

N87-1043-7-81

1986

26P

NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

MARSHALL SPACE FLIGHT CENTER
UNIVERSITY OF ALABAMA

49623

OPERATIONS PLANNING AND ANALYSIS HANDBOOK FOR
NASA/MSFC PHASE B DEVELOPMENT PROJECTS

Prepared by: Robert G. Batson, Ph.D.

Academic Rank: Associate Professor

University and Department: University of Alabama
Department of Industrial Engineering

NASA/MSFC:
Laboratory: Systems Analysis and Integration
Division: Operations Development
Branch: Operations Planning and Analysis

MSFC Colleagues: Michael Naumcheff
David L. Shipman, Ph.D.

Date: August 1, 1986

Contract No: NGT 01-002-099
The University of Alabama

ABSTRACT

Current operations planning and analysis practices on NASA/MSFC Phase B projects were investigated with the objectives of (1) formalizing these practices into a handbook and (2) suggesting improvements. The study focused on how Science and Engineering (S&E) Operational Personnel Support Program Development (PD) Task Teams. The intimate relationship between systems engineering and operations analysis was examined. Methods identified for use by operations analysts during Phase B include functional analysis, interface analysis, data flow diagrams, mission timelines, and specialty analysis methods to calculate/allocate such criteria as reliability, maintainability, and operations and support cost.

Conclusions are that at NASA/MSFC, S&E operational activities during Phase B may be characterized by:

- 1) Phase B operations planning and analysis based on experienced judgment.
- 2) Operations and servicing concepts and criteria not sufficiently developed/represented on task teams, although contractor efforts in these areas are adequate.
- 3) EL12 has limited formal methods/data bases/procedures in-house to cross check contractor claims, estimates, and decisions.

Recommendations are to:

- 1) Develop operations analysis data bases, methods, and specialists to adequately staff each Phase B task team.
- 2) Give operations and maintenance personnel an equal level of authority to system engineering on these teams.
- 3) Conduct formal operational studies prior to or early in Phase B in order to define operational and maintenance concepts prior to system configuration studies.
- 4) Assure operational effectiveness criteria and personnel are integrated into each Phase B task team.
- 5) Upon receipt of Phase B reports, use formal and structured in-house methods to validate contractor findings.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
ABSTRACT	VII-1
INTRODUCTION	VII-1
OBJECTIVES	VII-5
RELATION OF OPERATIONS TO SYSTEM DESIGN	VII-6
METHODOLOGY FOR OPERATIONS PLANNING AND ANALYSIS	VII-11
NASA SUPPORT DOCUMENTS FOR OPERATIONS PLANNING AND ANALYSIS	VII-20
CONCLUSIONS AND RECOMMENDATIONS	VII-21
REFERENCES	VII-23

INTRODUCTION

Major system acquisitions by NASA are conducted under the guidance provided in NASA Management Instruction 7100.14A, NASA's implementation of the guidance specified in the well-known OMB Circular A-109. The term "Phase B" refers to the step in the system acquisition process following Mission Need Determination and preceding Full-Scale Development (see Figure 1). Phase B studies may be done in-house, in parallel with one or more contractors, or by contractors only. The purpose of Phase B studies are to establish technical feasibility, to estimate costs and schedules, and to establish confidence that a design concept has progressed far enough into preliminary design that NASA can commit to full-scale development. Thus, Phase B is the critical transition from task team to project office. 80-90% of the critical parameters (life-cycle cost, mission reliability, etc.) are determined during Phase B, although only 10-20% of the engineering effort will have been expended. It is therefore absolutely necessary that mission operations and operations effectiveness criteria be adequately considered during Phase B.

Prior to Phase B, the mission development process is highly unstructured and documentation is generally uncontrolled, i.e. mission documentation consists of a set of memos, operational concept papers, and NASA center position papers. The only formal document is the required Mission Need Statement which includes the following operations oriented sections:

- b. Mission Purpose
- c. Existing Capability
- f. Value or Worth of Meeting Need
- h. Operating Constraints

Engineers in EL12, Operations Planning and Analysis, who are assigned to participate in a Phase B Task Team therefore are generally asked to either produce planning documents and/or evaluate contractor studies under the following limitations:

- little program-specific operational data.
- limited historical data, unless the current system is similar to a previously developed system.
- no formal methodology to perform their role, i.e. no standard methods to perform the functions of planning, structuring, analyzing, and deciding.

Further complications for the operations-oriented engineer in Phase B are due to the nature of space activities and the way NASA operates as an agency:

- mission operations are 5-10 years in the future.
- segments and elements of a mission are widely dispersed geographically.

