        else
            sum=Eij
            for k=1 to j-1
                sum=sum-LikLjkEkk
            end for
            Lij=sum/(EjjLjj)
        end if
    end for
end for
```

Third, generate a vector of zero-mean Gaussian random numbers, n_i, i=1,2,...,9, with the standard deviation of the ith random variable equal to the square root of the ith diagonal entry of the error covariance matrix. The n_i can be efficiently generated by using, for example, Marsaglia and Bray's polar method (Maindonald, 1984). These random variables have the desired standard deviations but are uncorrelated.

The next (fourth) step is to map this vector of uncorrelated random variables into a vector with desired correlation (as specified by the off-diagonal elements of the normalized error covariance matrix). Premultiply the vector from the third step by the matrix, L, from the second step. The resulting random perturbative vector is then added to the nominal state vector. The resultant vector is then chosen as a new initial state vector of the spacecraft for each Monte-Carlo trajectory.

The second step above is performed once; at the beginning of a set of Monte-Carlo trajectories. The third and fourth steps are performed prior to the simulation of each Monte-Carlo trajectory.

The product of the many Monte-Carlo runs is a statistically valid estimate of the correlated spacecraft initial state vector errors (position, velocity, and attitude). The beauty of the technique is that: 1) the user can study or simulate an arbitrary part (e.g., atmospheric braking) of the mission without having to start each trajectory simulation from the very beginning of the mission, and 2) the user does not need to be concerned with the cause of the state vector errors.

5.0 PROCESSES & CHECKLISTS

5.1 DESIGN REVIEWS

5.1 BASELINE DESIGN REVIEW PROCESS

The following list is a partial listing of topics that may be used as "memory joggers" by the system engineer during the design and review process to help ensure that all factors affecting the product are considered.

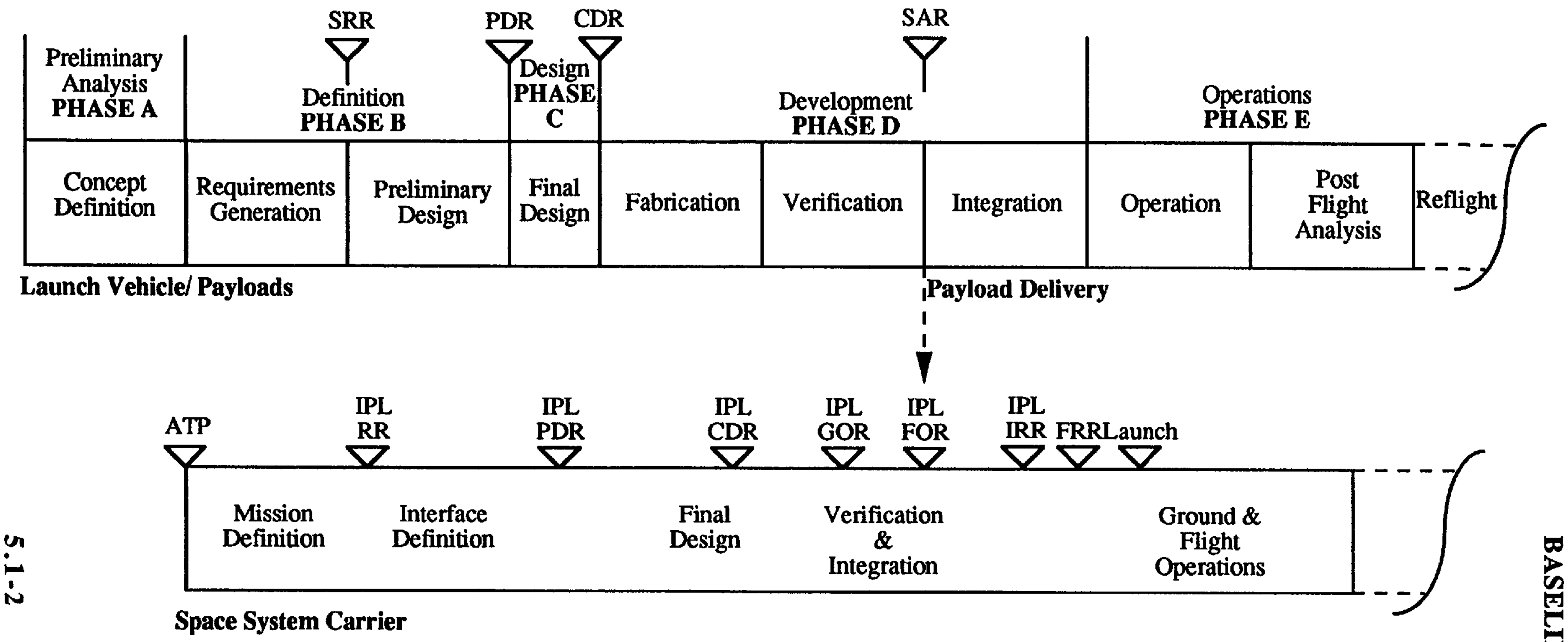
In Volume 1, formal design reviews were mentioned briefly and their phasing in the project life cycle discussed. For convenience, Figure 5.1-1 shows the identical program review phasing as shown in Figure 8, Volume 1. In the following section of this volume, each of the formal reviews will be discussed individually and in greater detail. The purposes of the various reviews and the specific technical thrusts of the reviews are presented to highlight their differences.

In general, the planning for and conduct of design reviews is the responsibility of the Program/Project Office. A plan is developed by the Program/Project Office and concurred in by S&E for each review. These plans define the objectives of the review and the review policies and procedures.

Review teams are established to represent specific areas of expertise, such as software. Normally there is a Systems Team, and this is where the systems engineer will most likely be represented.

As a member of a Systems Team, you will be required to review and assess all technical documents and drawings in the Review Data Package. In early reviews, the emphasis should be on assessing the completeness and accuracy of the requirements documentation. Although in later reviews the requirements will continue to be reviewed, emphasis will shift to evaluating the evolving hardware and software designs to ensure that system requirements are being met and that the interfaces are compatible. In addition, the overall system design should be evaluated to ensure the design remains optimized from the systems point-of-view.

Table I is a checklist of typical items which should be considered during every design review. This list is based on many years of experience and can help focus the system engineer's effort in areas which have been the source of problems on past programs/projects. The list is intended as a guide and should not be considered all-encompassing nor are all items listed applicable to all projects or all reviews.



Notes: SRR- System Requirements Review
PDR- Preliminary Design Review
CDR- Critical Design Review
SAR- System Acceptance Review
ATP- Authority to Proceed
IPL- Integrated Payload

RR- Requirements Review
GOR- Ground Operations Review
FOR- Flight Operations Review
IRR- Integrated Readiness Review
FRR- Flight Readiness Review

Note: Program Phases based on NMI 7120.4

Figure 5.1-1. Typical Program Review Phasing

TABLE I. PAYLOAD/EXPERIMENT REVIEW CHECKLIST

TOPIC/AREA	REMARKS
A. ELECTRICAL	
1. Circuit Protection (rating/trip characteristic/verification)	Ensure compatibility and sizing. Based on wiring or component protection?
2. Average/Peak Power/Power Margin	Adequate margins for program phase?
3. Energy margins	See 2.
4. Internal ground isolation/single point ground	Single grounding philosophy. Exceptions?
5. Signal return isolation	Wire or via structure?
6. Operating voltage range (max/min)	Margins?
7. Corona protection	Is equipment powered during ascent?
8. Chassis grounding	See item 4.
9. Silver-plated copper wire	Problems have been experienced due to lack of moisture control during manufacturing process.
10. Pyro circuit protection/arming	Approach to ensure no fire/all fire?
11. Electrostatic discharge	Conductive surfaces, paints.
12. Lightning protection	Analysis or test?
13. EMI Sources	Analysis or test?
14. Kapton wire usage	Temperature range of application?
B. STRUCTURAL/MECHANICAL	
1. Factors of safety (MSFC-HDBK-505A)	Metallic/nonmetallic test philosphy
2. Fracture critical analysis (MSFC-HDBK-1453)	
3. Nondestructive evaluation requirements (MSFC-STD-1249)	

4. Venting analysis (consider emergency depressurization/repressurization)	Ensure adequate venting during all mission phases.
