SPACE STATION
OPERATIONS TASK FORCE

PANEL 2 REPORT

GROUND OPERATIONS
AND
SUPPORT SYSTEMS

DECEMBER, 1987

FORWARD

This report contains the results of the Ground Operations and Support Systems Panel's deliberations for the Space Station Operations Task Force. This report forms the basis for some of the recommendations summarized in the SSOTF Summary Report dated December 1987 and describes in greater detail the Ground Operations and Support Systems' major function of the Space Station Operations Concept. To obtain a full appreciation of the contents of this report the reader is advised to read first the Summary Report which describes the Ground Operations and Support Systems function in context with the other major functions as part of the overall developed end-to-end operations concept. It should be noted that the subsections of this report were developed and written by subgroups of the panel. As such, the reader may note differences in style and continuity between subsections. Due to time and resource limitation, no effort was made to provide for stylized editing. Also, the terminology used in this report to describe the Ground Operations and Support Systems major function may differ slightly from that used in the Summary Report in order to impart a finer grain of knowledge to the reader. However, the official Space Station Operations Concept Lexicon is contained in the Summary Report, and terms introduced in this book, that are not used and defined in the Summary Report or are used in substitute of a term or part of a term in the Summary Report, are listed on page vii with an explanation and further definition if appropriate. Should the definition of a term in this book be interpreted by the reader to conflict with the corresponding definition in the Summary Report, the definition in the Summary Report will take precedence.

Lastly, where recommendations in this report differ from those in the Summary Report, the Summary Recommendations take precedent. (Recommendations of all panels were reviewed and debated by the Task Force and in some instances were changed.)

Any questions or clarifications needed concerning details or recommendations contained in this report should be addressed to the Panel Chairman, Mr. Charles Mars, (703) 487-7254.

Charles B. Mars 6-8-88

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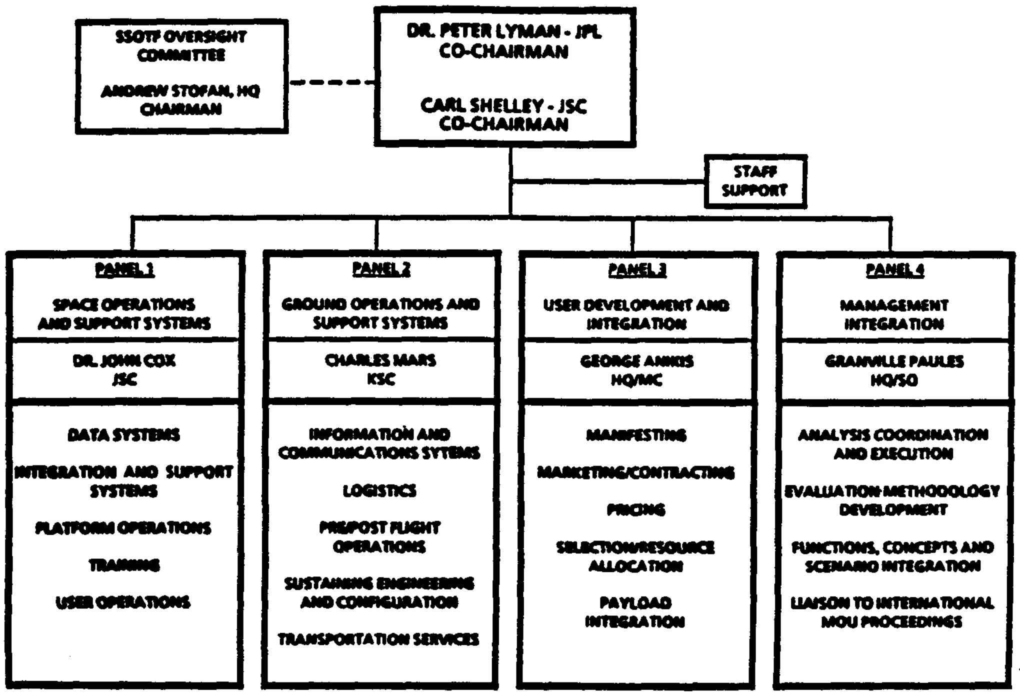
The following is a listing of all participants in the Space Station Operations Task Force (SSOTF). It has been extracted from the SSOTF Summary Report.



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BACKGROUND BRIEFINGS COMPLETED

- SSOTF Special Directions .... A. Stofan
- What is a Space Station .... T. Finn
- Background and Status of Agreements with Internationals .... G. Rice/M. J. Smith
- Space Station Baseline Configuration .... T. Bonner
- Space Station Evolution Configuration .... D. Black
- Development Program Management .... J. Aaron
- Space Station Budget Perspectives .... J. Sheahan/D. Bates
- Columbia Lakes Operations Symposium Review .... C. Mathews
- Integration Assembly and Checkout .... H. Benson
- Characteristics of R&D vs. Operations Organization .... J. Hunsucker
- Pricing Policy Overview .... J. Smith
- Space Station Information Systems (SSIS) .... D. Hall
- Technical and Management Information Systems (TMIS) .... C. Harlan
- KSC Operations Lessons Learned .... J. Ragusa
- Congressional Perspectives .... M. D. Kerwin
- SS Work Breakdown Structure .... W. Whittington
- Commercial Operations .... Coopers-Lybrand/J. Egan
- Space Policy .... CSP/M. Vaucher
- Soviet Space Station .... DoD and B. J. Bluth
- Program Logic .... W. Whittington
- Automation and Robotics .... G. Varsi
- Astrophysics .... F. Martin
- Lessons Learned From Other Programs .... Skylab, Spacelab, et al.

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Bold means Briefed Task Force

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GROUND OPERATIONS

Executive Summary

Introduction

The Ground Operations Concept embodied in this report, provides for safe multi-user utilization of the Space Station, ~~and is safe,~~ eases user integration, and gives users autonomy and flexibility. It provides for meaningful multi-national participation while protecting U.S. interests. The concept also supports continued Space Operations Technology Development by maintaining NASA expertise and enabling technology evolution.

This is accomplished by a clear leadership and control of requirements during the Design/Development Phase by the Design Centers/Work Package Contractors with integration accomplished through a strong A' organization. Work Package Contractors are required to develop plans and technical documentation so that the whole program could be turned over to an operations contractor with no adverse impact. This will allow for an orderly transition of leadership and control of operations to the Operations Centers as the mature operations phase is achieved.

Pre/Post Flight Processing

Pre/Post flight processing of payloads is an operational task which will be an on-going operations function performed under the NASA Integrated Operations Management System. In order to process and integrate user experiments/payloads in an efficient, user friendly manner, A Payload Accommodations Manager (PAM) function is required to manage the experiments/payloads both for ground and flight processing. For the ground processing flow, the PAM has to work with the users during the initial generation of the users requirements, through the ground hardware flow, to the return of the product from the Space Station. The flight counterpart of the PAM would work the experiment/payload on-orbit, from a designated support center.

When a user experiment/payload, either International or United States, is designated to fly on Space Station, a launch vehicle (U.S. ELV/International ELV or Space Shuttle) will be assigned. If the experiment requires a rack buildup, the buildup will take place at: 1) Science and Technology Centers), 2) International rack build-up areas, 3) Kennedy Space Center. This user friendly approach allows maximum flexibility for experiment build up in a parallel schedule mode. The integrated racks will undergo a rack interface test with a SS interface simulation to assure an optimum safety and, SS interface certification. Also multiple launch vehicle capabilities and parallel build-up allow for flexibility in up-load manifesting. A representative of the Payload Accommodations Manager will manage the flow support through the entire process. The PAM concept allows a consistent NASA involvement throughout the processing of payloads/experiments.

The logistic module will be utilized to both up-load and down-load payload to the Space Station. A early/late access is required for the logistics module for landing/launch time frames. Life Science Experiments as well as time/temperature/environment critical experiments will require expeditious handling both at the launch and landing sites. The early/late access capability needs to be incorporated in the U.S. or International logistics modules.

Integrated Logistics Systems

The Integrated Logistics System report addresses the following major functions:

Maintenance on Orbit	Packing and Handling

Maintenance on Ground | Facilities
Material Management | Technical Documentation
Transportation | User Support
Training | Logistics Management

Maintenance and resupply/return are the two prime tasks for S.S. Logistics in the operational phase. The management structure necessary to ensure the effective and efficient management of Space Station maintenance and resupply/return must cope with the diversity of integration and management interfaces. It must be capable of integrating strategic, tactical and execution level planning. It must identify accountability for Space Station performance and it must manage the systemic processes and issues which cross institutional and management level boundaries.

In the recommended concept, the level A' organization would provide the strategic and tactical integration across requirements and integrate the planning requirements across ground operations, logistics and on-orbit operations. The Logistics Operations Center, located at the Ground Operations Center, would provide the day to day management of Space Station logistics support. It would provide technical logistics support to the TOCB process and would manage resupply/return, and maintenance both on-orbit and on the ground.

The establishment of the dedicated headquarters logistics function and the Logistics Operations Center will provide the continuity of logistics planning and execution necessary to support the program. The remaining Integrated Logistics Functions are addressed in detail in the Logistics section of the report. Significant findings of the Integrated Logistics Panel are elaborated in white papers. Some of the findings are as follows:

1. Current planning for logistics facilities equipment and manpower is based on an estimated 60,000 line items of

inventory, while the Task Force estimates 300,000 line items.

2. Lessons Learned from LPS Development
   - Specifications and purchase documentation up front (including testability and diagnostics) testability
   - Plan for assumption of maintenance
   - Plan for ATE and AI
   - Provision lifetime spares during manufacturing

3. Review of Air Force Recon Program
   - Use standard state-of-the-art hardware, software and firmware
   - Uniform R&M design requirements
   - Make manufacturer responsibiliyt for reliability of BITE
   - Business strategy needs to support logistics strategy
   - Maintenance data gathering should be automated, user friendly and useful to inputter
   - Operations contractor should be part of design process
   - Buy complete technical data in acquisition process

Logistics operations (up-load, down-load, SS system refurbishment) will be one of the largest operational tasks and cost drivers of the mature Space Station program.

Sustaining Engineering

Sustaining Engineering is an assigned role of the Space Station Program and is an on-going operational function performed under the integrated operations management system of the Space Station program. Sustaining Engineering is defined as maintaining a design that fulfills original design intent and is compatible with intended operational use. Problems are resolved to keep the hardware/software systems in an operational status. Operational performance is enhanced through product improvement/redesign for more cost effective and efficient operations. Approved changes in design and requirements are incorporated as a part of system evolution. Sustaining Engineering excludes major upgrading of existing systems or the acquisition of new systems if more than incidental research and development is required, but supports new development to gain the expertise necessary to operationally sustain new systems after turnover from the Development Centers.

The Space Station consists of flight elements designed and developed by NASA, Internationals, and Users. Each of these elements will be responsible for the Sustaining Engineering of the hardware and software provided for that element of Space Station Operations. NASA has the overall responsibility of performing the analysis to ensure the compatibility and safety of user/International design performance.

The Space Station Sustaining Engineering Organizations at the Operations Centers will accómplish the major functions of Sustaining Engineering under the centralized management and control system at NASA Headquarters. This provides a singular management interface to the Internationals and users, as well as a single approach to maintenance of the Space Station Engineering Data Base (SSEDB) throughout mature operations. A standard system will be provided for processing engineering changes and updating affected Space Station Documentation. The Operations Centers provide the technical support and analysis for the tactical planning.

NASA lead Centers have expertise in various disciplines which are reflected in the Space Station Work Package Concepts required to design and develop the Space Station. The Space Station Program has been divided for design purposes into three phases, 1) Design and Development (D&D),
2) Transition and 3) Mature Operations. For the D&D Phase the work package centers will design the Space Station

hardware/software. In order to sustain an operational program for a twenty to thirty year period, the NASA Development Centers should be released from the development engineering role on the Space Station at the earliest opportunity as their resources are required for other long range national programs. A concerted plan between NASA Space Station Operations and the NASA Development Organizations must define the transition phase required to obtain the mature operations phase.

The recommended transition concept is to have the Launch Site Sustaining Engineering representative involved with the early development and design of the Space Station hardware/software. Approximately three years prior to Initital Operations Capability (IOC), the Launch Site Sustaining Engineering Operation should be in-place; thereby, allowing an orderly turnover of engineering from the Development Centers on a system by system basis. The turnover would be done incrementally depending on system design maturity and complexity.

All Development Test beds and equipment required for future National Research would remain at the Development Centers. Space Station peculiar support equipment would be centralized at the Launch Center for mature operations. The Launch Center Sustaining Engineering would retain and update the Space Station Engineering Data Base and have the capability to accomplish the Sustaining Engineering for Space Station during the mature operations phase.

Transportation Services

The Space Station in the operational era will require heavy support of Space Transportation Systems. Transportation Systems include those used for launch from earth, on-orbit mobility, crew rescue and return to earth.

During the Space Station operational era a mixed fleet of launch vehicles is required. The payload capacity of the Space Shuttle is only thirty to forty thousand pounds (depending on which orbiter is used) which is insufficient for many Space Station applications. The down-load of the shuttle orbiters is even less than the up-load. With the expected orbiter fleet of four vehicles, the expected flight rate will only be about 14-16 flights per year. Use of other vehicles, such as Shuttle Derived Vehicles (SDVs), expendables (International and U.S.), that do not require manned flight, would greatly relieve the scheduling load on the shuttle. Use of ELV's and SDV's is mandatory for a viable Space Station Program. The shuttle would still be used for crew rotation.

An interesting facet of the logistical use of International Expendable Launch Vehicles for up-load and down-load payload to the Space Station is that a barter system could be arranged to allow a trade of services between the U. S. and International Partners in a mutually complimentary manner.

The ability to rapidly rescue the entire crew from a disabled Space Station is a major requirement. The safe haven capability that is provided on the Space Station cannot adequately address failure modes. A means for rescue must be provided. Rapid return to earth of a seriously ill crewman is also desired so that proper medical attention can be obtained. Options include: 1) an orbiter on standby, 2) orbiter on orbit, 3) a crew emergency return vehicle, and 4) international shuttle/expendable rescue vehicles. Of the options considered, an automated Crew Emergency Return Vehicle (CERV) attached to the Space Station is the most viable. The CERV could serve either as an rescue vehicle or a safe haven in an emergency situation without dependency on an earth based capability.

Transportation Services will be one of the largest cost drivers of the Space Station Program during the mature operations phase.

Information Systems and Communication

The complexity of the operation of the Space Station, its physical remoteness, the continuing change of mission as new experiments are taken up to the Station, and the importance of safety and reliability all place heavy burdens on the requirements for, and importance of, ground information and communication systems. User needs for access to their experiments, either in ground test facilities or in the Station and the associated data, will also rely on these systems to some extent. The proper implementation and operation of these systems will contribute significantly to the overall effectiveness of the Space Station operations.

The Information and Communications Systems during the operational phase of the SSP must be highly intergrated with the many computer systems networked for the sharing of data on a large scale. There must be interfaces among all organizational aspects of the program, including flight operations, ground processing, logistics, and sustaining engineering. Planning must be initiated now to eliminate pockets of "uniqueness" whether generated by desire to stay with old systems or because of political boundaries. A high level of control and management commitment must be in place to manage database and network architecture and design.

Evolution must be planned for in all operational information systems. Budget projections must include capital costs.