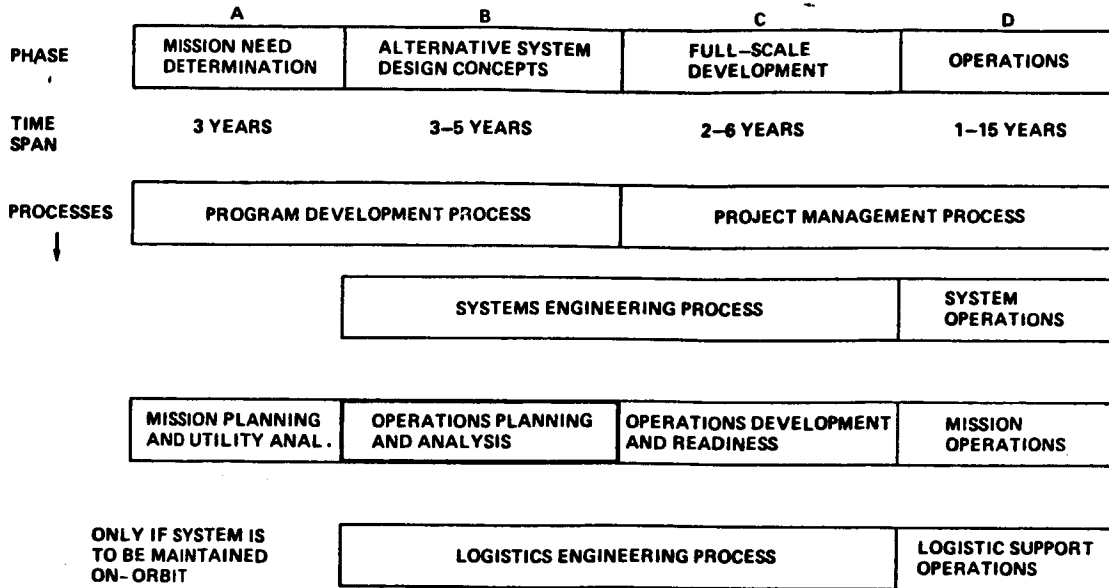


FIGURE 1 INTERECTING PROCESSES IN NASA SYSTEM ACQUISITION

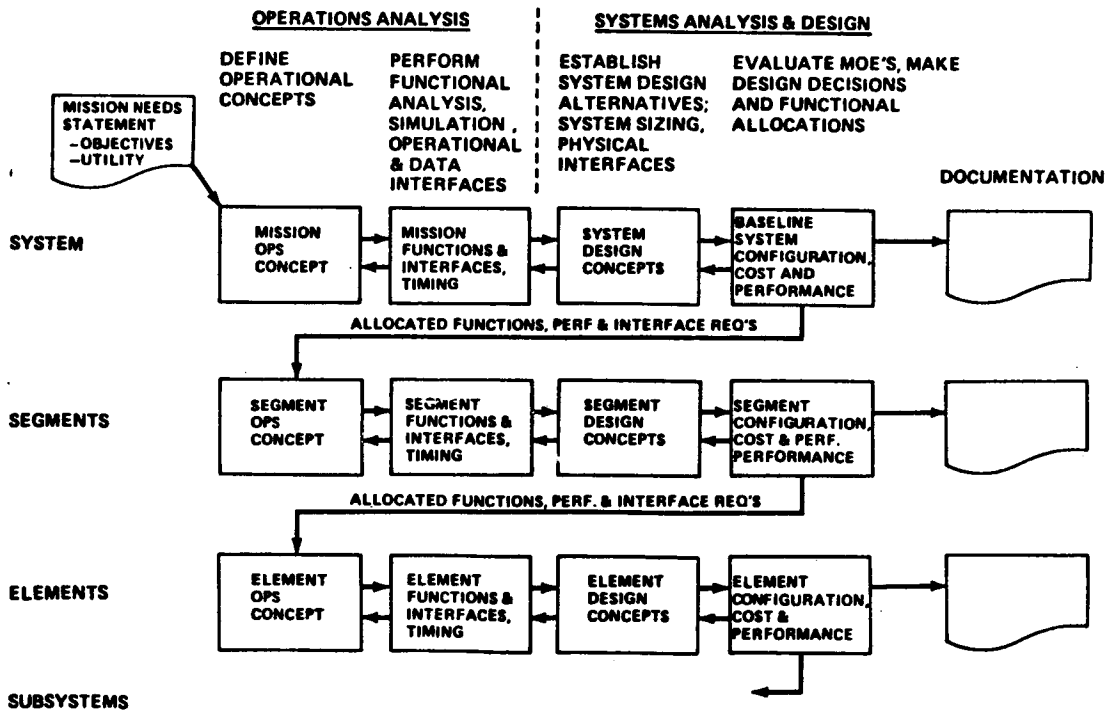


FIGURE 2 ONE VIEW OF SYSTEMS ENGINEERING PROCESS

ORIGINAL PAGE IS OF POOR QUALITY

- responsibilities for mission and system development divided among NASA centers, various contractors, and various users (e.g., scientists, faculty, military).

At Marshall Space Flight Center (MSFC), mission operations responsibility has changed hands a number of times in the past twenty-five years. At one time, there was a program office called Mission Operations which handled all activities including data management. During the 1970s the program office was abolished and all mission operations was moved to the Science and Engineering Laboratory but with responsibility divided. Data management went to a Data Management Division and the remainder went to Systems Analysis & Integration Laboratory (SA&IL). After a few years, the data management and mission operations functions are together again but at a lower level, that is, the Operations Division.

The role of MSFC mission operations has also changed. In the early days, the missions were few and the center was in a support role to Johnson Space Center (JSC). Since 1980 the center has had a more active mission operations role beginning with the Spacelab. The center now has the capability to control science and experiment missions from Huntsville.

The key principles which should guide the development of an Operations Planning and Analysis Handbook are these:

1. Any system NASA procures and eventually flies has a dual nature, technical (hardware and software) and social (humans--their organizations, responsibilities, roles, and role relationships). Thus, system design and operational design must occur simultaneously.
2. Baselines must be established early in Phase B and controlled/expanded through later phases. There are at least three types of baselines: program, system, operations. For systems to be maintained on-orbit, the support concept of Phase B becomes part of a logistics baseline.
3. Requirements flow from top-level mission needs/objectives. Both technical and operational requirements are derived by a continuing iteration between operations analysis and system design (Figure 2) at each level of the system hierarchy.
4. Each requirement should be traceable back to its source, with access to supporting analyses, policy decisions, reasoning, etc.
5. Each operational requirement should be documented: how derived, how allocated, how to be verified.

6. In design decisions, operational effectiveness criteria are of equal significance with programmatic criteria (acquisition cost, schedule and risk) and system performance criteria (weights, data rates, pointing error, etc.). Operations effectiveness criteria include:

- reliability
- maintainability
- safety
- quality, inspectability, producibility
- supportability (if applicable)
- contamination control
- manability, repairability
- operations and support (O&S) cost

7. Appropriate emphasis on operational effectiveness during Phase B can save NASA money and improve programs stability by:

- reducing design changes
- reducing training complexity
- reducing risk of cost/schedule overruns

OBJECTIVES

The objectives of the study reported here were to:

1. Determine the nature of mission operations analysis performed by NASA/MSFC during Phase B studies:
 - a. Extent of studies
 - b. Output of studies
 - c. Methodology
 - d. Interaction with systems engineering organizations in SA&IL and on PD task teams/project offices.
 - e. Interaction with program planning, especially the development of operational schedules and O&S cost estimates.
2. Identify ways to improve communications of and emphasis of operational concepts and criteria during Phase B:
 - a. In-house, among various MSFC organizations and people
 - b. Among NASA centers
 - c. To and from NASA contractors.
3. Identify opportunities to use formal scientific methods to increase the rigor of:
 - a. interface definition, analysis, and control
 - b. allocation of functions and responsibilities to elements of the social system
 - c. resolution of conflicting objectives
 - d. quantifying the probability that mission objectives will be met.