5. Alignment	
6. Stress analysis	Ensure positive margins.
C. THERMAL	
1. Environments	Using latest databases?
2. Thermal control system design	New or proven design?
3. Temperature limits vs. predictions (operational, non-operational, turn-on, survival)	Adequate margins?
4. Verification	Verification of models by test?
D. COMMAND AND INSTRUMENTATION	
1. Command requirements	Adequate margins?
2. Measurement requirements	Adequate margins?
3. Calibration requirements	Adequate margins?
4. RF/Communications margins	Adequate margins?
E. SOFTWARE AND DATA MANAGEMENT	
1. CPU utilization/margins	Adequate margins?
2. Software requirements	
3. Memory requirements/margins	Adequate margins?
4. Verification/validation process	

F. MATERIALS	New or proven?
1. Stress corrosion	Meets spec./MUAs?
2. Flammability	Meets spec./MUAs?
3. Contamination	Meets spec./MUAs?
4. Outgassing/Offgassing	Meets spec./MUAs?
5. Hazardous materials	Meets spec./MUAs?
6. Toxicity	Meets spec./MUAs?
G. VERIFICATION	
1. System/Subsystem/Component functional verification (MSFC-HDBK-2221)	Verification techniques
2. Environmental tests (MSFC-HDBK-670)	Which tests apply or are planned? Are protoflight values applicable?
a. Thermal	
b. Vacuum	
c. Vibration	
d. Acoustic	
e. Shock	
3. EMI/EMC	
4. Corona	
5. High-Low voltage	
6. JA-061/081 Verification closeout	
7. Was hardware powered during qual/acceptance testing?	
8. Use of analysis? Documented?	

H. DOCUMENTATION	
1. Configuration control record	
2. Logbook	Complete/up to date?
3. Open Items List	Status
4. Waivers, deviations, discrepancy reports - status	Open items/issues
5. Error budget	
I. GENERAL SYSTEM ENGINEERING TOPICS	
1. Experiment/payload classification	
2. Safety compliance data/reviews - status	Open items/issues
3. Residual hazards	
4. Extent of FMEA/CIL and Hazard Analysis performed	
5. Status of RIDs from earlier reviews	Open RIDs - plan for closing
6. Signatures and closeout dates for each RID action	
7. Processing of comments received on referenced documents	How were they assessed?
8. Use of NASA Standard Initiator (NSI) and Pyrotechnic Initiator Controller (PIC) for ordnance initiation	New or proven design?
9. Mass properties (c.g.)	Maturity
10. Resource margins and contingencies	Adequate for program phase?

5.1.1 SYSTEM REQUIREMENTS REVIEW (SRR)

I. OPR

EL51

II. PURPOSE

The **System Requirements Review (SRR)** confirms that the requirements and their allocations contained in the System Specifications are sufficient to meet project objectives.

III. DESCRIPTION

The **SRR** may be thought of as the culmination of the early Definition Phase (Phase B, as shown in Figure 5.1-1) of a program. For major programs, such as the Space Shuttle, major subsystems can have their own SRR prior to a system-wide SRR. In addition, reviews may be held at any level of assembly, from components, to the complete program/project.

The SRR Board is chaired by the Project Manager at the designated NASA Center. In cases where large and complex programs require the utilization of major resources of multiple Centers, this project/program management responsibility may be established at the Headquarters level by the Administrator.

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

* Overall program plan, schedule and WBS (Work Breakdown Structure)
* Mission and requirements analysis (includes missions operations activities, feasibility and utility analysis)
* Requirements definition and allocation, in the form of a System Specification (SS)
* Functional flow analysis
* Software systems requirements
* Systems analysis and models, including performance and requirements analysis, technology/risk assessments, cost risk analysis and assessment
* Systems trade studies (e.g., cost, schedule, lifetime and safety)
* Science and engineering development plan
* Design analysis and trade studies
* Preliminary interface requirements (i.e., *interface control documents*)
* Interface requirements (i.e., *interface requirements documents*)
* Instrument interface agreements (IIA's), operations and interface agreements (O & IA's), verification plan
* Verification approach
* Payload integration requirements (including use of the MROFIE -- Mission Requirements On Facilities/Instruments/ Experiments document)
* Flight and ground operations plan
* Synthesis activities
* Logistics support analysis
* Specialty discipline studies (i.e., structures and dynamics, safety and reliability, or maintainability analyses; materials and processes considerations; electromagnetic compatibility/interference, inspection methods/techniques analysis, or environmental considerations)
* Integrated test planning
* Data management plans

* Configuration management plans
* System safety reports
* Human factors analysis
* Value engineering studies
* Life cycle cost analysis
* Manpower requirements/ personnel analysis
* For manufactured items producability analysis, preliminary man acturing plans

The total System Engineering Management activity and its output shall e reviewed for responsiveness to the Staten it of Work and system requirements. Procuring activity direction to the contractor will be provided, as necessary, for continuing the technical program and system optimization.

This review is typically held about a year following the contract award for Phase B. The SRR should encompass all major participants, both NASA and contractors. During the review, the SRR team should verify configuration concepts and requirements, verify mission objectives, define the qualification approach, evaluate the system safety and quality assurance plans, and establish and approve the program requirements and system requirements baseline.

Outputs from this review include:

* Baseline System Specification, placed under configuration management control
* Qualification approach
* Configuration co... pts and requirements
* System requirements baseline
* Safety assessment plans
* Determination of required support (logistics, transportability, etc.)

Coordination, review, and approval occurs through the Program or Project Manager. Products are dispositioned to NASA Center organizations and the NASA contractor team as required to support the Program or Project. This review leads to a formal decision by a Program Associate Administrator (PAA) to proceed with preparations for requesting a proposal for project implementation (Phases C/D/E) on major programs/projects.

IV. REFERENCES

A. MMI 8010.5: "MSFC Baseline Design Reviews," December 14, 1989.

B. MIL-STD-1521A (USAF): "Technical Reviews and Audits for Systems, Equipments, and Computer Programs," 1 June 1976, revised 21 Dec. 1981.

C. MM 7120.2A: MSFC Management Manual, "Project Management Handbook," June 12, 1989.

D. JA-447, Revision B: Mission Requirements On Facilities/Instruments/ Experiments (MROFIE.) for Space Transportation System (STS Attached Payloads, MSFC Document, November 1987.

E. NHB 7120.5, "Management of Major System Programs and Projects"

5.1.2 PRELIMINARY DESIGN REVIEW (PDR)

I. OPR

EL51

II. PURPOSE

The Preliminary Design Review (PDR) is held at the system, subsystem, and component levels to demonstrate preliminary designs meet system requirements with acceptable risk. All interfaces and verification methodologies must be identified. The PDR is one of only two mandatory reviews required by NMI 7120.4.

III. DESCRIPTION

The PDR is a technical review of the basic design approach for configuration items to assure compliance with program (at Levels I and II) and project (Level III) requirements. PDRs may be conducted at the program or project level. The PDR is typically conducted near the end of Phase B (see Figure 5.1-1), when the basic design approach has been selected and the necessary documentation is available.

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

The objectives of the PDR are to assure that:

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

The program PDR Board is chaired by the Program Manager and includes all major participants (NASA and contractors). The project PDR is chaired by the Project Manager and includes the major organizations of the NASA Center and the prime contractor.