2.0 PRE/POST FLIGHT OPERATIONS

2.1 OVERVIEW

The Pre/Post Flight Operations subpanel of the Ground Operations and Support Systems Panel was chartered with the task to develop the concept for conducting pre/post flight operations for Space Station incremental missions. These operations include: 1) analyze and verify the mission complement to the Space Station and National Space Transportation System (NSTS) carrier; 2) perform physical integration and verification of the mission hardware; 3) provide for late/early stowage of mission items; 4) perform recertification of flight hardware; and 5) define facilities to support mission processing. The concept addresses mature operations, that is, operations in the year 2010, however, specific recommendations are presented for implementation during the C/D phase that will enhance achieving the mature operations concept.

The concept developed will be focused on the three main elements of pre/post flight operations: analytical integration of payloads, physical integration of payloads, and support functions for payloads processing.

The concept for the accomplishment of the payloads analytical integration entails the optimum utilization of four major participants which are: the users, Science and Technology Centers (S&T), Payload Integration Organization (PIO), and the NSTS. The users, if a member of a discipline of a S&T Center, will interface through the S&T Center for the analytical integration activities. If the user is not represented by an S&T Center, he will work directly with the PIO. The S&T Center not only will be the interface for their users, but will provide coordination support, and interface to the PIO for payloads in their particular discipline. The PIO is the responsible organization for performance of the total mission analytical integration and it will provide the interface and support to the NSTS. The NSTS is the responsible organization for the NSTS flight for the Space Station mission.

The concept for the physical integration activities is one of decentralization/centralization. The Space Station payload support elements; i.e., racks and Payload Interface Adapters (PIA), will be provided to the S&T Centers or to other Space Station approved organizations; i.e., international or commercial, to perform physical integration and interface testing of the payload to the support elements. The integrated racks or PIAs would then be delivered to the launch site where they are integrated with the Space Station interface simulation equipment for payload to Space Station interface functional compatibility verification and then final launch preparation. Space Station platforms would be integrated and functionally verified at their final assembly and integration site and then provided to the launch site for launch preparation. Provisions would be provided by the Space Station Program to accommodate late stowage (on the pad) and early removal (at landing strips), in/from the Space Station logistic carriers of payload items.

In the area of support to payload processing, the concept addresses recertification of the flight hardware and payload unique support facilities for payload processing. The Space Station Sustaining Engineering Organization would manage and control the requirements for recertification with implementation of the requirements by the launch site organization.

Unique payload support facilities have been identified. The programmatic provisioning; i.e., commercial rental, NASA facilities with user rental fee, etc., is dependent on individual requirements.

The functioning of several organizations performing defined roles is required for implementation of the operations concept. These organizations and their major roles are as follows:

Users - Develop and provide payload hardware and participate in and support the integration process.

Science and Technology (S&T) Centers - Integrate discipline users requirements and provide surrogate role and support for them during the integration process.

Payload Integration Organization (PIO) - Manages and performs analytical integration activities

Launch Site - Manages and performs launch site processing. Performs build up of payloads not assigned to S&T Centers or others; i.e. commercial, DoD, etc.

National Space Transportation System (NSTS) - Manages and provides flight services for Space Station missions.

Recommendations from the Pre/Post Flight Operations Subpanel for consideration by the Space Station Program for implementation during Phase C/D are as follows:

- Procure the required complement of Space Station hardware; i.e., rack, Payload Interface Adapters (PIA), Simulators transportation GSE, etc., required to implement the concept of decentralization of payload physical integration.

- Establish the organizational structure for the Payload Integration Organization and implement the PIO to perform the payload integration functions.

- Provide capability in the logistics elements for late/early payload accessibility.

2.2 DETAILS OF CONCEPT

2.2.1 <u>Roles/Responsibilities</u>

The implementation of the operations concept for pre/post-flight operations during the operational phase of the Space Station Program will entail the functioning of several organizations. These organizations will be interactive and they must understand the roles, functions, and responsibilities of each other and operate within the roles framework to achieve optimum efficiency. This section will endeavor to delineate the roles, functions/responsibilities of each of the organizations. The organizations or major functional entities in the concept are: the users, Science and Technology Centers (S&T), Payload Integration Organization (PIO), National Space Transportation System (NSTS), and the launch site organization. The diagram of the concepts' organizational structure is presented in Figure 2-1.

<u>Roles</u>

The prime roles of each of the functional entities are defined in the following paragraphs.

<u>Users</u> - The major role of the users will be to conceive, design, and develop experiments to be performed on Space

PRELAUNCH/POSTFLIGHT FLOW

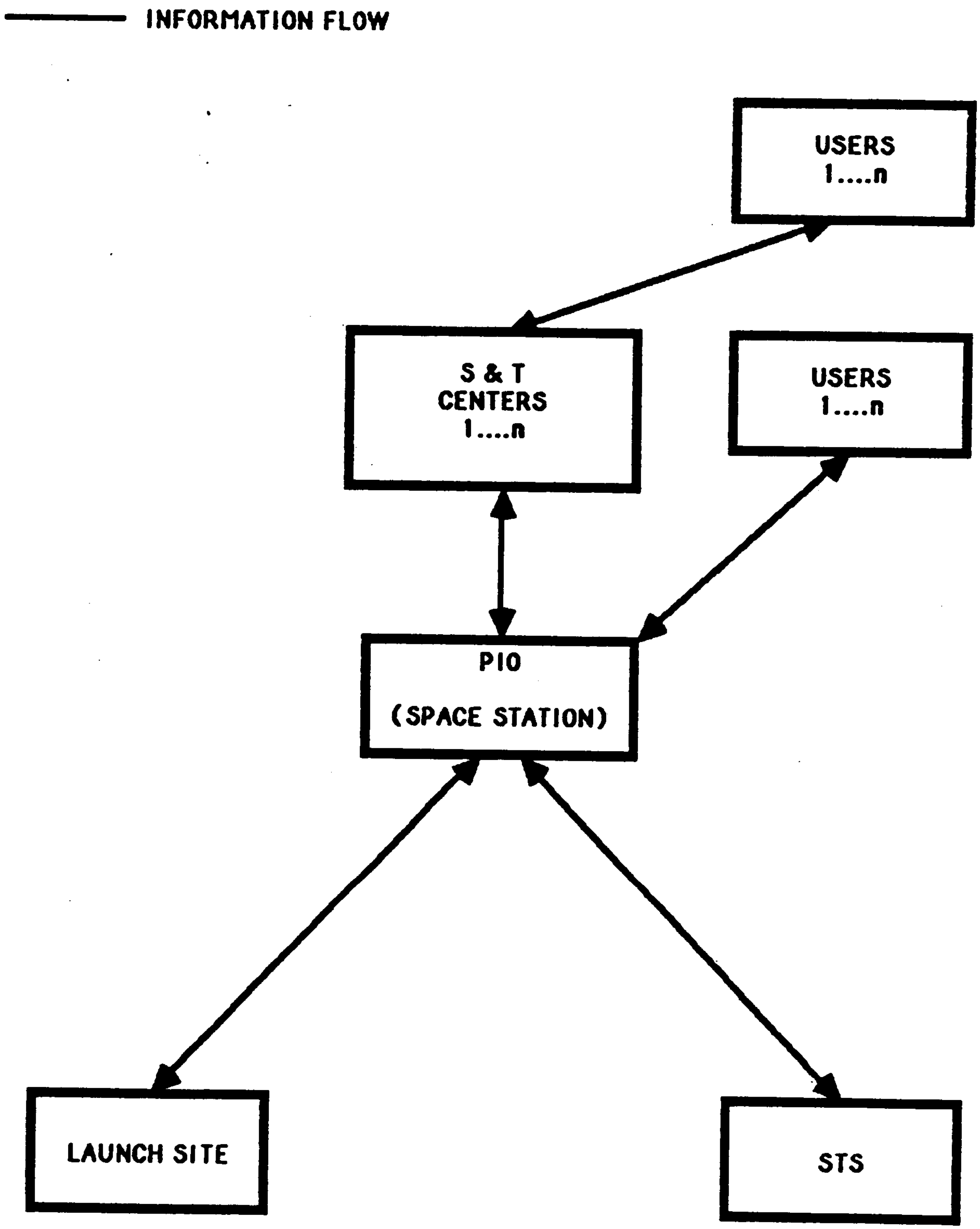


FIGURE 2-1 PRELAUNCH/POSTFLIGHT FLOW FUNCTIONAL STRUCTURE

Station. This may entail the development of payload hardware to be sent to the Space Station or use of payload hardware already onboard Space Station. The user, once selected for Space Station operations, will provide his requirements for utilization of Space Station Program resources, support the activities associated with integrating his requirements into Space Station operations, support and/or conduct on-orbit experiment operations, and then, as required, report on his experiments status.

Science and Technology (S&T) - The S&T Centers serve a vital role in integrating user experiments into the Space Station program. Beginning with the concept of Space Station, the S&T expertise has been applied in defining facilities and requirements for the elements of Space Station including the laboratory pressurized module, the habitability facility, platforms, and attached payloads. The S&T Centers maintain active R&D programs encompassing activities representative of proposed 0-g experiments. Their natural role is to serve as representatives of the science proposer in the various disciplines, i.e., JSC for human associated life sciences activities, ARC for nonhuman (animals, plants, microbiologicals, exobiology) associated life sciences, MSFC for materials processing, GSFC for astrophysics and earth sciences, and LeRC for microgravity technology.

Payload Integration Office (PIO) - The PIO will perform the primary role of integrating users requirements into the ongoing Space Station physical plant and operations. The PIO role will be to perform the function required to integrate, verify, and certify for the Space Station and to the NSTS each Space Station Incremental Mission.

National Space Transportation System (NSTS) - The role of the NSTS organization in the Space Station era will be basically as it is today. The NSTS will have the primary role of integrating Space Station payloads to the launch vehicle, launching the launch vehicle, and conducting in-flight operation, to deliver payloads to the Space Station. The NSTS will perform a similar role for returning payloads from the Space Station.

Launch Site - The launch site role in the processing of Space Station payloads will be very similar to what is being done now in the Spacelab Program. The launch site will perform physical integration of experiments not assigned to S&T Centers or others (DoD, commercial). The launch site prime role for Space Station payloads will be to physically integrate the individually provided payload elements into a Space Station Incremental Mission payload complement and perform the integrated interface compatibility verification of this payload complement to a Space Station simulator. It will subsequently integrate/verify Space Station carriers and perform prelaunch activities. A corresponding role will be performed as required for the return flight from the Space Station.

Functions/Responsibilities

Users - The functions that are the prime responsibility of the users and/or his representative and to be performed to implement the pre/post flight concept are listed below.

- o Develop experiment hardware/software
- o Define/document Space Station resource requirements
- o Define/document Space Station interface requirements

- o Define/document pre/post flight ground processing requirements
- o Review PIO prepared documentation
- o Support payload integration reviews
- o Perform/document experiment verification analyses and test
- o Perform/document safety analyses and provide safety compliance
- o Interface to S&T Center or PIO as appropriate
- o Perform/support experiment hardware integration and test
- o Support pre/post launch activities
- o Conduct/support on-orbit Space Station operations
- o Receive, process, analyze experiment returned hardware, products, data, etc.
- o Reports on status of experiment operations

Science and Technology Centers (S&T) - In the event the user is represented by an S&T Center, the S&T Center, in actuality, performs the functions described under the preceding section. The S&T Center is responsible for the following:

- o Design Engineering
  - Payload analytical integration
  - Experiment hardware design and fabrication
  - GSE design and fabrication
- o Operations
  - Experiment requirements preparation with user and science representative
  - Hardware physical integration and test

- Hardware verification and safety
- Assemble all PIO/payload required documentation
- Phased and flight training
- Flight support with analyses
- Formal interface to PIO

o Data Systems

- Define, design, implement experiment flight and ground software

o Science

- Assure user science objectives are met in experiment design
- Provide biocompatibility support testing of flight elements
- Support in-flight and post-flight experiment analysis

o Sustaining Engineering

- Maintenance of on-board experiment facilities

Payload Integration Organization (PIO) - The functions/responsibilities to be performed by the Payload Integration Organization (PIO) in the implementation of the pre/post flight operational concept are listed below.

o Develop user friendly documentation covering Space Station operational and functional capabilities

o Provide single point contact for payloads for S&T and/or users

o Provide single point contact for Space Station Mission to the NSTS

o Obtain/coordinate Space Station resource requirements, and ground processing requirements for payload elements from S&T Centers and/or users

- Perform analytical integration of integrated mission to confirm compatibility of payload mission requirements, to Space Station, Space Station logistic carriers, and STS launch vehicles

- Obtain/assess payload elements verification data from S&T Centers and/or users

- Perform mission integrated payload verification

- Obtain/assess payload elements safety compliance from S&T Center and/or users

- Perform mission integrated safety analysis and provide safety certification

- Develop payload mission integrated documentation

- Develop and provide to NSTS mission payload data for developing NSTS Payload Integration Plan (PIP) documentation

- Develop and provide to launch site mission payload ground processing requirements

- Obtain and integrate Logistics requirements into mission payload

- Verify/certify flight readiness of integrated mission Space Station payload

National Space Transportation System (NSTS) - The function/responsibilities of the NSTS organization in support of Space Station missions will be essentially as for standard NSTS missions. Some other specific functions that may require significant interaction to the PIO are listed below.

- Develop NSTS PIP documentation in conjunction with PIO

- Provide crew training for payload unique operations

- Provide access and/or perform late loading of payload items

- Provide access and/or perform early removal of payload items after return from Space Station

- Provide standard launch/flight operations

Launch Site - The functions/responsibilities to be performed by the launch site in the implementation of the pre/post flights operations concept are listed below.

- Conduct ground operations review to assess/work payload problems
- Develop ground integration/test procedures from payload element inputs
- Perform payload physical integration/deintegration, where required
- Receive payload integrated (racks, PIA) elements
- Perform integrated payload mission testing to Space Station simulator for interface compatibility and safety
- Perform integration/deintegration of Space Station logistics carriers
- Perform Space Station logistics carrier/payload interface testing
- Integrate and verify Space Station logistics carrier to launch vehicle

2.2.2 Space Station Program

Introduction

Pre/post flight operation functions begin subsequent to the selection and manifesting of a user to a Space Station mission segment and the supporting NSTS flights and carries through to the return of products and/or hardware from orbit. The period of user involvement, in most cases, will be of a multi-year time span. The degree of user involvement will be a function of the payload hardware and functional interfaces to the Space Station, the NSTS payload carrier and to the NSTS launch vehicle. Pre/post flight operations include considering the logistics resupply (Orbit Replaceable Units, supplies, etc.) as a user payload to be manifested along with experiment payloads in the logistics carriers.

The areas which were identified as significant to pre/post-flight processing and for which various options were evaluated to arrive at a pre/post flight concept are as follows:

- o Analytical integration of payloads with the Space Station program (and the NSTS) including:
  - Involvement/interface of the Space Station with the NSTS
  - Payload interface analyses with the Space Station and NSTS Programs
  - Documentation type and mode to support user analyses.
- o Physical integration/deintegration of payloads with the Space Station program including:
  - Payload and logistics carrier hardware/software buildup
  - Level/degree of verification testing
  - Distribution of payload early removal items
  - Late access to/early removal of payload items.
- o Support of pre/post flight operations including:
  - Recertification of flight hardware
  - User support facilities.

Various assumptions and guidelines were established to aid and focus the option evaluation process to significant areas of consideration. Guidelines and definitions are identified in Appendix A.