RELATION OF OPERATIONS TO SYSTEM DESIGN

Large technical organizations such as NASA, according to sociotechnical systems theory, are best understood as a complex interaction of technical and social factors engaged in transforming inputs to achieve desired outputs. More precisely, the technical system consists of the means (i.e., hardware, software, procedures) by which the people transform the inputs. The social system is the adaptive, mediating device between the limits and capacities of the technical system and the requirements of environment. The technical system is only adaptive in a limited range, and redesign is required to perform unanticipated functions or functions in different orders or environments than planned. The response modes and means for adaptation of the social system must also be designed--not established on an ad hoc basis and not as a fall-out of technical system design.

OPERATIONAL DOCUMENTATION INITIATES DESIGN PROCESS

Operations documentation at a specific phase of a NASA project specifies what the organization knows about ends-means relationships in the system and adaptive processes to be used to control the system. The first half of Phase B is often called conceptual design (or feasibility analysis). The product of conceptual design is called a technical baseline and typically consists of:

1. A System Operational Concept
2. A System Maintenance Concept
3. A Preferred System Configuration
 - a. Functional Configuration (Set of functional block diagrams)
 - b. Preliminary sizing/physical characteristics

A common problem in systems engineering is that system configuration studies are initiated prior to definition of operational and maintenance concepts, receive much more manpower and management attention, and fail to properly consider operational/maintenance criteria in decision-making. Two ways NASA can avoid this dominance by the configuration studies are to either:

1. Provide Phase B contractors with a good Preliminary System Operational Concept (PSOC) document at the beginning, or
2. Require contractors to fully develop operational and maintenance concepts in parallel to, or slightly ahead of, configuration studies.

There is no standard format for a PSOC, although there are generally accepted rules for what make up an operational concept, a maintenance concept, and an organizational concept during conceptual design. We discuss the contents of these three concepts briefly.

An operational concept defines how the system will be deployed and used, and should include:

1. Mission definition--prime operating mission of the system along with alternative or secondary missions, defined through one or a set of scenarios or operational profiles.
2. Performance and physical parameters--definition of the operating characteristics and functions of the system in broad terms.
3. Operational deployment and geographic distribution--identification of quantities/sizes of facilities, equipment, personnel along with transportation, mobility, and communication requirements.
4. Operational life cycle--anticipated system life, total inventory profile, assignment of units to bases, etc.
5. Utilization requirements--utilization rates, on-off sequences, cycles per year, etc.
6. Effectiveness factors--system requirements specified in terms of operational effectiveness factors such as mean time between (MTBF), maintenance man-hours per operational hour (MMH/OH), operator skill levels, safety, and so on.
7. Environment profile--for mission as well as transportation, handling, assembly, storage modes.

The maintenance concept defines how the system will be supported throughout its life-cycle. It delineates:

1. The levels of maintenance support envisioned (e.g., most USAF systems use three levels: operational, intermediate, and depot).
2. Repair policies--which items will be replaceable, which items will be replaced regularly and which only upon failure; which removed items will be repaired and which discarded; who will be responsible for each maintenance activity. The repair policies at Phase B are by no means fixed, but must be assumed in order to proceed with design; they are amended later.
3. Maintenance environments, e.g. weightlessness, temperature, lighting, etc.
4. Maintenance effectiveness measures including maintenance costs, maintenance skill levels, test equipment reliability and quantities, supply responsiveness, etc.

The maintenance concept serves two important purposes:

1. It is the baseline for the establishment of supportability requirements and features in the configuration design activity.
2. It is the starting place for establishing the logistics support requirements for the system. The maintenance concept, supplemented by logistics support analysis, leads to identification of the maintenance tasks, skill levels, equipment, supply support, facilities, and data.

Early NASA operational documents (often called a preliminary mission operations plan) tend to be heavily oriented toward the organizational concept for procuring, testing, and operating the system. Organization structure, responsibilities, and interfaces are specified. Some discussion of manning, e.g. contractor vs civil servant, is provided along with communication and control process top-level descriptions. These organizational details are certainly necessary for both NASA and the contractor, but should not be considered as sufficient input of NASA operational personnel to Phase B studies.

The term System Concept is usually synonymous with the "preferred system configuration" we listed as the third output of conceptual design. One other concept type important to NASA is that of an End-User Concept which defines, in preliminary terms, how the end-user of the system will use the productive output of the system. For example, the Science Operation Concept for AXAF, or the Military Operations Concept for a military force delivered to the front-line by a C-130 aircraft.

OPERATIONAL CRITERIA INFLUENCE DESIGN DECISIONS

As shown in Figure 3, operational criteria must be considered in design decision-making. Other types of criteria are programmatic (acquisition cost, schedule, and risk) and performance (range, speed, timing, pointing error, data transfer or error rates, etc.), neither of which adequately address operational effectiveness--how well will the system, segment, element perform its function during a mission. Among the operational criteria that may be appropriate for a given design decision are:

- reliability, maintainability, availability
- safety
- inspectability, producibility
- supportability
- operations and support (O&S) cost
- habitability (long-term human occupation), manability
- contamination and corrosion control