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

* Preliminary design drawings
* Development plans
* Flow diagrams
* Safety analysis reports
* Preliminary Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL)
* Test verification/validation plans
* Configuration management plans
* Interface Control Documents (ICDs)
* Systems description document
* Work Breakdown Structure and Dictionary
* Software documents
* Spares philosophy
* Preliminary launch site requirements

* Preliminary GSE requirements
* Part I Contract End Item (CEI) update
* Fracture control plan (updated)
* Preliminary strength and fracture mechanics analysis
* Proof of concept engineering analysis

PRR/PDR GUIDELINES

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

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

Outputs of the PDR process include:

* Update to the System Specification (for Program PDRs)
* Baselined Part I CEI Specification, placement under Configuration Change Board (CCB) control
* Preliminary Interface Control Drawing update
* Preliminary design drawings
* Development plans
* Flow diagrams
* Safety analysis reports
* Preliminary Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL)
* Test verification/validation plans
* Configuration management plans
* Interface Control Documents (ICDs)
* Systems description document
* Work Breakdown Structure and Dictionary
* Software documents
* Spares philosophy
* Preliminary launch site requirements
* Preliminary GSE requirements
* Part I CEI (update)
* Fracture control plan (updated)
* Preliminary strength and fracture mechanics analysis
* Proof of concept engineering analysis

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

VI. REFERENCES

A. MMI 8010.5: "MSFC Baseline Design Reviews," December 14, 1989.

B. MIL-STD-1521A (USAF): "Technical Reviews and Audits for Systems, Equipments, and Computer Programs,"

June 1, 1976, revised December 21, 1981.

C. MM 7120.2A: MSFC Management Manual, "Project Management Handbook," June 12, 1989.

D. JA-447, Revision B: Mission Requirements On Facilities/Instruments/ Experiments (MROFIE) for Space Transportation System (STS) Attached Payloads, MSFC, November 1987.

E. NHB 7120.5, “Management of Major System Programs and Projects”, November 8, 1993.

5.1.3 CRITICAL DESIGN REVIEW (CDR)

I. OPR

EL51

II. PURPOSE

The Critical Design Review (CDR) confirms that the project's system, subsystem, and component designs, derived from the preliminary design, is of sufficient detail to allow for orderly hardware/software manufacturing, integration, and testing, and represents acceptable risk. The CDR is the second of only two mandatory reviews required by NMI 7120.4.

III. DESCRIPTION

The CDR is the technical review of the detail design of the selected configuration. This review is generally held at the end od Phase C (see Figure 5.1-1). This review provides assurance that the detail design is in accordance with the Part I Contract End Item (CEI) Specification prior to its release to manufacturing. Configuration Item (CI) and computer program CI critical design reviews are normally contractually required and are attended by the customer. Critical design reviews are normally conducted on the same items as preliminary design reviews, and as such warrant an in-house review prior to the formal critical design review.

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

The objectives of the CDR are to assure that:

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

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

Outputs of the CDR process include:

* Formal identification of specific engineering documentation that will be authorized for use to manufacture the end items
* Authorized release of the baselined design and the required data, including as appropriate:

- Software definition
- Detail design/drawings
- ICDs
- Preliminary test results
- Failure Modes and Effects Analysis/Critical Items List (FMEA/CIL)
- Integration plans and procedures
- Subsystem description document
- Launch site requirements
- Detail design specifications

- Component, subsystem and system test plans
- Analyses reports
- Safety analysis/risk assessment
- Hazard analysis
- Spares list
- Fracture control plan (updated)
- Strength and fracture mechanics analysis

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

IV. REFERENCES

A. MMI 8010.5: "MSFC Baseline Design Reviews," December 14, 1989.

B. MI STD-1521A (USAF): "Technical Re ws and Audits for Systems, Eq ments, and Computer Programs," Ju , 1976, revised December 21, 19..

C. MM 7120.2A: "Project Management Handbook," June 12, 1989.

D. JA-447, Revision B: Mission Requirements On Facilities/Instruments/ Experiments (MROFIE) for Space Transportation System (STS) Attached Payloads, MSFC, November 1987.

E. NHB 7120.5, "Management of Major System Programs and Projects"

5.1.4 GROUND OPERATIONS REVIEW (GOR)

I. OPR

EL43

II. PURPOSE

The purpose of the Integrated Payload Ground Operations Review (IPL-GOR) is to ensure that the physical integration requirements have been defined and that the necessary support has been allocated. In addition, KSC planning documentation will be reviewed to allow MSFC to finalize their planning for support of the physical integration and launch.

III. DESCRIPTION

This review is generally held during the Verification Phase (see Figure 5.1-1).

Documentation required for this review includes:

A. Baselined Ground Integration Requirements Document (GIRD)

B. Baselined/updated Operations and Integration Agreement (O&IA) for each element

C. Baselined Integrated System Verification Plan

D. Baselined Assembly and Installation Drawings

E. Baselined Interface Schematics

F. Preliminary Destowage Plan

G. Updated Payload Operations Control Center (POCC) data base

H. Launch site support plan

I. Baseline issue integrated payload safety compliance data.

IV. REFERENCES

A. MMI 8010.5, "MSFC Baseline Design Reviews," December 14, 1989.

B. JA-447, Revision B: "Mission Requirements On Facilities/Instruments/ Experiments (MROFIE) for Space Transportation System (STS) Attached Payloads," MSFC, November 1987.

5.1.5 FLIGHT OPERATIONS REVIEW (FOR)

I. OPR

Mission Operations Lab

II. PURPOSE

The purpose of the Integrated Payload Flight Operations Review (IPL-FOR) is to ensure that the flight operations planning and flight support requirements have been defined and the necessary resources have been planned and allocated.

III. DESCRIPTION

This review occurs in conjunction with delivery of the payload for integration with the space system carrier (see Figure 5.1-1).

Documentation required for this review:

A. Baseline issue/baselined Operations and Integration Agreement (O&IA)

B. Baseline issue Flight Definition Document

C. Baseline issue Flight Supplement Payload Operations guidelines

D. Baseline issue Payload Operations Checkout Center (POCC) Requirements Document

E. Baseline issue flight planning

F. Baseline issue flight operations support

G. Baselined training

H. Baselined Integrated Training Plan

I. Baseline issue payload data processing requirements

J. Preliminary Payload Flight Data File

K. Baseline issue POCC data base

L. Baseline issue Spacelab Data Flow and Data Configuration Document

M. Baseline issue Postflight Evaluation Plan.

IV. REFERENCES

A. MMI 8010.5, "MSFC Baseline Design Reviews," December 14, 1989.

B. JA-447, Revision B: "Mission Requirements On Facilities/Instruments/ Experiments (MROFIE.) for Space Transportation System (STS) Attached Payloads," MSFC, November 1987.

5.1.6 DESIGN CERTIFICATION REVIEW (DCR)

I. OPR

EL51

II. PURPOSE

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

III. DESCRIPTION

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

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

Program/Project Offices are responsible for the initiation and overall conduct of the DCR, as they are for all design reviews. This responsibility includes preparing a Configuration Management Plan (see MM 8040.12 and Section 2.1.4 of this volume) and preparing a detailed review plan for each review.

The DCR review criteria include the following:

* CEI Specifications
* Verification Plan and requirements
* ICDs
* Design requirements
* Configuration Control Board Directives (CCBDs)

Data required for this review are as follows:

* Drawings/Engineering Orders
* Manufacturing records
* Verification Test Reports
* CDR RIDs and dispositions
* Requirements Compliance Reports
* Engineering analyses
* FMEAs/CIL
* Open Work List
* Non-conformance Reports/Status
* Certifications of Quality (COQs)
* Hazard Analysis/Risk Assess-ment
* Waivers and Deviations
* Certificate of Configuration Compliance (COCC)
* Vendors Certificate of Flight Worthiness (COFW)
* Mission Constraints
* Materials Usage Agreement (MUA)
* Flight Data File
* All software development documentation
* Fracture Control Plan
* Strength and Fracture Mechanics for as-built hardware

IV. REFERENCES

A. MM 7120.2, "Project Management Handbook," June 12, 1989.

B. MMI 8010.5, "MSFC Baseline Design Reviews," December 14, 1989.

C. MM 8040.12, "Contractor Configuration Management Requirements MSFC Programs."