Background. During the Phase B activities of the Space Station Program, consideration was given to areas of pre/post launch operations, ground processing facilities and equipment, and Space Station program integration with the NSTS. The focus of these considerations was mainly on the assembly and checkout phases leading to Initial Operational Capacity of the Space Station. Program level requirements and planning documents were baselined for these areas as follows:

JSC 30000, Program Definition and Requirements Document (PDRD), Section 4, Part 1, Prelaunch/postlanding operations requirements.

JSC-30202 11/18/86, Prelaunch/Postlanding Operations Plan.

JSC-21053 Space Transportation System/Space Station Program/Payload Integration Plan.

KSC-STA-60.01 12/17/86, Space Station Processing Facility, (SSPF) Facility and Equipment Requirements Document (FERD).

JSC 30000, PDRD, Section 3, Part 4.1: Master Verification Requirements

These documents provided background information for consideration of the various concepts associated with pre/post flight operations for the mature operational phase of the Space Station Program.

Numerous briefings were held which provided useful data related to the past experiences of the STS program (payload integration), the Spacelab Program (multiple users integrated into the Spacelab), various users and user community representatives, and USAF payload programs. See Appendix B for a listing of briefings/documents. Useful information was obtained from these sources in the areas of level of verification, analytical and physical integration of payloads, and documentation.

The method used to evaluate the various options identified for the analytical and physical integration and support of payload processing was a subjective rating/ranking of the attributes of each option against the following criteria:

- o Feasibility
- o Flexibility
- o User friendliness
- o Transition from development phase to mature operations
- o Effectiveness of management, cost and performance
- o Safety
- o Ease of proprietary operations.

For a definition of these criteria as used in pre/post flight operations considerations see Appendix C. The rating/ranking of the options varied among the evaluators but generally led to a predominant choice of option. The ratings for each option were thoroughly discussed, particularly for those options with widely differing ratings, to identify the key qualities of each option. An attempt was made in each area to arrive at a consensus choice, with all concerns discussed and evaluated.

The options selected for the pre/post flight functions will be presented within the framework of the flow of hardware and documentation for processing of payloads to orbit and for payloads returned from orbit. The key attributes of the selected option will be identified, particularly against the major criteria of user friendliness, management effectiveness, and cost effectiveness.

Pre/Post-Flight Operations Concept. The conceptual flow of hardware and documentation from the user community to the Space Station program under the pre/post flight operations concept for payloads selected to be manifested is shown in Figure 2-2. The concept description that follows covers the previously identified elements: analytical integration, physical integration, and support functions to processing.

The analytical integration concept begins with a description of user interfaces with the Space Station program, including the supporting documentation for user analyses and the involvement of the NSTS program with the Space Station/user.

The physical integration concept starts with a description of experiment integration with Space Station flight elements including a discussion of the level of and approach to verification. The process continues with a description of the integration of payload hardware into the logistics carriers, including a discussion of the approach for late access/early removal of payloads, experiments, products etc. The process is concluded with a description of the approach to distribution of early removal items to the users.

Two areas of support to the pre/post flight operations described are: recertification of flight payload processing hardware and user support facilities.

PRELAUNCH/POSTFLIGHT FLOW

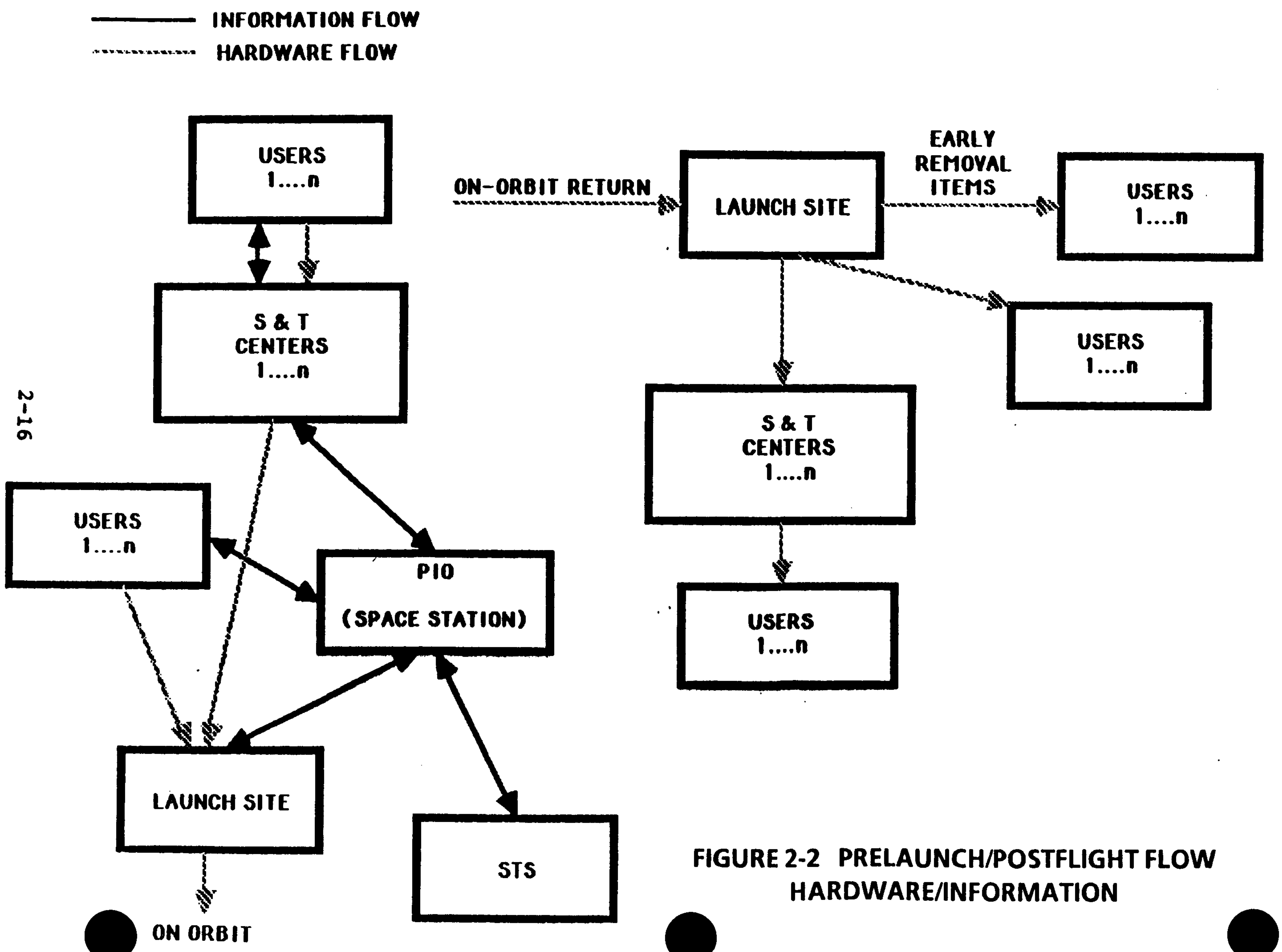


FIGURE 2-2 PRELAUNCH/POSTFLIGHT FLOW HARDWARE/INFORMATION

Analytical Integration

Payload Analysis - The payload analytical integration process for the user begins once he has been manifested for a Space Station incremental mission and the supporting NSTS flights for the mission interval. The scope of the analytical integration process encompasses the following: determination of the users requirements for interfaces to Space Station elements, Space Station logistics carriers and NSTS; development of requirements for prelaunch/post-landing processing, logistics, software, safety, and verification compliance; performance and documentation of the analyses/test to verify the compatibility to payload element interfaces, functional operations, and safety to the Space Station, Space Station logistics carrier and NSTS, as appropriate; and performance and documentation of the integrated analyses of the total payload complement to the Station or NSTS carriers. In summary, the analytical integration process provides the requirements/planning for the physical integration activities, and accomplishes the planning, analyses, reviews, verifications, compliances, certification, etc., that are required to integrate the new payload elements into the ongoing Space Station operations and verify that they are ready for flight and on-orbit operations.

The accomplishment of analytical integration activities requires detailed interfacing with the users, Space Station elements, and the NSTS organization. The user involvement can be quite extensive and extend over a protracted period of time, depending on his payload element. For the highly autonomous payload with few or very benign interfaces, the process will be mainly concerned with the safety compliance of the hardware. However, for the complex, highly interactive payloads, the process will be very detailed and demand high involvement by the user. The concept that has evolved recognizes this and provides the flexibility to simplify the user involvement.

CONCEPT - The concept of the functional structure required to accomplish the payload analytical integration functions is presented in diagram form in Figure 2-3 In the concept, both Science and Technology (S&T) Centers and the Payload Integration Organization (PIO) are major participants. As can be seen from the Figure, the concept would provide a separation between the Space Station and NSTS Programs. The PIO would be an integral part of the Space Station organization. The S&T Center for the particular science or technology that the user is engaged in would provide the primary interface for that user. The S&T Center would act as a surrogate for the user and support him in defining his requirements, understanding Space Station and NSTS requirements, performing and documenting the required analyses/test to verify/certify his hardware interface compatibility, and verification of safety compliance. The PIO, which is a functional element of the operational Space Station Program, would perform the total integrated payload analysis function. The PIO would perform the prime interface functions to the NSTS and would interface to the S&T Centers to accomplish the analytical function associated with the user payloads that these Centers represent. For commercial, international, scientific/technology, or other independent type users who are not, or choose not, to be represented by an S&T Center, the PIO would provide the single point interface to the Space Station Program. The PIO would provide full support to these users in a manner analogous to that described previously for the S&T Centers. The PIO would provide the final verification/certification for the Space Station and NSTS Programs that the payload is ready to fly.

RATIONALE - This concept incorporates the best features of the various options that were studied. The primary user friendly feature and strong scientific, technical interaction that the S&T Centers maintain with their discipline colleagues is utilized. In addition, the centralized, dedicated PIO with its unique skills and analytical tools for performing the planning, analyses, and interfacing to NSTS is established. This concept provides a friendly atmosphere of a single interface for users to work with, permits a management structure that allows definition of well defined roles and responsibilities for all parties, and is an ideal arrangement for management by exception. The negatives to this concept are the increase in the

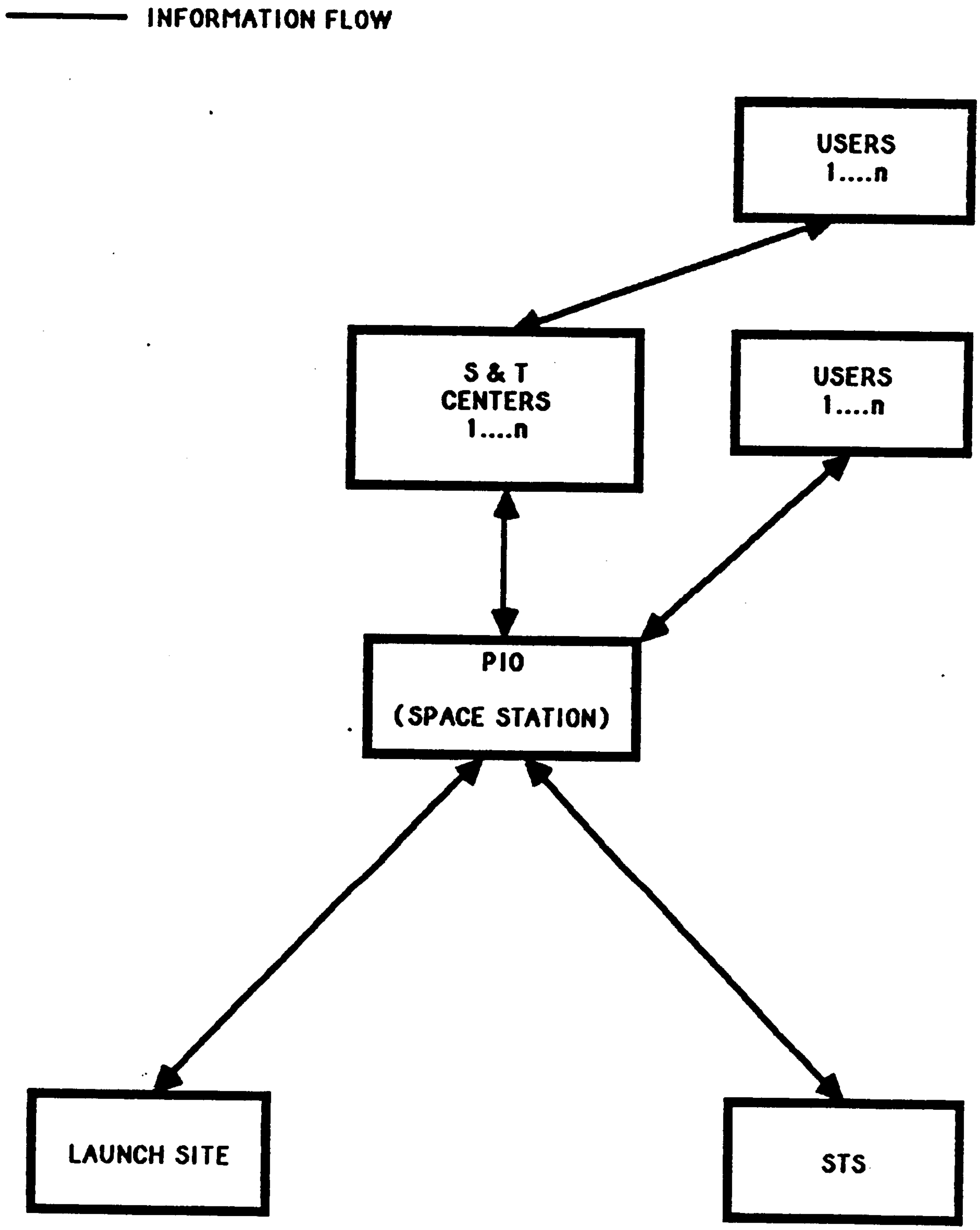


FIGURE 2-3 PRELAUNCH/POSTFLIGHT FLOW
FUNCTIONAL STRUCTURE

number of organizations involved, which will increase the overall total organizational levels of interfacing and management structures. Obviously, with this will be some attendant increase in cost. However, in the long run, the costs will probably average out and the other features of the concept make it most attractive.

Documentation System - An important and necessary aspect of the payload integration process for the Space Station program will be the documentation required to support the analytical, integration, and verification efforts. Previous experience with such documentation systems were for payloads to be flown on the NSTS, on Spacelab, and payloads launched by ELV's. The main objective of any document system selected for the Space Station program would be to provide the proper information for payload interfaces with the NSTS and Space Station and to identify safety issues for both Space Station and NSTS operations. The selected system should provide traceability of payload processing operations and should aid in anomaly resolution. The document system would not concern itself with payload operations other than safety implications and interface compatibility for the NSTS and Space Station.

A major concern is that the documentation system allows a single NASA interface for all users and that the documentation be as simple and concise as possible. The documents should be tailored to the class of users (type, size, discipline) and be formatted to minimize redundancy. Table 2-1 is representative of the types of documentation required during various phases of payload integration.

CONCEPT - The documentation system would utilize the existing NSTS PIP and annex system to document the integration of the Space Station logistics carriers and payloads to the NSTS. It is expected that the interfaces between the Space Station logistics carrier/payloads and NSTS Systems will be kept to a minimum, thus allowing the documentation to be simplified.