ORIGINAL PAGE IS
OF POOR QUALITY

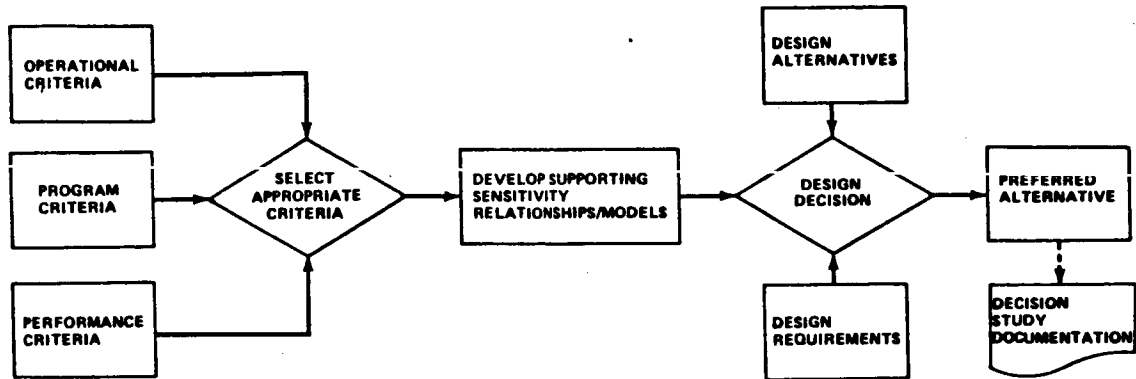


FIGURE 3 ROLE OF CRITERIA AND MATH MODELS IN DESIGN DECISION MAKING

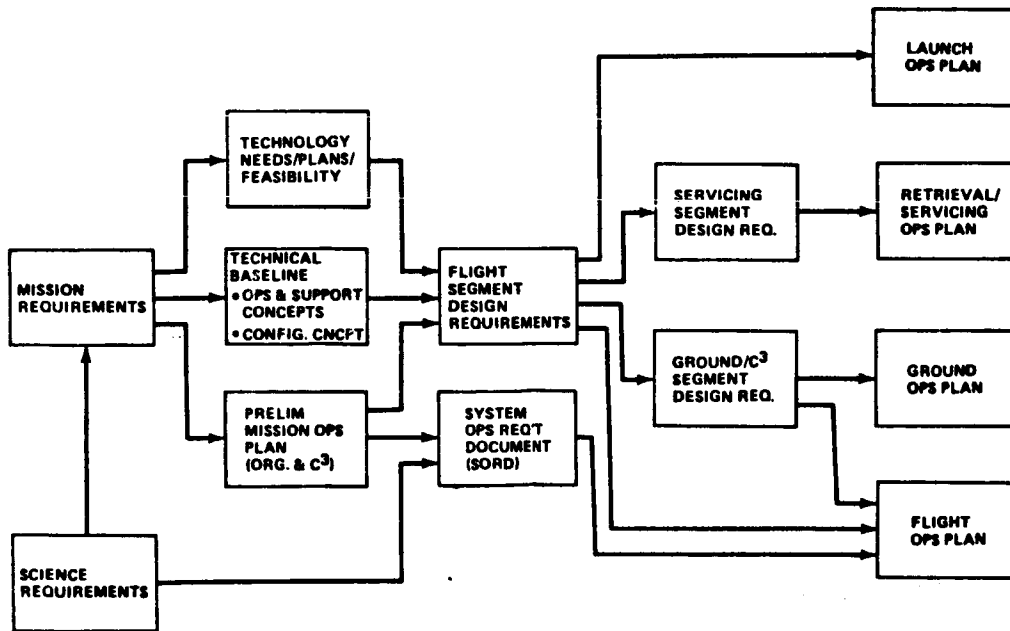


FIGURE 4 FLOW DIAGRAM FOR PHASE B PLANNING AND REQUIREMENTS DOCUMENTS

It is significant to note that all of the above criteria reflect either man-machine interfaces or machine-environment interfaces. Trade-offs at the man-machine interface occasionally drive design in those cases where mission-critical timing or safety are potentially threatened. It is also important to note that design decisions not only involve trade-offs among operational criteria, but also across criteria types. Classic examples would be trading O&S cost for acquisition cost, or performance for reliability or safety.

OPERATIONAL PLANS ARE GROUND RULES FOR DESIGN

Phase B design studies take a proposed system from conceptual design to roughly half-way through preliminary design. Design is based on assumptions, constraints, and requirements which are documented in a group of formal planning and requirements documents. The documents produced by systems engineering are hardware/software oriented and typically include the word "requirement" in their title. The documents produced by operational personnel may be called either plans (how operations will be conducted) or requirements documents. One possible view of the interaction between systems and operational documentation during Phase B is shown in Figure 4. Note that these documents are all preliminary to a Preliminary System Specification, which is usually included in the RFP for Phase C/D procurement.

METHODOLOGY FOR OPERATIONS PLANNING AND ANALYSIS

Engineers at NASA/MSFC are involved in three types of Phase B operations planning by virtue of their assigned projects, existing facilities, and interfaces required with the other NASA centers:

- Mission operations planning
- Ground/C3 segment operations planning
- Payload/POCC element operations planning

To support these planning activities, and to support the system design process, there are three generic types of analyses that may be conducted during Phase B:

- Interface Analysis
- Functional and Timeline Analysis
- Operations Effectiveness Analysis

We will briefly discuss these planning and analysis activities in turn, with the objective of identifying methodology that can be used to accomplish each.

MISSION OPERATIONS PLANNING

Mission Scenario Development is the earliest method used by operations planners. Various aspects of the total mission and its environment are described, such as orbital destination, time-frame, equipment, launch and landing site, duration, mission constraints, estimated crew size and make-up, and so on. One or more mission profiles are prepared, which is a "plan to" mission timeline that can be used by various program and engineering organizations. In Phase C/D, mission profiles are modified into preliminary mission timelines in the form of STS timelines and payload timelines.

Flight phases (ascent, orbit, deployment/retrieval), maneuver sequences (rendezvous, orbital adjustments, deorbit), and crew activity block designation are part of early Flight Design. Aspects of flight performance are estimated including trajectories, consumables usage, attitude and pointing, navigation, and deployment/retrieval sequences. Analysis of electrical, communications, maintenance, lighting, and environmental needs lead in Phase C/D to decision on whether to include various flight kits.

The use of Lessons Learned is important in mission planning. For example, a Spacelab 3 Lessons Learned was published in September 1985 and will be used to plan subsequent Spacelab mission and support activities. Finally, the use of Checklists is a common practice in the early mission planning. The EL11 division manager has a Phase B mission operations checklist which touches in some detail upon the following criteria/watchsigns:

- End-to-End Test
- Sensitivity to variations in natural and induced environments
- Independently functioning systems/payloads
- Interlocks to prevent equipment damage due to improper human procedures
- Automatic motor cutoff whenever restrained by mechanical contact
- Alignment markings for when multiple orientations exist
- Automatic onboard checkout/diagnostics
- Commonality
- Minimize training
- Maximize maintainability
- Maximize flexibility
- Notification of automatic switchover
- Monitoring of system status and notification of failure
- Minimize sensitivity to contamination
- Notification of low levels of consumables
- Avoid irreversible characteristics

Note that at least half of these deal with interfaces.

GROUND/C3 SEGMENT OPERATIONS PLANNING

These activities are conducted jointly by one or more NASA centers, often with reviews/inputs from Phase B contractors. For example, on AXAF the Mission Operations Plan (MOP) evolved by review/revision cycles at MSFC, GSFC, Lockheed, and TRW. The Ground/C3 Segment of a NASA mission includes: all ground-based mission support facilities, computers, software and procedures; the organizations which use the above hardware/software to support/control the mission; and the ground-based and orbiting relay elements. This explains why the MOP is so heavily oriented toward organization structure and responsibility, data flow and use, and command, control, and communication (C3).