D. MSFC-HDBK-1912, "Systems Engineering Handbook", Volume 2, Section 2.1.4.

5.1.7 CONFIGURATION INSPECTION (CI)

I. OPR

EL51

II. PURPOSE

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

III. DESCRIPTION

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

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

Review criteria include the following:

* CEI Specification
* Release records
* Test requirements and procedures
* Drawings and engineering orders (EOs)
* Configuration Control Board Directives (CCBDs)
* System schematics

Required data for this review are listed below:

* Deviations
* Inspection tags
* Test log book
* Test Reports
* Certifications Of Quality
* Materials certification
* Special handling procedures
* Contamination Control Records
* Open Work List
* Work Orders
* Drawings and EOs
* CCBDs
* Materials Process Certification
* Materials Utilization List (MUL)
* Vendor Certificate Of Flight Worthiness (COFW)
* Non-conformance Report Status
* Hardware shortages
* Installed non-flight hardware list
* Safety Compliance Data
* Software
* Fracture Control Plan
* Strength and fracture mechanics analysis for as-built hardware

IV. REFERENCES

A. MM 7120.2, "Project Management Handbook," June 12, 1989.

B. MMI 8010.5, "MSFC Baseline Design Reviews," December 14, 1989.

5.1.8 SYSTEM ACCEPTANCE REVIEW/INDEPENDENT READINESS REVIEW (SAR/IRR)

I. OPR

EL51

II. PURPOSE

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

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

III. DESCRIPTION

These reviews occur at the completion of the payload verification phase and the carrier verification and integration phases, respectively (see Figure 5.1-1).

Documentation required for this review:

1. Acceptance data package (ADP) which must include:

- As-built configuration assembly and installation drawings
- Final Mass Properties Status Report including weight and balance sheets
- Baselined interface schematic drawings
- Phase III safety compliance data package which includes the final experiment safety package cover sheet, and complete hazard reports with supporting data
- As-built certification data on safety critical structures data package
- Final Verification Analysis Reports
- Final Verification Test Reports
- Update of pointing and control dynamics data requirements document

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

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

3. Open Work List which must identify and describe any work that was intended to be completed before shipment to KSC but was actually not. It must also include any work or test that previously was not required to be performed at KSC. These items must be categorized as follows:

- To be done before shipment
- To be done at KSC:

  -- Off-line/pre-level IV

  -- Level IV

4. Status and discussion of all:

- Waivers/Deviations/Engineering Change Requests (ECR's)
- Material Usage Agreements
- Hardware modifications (planned/proposed)
- Phase-down/phase-up plans
- Open Review Item Discrepancies/Discrepancy Notices (RID's/DN's)
- All alerts

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

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

* Completeness
* Interface safety requirements satisfied inspection
* Configuration at IRR versus Flight Configuration

Upon successful completion of all activities, a certificate of acceptance is signed by the mission manager.

IV. REFERENCES

A. MM 7120.2, "Project Management Handbook," June 12, 1989.

B. MMI 8010.5, "MSFC Baseline Design Reviews," December 14, 1989.

C. JA-447, "Mission Requirements On Facilities/ Instruments/Experiments (MROFIE) for Space Transportation System (STS) Attached Payloads, MSFC, November 1987.

5.1.9 FLIGHT READINESS REVIEW (FRR)

I. OPR

Mission Operations Lab

II. PURPOSE

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

III. DESCRIPTION

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

For STS attached payloads (Ref. B), the FRR is held in two phases. **Phase I** is held at the completion of Level III/II payload integration requirements as defined in the Ground Integration Requirements Document (GIRD). It is typically held at the start of Level I payload integration requirements. Successful completion of the FRR Phase I review verifies:

1. Recertification of interface requirements
2. Recertification of safety requirements
3. Level I integration requirements have been defined
4. Payload is ready for Level I integration
5. Payload requirements identified in the Ground Integration Requirements Document (GIRD) have been satisfied

Phase II commences at completion of Level I integration and ensures that the payload and the operations team are ready for flight (see Figure 5.1-1).

IV. REFERENCES

A. MM 7120.2, "Project Management Handbook," June 12, 1989.

B. JA-447, "Mission Requirements On Facilities/ Instruments/Experiments (MROFIE) for Space Transportation System (STS) Attached Payloads," November 1987

C. NHB 7120.5, "Management of Major System Programs and Projects."

5.1.10 REVIEW ITEM DISCREPANCY (RID)

I. OPR

EL31

II. PURPOSE

The Review Item Discrepancy (RID) process is the formal method used for documenting and tracking discrepancies/problems discovered during the design review process.

III. DESCRIPTION

A RID is an approved 2-sheet form (MSFC Form 3739) shown in Figures 5.1.10-1 and 5.1.10-2. Use of this form, or a computer-generated replica is required by MMI 8010.5 to be used in the design review process. Copies of the form and its instructions may be obtained from MSFC supply. A list of RID groundrules is included as Appendix E of MMI 8010.5, and this should be reviewed prior to completing the RID form.

The specific process of numbering, reviewing, and dispositioning RIDs is normally defined in a separate plan for each formal design review. Once a RID is prepared, submitted, and accepted, it is tracked and all accepted RIDs remain open until the RID closure portion is satisfactorily completed. Although the RID form does not have a block for the RID initiator's signature in closing the RID, most projects require that the RID initiator concur in the closeout of the RID. The RID tracking is usually accomplished by the responsible Project Office with support from Configuration Management personnel.

IV. REFERENCES

MMI 8010.5, "MSFC Baseline Design Reviews," December 14, 1989.

1. TYPE OF REVIEW:

2. PROJECT:

3. DATE:

REVIEW ITEM DISCREPANCY

4. NUMBER:

5. RELATED RIDS:

6. INITIATOR/PHONE:

7. ORGANIZATION:

8. ITEM REVIEWED:

9. TEAM NAME:

10. RID SUBJECT:

11. DISCREPANCY/PROBLEM:

12. CONSEQUENCES IF NOT CORRECTED:

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (OPTIONAL):

14. DEVELOPER'S COMMENTS:

☐ COST IMPACT ROM: ______ ☐ SCHEDULE IMPACT ROM: ______

14.a SIGNATURE:

15. TEAM RECOMMENDATION:

☐ RID ACCEPTED
☐ RID ACCEPTED FOR STUDY
☐ RID ACCEPTED PER REMARKS
☐ RID DISAPPROVED (INVALID)
☐ RID WITHDRAWN BY INITIATOR
☐ SUBMIT TO PREBOARD

REMARKS:

15.a ACTIONEE:

15.b SUSPENSE DATE:

15.c TEAM CAPTAIN SIGNATURE:

MSFC-Form 3739 (Rev. October 1989) SHEET 1 OF 2

Figure 5.1.10-1. Sample RID Form (Page 1)

16. PREBOARD RECOMMENDATION: | RID No. | PAGE 2

- ☐ RID ACCEPTED
- ☐ RID ACCEPTED FOR STUDY
- ☐ RID ACCEPTED PER REMARKS
- ☐ RID DISAPPROVED (INVALID)
- ☐ RID WITHDRAWN BY INITIATOR
- ☐ SUBMIT TO BOARD

REMARKS:

16.a ACTIONEE:	16.b SUSPENSE DATE:	16.c PREBOARD CHAIRMAN / DATE

17. BOARD DISPOSITION:

- ☐ RID ACCEPTED
- ☐ RID ACCEPTED FOR STUDY
- ☐ RID ACCEPTED PER REMARKS
- ☐ RID DISAPPROVED (INVALID)

REMARKS:

17.a ACTIONEE:	17.b SUSPENSE DATE:	17.c BOARD CHAIRMAN / DATE

RID CLOSURE RECORD

18. IMPLEMENTATION:

ACTIONEE / DATE

19. CLOSURE APPROVED: CHIEF ENGINEER / DATE	20. CLOSURE APPROVED: PROGRAM OFFICE / DATE

SHEET 2 OF 2

Figure 5.1.10-2. Sample RID Form (Page 2)

5.2 CONFIGURATION CONTROL

5.2.1 DOCUMENT RELEASE PROCESS

I. OPR

EL31

II. PURPOSE

When an engineering document has been prepared, it must be released and distributed or made available to all project participants. This fact sheet describes the formal release process for documents which are baselined. Note that not all engineering documents (this handbook, for instance) are baselined, but the release process for these documents will not be addressed here.