TABLE 2-1

DESIGN	VERIFICATION AND PHYSICAL INTEGRATION	SPACE TRANSPORTATION	SPACE STATION FLIGHT PLANNING AND IMPLEMENTATION
O ICD	O ANALYTICAL (SS AND TRANS) STRUCTURAL THERMAL	O EQUIP ASSEM REQ (ASCENT)	O FLIGHT PLANNING
O DATA PACKAGE		O EQUIP ASSEM REQ (RETURN)	O FLIGHT OPS SUPPORT REQ
O SOFTWARE DATA SYSTEM	O EQUIPMENT BUILDUP (SS CONFIG)	O EQUIP DISPERSAL (POSTLANDING)	O TRAINING
	O JOINT SS/USER TEST PREFLIGHT ON ORBIT		O POCC INTERFACE
O SAFETY*	O SAFETY*	O SAFETY*	SAFETY*

* Safety is an ongoing consideration from design through postlanding requiring periodic reviews and approval.

A separate document system would be developed to cover payload interfaces and safety consideration with the Space Station systems. Precedent for such an approach can be found in the Spacelab program. That program created a mission requirement for payloads documents which established the integration, verification, and safety data required for payloads interfacing with the Spacelab. The documentation system for the Space Station program would cover the interfaces with Space Station Systems such as the Data Management System (DMS), power, thermal, structure, and ELCSS. In addition, verification, training, safety compliance, payload resource requirements, mass properties, data flow, flight definition, and payload operations would be documented. The top level documentation tree envisioned is shown in Figure 2-4.

With this two document system the user would provide information to and interface with the S&T Center or to the PIO organization responsible for the Space Station document. These organizations would then develop the integration data needed for the NSTS PIP document system. All the user requirements would be covered in one document that the user would submit to the PIO or S&T Center.

The PIO would coordinate the development of all documentation and will develop with the NSTS the appropriate NSTS documentation. The PIO would provide appropriate documents to the user for review, again working through the original single interface point, either the PIO or the S&T Centers.

RATIONALE - There are some concerns with the friendliness of a two document system to the user. These concerns center around the need to maintain a single source point of contact for the users. With a two document system there is a chance for redundancy in requirements and additional interfaces. However, it is possible to tailor the Space Station document to the various class of users and assure that the Space Station document would be the single point of contact for the users. The PIO would then work the interfaces required with the NSTS PIP and annexes.

Effective management would be able to be achieved even though there would be two organizations involved in document preparation. Based on Spacelab experience, clear responsibilities and document scope could be established and management control over these areas could be put into effect.

DOCUMENTATION

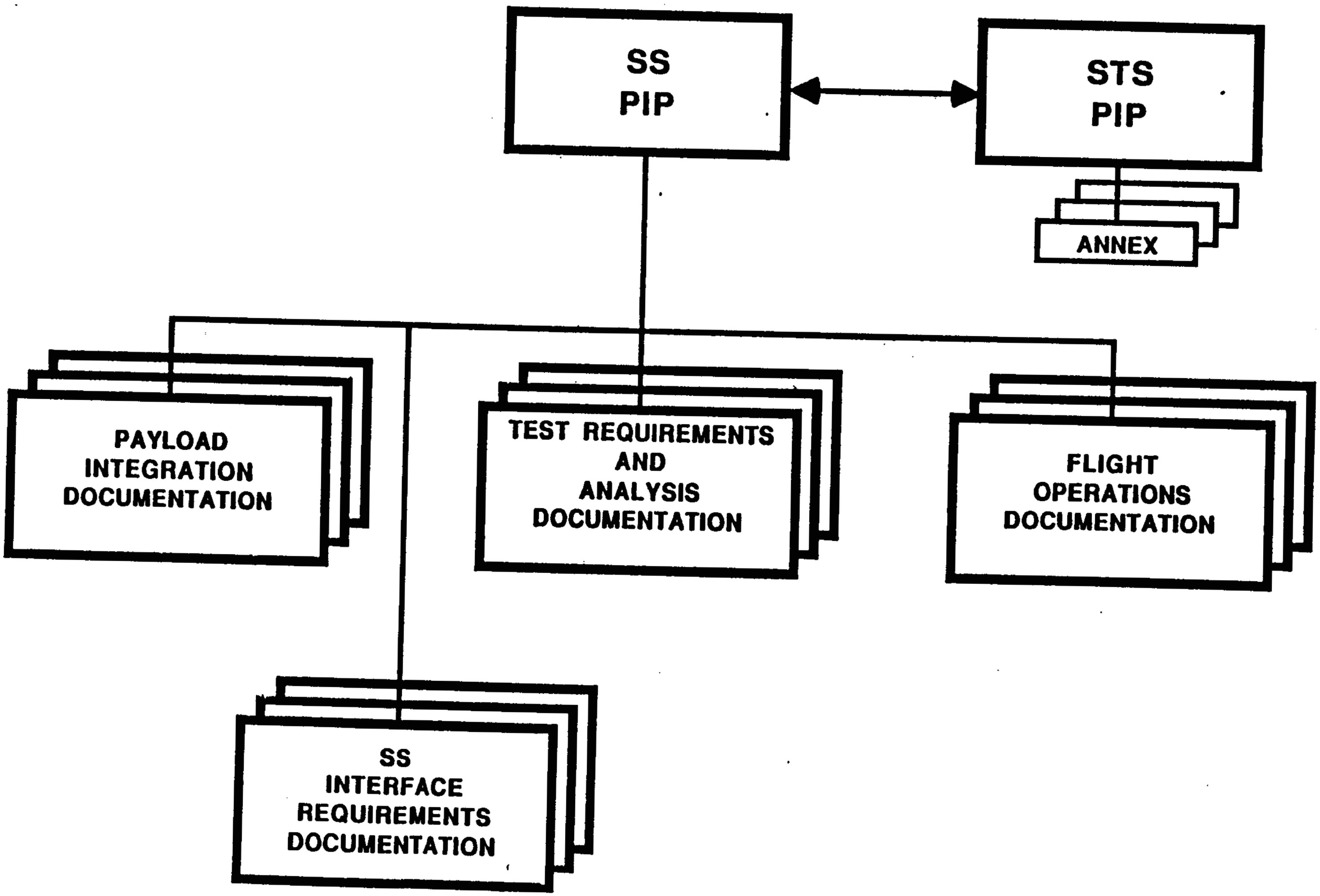


FIGURE 2-4 DOCUMENTATION TREE

The performance effectiveness of a two document system should be reasonably high due to the opportunity to streamline and tailor the documents to the Space Station program needs. There is the potential in the Space Station documents to break away from the constraints and framework exhibited by the NSTS PIP and be more innovative in formatting the Space Station document. The two document system will have to address the concern that important data or requirements will be overlooked and not be covered in either document.

Initial consideration of the cost of a two document system would indicate potentially higher costs, however, with the opportunity to tailor the Space Station document (rather than force fit into the NSTS framework) the long term costs should prove to be lower.

Two modes or media to be used in preparing, distributing, or transferring the required Space Station documents were considered: the existing paper system used on NSTS and Spacelab Programs and the concept of a paperless document mode. Using a paper document system similar to NSTS will prove to be an extensive array of documents due to the complexity and scope of the Space Station program. Such a large system will be cumbersome to utilize efficiently.

Electronic data base document systems are currently being established in the Space Station program and should be used to the greatest extent practical. However, limitations of handling data bases need to be recognized. Such a system needs to be structured to impose safeguards on information transfer and to establish methods to simplify the management of complex data bases. Electronic data bases for documents should prove beneficial to cross-checking safety requirements.

Separate NSTS and Space Station document systems were highly rated in the key areas of user friendliness, cost and management. The key features of this concept are: the use of the separate NSTS system with which the Space Station program could readily interface; the opportunity to tailor the Space Station program document to the various user classes; and the chance to be innovative in designing the format of the Space Station document system based on lessons learned from the NSTS and Spacelab programs.

The development of electronic data bases for documents should be expanded as practical during the development of the Space Station program, thus reducing reliance on a paper document system.

Physical Integration/Deintegration

Payload Integration - Physical integration, in the context of user provided flight experiments/equipment for Space Station application, is defined as an early activity in overall experiment ground processing where the actual flight experiment hardware transitions from a "stand alone" support structure to a flight qualified support structure. This hardware combination will ultimately be functionally operated in the micro-gravity environment of Space Station.

Deintegration is the post flight removal of experiment hardware from the flight support element. The Space Station Program provided flight support element would then be configured as required for next flight.

Unlike the NSTS Spacelab, the Space Station will have many permanent facilities outfitted within the orbiting laboratories by IOC. In addition to these, additional experiment/user hardware will be introduced which will be in several categories, such as:

- New first time/repeat flights of complete payload rack(s)
- Partial rack complements requiring integration with other users in the rack
- Payload elements which can never be completely integrated until in orbit and must use simulators and the telescience loop while on ground.
- Externally attached payloads mounted on the Space Station truss structure.
- Payloads to be mounted on platforms in orbit.

The integration concept must reflect a processing flow providing minimum time for experiment hardware and personnel at locations away from the principal investigator/hardware developer sites in order to encourage and facilitate Space Station user development. The concept should reflect a flexible flow enabling easy change out of experiment elements, additions, deletions, change in manifest, early and late access, and user friendly accommodations.

CONCEPT - The concept is to provide decentralized locations for experiment physical integration in/on Space Station flight support elements. These locations are defined as other facilities in addition to the Space Station Processing Facility (SSPF) located at Kennedy Space Center. The candidate decentralized facilities will be the U.S. Science and Technology Centers, International Partner S&T facilities and select international or commercial organizations approved for performance of this activity by the Space Station Program. The proper assignment of physical integration facility would be based on criteria such as: availability of integration facility, scheduling of flight elements, duration of experiment, and user discipline.

This concept will make use of the launch site Space Station simulation capability to perform integrated payload final interface functional compatibility tests prior to launch package integration and installation into the Orbiter. The launch site Space Station simulator will have been utilized during the Space Station assembly sequence build up phase and would continue to function during the mature operations phase. The integrated experiment will arrive at the launch site and be removed from their transportation equipment in the SSPF receiving area. Following visual inspections, the experiment package would be placed, if necessary, in the appropriate Space Station simulator device and functional interfaces to Space Station would be verified. After completion of necessary checks, the experiment would be removed from the simulator and installed in the appropriate logistics carrier for launch package integration. Upon completion of the mission, the experiment is returned to the SSPF where it will be removed from the logistics carrier and either deintegrated in the SSPF or shipped back to the S&T development center for final deintegration. The concept would provide for payload pre/post flight hardware flows as shown in Figures 2-5 and 2-6.

RATIONALE - The concept of decentralized physical integration allows flexibility and user friendliness. Its ability to respond to new situations should be excellent due to the decentralization of the hardware buildup with the availability of the engineering expertise and material resources at these sites. This factor also enhances the user friendliness due to users view of autonomy during these activities. The management structure will have well defined and clear interfaces and accountability for both the user and Station organizations. It also takes advantage of continued use of Space Station simulators at the launch site which will be in place and functional from the Assembly Sequence phase of Space Station. Cost impacts to Space Station Program includes the procurement of additional flight support elements to extend the pipeline to S&T Centers and management logistics for shipment and configuration control. (ref Appendix D Flight Rack Processing Analysis). Overall performance should be excellent under this concept with a high potential for operational success. Proprietary operations should also be very compatible.

Verification - An important element of the physical integration of payloads into the Space Station program is the level of and approach to verification testing. The purpose of final interface verification testing is to demonstrate that the users flight equipment and software are compatible with the Space Station and its interfaces. It is expected that user hardware will be tested in the process of its buildup to meet the specified operations and interface requirements of the Space Station program. However, it is desirable to have a final ground test, with realistic Space Station interfaces, to be certain the assembly and previous verification was done right. If inadequate user hardware or software were launched, and it was found not to fit, or otherwise be unacceptable for use in the Space Station, then it would need to be returned, repaired, and relaunched. A ground simulation of the Space Station environment that the user will meet would save him, and Space