Formal methods are available for developing MOPs. The first is Organizational Design methodology which has evolved over the past 20 years. This methodology addresses the problem of specifying strategies for generating and distributing information within the organization so as to facilitate effective decision making. Specific strategies for technically-oriented and highly complex organization such as those which conduct NASA missions have been developed. They emphasize two critical points:

- combining bits and pieces of other organizations to meet a new need is no alternative to rational organizational design
- organizations and their mission have a technical side and a human side, whether at the organization, group, or individual work level.

It is interesting (frightening?) to realize that most technical organizations in the U.S. are designed by engineer or scientists with no training in organizational design. Also, most technical systems are designed with operations and human criteria having limited impact on early decisions.

A second method for MOP development is the Structured Software Specification methodology of Yourdon, specifically data flow diagrams (Figure 5), data dictionaries, structured English, and decision tables. Recent advances have been made in structured methods for specifying real-time systems such as NASA uses during missions (see Mellor and Ward).

Finally, techniques of C3 Design may be applicable to the planning of NASA missions, especially those with much automation. C3, of course, is part of every system regardless of size, providing a means of direction, coordination, and tasking. NASA missions involve highly complex forms of C3 because segments and elements are located throughout the world, because of time-critical activities on-orbit, and because of the overall emphasis on safety on manned missions or while manned spacecraft are nearby. C3 network engineers should model the mission and calculate high-level effectiveness measures such as network reliabilities, data rates, bit error rates, data queue lengths at nodes, etc.

Mission operations are the set of mission functions allocated to humans. These operations are allocated either to the ground or flight segment, and through timeline and task analyses result in performance specification for the C3 elements, which include the Payload Operations Control Center (POCC). Other elements are typically a communication element, a processing element, and a dissemination/archiving element. Analytical techniques to support C3 operations planning include:

- Functional analysis--leveled flows of activity
- Functional allocation of timing, performance, and error budgets
- Interface Analysis

PAYLOAD/POCC OPERATIONS PLANNING

This planning is in anticipation of payload crew operations, POCC operations, and payload data management. For manned missions, payload crew operations which must be planned are flight specific procedures, mission dependent training, flight data file preparation, and conduct of on-orbit mission activities. This planning during Phase B is quite limited--developing crew functional flows, preliminary timelines for entire experiments, and crew schedule only to enough detail to estimate payload crew size. Preliminary estimates of training requirements, including new facilities, may be developed during Phase B.

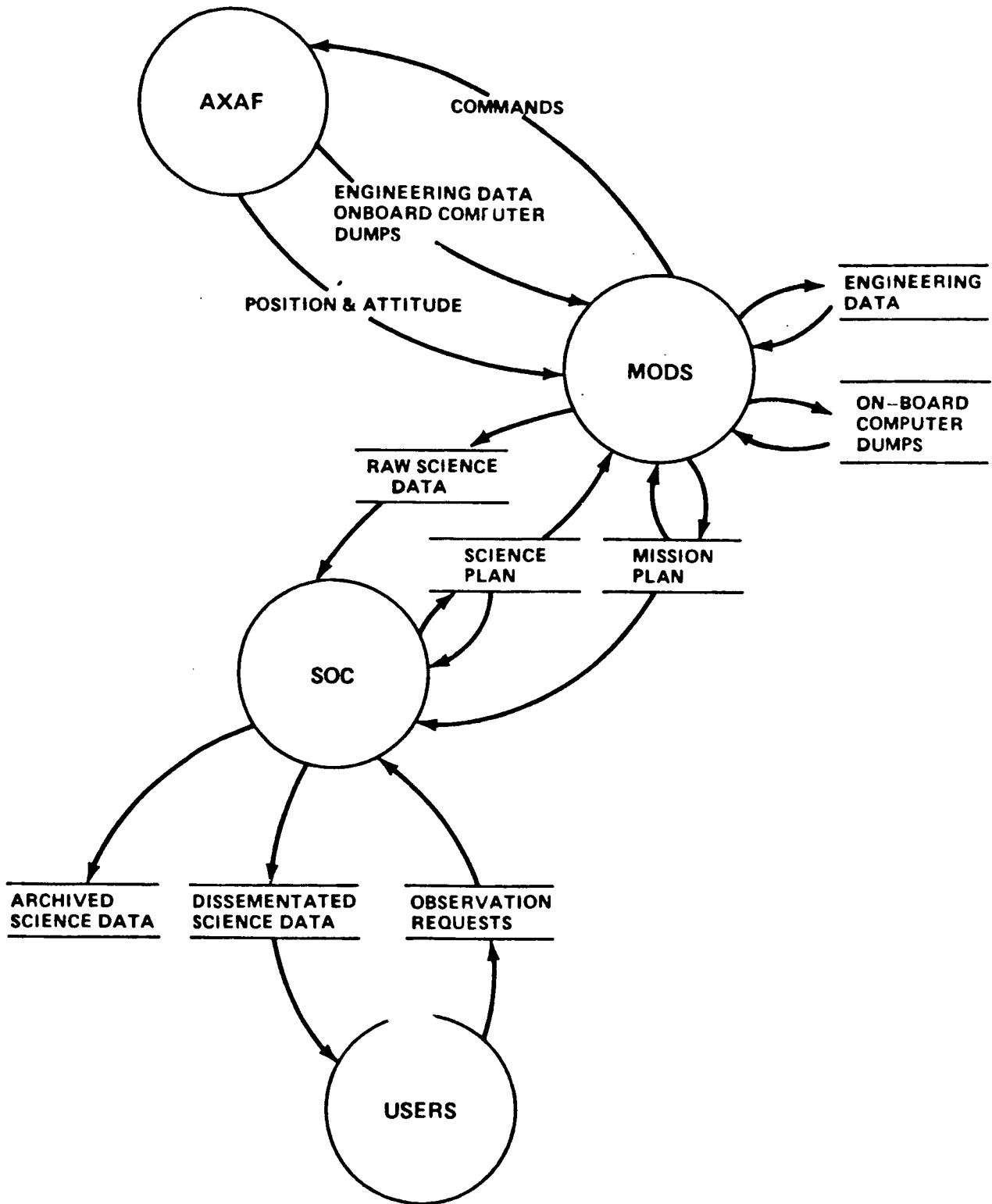


FIGURE 5 AXAF OPERATIONS TOP-LEVEL DATA FLOW DIAGRAM

For unmanned mission, the Payload/POCC operations planning during Phase B is much more critical. The elimination of the human and the dependency on automation reduces flexibility, while increasing safety. Reliability generally increases with automation because of repeatability and redundancy which is designed in. Ground-controlled or automatic operations and data analysis now occupy a central role in the mission. The effectiveness of the entire mission is (for unmanned missions) deeply rooted in the decisions made during phase B. Often these decisions are management and organizational in nature, and must be wisely made to assure success mission operations, mission data capture and processing, and science data distribution and archiving. Planning for the ultimate scientific use of the mission data is much more significant than for manned missions with attached payloads. The data management function (acquisition, analysis, distribution, and archiving of data) replaces the safety of payload operations as the primary mission planning concern.