III. DESCRIPTION

The MSFC Release Desk is the single point for release of MSFC flight and ground support equipment engineering documents, and is the custodian of the MSFC engineering requirements document numbers, except the DR and MM numbers.

The general process flow for document release is different depending on whether or not a Configuration Control Board (CCB) has been chartered. When a CCB has been chartered, the Office of Primary Responsibility (OPR) organizes the document package as shown in Figure 5.2.1-1 depending on whether this is an initial release, a change package, or a complete revision. The OPR delivers the document package to the appropriate CCB Secretariat for review and disposition. After the CCB issues its directive, the OPR incorporates the necessary changes in the document package and submits it to EL33 for checking and Release Desk processing.

When a CCB has not been chartered, the OPR must obtain all necessary approvals and signatures before delivering the package to EL33 for checking and Release Desk processing.

The specific detail requirements for coordination and approval can be found in the reference. You should always go to the reference to ensure you are following the latest approved policies and procedures.

IV. REFERENCES

MSFC-STD-555, "MSFC Engineering Documentation Standard."

V. FIGURE

Figure 5.2.1-1 provides a graphical depiction of the forms needed for first release, complete revision, and document change packages.

Acronyms and abbreviations used in this figure are defined below.

ECR - Engineering Change Request

DP/RS - Documentation Package/Routing Slip

DRL - Document Release List

SCI/DCI - Specification Change Instruction/ Document Change Instruction

SCN/DCN - Specification Change Number/Document Change Number

SRP/DRP - Specification Replacement Page/Document Replacement Page

CHANGE PACKAGE REQUIREMENTS
FOR
DOCUMENT/SPECIFICATION RELEASE

IF "FIRST RELEASE"; PACKAGE SHOULD CONTAIN:	IF "COMPLETE REVISION"; PACKAGE SHOULD CONTAIN:	IF CHANGE(S), BUT NOT COMPLETE REVISION, PACKAGE SHOULD CONTAIN:
PACKAGE TO CCB SECRETARY FOR CCB REVIEW AND DISPOSITION		
1. ECR 2. DRL 3. DP/RS 4. SPEC/DOC 5. SCI/DCI	1. ECR 2. DRL 3. DP/RS 4. SCN/DCN 5. SCI/DCI	1. ECR 2. DRL 3. DP/RS 4. SCN/DCN 5. SCI/DCI
PACKAGE TO EL33 CHECKING AFTER CCB DISPOSITION		
1. DP/RS 2. DRL 3. CCBD (if applicable) 4. SCI/DCI 5. Speci[illegible]/Document	1. DP/RS 2. DRL 3. CCBD (if applicable) 4. SCN/DCN 5. SCI/DCI 6. Revised Specification/Document	1. DP/RS 2. DRL 3. CCBD (if applicable) 4. SCN/DCN 5. SCI/DCI 6. SRP/DRPs
NOTE: a. The Doc/Spec cover should be printed on card stock using (MSFC-Form 454).	NOTE: a. The Doc/Spec cover should be printed on card stock [illegible] (MSFC-Form 454).	NOTE: a. If the Doc/Spec cover is changed, it should be printed on card stock using (MSFC-Form 454).
b. The Doc/Spec should contain a signature sheet formatted as described in (MSFC-STD-555).	b. The Doc/Spec should contain a signature sheet formatted as described in (MSFC-STD-555).	b. A new signature sheet is not required.

Figure 5.2.1-1 Requirements for Document/Specification Release

5.2.2 ENGINEERING CHANGE REQUEST

I. OPR

EL31

II. PURPOSE

The Engineering Change Request (ECR) process is a formal method used for changing baselined documentation and drawings (hereafter referred to as "documents").

III. DESCRIPTION

The ECR process takes its name from the ECR forms used to formally track requested changes to documents after they have been baselined and released through a Configura-tion Control Board (CCB).

When a change is required in a baselined document, an ECR is prepared. After the form is complete, and the change is reviewed and signed by concurring persons and given technical approval, the completed form is delivered to a Configuration Control Board (CCB), which either accepts or rejects the proposed change. If it is accepted, the CCB assigns an action to implement the change. This CCB action takes the form of a Configuration Control Board Directive (CCBD). Closure of the CCBD requires release of a new document, a complete revision, or changes in the form of change notices (DCN or SCN) or Engineering Orders (EOs).

Anyone connected with a project may write an ECR. The form, as shown in Figure 5.2.2-1, is filled out according to the procedures in the reference documents. Enclosures should be used to provide comprehensive information in sufficient detail to enable an understanding of the total impact of the change. These enclosures could take the form of sketches, tables, drawings, or segments from other documents.

IV. REFERENCES

A. MMI 8040.19, "Engineering Change Requests."

B. MSFC-STD-555, "MSFC Engineering Documentation Standard."

1. NUMBER:	2. PCN:	MSFC **ENGINEERING CHANGE REQUEST** *(See Instructions on reverse)*	3. DATE:	4. PAGE: 1 OF

5. TO:	6. THRU:	7. FROM:

8. TITLE OF CHANGE:

9. RECOMMENDED PRIORITY: ☐ *Emergency* ☐ *Urgent* ☐ *Routine*	10. NEED DATE:
11. PROGRAM(S)/PROJECT(S) AFFECTED:	12. END ITEM(S) AFFECTED BY NOMENCLATURE:
13. RECOMMENDED EFFECTIVITY:	14. BASELINE DOCUMENTATION AFFECTED (Specs, ICD, etc.):

15. RELATED CHANGES (ECR, ECP, CR, etc.) BY NUMBER:

16. JUSTIFICATION FOR CHANGE (Includes effect if not incorporated)/(If necessary, continue on MSFC - Form 2327-1, continuation sheet):

17. EFFECTS ON:

☐ *Hardware* ☐ *Facility* ☐ *Schedule (See Enclosure ________ for impact)* ☐ *Other (Specify)*

☐ *Software* ☐ *Requirements Documents* ☐ *Cost (Estimated cost included in Enclosure ______)*

18. DESCRIPTION OF CHANGE (Include reference to enclosures)/(If necessary, continue on MSFC - Form 2327-1, continuation sheet):

19. SIGNATURE OF ORIGINATOR:	DATE:	TELEPHONE NUMBER:	OFFICE SYMBOL:

20. CONCURRENCE

SIGNATURE & ORGANIZATION	DATE	SIGNATURE & ORGANIZATION	DATE

21. TECHNICAL APPROVAL

SIGNATURE & ORGANIZATION	DATE	SIGNATURE & ORGANIZATION	DATE

MSFC-Form 2327 (Rev. March 1974)

Figure 5.2.2-1. Sample ECR Form

6.0 SYSTEM ENGINEERING TOOLS

6.0 SUMMARY OF SYSTEM ENGINEERING TOOLS

I. OPR

EL51

II. PURPOSE

The following listing provides a summary of a variety of computer-based tools used in the system engineering process at MSFC. It is provided to assist the system engineer with a shopping list of available tools from which to select when performing system engineering trades and analyses. Please note that this is not a complete listing, and if you are using tools not listed here, please consider submitting them for inclusion in the database. Note that the EL58 tools described in this section are developmental in nature and their configuration is updated and managed within the Flight Mechanics Branch as needed by branch engineers to satisfy unique mission analysis requirements. For this reason, formal documentation of the programs are not available. Only informal working documentation of the programs are maintained and often in the form of comments embedded within the FORTRAN code. This software can be provided in source code file format to outside organizations upon request to the EL51 division office. However, no warranties and no formal documentation can be provided to the user/engineer because of the continuing evolution of the programs.