EXPERIMENT RACK AND PLATFORM FLOW PREFLIGHT

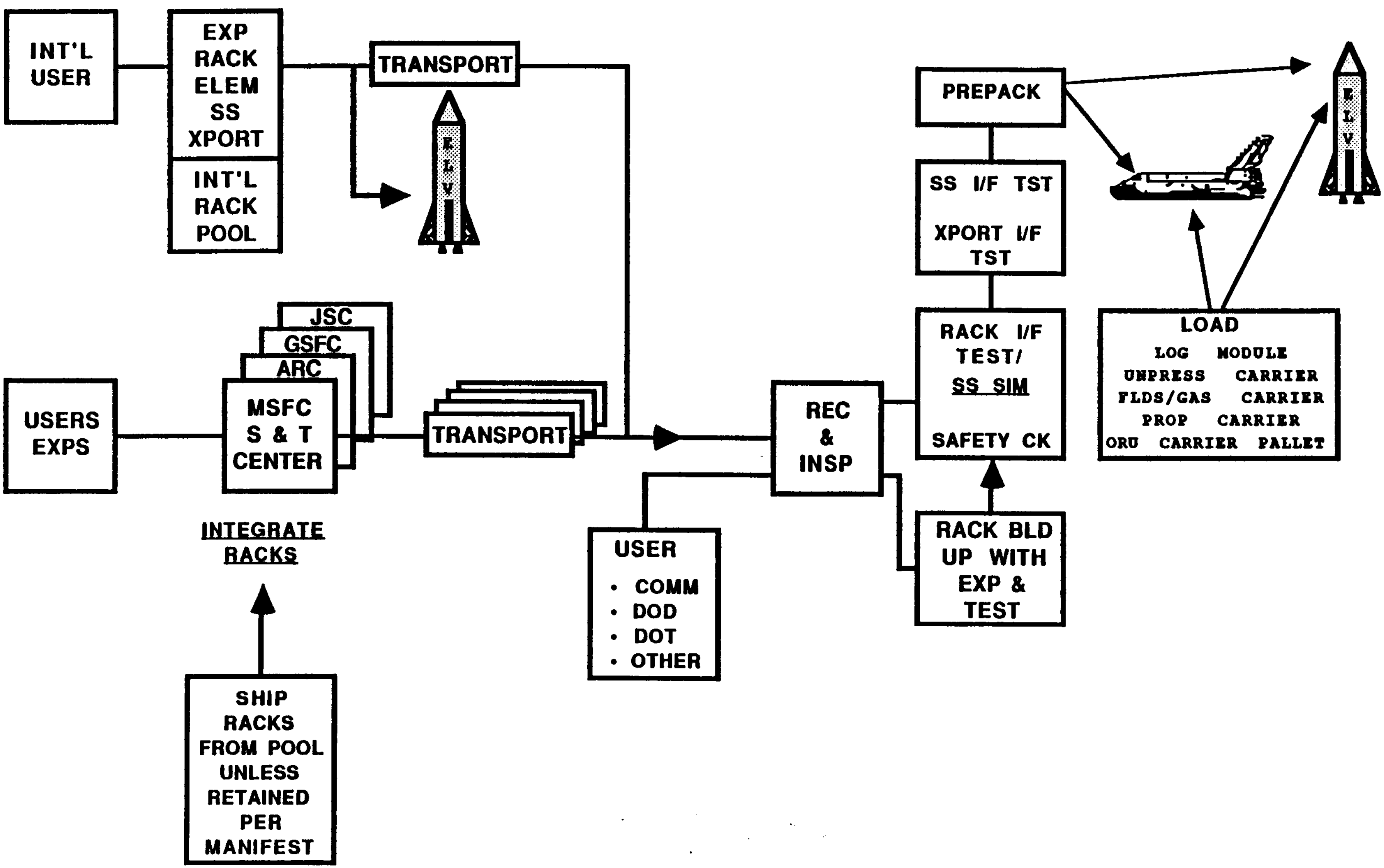


FIGURE 2-5 EXPERIMENT RACK AND PLATFORM FLOW PREFLIGHT

EXPERIMENT RACK AND PLATFORM FLOW POSTFLIGHT

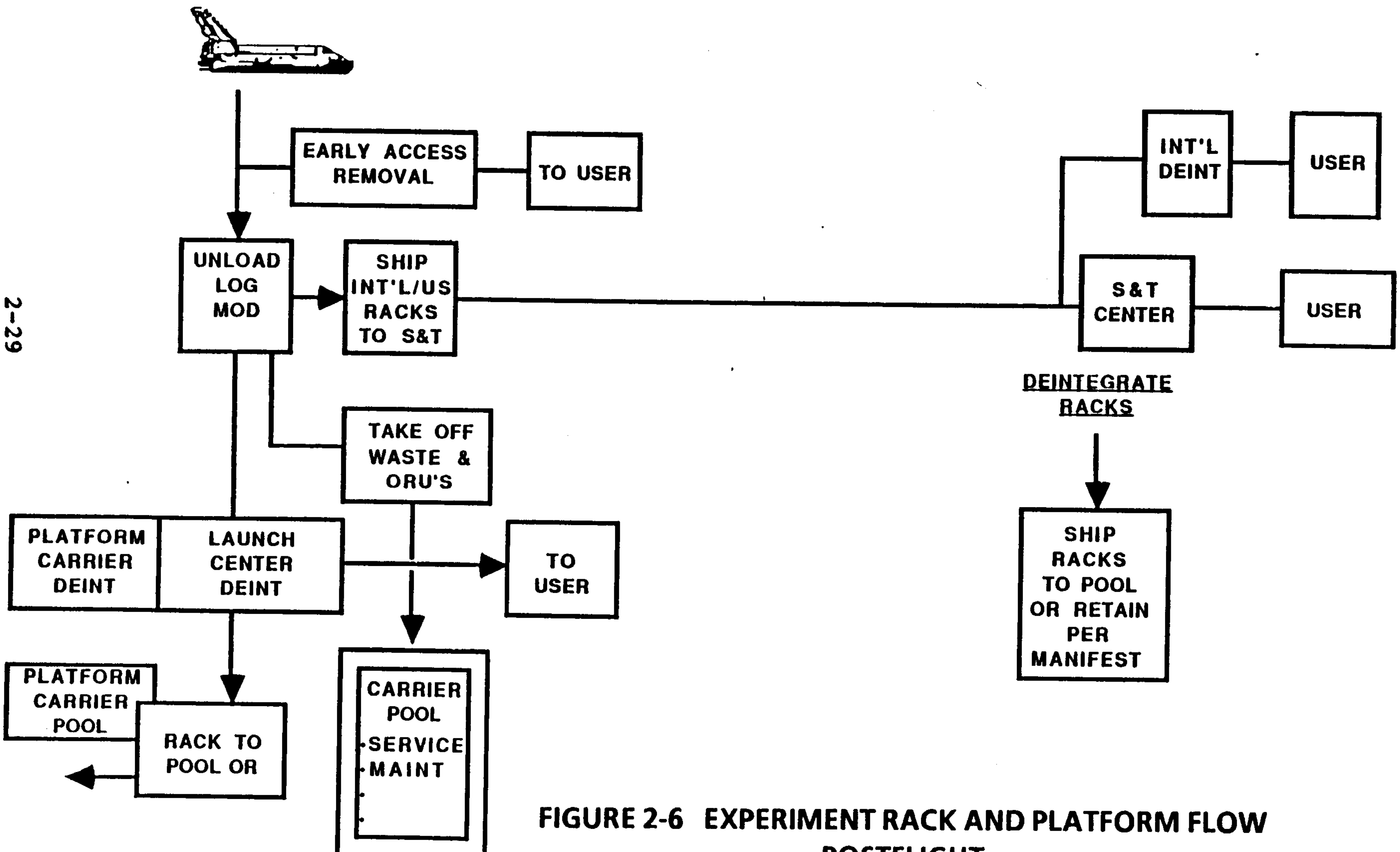


FIGURE 2-6 EXPERIMENT RACK AND PLATFORM FLOW POSTFLIGHT

Station, trouble and expense. To do this verification, the real characteristics of the Space Station side of the interface must be simulated to the maximum extent feasible. Some of the Space Station side might even be duplicated, with flight type hardware. Testing the user's equipment with this Space Station simulator demonstrates to the user what resources of power, data handling, cooling and communication the Space Station will provide him, and demonstrates for the Space Station that the experiment will not degrade or hinder Space Station system operations, or other users.

CONCEPT - The verification testing concept is to perform testing to rack or attached payload level on ground with simulated Space Station interfaces and then final testing to the Space Station elements while on-orbit. This would require that the ground duplication of interfaces to be met on Space Station would be only as accurate as is cost effective. The duplication of mechanical interfaces of sizes, hinges, latches and connectors could be very accurate. Duplication of data, power, thermal and communications systems would be to interface specification. Other adjacent users would be simulated to only a limited extent. Simulated Space Station power and thermal control system fluctuations would stay near nominal levels. The conductive electromagnetic environment would be only partly simulated. Systems software would be duplicated. The data bus loading due to other users would be simulated by insertion of dummy data packets. It is expected that for this concept only minor or subtle malfunctions would not be caught. It is believed those could be worked around if they did occur on orbit.

RATIONALE - The concept of payload verification by testing to Space Station specifications during the process of buildup, testing to a reasonable level on the ground, and then completing the testing in orbit is considered the most feasible to execute at reasonable cost to the Space Station program during future Space Station operations. Feasibility is good because adequate and mature simulation of the various kinds of user interfaces to Space Station will already exist from the Space Station buildup phase. Flexibility for the user is good because the user can perform reasonable tests during his buildup. Final interface tests will involve only minimum interfaces to the Space Station. The effect of adjacent users can be reasonably simulated in the final interface test. It is considered user friendly because the Space Station interfaces are defined and predictable. The user can do whatever tests he wishes to verify his payload during buildup. As long as he passes Space Station safety standards and final interface test, he will be acceptable to Space Station. The final interface test is not intended to enforce any Space Station specified internal quality level on the user's equipment.

The effectiveness of transition to operational use is high and mainly a matter of stabilizing the Space Station procedures and documents to a configuration that minimizes cost and trouble for both the users and Space Station program. Management of final interface simulators would remain under the Space Station program. The cost of simulator facilities would be already paid for, with only some upgrade needed to optimize the balance between increasing the chance of catching user anomalies versus the cost of verification equipment. The effectiveness of verification performance will be good, commensurate with the quality of the simulation. The safety for Space Station and user will be good because finding safety anomalies is the object of several reviews and the final testing will be done by experienced Space Station personnel. Ease of proprietary operation is satisfactory because the users will need to reveal only as much of their payload content as is required by safety considerations. Any final interface test need not compromise the security of user's payload.

Logistics Module Buildup - Subsequent to payload integration and testing of the Space Station flight support elements, the next step in the physical integration/deintegration process is the buildup of the logistics elements, which include U.S. and International Partners proposed elements. The International Partner elements, if launched in the United States, would follow the same processing flow as the U.S. element with responsibilities and performance being in accordance with international agreement.

The logistics module; unpressurized (dry) carrier; propellant carrier; and fluids and gases carriers make up the U.S. logistics elements. The logistics module, which provides pressurized volume, is the primary vehicle for uplifting and downlifting (returning) both Space Station and payload items.

The dry carrier, propellants carrier and fluids and gases carriers are special purpose carriers. Processing flow of these carriers will be as required by the logistics resupply of Space Station systems. Payload user items to fly on these carriers would be recognized as part of the overall Space Station requirement and integrated into the normal processing flows. Some large attached payloads will provide their own carriers.

CONCEPT - The concept for the buildup of the logistics module (LM) is to perform the processing at the launch site. The following are the major flow operations required for this processing:

1. Handling of logistics module within launch site processing facility after removal from the Orbiter.

2. Inspection for visual problems and of areas required by design element in requirements and specifications document.

3. Returned configuration verification to module replacement unit level such as stowage lockers is accomplished before module deintegration. Inventory within stowage lockers will be accomplished later in an off-line location.

4. Deintegration and/or removal of those items not planned for reflight and those which require some operation outside of logistics module.

5. Post-flight verification test.

6. Repair and maintenance.

7. Incorporation of design changes (modification kits).

8. Installation of module LRU's required by next Space Station flight configuration.

9. Installation of payload user items (see rack processing for flow description of user items).

10. Test of module system. Interface check to payload user items where required.

11. Recertification of flight condition of module systems per system provided requirements and criteria (OMRSD). This would include any new requirements resulting from ground and flight problems, trend analyses, life cycle requirements, etc., as designated and required by sustaining engineering.

12. Installation of logistics module into the transport vehicle (Orbiter).

13. Orbiter-to-LM interface tests.

RATIONALE - Utilizing the Launch site processing location reduces the number of handling and shipping operations. Processing time is reduced by the amount of time which would be required for additional shipping and handling operations. The number of NASA interfaces to LM users is reduced. Number of logistics modules required to meet processing flow is minimized without need to provide for the additional shipping and handling time involved with remote site.

Transition from development flight phase, Space Station Program management, and ease of proprietary operations would, for long-range operational life, be enhanced by processing at launch site only, as opposed to multiple sites processing.

Documentation at the launch site follows a more formal flow and is less flexible with respect to changes. A "get ready to launch" environment exists and puts pressure on personnel processing hardware to meet launch goals. The second set of the design and development personnel eyes regarding quality and reliability, which is inherent in using site where item is built as opposed to the launch site, is lost.

Close proximity to logistics holding area or spares stores area; minimization of turnaround time since shipments in and out of prelaunch area and post-launch (deintegration) areas are eliminated; provide best flexibility and cost for a operational program.

The number of interfacing locations to which users (Space Station systems and payload/experiment) would need to support is kept to a minimum.

It is recommended that the logistics module development should emphasize: modularity, provisions for early and late user access, development of flexible accommodations which meet maximum user hardware fabrication tolerances, modular data bases facilitating changes between mission flight complements, reverification of mandatory recertification requirements and criteria, and standardization of procedures.

Late Access/Early Removal of Payload Items - The final stage of physical integration of payloads into the Space Station Program is the availability of late access (approximately 72 hours prior to launch) to the experiments (in the case of a returning payload it is early removal from the Orbiter).

The current configuration of the Logistics Module (LM) does not accommodate access to the module after integration is completed at the Space Station processing facility, two months prior to launch. Pad access has been a requirement of payloads dating back to the days of Gemini. Both the NASA and NASDA Life Sciences organizations have stated a requirement for late access at the pad and early removal at landing for live biological specimens.

Transport systems to Space Station need to be maintained in a pressurized environment and require power and an ECLSS. The Orbiter middeck is the only pad/landing accessible area, currently available. Use of middeck lockers for transfer of rodents to Space Station is limited to numbers of animals and 350 gram size. Squirrel monkeys or larger primates, which are planned for experiments in Space Station cannot be accommodated in a middeck locker.

Animal holding facilities will be available from Spacelab which could be utilized as transporters in the LM when Space Station operations commence. These units are capable of maintaining animals up to 10 days.

CONCEPT - The concept for late access/early removal is to provide this capability through a change to the preliminary design of the Space Station logistics module.

RATIONALE - This concept might appear to be costly to NASA and the Space Station, but in the long run, because of the availability of existing holding facilities and in terms of public opinion for animal rights, this may prove the least costly to the program.

Design changes must consider safety of entry and not rely on the type of access utilized in Spacelab; i.e., suspension on a "Bowswain's chair". Timely access to the LM may also prove to be a safety issue for the program, both on launch and landing for other reasons; i.e., toxic wastes, contingency power, or fire suppression.

Distribution of Payload Early Removal Items - For payloads/experiments returning from orbit that require early removal from the Orbiter, distribution of these early removal items (post-flight) must be considered.

During the Space Station operational era, the opportunity is available to transfer biological and nonbiological systems to the Space Station 0-g environment for long-term studies and sampling, to create systems both biologically, chemically, and physically, and to return such samples and systems to the 1-g for extended analysis by the user. Though the systems may be altered in the 0-g environment, they may still require unique support and maintenance during return, landing, and post-landing operations.

Nonbiological systems may also require sustained temperature or specific gaseous-rich environments to reduce the potential of degradation during transit and return to the 1-g environment.

Carriers were addressed which would be required for downloading mission waste and user specimens other than animal. Because of the nature of wastes; i.e., gases, chemical, radioactives, containment for transfer from Space Station and disposal requirements are best resolved by one organization (Space Station). Carriers for experimental products should be addressed by the user for his specific needs.

CONCEPT - The concept for distribution of early removal items is that the user can negotiate with the Space Station Program the extent of handling and delivery of the payload that Space Station logistics would provide.

RATIONALE - This concept has been a mode of operation through the NSTS activities and has proved effective for the user. This combination allows logistics control of hardware items required for return and also assists the user in processing and returning his samples to his home site in a timely manner. Through a negotiated process, a face to face interaction with the user is positive in avoiding potential for mistakes occurring from inaccurate assessment of requirements from a user document.

Arguments in favor of this concept are that the Space Station Program must provide logistics functions at the landing site to handle the Space Station logistics carriers and the additional costs for handling and delivering as negotiated user items requiring early removal would represent only minor additional cost to the Space Station Program. This concept would be friendly to the user, since it would allow negotiation for services that the user sees as necessary to early removal item processing. Negotiation of services should be achieved at the execution level.

Support Functions

Recertification of Flight Hardware - An area of support required for the pre/post-flight operation processes is the recertification of payload processing flight hardware.

Recertification is the process by which acceptability for next use of flight hardware is verified. Recertification verifies that performance of all activities such as, but not limited to, inspections, tests, maintenance, servicing, calibration, replacement of limited life or failed parts and components, etc., of Space Station hardware and software have been accomplished satisfactorily.

Criteria for inspections, tests, maintenance, servicing, calibration, replacement, etc., of Space Station systems hardware and software between flight and/or on a periodic basis are key factors required for success of long life operations and cost management. The criteria and procedures need to be in place for first flight. Update as changes are made and problems occur during the development flights should be accomplished in such a manner as to support the transition of Space Station from development to operational status. Emphasis in this area and coordination with logistics on sparing and reverification is an essential part of the proper selection of spares for the long life of Space Station. A separate method of providing management visibility and control of the recertification criteria and specifications is needed. The Sustaining Engineering Organization should have responsibility for overall management of recertification with both flight and ground operations providing timely implementation and information on results of recertification and comparison trends versus problems experienced.

For international users, the NASA problem report and corrective action system will provide visibility into station problems on his provided hardware. NASA Space Station sustaining engineering will request corrective action where overall Space Station systems performance is impacted.

For U.S. provided hardware and software, the tracking and reporting on problems will be within the NASA problem report and corrective action system. Responsibility for assessing, controlling requirements, and evaluating effectiveness of recertification of Space Station system hardware is assumed to be a sustaining engineering function.

CONCEPT - The concept for recertification entails the management and control of the recertification requirements by the Space Station sustaining engineering organization and the implementation of these requirements by the launch site organization.