POCC operations planning (manned or unmanned mission) during any Phase B involves definition and preliminary resource scheduling/estimating. POCC tasks for the mission must be defined. Organization and operations/data interfaces are defined. Organization structure is defined only to a level to permit sizing the facility and the quantity and job categories of personnel. These preliminary POCC documents support NASA budget requests and also are supplied to contractors as part of the mission operations data.

INTERFACE, FUNCTIONAL, AND TIMELINE ANALYSIS

Interfaces arise in all design activities as top-down design hierarchies subdivide the system into subsystems, assemblies, subassemblies, etc. and as top-down functional allocations subdivide human activities into smaller and smaller packages to the job, task, and step level. The interfaces most appropriate for Phase B operations personnel to analyze are of these types:

- organizational
- data/functional
- man-machine

Analysis of organizational interfaces is critical to NASA mission planning when one considers the complexity of these interfaces:

- NASA/Systems Integration Contractor
- Contractor/Subcontractor/Suppliers
- Intra-NASA
 - Program/Project
 - Center#1/Center#2

A useful tool for organizational interface analysis is the N2 Chart, originated at Bell Labs and developed by R. Lano at TRW. The N2 chart concept is illustrated in Figure 6 for a NOAA Ocean Surveillance Satellite (OSS). The organizational elements are displayed on the diagonal of an NXN matrix, with the (I, J) position occupied by information/commands element J receives/requires from element I. As can be seen in Figure 7, control loops, critical functions, complex interactions, etc. can then be discerned. Such a chart developed from the AXAF MOP shows the critical function played by the Science Operations Center (SOC), with its interfaces to both the POCC, the scientific users, and the NSSDC.

Interface definition is a critical part of the C3 design process. At the top level, interfaces can be defined generically (telemetry, schedule request, engineering data, etc.). Detailed quantification (data rates, quantities, formats, etc.) is required as design proceeds in order to establish throughput and computational performance requirements. Information interfaces can initially be defined by N2 charts, later in interface requirements documents, and finally in interface control documents (ICDs). Functional interfaces are documented in requirements specification documents as they are identified in the system design process. As the total system is decomposed into functional areas, interfaces between areas appear. These may be physical, operational, or both (man-machine) but are usually characterized by transfer of energy or data, or by procedures with data requirements.

We have already mentioned data flow diagrams for defining data interfaces between elements or processors. A related method used to define and analyze man-machine interfaces are Functional Flow Diagrams (Figure 8), which are function-oriented as opposed to hardware-oriented. They provide a time-sequenced understanding of the total operation of a system or payload, serve as a basis for development of operational and contingency procedures, and pinpoint areas where changes in operational procedures could simplify the overall system operation. Timeline Analysis (Figure 9), is a companion methods to functional flow diagrams, which only show sequencing of tasks and not timing. Task Analysis takes a composite or related activities (a task) and breaks it into discrete actions of limited nature (sub-tasks), and and these into task elements (actuate a control switch, read a dial, interpret a signal, etc.).

Finally, man-machine interfaces may be analyzed by Physical Models, often only soft mockups (or perhaps plywood) during Phase B. These are used to:

- identify operational constraints
- verify predicted capabilities, such as response times
- locate controls, harnesses, access holes, foot holds, etc.
- establish maintainability characteristics
- safety analysis

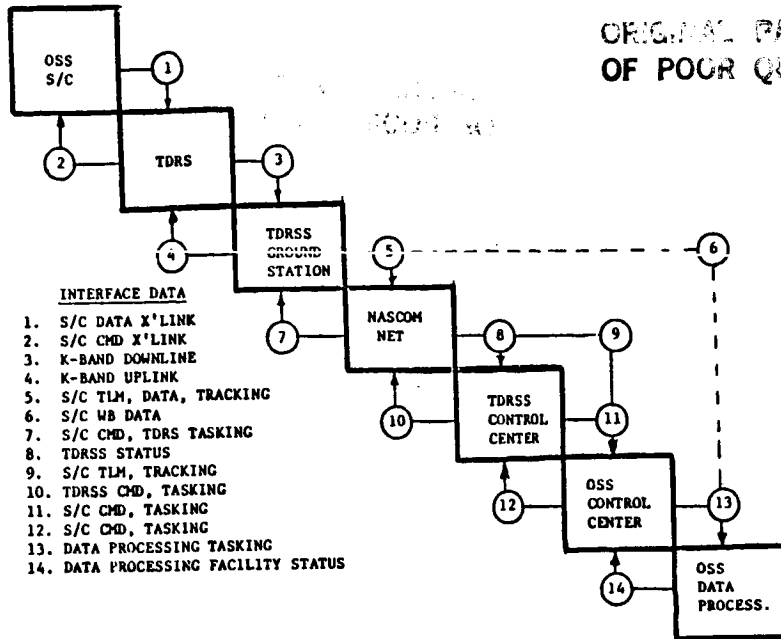


FIGURE 6 N² CHART FOR OCEAN SURVEILLANCE SATELLITE (OSS)