III. DESCRIPTION

The summary which follows is an output report from a Macintosh 4th Dimension™ database file which contains important attributes for each computer program listed. For additions, changes, or deletions contact MSFC/EL51.

The column headings are self-explanatory with the possible exception of CATEGORY. The CATEGORIES are defined in Table I.

Table I. System Engineering Tool Categories

1 - Requirements Tracking	7 - Orbital Mechanics/ Spacecraft Nav
2 - Budget/Resource Tracking	8 - Engineering - Mechanical Properties
3 - Cost Estimation - DDT&E	9 - Engineering - Signal Proc/Data Mgmt
4 - Cost Estimation - Operations	10 - Engineering - Integrated Logistics Support
5 - Cost Estimation - Life Cycle	11 - Engineering - Other
6 - Scheduling/Planning	12 - Mission Effectiveness

Tool Name	Category	Description	Platform	MSFC POC
AUTO DATA REQTS MANAGEMENT SYS	1	Provides MSFC-wide on-line capability for preparation, coordination, and tracking of data requirements management elements such as Data Requirements Descriptions (DRDs) and Data Requirements Lists (DRLs).	MAINFRAME	EL31
VERIFICATION STATUS AND TRACKING	1	The Verification Status and Tracking tool is a database application developed using the EXCEL spreadsheet software on a MacIntosh computer. The database tracks verification items and their associated completion dates. The output is a status report in tabular form for each subsystem. It is used by the Chief Engineer's Office as a status completion indicator and as a forecast tool for verification activities. Special output products can be accommodated.	MAC	EL44
DOCUMENT DIRECTOR	1	The REQMGR(TM) program is a requirements management tool that combines the features of a word processor with a database management system. This is a document management system that allows requirements to be documented, allocated to lower-level requirements documents, and supports requirements linking and traceability.	IBM-PC	EL51
SYSTEM ENGINEERING DATA BASE (SEDB)	1	The SEDB is a commercial product of Ascent Logic Corp. It is a relational database designed to provide on-line access to progam requirements, their inter-relationships, and their verification status. It can serve as a front-end for the RDD-100 tool described elsewhere in this listing.	Mac, PC	EL56
XRCF ACTIVATION NETWORK	6	This tool is used to plan, schedule, and status activation and test activities in the X-Ray Calibration Facility (XRCF). Tracks resource allocations and use, and calculates critical path and float. Outputs include project schedule, resource profiles, logic diagrams, time-scaled diagrams, and bar charts. Uses PERT/CPM methods of analysis.	IBM-PC	EL63
ATTITUDE PROFILE DESIGN (APD)	7	The APD program is designed to be used as a stand-alone addition to SCOOT. The program uses information from a SCOOT output file and the user-defined attitude profile to produce histories of attitude, angular body rates, and accelerations. The output of this program is used as input into the Strapdown Navigation Analysis Program (SNAP).	MAINFRAME	EL58
BOEING LUNAR TRAJECTORY (BOLT)	7	Used to analyze high-thrust lunar missions, from start to finish, including constraints. Used in conjunction with Lunar Mission Survey (LMS) which contains a database of calculated lunar trajectories that can be used as starting values by BOLT. The BOLT program allows accurate modelling of trajectories and some optimization.	MAINFRAME	EL58

Tool Name	Category	Description	Platform	MSFC POC
IMPULSIVE MISSION ANALYSIS	7	The IMA program provides a user-friendly means of designing a complete Earth-orbital mission profile based on implusive burns. The program produces a trajectory summary, an output file for use by the SCOOT program, and several graphics including ground tracks on a world map, altitude profiles, relative motion plots, and sunlight/communications timelines.	MAINFRAME	EL58
LANDER	7	Lander predicts trajectory and flight performance of a spacecraft ascending or descending between a low lunar orbit and the lunar surface. It uses a specific trajectory procedure (de-orbit burn, gravity turn, descent, etc.) and optimizes certain parameters with[illegible] procedure.	MAINFRAME	EL58
MULIMP and MIDAS	7	Optimizes interplanetary trajectories, including intermediate impluses, using patched conic approximations. Allows for intermediate planet swingby, asteroid missions, and round-trip missions.	MAINFRAME	EL58
OPT. TRAJ. BY IMPLICIT SIMULATION (OTIS)	7	Optimization of any trajectories (with constraints) about Earth, Moon, or Mars, except for low thrust trajectories. Both 3-DOF and 6-DOF models are available.	MAINFRAME	EL58
PROGRAM TO OPT. SIMULATED TRAJ. (POST)	7	Allows optimization of ascent/descent trajectories (with constraints) from Earth, aerocapture trajectory computation, and guidance analysis for ascent and aerocapture. Minor modifications would allow flight around the Moon or Mars. Both 3-DOF and 6-DOF models are available.	MAINFRAME	EL58
QUICKTOP and VARITOP	7	Low-thrust interplanetary trajectory optimization. Quicktop is easier to run and uses approximate optimization methods. Varitop uses Calculus of Variations methods to obtain a true optimum, but is more difficult to run. Both programs are 2-body trajectory programs.	MAINFRAME	EL58
SIMPLEX COMP. OF OPT. ORB. TRAJ. (SCOOT)	7	SCOOT uses the Simplex Algorithm of linear programming iteratively to determine the quasi-optimum exoatmospheric trajectory of a space vehicle. The output of this program is used as input to the APD program.	MAINFRAME	EL58
SPACECRAFT CONTROL SIMULATION (SCS)	7	The SCS is a time-domain simulation PC program for modeling multiple b[illegible] in space. Its main purpose is the development and analysis of Reaction Control Systems and Thrust Vector Control Systems. The predominant modeling technique is a state-space realization, however, difference equations can be used for emulating software-based controllers. The simulation can be expanded to model all phases of space flight.	IBM-PC	S&D Lab

Tool Name	Category	Description	Platform	MSFC POC
STRAPDOWN NAV ANALYSIS PROGRAM (SNAP)	7	The SNAP is a generalized navigation analysis program in which it is possible to configure up to 10 gyros and 10 accelerometers in an inertial navigation system. The SNAP is user-friendly, and configures to run on a VAX. The program requires input files of acceleration and altitude information and can be used to perform a deterministic or Monte-Carlo error analysis.	MAINFRAME	EL58
SWINGBY-STOPOVER TRAJ OPT (SWISTO)	7	Analyzes interplanetary missions with planetary swingbys (if desired) using approximate (patched conic) trajectory analysis. The SWISTO program iterates through possible trajectories to find the ones with the lowest initial mass in low Earth orbit. Does not allow for any deep space impluses. Analyzes one-way and round-trip missions.	MAINFRAME	EL58
ASEP	7	This program generates the ephemeris (time history of position and velocity) of a near-earth satellite. Its operating range of altitudes is from just above the sensible atmosphere (~300 km) out to geosynch. It generates approximately 100 parameters of interest to mission planning and orbital analysis such as Beta angle, time-in-sun, etc. Also generates and plots ground tracks. Analytical and very fast execution.	MAINFRAME	EL58
QUICK GUIDANCE ANALYSIS PROGRAM (QGAP)	7	The QGAP is a 3 degree-of-freedom launch vehicle ascent simulation that serves as a testbed for guidance scheme analysis and launch vehicle performance. The program is still under development with enhancements such as a 6 DOF option and simulation of orbital transfer vehicles planned.	MAINFRAME	EL58
GRAVE	7	The program is a numerical ephemeris generator which includes gravitational effects of the Sun and Moon. This is used for very high orbits (geosynch) such as AXAF-I where the solar and lunar effects are significant.	MAINFRAME	EL58
LTIME	7	Used to estimate lifetimes of satellites which are decaying because of atmospheric drag. It uses JACCHIA to compute the atmospheric density.	MAINFRAME	EL58
NSEP	7	Similar in function to ASEP except the integration is done numerically and thus is slower in execution than ASEP. Includes the effects of atmospheric drag on a satellite while ASEP does not.	MAINFRAME	EL58
RADI2	7	This program contains models of the trapped proton (AP models) and trapped electrons (AE models) radiation environments about the Earth. These models were developed at GSFC. The program propagates a satellite in orbit and computes the trapped radiation environment (flux density and energy levels) that the spacecraft will encounter. Will accumulate this information over the entire mission.	MAINFRAME	EL58

Tool Name	Category	Description	Platform	MSFC POC
RELMOT	7	Computes the relative motion between two spacecraft in orbit in close proximity to each other by the Clohessy-Wiltshire equations. It can be used in an initial value mode or in a two-point boundary value mode (the Lambert problem).	MAINFRAME	EL58