The major functions of the recertification concept are as follows:

- o Maintain and update recertification criteria. Maintain and update procedures for inspections, tests, and calibrations. Maintain and update historical records as required by specification and requirements documents and quality and reliability and safety documents where applicable.

- o Verify that records indicating required tests, inspections, maintenance, calibration, replacements, rework, modifications, etc., have been accomplished. Establish and maintain standard operation procedures for recertification.Initiate and maintain certification records.

The concept to perform recertification of flight hardware at the launch site includes the following features:

- All documentation, certifications, tracking and reporting, records of certification are responsibility of launch site.

- Launch Center certifies recertification status at flight readiness reviews.

- Space Station sustaining engineering organization provides changes in criteria and specifications needed for certification as evidenced by performance, via formal change request process.

RATIONALE - Performance of recertification of flight hardware at the launch site involves the following attributes:

- o This concept provides a central source for documents - problem reports, test reports, data packages, etc., needed for recertification. The most experienced test personnel during the operational phase will be at the Launch Center.

- o Recertification before higher level integration is a constraint to most milestones and status needs to be known for work planning impact assessment.
- o Launch operations personnel are more sensitive to immediate processing flow schedule priorities than independent integrator.
- o The major factor favoring the concept of Launch Center recertification is that records, hardware, and problem resolution experience are more concentrated in the Launch Center during the operational phase.

User Support Facilities - Pre/post-flight operations involve user support facilities at the launch/landing site. The NASDA have indicated requirements for facility space for final integration and checkout of their ELM, plus animal handling facilities and phytotrons. U.S. users in the Microgravity and Materials Processing and Life Sciences disciplines will also require facilities supporting pre/postflight operations involving biologicals and crew baselining.

A crew Baseline Data Collection Facility (BDCF), will be required at the launch site and the landing sites (Dryden and Kennedy Space Center). Such facilities with their complement of equipment, must be in place prior to launch and must be available immediately at crew landing. Deconditioning, dependent on the function, can occur within 10-20 minutes after reintroduction to 1-g. Current Life Sciences planning will closely analyze all mission crew physiological changes in an effort to determine the potential of the long term Humans In Space Program. A BDCF would be a long term use facility.

Similarly, the science community addressing functions in non-human systems will require facilities for immediate post flight analysis and testing of live specimens. Animal handling facilities of this type exists for the Spacelab program and could accommodate pre/post-launch and early access/removal activities for the Space Station.

It is assumed that NASA will maintain the same requirements for NASDA and/or ESA biological specimens as those placed on their U.S. experimenters. This issue must be addressed if a single transport containment system is used for all animals as indicated by NASDA.

Other potential preflight operations requiring unique support would include sterilization (autoclave, ethylene oxide, and irradiation), system evacuation and pressurization, incubation. These capabilities could potentially be procured.

> CONCEPTS - No clear choice among the concepts considered for user support facilities emerged from the evaluation process, therefore a description and assessment of each concept was presented.
>
> A concept of the user contracting for off-site facilities allows the user to contract for a facility in which he may perform any prelaunch activities or to contract for services, i.e., sterilization/ cleaning activities cited. If NASA dictates this must be the mode of operation, there would have to be some assurance that such facilities an/or services exist within the launch area. Additionally, this implies that hardware must be moved from the off-site area to the launch processing facility. The latter activity places an added cost on the user or potentially on NASA, depending who transfers equipment from off-site to the launch site.
>
> The off-site facility for the BDCF equates to no facility at all because of the degradation in performance; i.e., the requirement for ASAP crew access post landing. For animals, off-site facilities may not be capable of accommodating stringent housing requirements; restricted public visibility and access; and contingency launch requirements. Off-site facilities may, in fact result in

added cost to NASA, may result in a management headache, and do not allow the flexibility necessary for late/early access and contingency delays.

A concept of a facility provided at the launch site with a rental fee to the user allows flexibility because of the nearness to the launch site. It also eliminates the potential that a commercial facility may simply not continue to exist for the operational lifetime of Space Station. It eliminates any contract or legal obligations NASA may face in stating that the user must find a facility off-site, i.e., if there were potentially multiple contenders to offer services. It would allow easier configuration for a dedicated user i.e., the BDCF or animal handling. It also maintains NASA requirements, i.e., American Association for Laboratory Animal Certification (AALAC) under government control and surveillance. For the animal handling capabilities, this is feasible; such facilities do exist and support SL activities.

A concept of providing a trailer lot with power hook-ups to the user at the launch site was reviewed. This is viable for short term proprietary activities. It would not be viable for rack integration, BDCF activities, or animal maintenance. Facility support is dependent on application requirements.

2.3 OTHER OPTIONS

2.3.1 Summary of Options Considered

The Space Station Operations Task Force Ground Operations Panel (Pre/Post-Flight Subpanel) developed and evaluated options for the Space Station operational phase. NSTS involvement included organizational interfaces and management methods of and between users, Space Station, and NSTS. Three options were developed and evaluated. Payload analytical operations and documentation requirements were reviewed for who performs, controls, and develops (four options). Physical integration included location of and who accomplishes performance of rack hardware/software performed (two options); location of and level of verification testing (four options); location and performance of deintegration (four options); flight hardware i.e., logistics module, racks, and pallet, recertification (three options); delivery and distribution of post-flight early removal items (three options); provisions for late access/early removal (supportability) (three options); analyses and integration (two options); and how and where user support facilities are provided (three options).

Major consideration was given to buildup of racks containing experiments, supplies, and operating system units that are to be placed inside the pressurized areas. Most of the references are to these racks. Strong consideration was also given to the pre and post-flight operations for experiments and operating systems that are attached externally on the nonpressurized areas of Space Station. The pre and post-flight operations for these external attached items are the same as for the racks. The pre/post flight operations for Space Station Platforms will be essentially the same as for other Space Station payloads, except that the GSFC has been delegated by the Space Station Program the responsibility for the integration and verification activities for these platforms. The ground operations associated with Space Station platforms are discussed in more detail in Appendix D.

NSTS involvement including organizational interfaces and management methods of and between users, Space Station, and NSTS options were developed and evaluated.

> Option 1 Current Spacelab Model - A Payload Integration Organization (PIO) manages interfaces to Space Station and NSTS users. The Space Station system organization accesses and insures or "buys off" on Space Station interface compatibility and safety. STS works the NSTS side interface, accepts inputs from Space Station on Space

Station interface and safety and from PIO on payloads. NSTS current PIP Annex documents are used to document system where applicable.

<u>Option 2</u> The STS and Space Station Management Teams and functions are combined and merged into one group. This group manages and controls all aspects of both Space Station and NSTS requirements, verification, documentation, etc. The combined group interfaces directly with user to obtain requirements, work the incompatibilities, problems, documentation, etc.

<u>Option 3</u> This modified model utilizes central Space Station (PIO) teams to interface with and provide inputs to NSTS and user. The NSTS uses presently defined PIP Annexes to document and control operations.

<u>Payload analyses</u> covering all aspects of flight and integration are performed as part of analytical activities. User interface analyses are performed on (a) payload relation to NSTS, (b) payload relation to logistic module, and (c) payload relation to Space Station.

<u>Option 1</u> User autonomy wherein the user reviews all requirements for interfacing and provides analysis results to Space Station organizations.

<u>Option 2</u> A user representative (a science and technology organization) inputs and coordinates interface aspects with the Space Station management organization. The user works with the Science and Technology Center on interfaces to Space Station and STS.

<u>Option 3</u> The user works with and through a defined Space Station element organization as a payload integration organization which interfaces to Space Station management.

<u>Option 4</u> User provides analysis to a payload integration organization or Science and Technology Center which inputs to a PIO.

Supporting <u>documentation system for analyses</u> includes experiment requirement documents, Program Implementation Plan (Annexes), Safety documents, ground integration requirements documents, Interface Control Documents, and verification documents.

System options for developing, controlling, using documents are as follows:

Option 1 The NSTS PIP Annex would be used for both Space Station and NSTS documentation.

Option 2 The NSTS continues to use PIP Annex system for NSTS only. Space Station uses a separate documentation system compatible with NSTS requirements which only requires single input to Space Station from user.

Option 3 NSTS documentation system is modified to meet Space Station requirements and combined with Space Station documentation.

Option 4 Guidelines are defined and provided to users who prepare the interface documents.

Physical integration including hardware buildup locations, logistics elements buildup, methods of performing verification testing in reference to hardware to be used, deintegration location and flow of hardware, recertification of flown hardware, distribution and shipment of early removal items, supportability to late access/early removal, and user support facilities options were developed.

Payload (attached or rack mounted) hardware/software integration/deintegration options follow:

Option 1 The Space Station support elements would be held at KSC. Hardware to be integrated into the racks would be shipped to KSC. KSC with user support would install user hardware.

Option 2 Science and Technology Centers who develop and verify experiments would build up complete experiment element complements for delivery to the carrier site where elements are to be installed. The S&T Center tests elements against interface simulator.

Option 3 Commercial facility and/or Science and Technology Center, and Space Station element processing site buildup

Space Station support elements. Final integrated element to Space Station interface checkout is accomplished at Work Package (WP) site.

Option 4 Commercial facility and/or Science and Technology Center, and Space Station element processing site buildup Space Station support elements. Final integrated element to Space Station interface checkout is accomplished at launch site.

Location for logistics module buildup included options to:

Option 1 Perform logistics module preparations off site and deliver it to the launch site. Only late stowage would be installed at launch site.

Option 2 Preparation of logistics module for flight is performed at launch site.

Verification location and level of testing options considered are as follows:

Option 1 The hardware being integrated is tested on ground in a "full-up" mode with high fidelity simulators used to simulate the Space Station system.

Option 2 Testing is accomplished at rack or attached payload level on the ground with minimum interface simulators. Complete system tests are only performed on orbit after mating with Space Station elements.

Option 3 All interface and system testing is performed while the hardware is on orbit with no rack or integrated ground testing.

Option 4 The data system and software testing is accomplished on ground using the Data Management System (DMS) on orbit system through up links and down links. Physical interfaces are verified with ground master gauge.

Flight hardware recertification is the process by which acceptability for next use is certified. Three options for hardware recertification were considered with sustaining engineering to have responsibility for management and control of requirements under all options. The three options assessed are as follows:

<u>Option 1</u> Launch center recertifies all program provided flight hardware.

<u>Option 2</u> A commercial integrator recertifies all program provided flight hardware.

<u>Option 3</u> Integrator (ie. S&T Center, International Partner, etc.) recertifies all program provided flight hardware just prior to installing experiment hardware.

<u>Post-flight distribution</u> of early removal items includes removal, packing and shipping, and turnover to the users of items which are time critical.

Three options involving shipping and turnover performance were developed and are as follows:

<u>Option 1</u> Space Station delivers all early removal items such as films, biologicals, experiment products, etc. to logistics at the landing site. Logistics performs shipping and transfer to user operations.

<u>Option 2</u> Space Station delivers early removal items to customer at the landing site. User handles all shipping associated activities after items are directly delivered to him.

<u>Option 3</u> Space Station delivers those items to logistics which ships for the users to designated location and/or users pickup and ship items which they identify must be handled by the user at the landing site.

Providing of capability enabling or <u>supporting late access/early removal</u> options are as follows:

<u>Option 1</u> Program makes no provisions for late access or early removal.

<u>Option 2</u> Provide access to the logistics module through a design change, including addition of ECLSS.

Option 3 Program provides special payload bay carriers to accommodate late access and early removal requirements.

User support facilities provisions within launch area including on site and off site considerations were evaluated. Options selected for detailed assessment are as follows:

Option 1 The user would contract with an off launch site facility for support to process his payload. The contractor providing the off launch site facility delivers payload to launch site (pre mission) and removes payload from deintegration location (post mission).

Option 2 Launch site provides user a facility where he can perform pre and post mission processing. Charges to user for support and the schedule for facility support period would be negotiated with launch center.

Option 3 Launch center areas where user can park and operate his payload support vehicle such as trailer or van are provided by NASA.

2.3.2 Details of Options Considered

NATIONAL SPACE TRANSPORTATION SYSTEM (NSTS) INVOLVEMENT

Concepts for Space Station involvement with the NSTS are focussed on how the relative roles, missions, and organizational interface are partitioned and what lines of communications are established between the involved elements of Space Station, users of Space Station, and NSTS. The three basic models considered are identified as (1) current Spacelab/NSTS model, (2) a combined Space Station and NSTS and, (3) modified approach. A third organizational element on the NASA side of the user interface is the Payload Integration Organization (PIO). The models treat variations on the relationships among these elements.

Option 1. Current Spacelab/NSTS Model - Even though the Spacelab Program is considered an integral part of the NSTS, there is a separate, identifiable organization of the Spacelab Program and also a separate identifiable organization that performs the function of a PIO. The PIO function is to provide all the necessary contact with users in identifying requirements for Spacelab and NSTS and then arranging and integrating the necessary ground and flight accommodations for the mission. A significant feature in this model is that the PIO interfaces directly with both Spacelab and NSTS for accommodations planning, and additionally, Spacelab would also coordinate select activities with the NSTS. This approach could also be applied to the Space Station/NSTS Programs, the key feature being a separate PIO function able to interface independently with either Space Station or NSTS.

Analysis - The feasibility of this option has been established by the current MSFC Spacelab Payload Program since this is the approach utilized and it works. The flexibility of this option in response to changes is good since there is a single point contact to users and to the NSTS for working changes and the PIO is the focal point for performance of all integration activities. The user friendliness of this option was rated rather poorly by some members who had experiences in the early Spacelab missions. However, the PIO provides a single interface for users and performs all functions for the user in relation to the NSTS thus letting the user stay out of that loop.

The effectiveness of the option was rated overall as average. The major detractors being the number of organizations involved with the attendant complexity in management interfaces. There is also potential for duplication of functions between the PIO and Space Station organizations. Costs were judged to be probably highest for this option.

Overall this option was rated last by the Subpanel. This rating was based primarily on the perceived lack of user friendliness and the complexity of the management structure with potential for high costs.

Option 2. Combined Space Station and NSTS Model - The combined Space Station and NSTS model would appear to the user to be a single organization providing all the necessary services for Space Station missions. The Space Station/NSTS points of contact to the user would provide all needed information, collect all known user requirements, perform required Space Station and NSTS analytical integration, and commit for the Space Station/NSTS organization all agreed accommodations. Additionally, the single organization would perform all necessary certifications for both Space Station and NSTS flight worthiness.

Analysis - The feasibility of this option was rated very low. Combining the Space Station into the NSTS at the IOC time frame did not appear to be practical or feasible due to fact that with two large programs of their magnitude that their combination could not be worked out. Such a large organization was not felt to be user friendly due both to its size and potential preoccupation with performing their prime functions.

The effectiveness was rated as good to excellent. This judgement was based primarily on the combining of the organizations, less management structure, reduced changes for duplication of efforts compared to separate organizations, and the hoped for reduced costs by going to a single organization. In terms of management efficiency and safety it was judged superior due to having a single interface and consolidation of all related activities under a single management.

The option was rated second by the Subpanel. The major strong points were the single organization, reduced chances for redundancy of efforts, and lower costs. The major weaknesses are the lack of flexibility, feasibility and the feeling that such an organization would not be very user friendly.