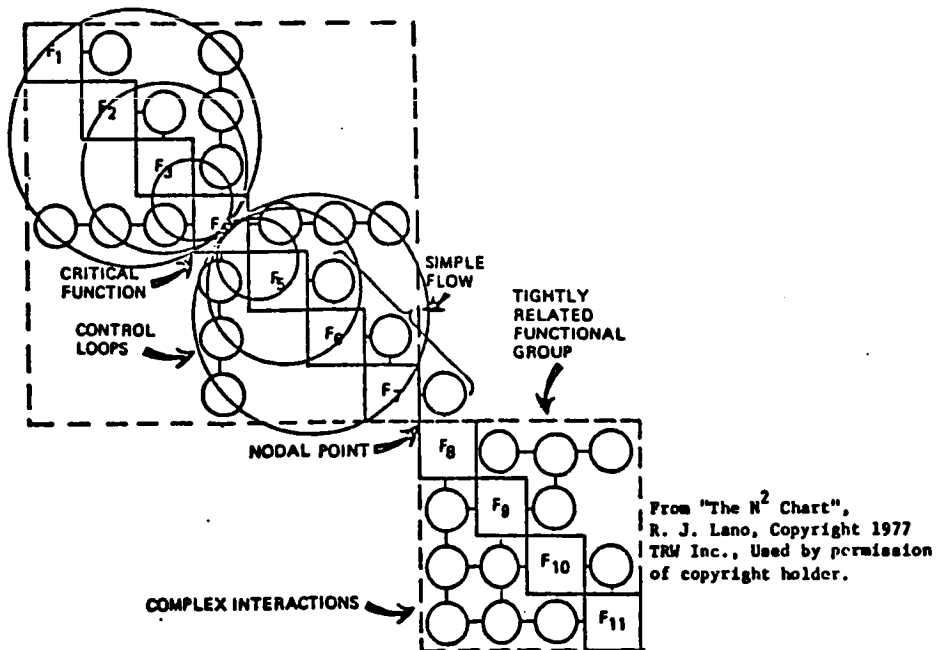


FIGURE 7 N² CHART KEY FEATURES

ORIGINAL PAGE IS
OF POOR QUALITY

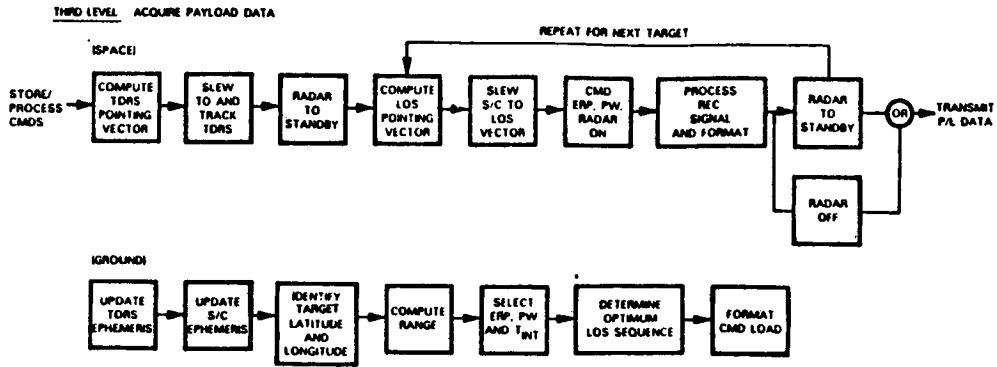


FIGURE 8 EXAMPLE FUNCTION FLOW DIAGRAM

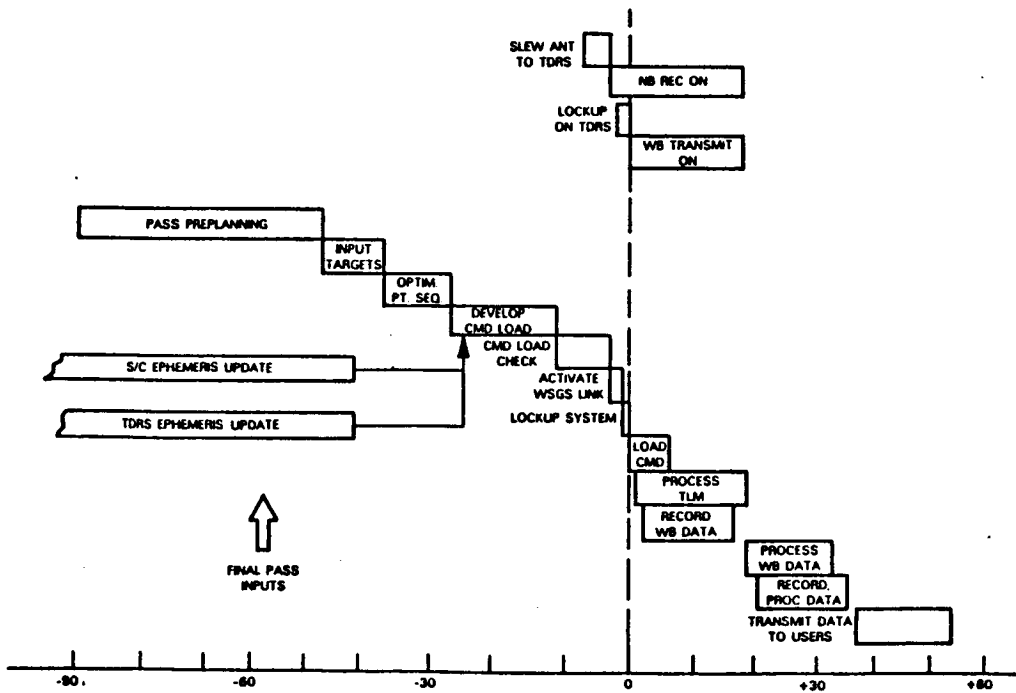


FIGURE 9 TIMELINE FOR ABOVE FUNCTIONS

OPERATIONS EFFECTIVENESS ANALYSIS

During conceptual and preliminary design, there is a natural tendency to permit design decisions to be driven by either performance, or acquisition cost. To counter this tendency, operations and support considerations must be consciously and constantly emphasized so that a balanced design approach will emerge. How to achieve this emphasis is a real challenge at NASA/MSFC, given the specialization of engineering disciplines, the general unavailability of engineers to work on Phase B Task Teams, and lack of a strong heritage of operations effectiveness analysis at this center.

A measure of effectiveness is a math variable that measures how well a system performs (will perform) its intended function in a given operational environment. Operational effectiveness is the probability that a system can successfully meet an operational demand within a given time when operating under specified conditions. Operations effectiveness analysis is the use of math models to predict operational effectiveness in advance of actual operations and often prior to operational test/simulations.

In phase B, reliability and maintainability (R&M) are the earliest measures for which estimates are needed, because:

1. Reliability of hardware is closely linked with ultimate mission success.
2. R&M are drivers in design decisions.
3. R&M are O&S cost drivers, and O&S costs are typically from 1/3 to 2/3 life-cycle cost.

Three system-level models which are critical for Phase B studies at MSFC are: (1) a system reliability model; (2) a system maintenance model; and (3) an O&S cost model. Human factors models to predict manability/habitability measures are important for manned payloads. For unmanned payloads that will be serviced on-orbit, human factors criteria are accessibility, repairability, safety, and contamination control. Manufacturing, while not part of operations, is part of Phase C/D and must be planned for in Phase B. Unless criteria such as producibility and inspectability are considered by Phase B engineers, cost and schedule overruns and quality control problems are created.