SALES	7	This program takes a point on the ground, such as a radar station, and determines when a satellite can be seen from it, as well as the time history of the azimuth and elevation of the satellite over the entire pass.	MAINFRAME	EL58
SHAD	7	Determines when a satellite will enter and exit the umbra and penumbra of the Earth. It models the Earth's shadow as a cone and the orbit plane by an ellipse and determines analytically when and where the ellipse intersects the cone.	MAINFRAME	EL58
SKYMAP	7	A catalog of all observable stars up to 9th magnitude in the visible range. This includes ~250,000 stars, each with 122 pieces of information (condensed versions of this catalog have been created). This data is used for creating guide star information for star trackers on spacecraft, for example.	MAINFRAME	EL58
STAR	7	Stellar Target Acquisition and Loss determines when various stars are visible to an orbiting spacecraft. It determines the acquisition and loss time for each defined star on each orbit for as many orbits as desired. This is used, for example, in scheduling observing prgrams for astronomy missions.	MAINFRAME	EL58
JACCHIA	7	This program models the Earth's upper atmosphere (90 - 800 km) as computed by the model developed by Jacchia of SAO in the 1970s. It computes the total atmospheric density as well as various species concentrations as a function of position (lat., long., alt.) and solar activity. Solar activity is an input obtained from predictions published by the environmental group in EL54.	MAINFRAME	EL58
PATRAN	8	The PATRAN+ is a pre- and post-processing software tool used in finite element analysis. Robust numerical algorithms provide for rapid analysis, model creation, and integration of other models for mass properties calculations and structural/thermal/CFD analyses.	MAINFRAME	ED01

Tool Name	Category	Description	Platform	MSFC POC
POGO STABILITY ANALYSIS PROGRAM	8	This program constructs a pogo system characteristic matrix in the LaPlacian domain and performs root locus and frequency response analyses of the system. Inputs to the program are high pressure oxidizer turbopump (HPOTP) pogo transfer equations, variable at which to open the loop, input variable, type of analysis desired, and definition of total system or subsystem to analyze. Outputs include nominal closed loop poles, open loop poles or zeroes, and phase and gain variations data. Phase and gain data as a function of frequency are also available in a printout file and a plot file for frequency response analysis.	MAINFRAME	ED01
ROCKET ENGINE TRANSIENT SIM. (ROCETS)	8	The ROCETS program is used to model rocket engine configurations for sizing and performance analyses.	MAINFRAME	S&D Lab
DATAVIEWS (DV-DRAW, DV-TOOLS)	9	This application animates data for screen and display development (including prototyping) for display use in control and testing systems. Very useful for prototyping displays (allows complete default data), and has "canned" building blocks. The DV-TOOLS portion is a C-language graphics library.	IBM-PC	N/A
SIGNAL ANALYSIS MODELING SYSTEM (SAMS)	9	The SAMS is an advanced database and sophisticated analysis system for data management systems (DMSs). Input is data from the Instrumentation Program and Command List (IPCL). Outputs include numerous status reports and DMS performance measures.	WRK STATN	EL56
AS-BUILT CONFIG. STATUS SYSTEM (ABCSS)	11	The ABCSS provides record of hardware configuration as manufactured. Allows comparison to "as-designed" configuration to verify hardware final configuration.	MAINFRAME	EL31
CHANGE PROC., TRACKING & ACCOUNTING SYS	11	Provides automated change status tracking, change processing, change status accounting, engineering change request, and subsequent configuration change board directive (CCBD) preparation and resolution. Provides engineering and CM personnel with predefined and user-specified report generation capabilities of change status and accounting information to a configuration baseline.	MAINFRAME	EL31
CONFIGURATION MANAGEMENT ACCOUNTING	11	Provides for the accounting and reporting of approved baselines and all approved changes to those baselines. Provides a variety of hard-copy reporting capabilities.	MAINFRAME	EL31
DIGITAL TRANSIENT MODEL	11	Very large, complex model for simulation of the Space Shuttle Main Engine (SSME). Intended primarily for control system analysis. Input files can be fully modified, and 600 commonly measured parameters are available as output. Model uses a combination of calculation methods including lookup tables, iteration, calculation and maps.	MAINFRAME	ED01

7.0 LESSONS LEARNED

7.0 Lessons Learned

This section of the handbook presents lessons learned from past programs and provides an important source of guidance in the system engineering process. The lessons learned have been structured to provide general program application and have been organized under headings identical to the major sections of Volume 1. The system engineer should periodically review these lessons for specific task applicability, both in the initial planning phases as well as during task completion. No priority or precedence is implied by the order of lessons in the following lists.

7.1 Planning and Definition

1. A project's justification and requirements should be tied to specific real missions which cannot be performed with any existing vehicles or systems. More than one such mission is needed.

2. All decisions on inter-center roles should be made prior to issuing the Phase C request for proposal (RFP). The addition of "new players" after contract award invites "new requirements" which can be viewed as contract changes by the contractor.

3. Plan ahead and try to anticipate and resolve issues before they become problems. BE PROACTIVE! Very few problems occur without early warning signs. The alternative is to be continually involved in "reactive system engineering."

4. Develop guidelines to assure more concise division of responsibility between experiment developer/supplier and MSFC in-house engineering.

5. Do a better job of preparing Statement of Work for payload/experiment procurements. Give more consideration to "lock and key" type experiment procurements, and total complement of documentation required for experiment development and integration should be supplied by the experiment contractor.

6. Establish the classification of a payload as early as possible as this is a major influence on determining program documentation and verification requirements and, thus, costs.

   -- Do a better job of prioritizing experiments - which ones should have in-depth performance reviews and which ones should be reviewed for safety and interface compatibility only.

7. When the program involves multiple centers/contractors/elements, establish an Interface Working Group early in Phase B to address interface issues and define interface details.

8. Take the time to identify and tailor RFP data requirements to be consistent with the project, S&E's role in that project, and MSFC's needs for contractor data to fulfill its role.

   -- Integrated hardware and end-to-end functional schematics have been shown to be an important aid in problem detection and identification. Be sure the RFP calls for these as data requirements, consistent with the size and complexity of the system under development.

9. One of the most over-looked and neglected aspects of system engineering is the importance of early planning and task identification and scheduling required to accomplish the total job.

10. Environmental effects on a spacecraft are strongly dependent on orbit altitude, inclination, spacecraft orientation and solar cycle phase. Typically, adverse environmental effects can be significantly reduced by altering these parameters, which ultimately reduces weight, cost, and schedule impacts at a later point in the design. Therefore, environmental effects should be reviewed prior to final orbit selection in the earliest possible phases of program planning.

7.2 Requirements Definition and Allocation

1. Where design reference missions (DRMs) are used to bound program requirements, strive to replace DRM parameters with specific performance requirements as early as practical.

   -- When DRMs are needed, there needs to be a close working relationship and team approach between the group performing the analyses and the environments specialist. Incorporating the correct representation of the flight environment at this early phase helps to reduce program impacts due to environmental effects later in the program design cycle.

2. Phase C contracts should not be signed with detailed contractor-derived requirements included. These requirements and the subsequent detail design should be finalized through the formal review process (SRR, PDR, CDR).

3. Overall weight and loads imposed due to lift-off and landing are more important factors governing payload manifesting than volume in the STS cargo bay. (Weight and center-of-gravity limits are usually reached long before the volume capacity has been reached.)