Option 3. Modified Model - The modified model would provide a separation between the Space Station and NSTS Programs, but the PIO function would be an integral part of the Space Station organization. The PIO would perform for the Space Station Program all the planning and implementation of a Space Station incremental mission. In this model, as in Option 1,the PIO would serve as the user point of contact. The PIO function would interface to the NSTS for defining requirements and arranging user accommodations. A single line of communication between the Space Station and NSTS is provided to carry all necessary communications for either Space Station unique functions or Space Station users's functions.

Analysis - This option was considered very feasible and desirable. Its flexibility in responding to changes will be good since there is a single organization working and focusing all changes. The PIO would again be the single interface to the user and the single interface into the NSTS, thus hopefully, achieving user friendliness. As in Option 1 the PIO would perform all integrated analytical integration functions for users and NSTS.

The overall effectiveness of this option was rated superior for it consolidates under a single management all of the activities associated with implementing a Space Station mission. This attribute will result in reduced management interfaces, reduced probability of redundant efforts, increased management efficiency, and reduced overall costs. Safety should be enhanced since all activities are focused in a single entity.

This option was rated best by the Subpanel. Prime reasons were the single Space Station organization to carry out all mission function, single point interface to both the users and the NSTS and great potential for reducing cost compared to the other options. The only significant distraction is, as compared to Option 2, a separate organization is required for operation of the NSTS. However, we really feel this separation is required and realistic.

Conclusions and Recommendations

The recommended option for the NSTS involvement is Option 3, the Modified Model, in which the PIO is integrated into the Space Station Program. This means the Space Station Program would have one organizational element, i.e., PIO, performing and accountable for Space Station incremental missions. The NSTS would remain as it is presently structured and only perform for Space Station missions the functions it now performs for all NSTS flights.

The prime rationale for this recommendation is the consolidation into a single organizational element with in the Space Station Program for all Space Station activities and responsibility for Space Station mission. As noted under analysis of Option 3 this should result in increased management effectiveness and reduced cost. At the same time this approach provides clear and straightforward interfaces for the users and the NSTS, allowing clear definition of roles and responsibilities in relation to these elements. With all factors considered this option came out the overwhelming choice of the Subpanel.

The Modified Model was rated best in the Subpanel assessment. The other two models were about equal in their lower rating. The significant detractors of Option 1, Spacelab/NSTS Model, were less user friendly and higher costs for the user. The multiple organizational interfaces for the PIO function was viewed as adding complexity, effort, risk of error, and increased costs. The detractors in Option 2, combined Space Station and NSTS, related to feasibility and transition into mature operations. The feasibility of merging two large programs, each with significant but diverse objectives, was viewed as being convenient for the user, but somewhat difficult to achieve.

Accountability of actions and costs in the "conglomerate" approach was a concern as well as concern for a stifling of advocacy for resources if Space Station and NSTS, with their diverse objectives, were joined as one Program.

The modified model was favorably rated by the Subpanel due to the clear separation of Space Station and NSTS organizations and the minimum number of organizational interfaces involved. The user has the advantage of working with an identifiable PIO function within the Space Station organization and there is a single line of dialog between the Space Station and NSTS organization. Transition into the mature operations phase is expected to be easy due to Phase C/D implementations. Accountability for actions taken and costs incurred will be clear.

PAYLOAD ANALYSIS

User Interfaces Analyses - A significant area that the Subpanel thought needed a detailed review and analyses was one dealing with the organizational structure and thus, the users interface for accomplishing the payload integration analyses functions. The functions addressed in relation to the user in the activities required for payload integration are those such as defining the user's requirements, establishing of his hardware interfaces to the Space Station, performing of the interface compatibility and safety analysis of his hardware to the Space Station, to the Space Station launch carrier; i.e., logistics module or some other carrier, and with the NSTS. The accomplishment of this analytical integration function requires, initially, the inputs from the user of his requirements, followed by review and concurrence by him of the resources he has been allocated and finally support to and participation in the required Space Station payload safety and verification program. Thus, the user will have a long term and potentially extensive interaction with whoever performs the integrated analytical integration function.

The scope of the payload integration analyses process that the Subpanel addressed did not include the selection and manifesting of the users. The process considered begins subsequent to the selection and manifesting of a user to a Space Station mission segment and the supporting NSTS flight and carries through to the return of his products and/or hardware from orbit. The period of the user's involvement in most cases will be of a multi-year's time span. The degree of the user's involvement will be a function of his payloads operational and functional interfaces to the Space Station, the NSTS payload carrier, and to the NSTS launch vehicle. For the simple, highly autonomous payload with few or very benign interfaces, the process will mainly be concerned with the safety aspects of the hardware. However, for the complex, highly Space Station interactive payloads, the process will be very detailed and demand a high involvement by the user. The system set up for accomplishing the payload analyses process must recognize this and be flexible enough to respond appropriately, only demanding from and involving the users to the minimal extent practical.

The Subpanel assessed and evaluated four options, which were felt to cover the spectrum of how one could set up and interface the users in the payload analyses process. Obviously, there are a number of variations on any of these options that could and should be considered in the final implementation; however, we limited our assessment to these prime four as we believe they identify and evaluate the critical factors concerning the user's interfaces to the payload analyses process.

Option 1. User Autonomy - This option, in a very high level diagrammatic form, is shown in Figure 2-7. In this option, the user would be provided the detailed set of requirements that he must comply with to participate with and fly on the Space Station and the NSTS. The user would then perform all the analyses, test, and provide documentation to prove and certify to both the Space Station and NSTS organizations that he is safe and interface compatible with the two systems. In this option, the Space Station and NSTS organizations would each perform their integrated payload analyses functions. This option provides the user the highest degree of autonomy to perform his job with the minimum amount of interaction with the Space Station and NSTS and to provide them a finished product.

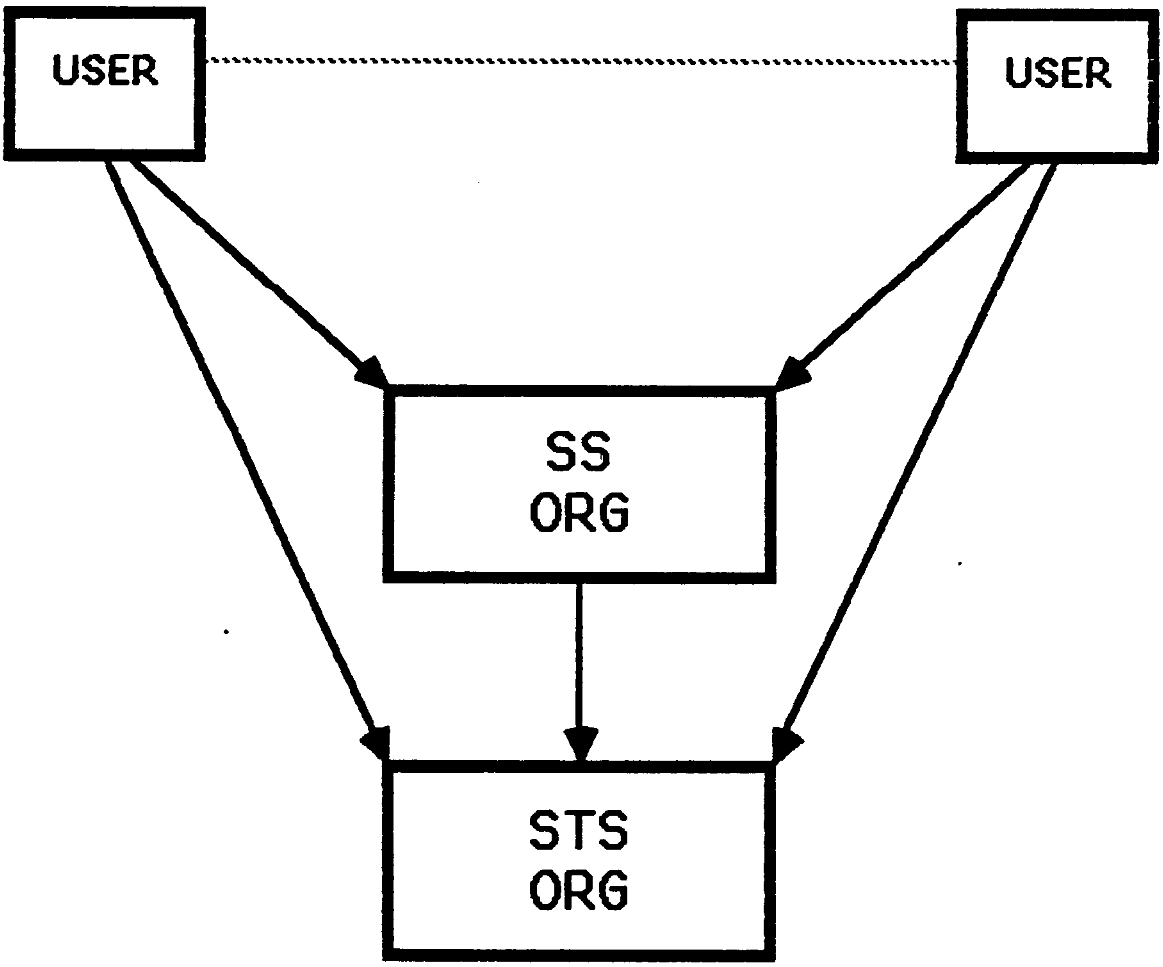


FIGURE 2-7 USER AUTONOMY

Analysis - This option was judged to present a relatively advanced concept from the way we have been doing business. The feasibility of this option was not considered very high due to fact that many of the users will not have the capability to perform the total analysis job. The option, though, does offer maximum flexibility for the user to get the job done in the most efficient manner, however, it limits the amount of flexibility of the Space Station organization as it must depend on users for all analyses. It was considered that from a user standpoint this would probably be thought the most "user friendly", however, it should be pointed out that once a user truly understands what is required he might very likely change his mind about its friendliness. In addition, the user would have to interface with two structured organizations that in general are most concerned with getting their prime job of running a Space Station and launching space vehicles accomplished.

In terms of effectiveness this option was not considered very favorably. The transition to it since it is such a major change would be very difficult. It would require each user to have or to "buy" the skills and tools to perform the job. This would increase cost and create a potential management problem for the user. Probably, a number of iterations would be required of the data and the analyses between the user and the Space Station and STS before an acceptable product was obtained, all increasing cost and jeopardizing performance and safety.

This option was rated last by the panel. The major point against it is that with the diverse number of users that the Space Station will encounter, the skills and capability that the users will possess will vary so much that it would not be practical to expect them to be able to perform all the analysis functions and for each to obtain the capability would be a major duplication of efforts with associated high cost and management inefficiencies.

Option 2. User Representative I - The simple diagram of this option is shown in Figure 2-8. As noted, the prime difference in this option is the addition of the Science and Technology (S&T) Center. In this case the user would interface with the appropriate S&T Center. The S&T would support and assist the user in performing and documenting the required analyses and test activities, represent the user to the Space Station and STS at major reviews; i.e. safety, flight readiness, etc., and perform the integrated payload analyses in their discipline area. The Space Station and STS organizations would still need to perform the total integrated payload analysis for their respective systems. For users not represented by a particular S&T Center, they would interface directly with the Space Station and STS organization as in Option 1.

Analysis - This option was definitely judged to be feasible, although we could not ascertain how many S&T Centers may come into being in the future. S&T Centers would provide good flexibility in responding to changes from a scientific viewpoint and would provide a very friendly and compatible interface to the users, since they all work in the same basic science or technology discipline. For the Space Station and NSTS organizations there would be fewer organizations interfacing with them than in the previous option, thus allowing them to assess and respond more rapidly to resources or mission changes.

The overall effectiveness of this option was rated average. The strengths lay in the management organization in relation to the users, the knowledge base between the two and being able to focus this into the analyses, and work relationships and

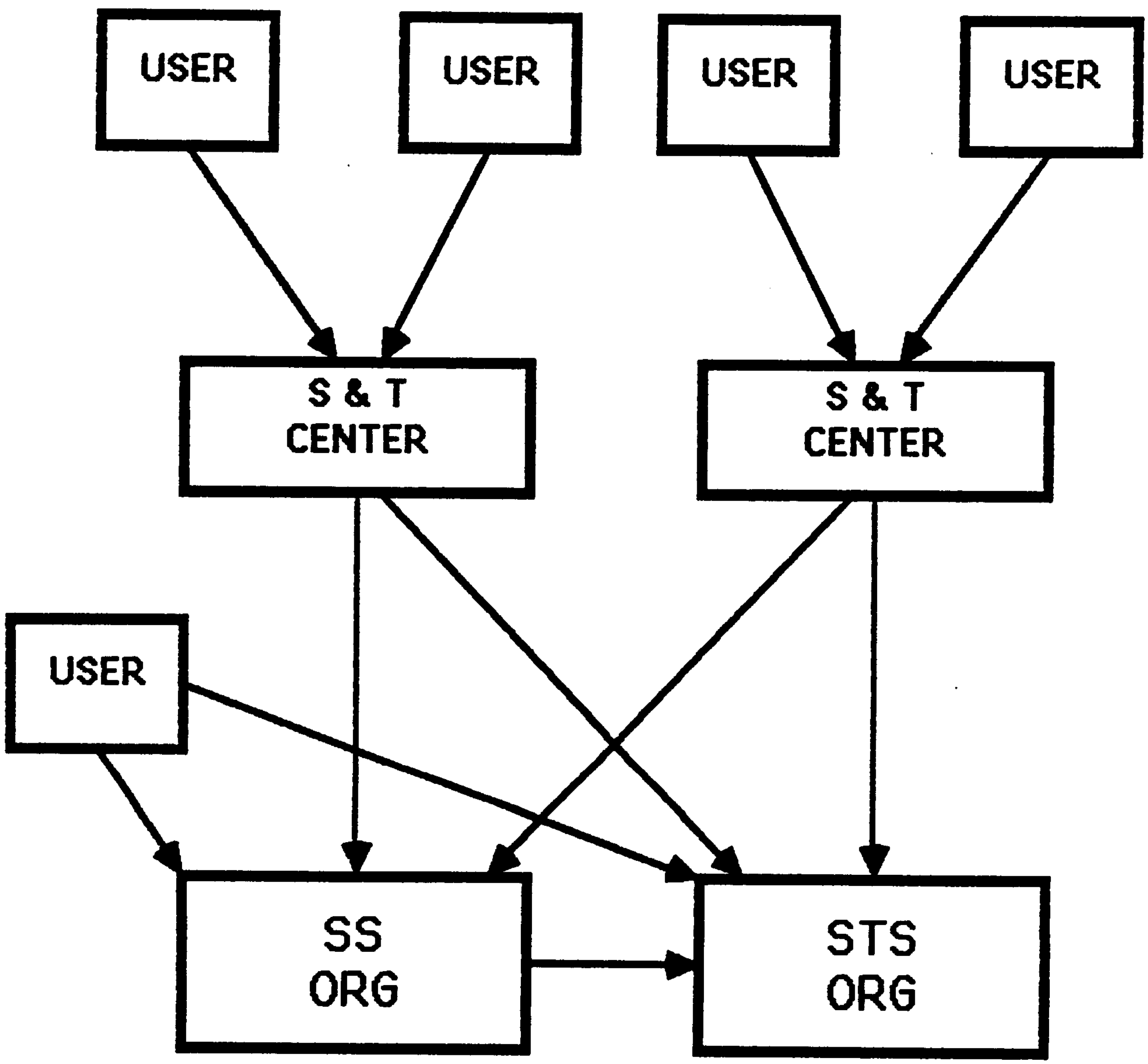


FIGURE 2-8 USER REPRESENTATIVE I
(S&T CENTER)

interactions with the Space Station and NSTS organizations. Duplication of the skills and tools required to perform the payload analyses activities by a number of organizations and the interfacing of these various S&T Centers to the Space Station and NSTS would not be the most cost effective or obtain optimum performance.