Above all, it is emphasized that engineering specialties and their associated effectiveness criteria/models must be integrated into the Phase B task team activities. They may be considered part of systems engineering or given co-equal status to systems engineering and called product support or operations effectiveness, reporting directly to the chief engineer. Their role is to define requirements in their area, conduct analyses in support of design, and participate in design reviews.

NASA SUPPORT DOCUMENTS FOR OPERATIONS PLANNING AND ANALYSIS

The following documents are available in EL12 Branch to support Phase B operations planning and analysis activities:

JA-063 Payload Mission Operations Plan (Generic)

JA-447 Mission Requirements on Facilities, Instruments, and Experiments

JA-053A POCC Telemetry Standards

JA-455 Integrated Payload Training Plan

JSC-14433 POCC Capabilities Document (2 Volumes)

JSC-07700 Space Shuttle System Payload Accommodation (Volume XIV)

NHB
1700.7A Safety Policy and Requirements for Payloads Using the Space Transportation System

MSFC Plan
904 HOSC Functional Requirements and Implementation Plan

Unnumbered Space Transportation System User Handbook

JSC STS Flight Operations Baseline Operations Plan

JSC-13000 STS Flight Assignment Baseline

JSC-11123 Payload Safety Guidelines Handbook

JSC-13830 NHB 1700.7 Supplement. Implementation Procedures for STS Payloads Safety Requirements

JSC-10615 Shuttle EVA Description and Design Criteria

JSC-14046 Payload Interface Verification Requirements

ESA SLP/
2104 Spacelab Payload Accommodation Handbook

GSFC STD
101.2 TDRSS User Guide

JSC-11804 Payload Operations Control Center for Attached Payloads

GSFC Payload Operations Control Center for Earth-Orbiting Automated Payloads

CONCLUSIONS AND RECOMMENDATIONS

Phase B studies are conducted from five to ten years prior to operations, making operations planning and analysis a difficult activity with many unknowns and little data. Hence it is natural that NASA/MSFC relies on experienced operational personnel and their supervisors to provide operational inputs/evaluations during Phase B. The process used is a write/review/rewrite cycle within NASA/MSFC and among NASA centers, using checklists, knowledge of existing facilities and capabilities, and experience on previous programs. Few data bases and quantitative methods are presently available to working-level NASA operations analysts to conduct Phase B operations planning and analysis activities.

Operations and servicing concept definitions, and inputs/evaluations by operations/maintenance specialists are considered part-time supporting roles to the Phase B task team, where the emphasis seems to be on systems engineering and configuration definition. Technical feasibility is often in question on NASA future missions; this justifies to some extent the preoccupation with sizing, performance, and technology-related issues in Phase B. Operational assumptions, groundrules, and guidance may evolve in conjunction with these systems studies with unfortunately little or no supporting analysis, especially with regard to cost and effectiveness of alternatives (be they alternative requirements levels or design options). Contractors do appear to be devoting adequate attention to operations and operations effectiveness criteria. However, NASA is not doing in-house studies to cross-check and verify contractor decisions--EL12 currently does not have the data bases, methodology, or personnel assigned to perform such analyses. Cross-checks are therefore conducted via telephoned/written clarification from the contractor. Some EL12 personnel likely have the potential to be outstanding effectiveness analysts for conceptual design, if they are given this career option.

Recommendations are to:

- 1) Develop operations analysis data bases, methods, and specialists to adequately staff each Phase B task team.
- 2) Give operations and maintenance personnel an equal level of authority with systems engineering on these teams.
- 3) Conduct formal operational studies prior to Phase B; or, require contractor to conduct them early in Phase B in order to define operational and maintenance concepts prior to system configuration studies.
- 4) Assure operational effectiveness criteria and personnel are integrated into each Phase B task team, especially as the affect design decision.

- 5) Upon receipt of contractor Phase B reports, utilize in-house methods to cross-check/validate contractor claims and estimates.

Organizational changes which may be necessary to implement the above recommendations are given in increasing level of change:

- 1) Require more emphasis on operations in Phase B either by emphasizing stronger integration of systems engineering and EL12, or by making operations/maintenance a co-equal level with systems engineering on all task teams.
- 2) Hire operations effectiveness engineers into EL12 and give them the charter/resources to develop computer-assisted methods to support Phase B Teams.
- 3) Create an operations effectiveness group within EL12.
- 4) Create a mission logistics group in EL11 or EG01 to perform:
 - a. maintainability analysis
 - b. spares policy studies
 - c. logistics support analysis

REFERENCES

Army Field Manual 770-78, System Engineering.

AXOP-701 AXAF Preliminary Mission Operations Concepts and Data System Requirements.

AXOP-702 AXAF Science Operations Requirement Document.

AXOP-703 AXAF Mission Operations Plan.

Blanchard, Benjamin S., Logistics Engineering and Management, Prentice-Hall, 1981.

Blanchard, Benjamin S. and Wolter J. Fabrycky, Systems Engineering and Analysis, Prentice-Hall, 1981.

Chase, W. P., Management of System Engineering, Wiley, 1976.

Connolly, Terry, Scientists, Engineers, and Organizations, Brooks/Cole Engineering Division, 1983.

Davis, Louis E., "Organizational Design," in Handbook of Industrial Engineering, Wiley, 1982.

Defense System Management College, System Engineering Management Guide, Contract Number MDA 903-82-0339, 1983.

DeMarco, Tom, Structured Analysis and System Specification, Yourdon Press, 1978.

Eady, J. R., "MSFC Integrated Payload Operations Training Program," NASA/MSFC EL15, Briefing Charts, March 1986.

Lano, R. J., The N Chart, TRW Corp., 1977.

Lockheed Missiles and Space Company, Space Systems Division, Corporate System Engineering Seminar Notes, Vol. I-III, August 1982.

Mellor, Stephen and Paul Ward, Structured Development for Real-Time Systems, Yourdon Press, 1985.

Merrifield, John T. "Lockheed Researchers Identify Issues of Human Productivity in Space," Aviation Week & Space Technology, June 16, 1986.

MIL-STD-499A(USAF), Engineering Management.

Yourdon, Edward, "What Ever Happened to Structured Analysis," Datamation, June 1, 1981.