4. A hard weight limit is necessary to cap weight growth. This may require funds to be spent to reduce weight during the design process. In one case, the load-carrying capability of the trunnion pins used to mount the vehicle in the STS payload bay proved to be the practical weight limit.

5. Requirements definition and allocation should include sufficient margins to assure a robust design with inherent growth capability. An example might be to require 3.0 db communication link margin at launch, 3.5 db margin at CDR, and 4.5 db margin at PDR.

6. Plan, identify, and perform necessary analyses to support systems requirements and design. Document and review requirements **before** initiating design.

7. Continually assess systems requirements to assure they are, in fact, requirements and not desires or design implementation. **Requirements which cannot be verified are not valid requirements.**

8. All concepts, requirements, and designs should give primary consideration to safety. Performance requirements can be negotiated; safety requirements cannot.

9. Ensure that requirements in a document are traceable both to its precedent and antecedent documents. That is, there exists a source document for each valid requirement and that all lower level requirements documents flowdown higher-level requirements.

   Should ensure a minimum of two review iterations or tabletop reviews prior to submitting a requirements document for a formal requirements review.

10. When defining and allocating functional and physical interfaces, strive to develop and allocate the least complex interfaces possible between program elements (i.e., keep it simple - KIS).

11. Ensure all functional areas and disciplines are involved in developing the initial system requirements.

    -- Requirements for long-term projects such as launch vehicles, space observatories, or space stations should emphasize low operations cost.

12. For delivery purposes, a good definition is needed of the documentation required in the Hardware Data Package for shipping and who is responsible for pulling the package together.

13. Once the system requirements have been documented, review them from the perspective of a designer. Do they have enough information to design the system? Do they impose design solutions or unnecessary constraints?

14. Use of computer tools for requirements management and traceability is strongly recommended. Use of such tools will be facilitated if only a single requirement statement is included in each sentence/paragraph. This structure also facilitates the writing of clear, concise, unique, and unambiguous requirements.

15. Establish design control parameters and related margins (i.e., weight, center of gravity, electrical power and energy, propellants, etc.) and place them under formal control as part of the SRR process. Report and track all control parameters and margins throughout the design process.

16. Typically, trade studies are necessary to develop final environment requirements. These trades should be performed as early in the design cycle as possible to provide optimum benefit to the program.

17. Verification of certain environmental requirements is very difficult and may require costly testing. This should be examined as the requirements are being developed.

7.3 Preliminary Design

1. Maintainability, on the ground especially and in space, if that is a requirement, should be given special attention from the beginning of the requirements definition and design process.

    --Increase subsystem accessibility. It is highly desirable to design subsystems that are more accessible to repair and changeout. Include operations people in the requirements definition and design process.

2. Design for modularity. As much as possible, components should be modular, standardized and interchangeable; however, modular spacecraft will be substantially heavier than those of unitary design.

    -- Reduce recurring ground operations costs by application of autonomous, high-reliability flight control and guidance systems.

    -- Consider use of built-in test and health monitoring systems for mechanical and fluid systems, as well as for electronic systems.

3. When planning and designing a new launch system, it is essential to consider the entire system as an interactive entity, including the operations infrastructure, and operations management. This enables system designers to anticipate potential operations and maintenance problems and provide for them *before* the system is built.

4. Reduce the number and complexity of tasks requiring human intervention.

5. Complexity of documentation, maintenance, and interfaces among subsystems generally lead to higher system costs.

6. Payloads should be designed to be as independent as possible of the launch vehicle. The payload-vehicle interfaces should be standard and incorporate automated checkout capability, off-line processing, and testing prior to delivery to the launch site.

7. Design for less toxic and environmentally safe propellants. For example, storable high-performance propellants such as nitrogen tetroxide or monomethyl-hydrazine are also toxic and corrosive, giving rise to human health risks and maintenance problems.

8. As a system engineer, take the time to understand the preliminary design to ensure system-level requirements have been interpreted correctly by the designers and that all such requirements have been satisfied.

9. A preliminary system/subsystem level FMEA should be available at the system PDR to provide a basis for evaluation of design alternatives to eliminate failure modes or incorporate redundancy, where appropriate.

10. Optimum benefit to the program can be realized if all environments definitions and requirements are finalized by the PDR.

7.4 Detail Design

Note: All preliminary design lessons learned are equally applicable in this phase.

1. When a design or hardware change is contemplated, give consideration to all disciplines which may impact the final change definition (responsibility of system engineer).

2. Use more restraint before contracted experiments that are in trouble are brought in-house to be "fixed."

3. As the design matures, perform system analyses considering tolerances and uncertainties to ensure that design and fabrication will produce a product that will satisfy requirements.

4. Analyze systems to ensure items which a subsystem or component designer might overlook will be considered (e.g., venting, contamination).

5. Use care in utilizing and qualifying by similarity hardware designed and used on other projects (legacy hardware). If used and so qualified, ensure its design requirements, verification, and environments are compatible with those of the new project.

6. Where electrostatic discharge is a concern in spacecraft design, ensure conductive materials and coatings are used to prevent excessive surface charge buildup.

7. For each program, prepare end-to-end system functional schematics and interconnect diagrams to provide definition of electrical and fluid systems. These drawings will facilitate system analysis during design and troubleshooting during operations. They will also enhance understanding of how the total system functions.

7.5 Fabrication and Assembly

1. Involve quality assurance personnel throughout the process to eliminate problems in getting hardware bought off.

2. For quality-sensitive hardware, be sure fabrication and assembly is done with released drawings.

7.6 Verification

1. Pre-flight systems mission sequence testing of flight hardware should be included in test planning to provide maximum assurance of hardware compatibility and mission success.

2. An end-to-end avionics systems test of the hardware and software should be considered and the cost factored into the program from the start.

3. The need for system-level propulsion tests depend upon the complexity of the systems proposed, but costs of such tests need to be included in cost trades made in selecting the final propulsion system.

4. A structural test article should be considered for any high performance propulsion vehicle or stage. The lack of such a test could result in higher system weight since MSFC practice dictates a 2.0 factor of safety without a test versus a 1.4 factor with a test.

5. Testing of quality-sensitive hardware requires released documentation.

6. Formal and derived requirements should be treated with the same level of importance in the system analysis activities for verification of system compliance.

7. Verification test data should be thoroughly reviewed and completely understood. If possible problems are indicated, they should be investigated.

8. When similarity is used as a basis for qualification, ensure that all parameters/limits relating to the new application are within the limits of the original application.

7.7 Launch Operations

None.

7.8 Flight Operations

None.

7.9 Post Mission Evaluation

None.

7.10 Configuration Management

The CM function is continuous throughout the life-cycle of the project, and lessons learned have been consolidated here rather than duplicated in each of the preceding sections.

1. Base requirements for deliverable documents on the requirements stated in the Statement of Work and not vice versa.

2. Assure that all applicable requirements and process documents are defined at the time of system and CEI specifications baselining.

   -- Assure documents are baselined based upon their having reached the appropriate level of completeness and maturity and not solely because the project schedule says they should be baselined by a certain date.

3. Always maintain the configuration definition current. Update the engineering drawings in a timely manner wherever a configuration change is authorized, including field engineering changes.

4. Jointly develop manufacturing planning documentation by involving design engineering, manufacturing engineering, manufacturing operations, and quality assurance. This necessary to ensure that the manufacturing planning is in compliance with the release engineering, manufacturing instructions are clear and utilize best practices, and that quality assurance can verify the work is properly accomplished.

5. Effect closed-loop accounting of parts, components, and other materials furnished to manufacturing operations in order to account for all parts.

6. Establish and enforce requirements to prevent use of non-controlled tooling in the actual manufacturing of flight hardware.

7. Assure that flight-configured hardware designated for "non-flight use" has adequate re-identification, markings, etc., to prevent its incorporation into the final flight article configuration.

8. Verification audits must penetrate beyond assessment of established procedures, and assure actual compliance with same is being accomplished and is satisfactory.

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DOCUMENT IMPROVEMENT PROPOSAL FORM

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