This option rated third in our rankings, based primarily on the duplication of analytical resources and number of interfaces to Space Station and NSTS. It was also questioned if all of the proposed S&T Centers would possess the capabilities for performing the analytical job. The major strength of this option is in its interface and relationship to the users from the science and technical discipline aspects.

Option 3. User Representative II - The Option 3 top level diagram is shown in Figure 2-9. In this option a Payload Integration Organization (PIO) is introduced. All users would interface to the PIO. The PIO would perform functions for the users and the program such as: define and help users in performing and documenting their analyses and verification activities; represent and respond for the users to the Space Station and NSTS organizations; perform the total integrated analyses and verification activities for the mission and support the on-orbit mission activities as required. The users in this option would have a single interface to work with that would represent them to the Space Station and NSTS organizations. This option is basically the same as the Mission Manager concept utilized by the MSFC Spacelab Payloads.

Analysis - This option essentially represents the current functioning of the MSFC Spacelab Payloads Program. Thus, it is definitely feasible and well understood as to what it takes to

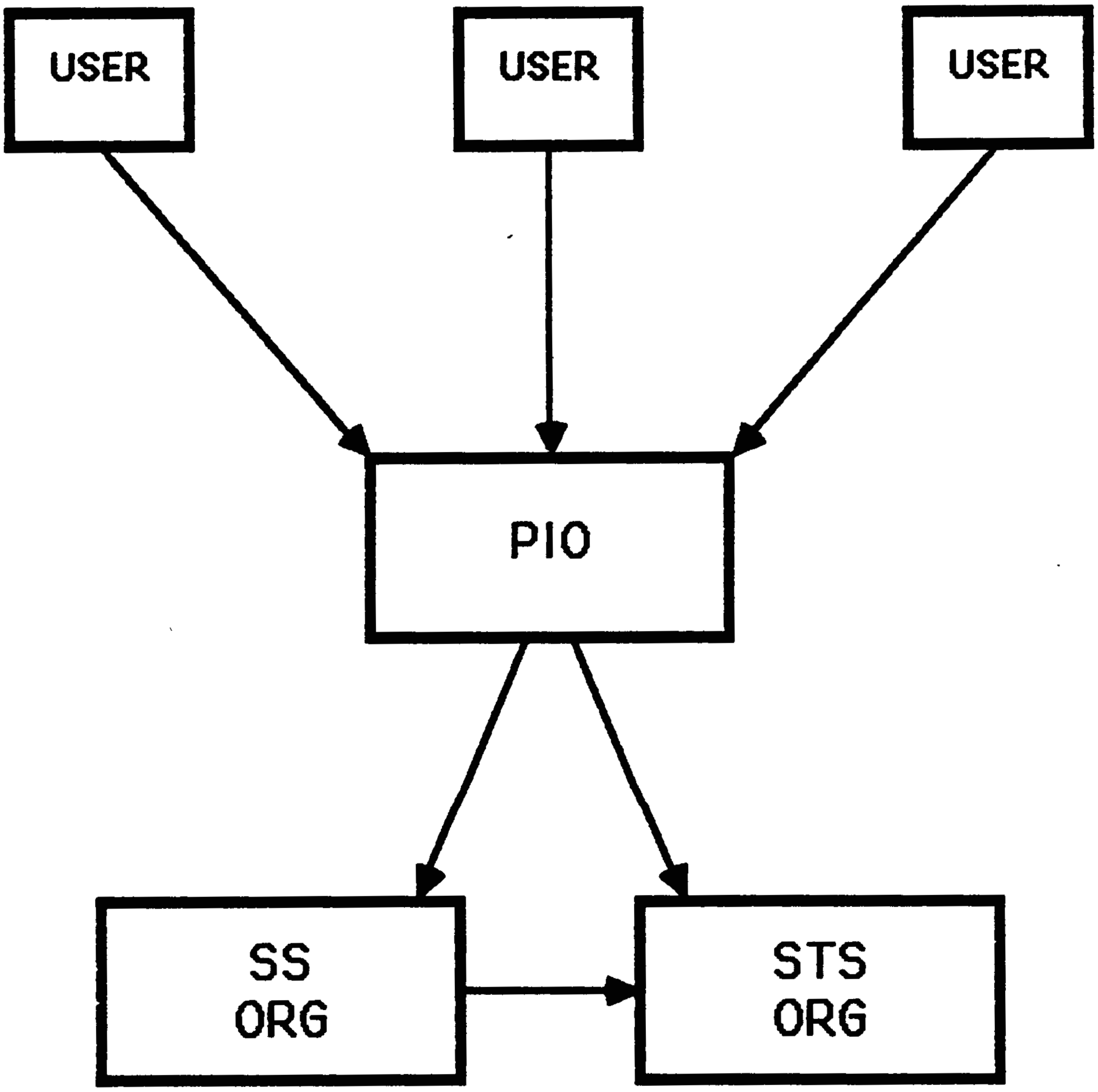


FIGURE 2-9 USER REPRESENTATIVE II
(PIO INTERFACE)

make it work. The flexibility of this option in responding to program changes and changes of payload and or resources is very good since there is a focused effort in assessments, all concentrated by a single organization. In the matter of user friendliness, this option was rated good. The user would only have to interface with one point of contact for all his needs and the PIO would work very closely and perform some of the analyses the user would normally be expected to perform.

For overall effectiveness this option was rated the best. It focuses all of the skills and analytical tools into a single organization that performs these functions repetitively, thus deriving increased efficiency. The single interface to the Space Station and NSTS allows for efficient and clear understanding of requirements and their implementation. The management structures are reduced and costs for the users, Space Station, and NSTS should be minimized.

This option was rated highest by the panel. The major strengths were the consolidation of all the required skills and tools in a single organization and the establishment of single interfaces with the Space Station and NSTS. The basic weakness is the user interface area, in that the PIO will not understand or be as attuned to the desires and needs of the user as would the S&T organization.

<u>Option 4. Combination</u> - This option is shown in a diagram form in Figure 2-10. This option is a variation on the previous options and takes the two main features of Options 2 and 3 and combines them. In this option both the S&T centers and the PIO are incorporated. The roles of each of these organizations would be basically as described under the appropriate option previously. The major difference would be that the S&T

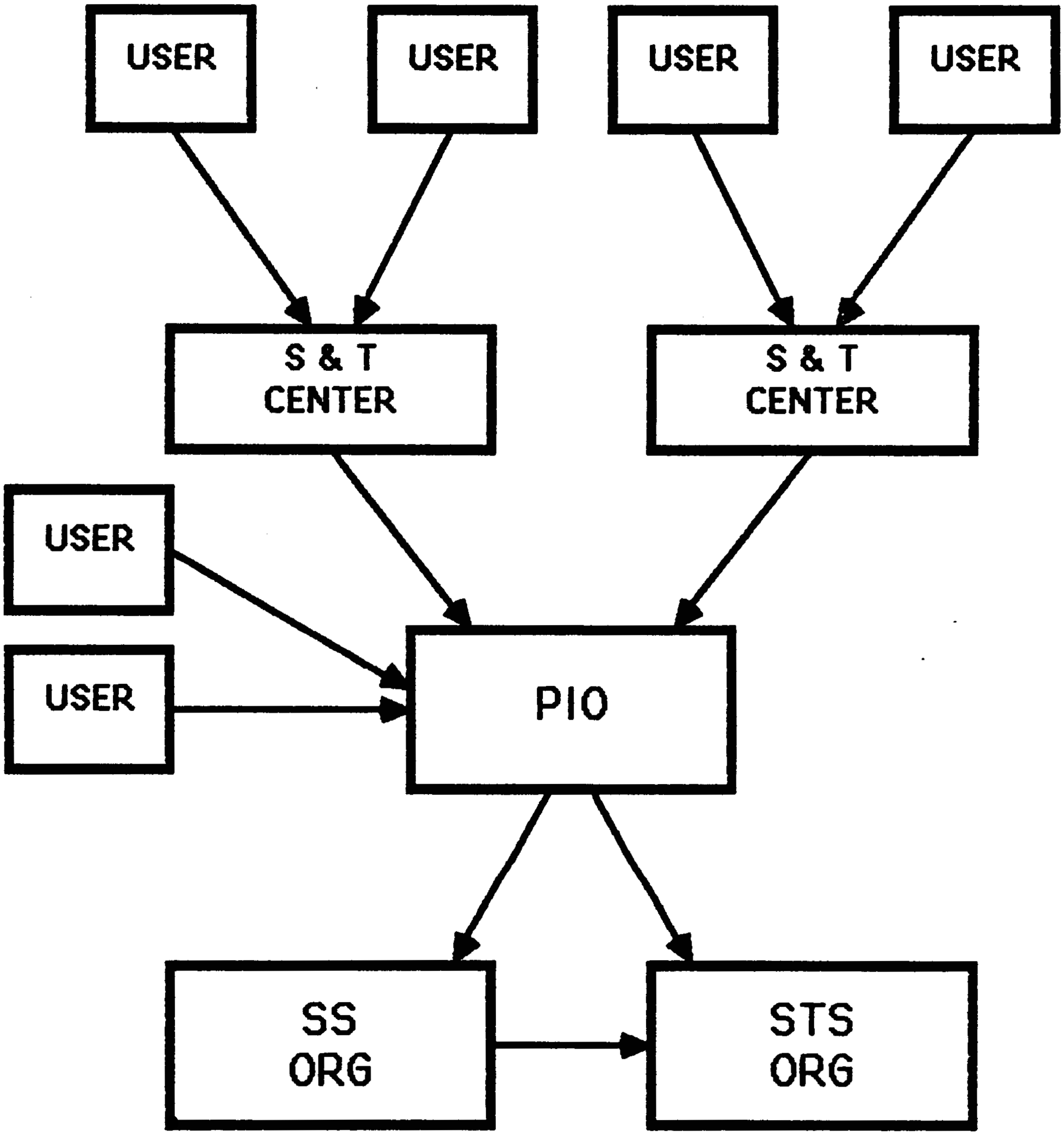


FIGURE 2-10 COMBINATION
(S&T AND PIO)

organization would only interface to the PIO and would do only a limited integrated payload function. It's prime function would be to support and act as a surrogate for its class of discipline users. The PIO functions would be essentially as defined in Option 3 except it would, where appropriate, work with and through the S&T Centers for those users. Again users not represented by an S&T Center would work directly with the PIO.

Analysis - The combination evaluated for this option was one of taking the S&T Centers of Option 2 and having them provide an interface function in Option 3. In particular areas, primarily Life Sciences, the Spacelab Payloads are integrated in this manner. This option incorporates the best features of the two options and molds them into a single strong one. The primary user friendly feature and strong scientific, technical interaction of the S&T organization is retained while the consolidated, dedicated PIO with its unique skills and tools is maintained. The negatives to this are the increase in the overall number of interfaces and participating organizations with their attendant increase in cost.

This option was picked second in our evaluations. The strong points is the utilization of two organizations with their own dedicated, special expertise doing what they can do best. The negative is, in the overall total program sense, the increase in cost due to the two organizations.

Conclusion and Recommendations

From our numerical grading system Options 3 was rated highest. However, during our discussions we came to the conclusion that the preferred, and thus our recommended option, would be Option 4. This recommendation is based on the facts as presented previously. Namely, that the utilization of the S&T Centers performing a major interface and support service for the users to the PIO which would perform the integrated payload analysis activities and provide the interface and required support to the Space Station and NSTS. This structure would provide the most user friendly environment and would be the best from an overall management viewpoint. Each participant would have well defined responsibilities and clear and simple interfaces. Assuming, as seems to be the case, that the science and technical disciplines are moving toward establishment of S&T Centers, as the Life Sciences have already done, then these S&T Centers would not be an added cost factor but could perform a very cost effective interfacing function in the Space Station era. The optimum utilization of the S&T Centers in combination with the PIO is the recommended approach for accomplishing the payload analysis function and thus providing the interface during its performance.

SUPPORTING DOCUMENTATION FOR ANALYSIS - An important and necessary aspect of the payload integration process for the Space Station Program will be the documentation required to support the analytical, integration and verification efforts. Previous experience with such documentation systems was for payloads to be flown on the NSTS, on Spacelab, and payloads launched by ELV's. The main objective of any document system selected for the Space Station Program would be to provide the proper information for payload interfaces with the STS and Space Station and to identify safety issues for both Space Station and STS operations. The selected system should provide traceability of payload processing operations and should aid in anomaly resolution. The document system would not concern itself with payload operations other than interface compatibility and safety implications for the NSTS and Space Station. In considering various options for documentation systems it was assumed that there will be a single authority source for all safety policies and procedures.

The options evaluated are as follows:

1. Use existing NSTS PIP System and annexes for both NSTS and Space Station documentation.

2. Use separate documents for NSTS and Space Station

    a. NSTS would use existing system

    b. Space Station would use separate but comparable system

3. Use a modified NSTS document system combined with Space Station documentation.

4. Use documentation prepared by users against guidelines provided by the Space Station program.

In addition, two modes of processing and distributing the documents were reviewed. These were a paper document system, and an electronic data file document system.

A major concern for the selected option is that it allows for a single NASA interface for all users and that the documentation be as simple and concise as possible. The documents should be tailored to the class of users (type, size, discipline) and be formatted to minimize redundancy.

Option 1. Use Existing NSTS PIP System and Annexes for both NSTS and Space Station Documentation - Use Existing NSTS PIP System and This option consists of using the NSTS Payload Integration Plan (PIP) and Annex format as it exists and folding in the requirements for Space Station program interfaces and safety into the appropriate PIP sections or annexes. The NSTS PIP defines the basic and optional services required by the payload for NSTS flight hardware, ground integration facilities, and flight payload operations control center and its interfaces with the mission control center. The PIP describes the launch parameters for the shuttle. Thus the PIP is a document system which delineates the analytical and physical integration, technical activities, interfaces, and schedules for payloads which are to be integrated, launched and deployed/operated on the NSTS. The PIP annexes are the source of detailed technical data supporting the payload integration process in the areas of payload data, thermal and structural loads and models, flight planning, flight operations support, training and launch site support planning.

The objective of this option would be to use this NSTS PIP format to incorporate the interface and safety requirements of payloads that are to be integrated into the Space Station. The data required to support payload integration to the logistics carrier, the core station (lab modules) and station interface adapter on the Space Station truss would be formatted to fit into the PIP annexes as they are now structured. Thus there would be a blend of information for the logistics carrier and payload interfaces with the NSTS system and the Space Station systems.

<u>Analysis</u> - From a feasibility standpoint this option would be difficult to achieve, even though NSTS is an existing system and users are familiar with the system. It is felt that the NSTS document system would be difficult to modify and to integrate the Space Station requirements into that format. The Space Station program will require information that is substantially different from NSTS integration information. An example is verification data requirements. A major expansion of the PIP and annexes would be needed to include the scope of the Space Station Program safety and interface requirements.

When considering user friendliness, Option 1, having one document system (versus multiple documents) would keep user interfaces to a minimum. However, based on past experience with the NSTS system, there are concerns with the friendliness of this system. The first time STS user has had difficulty in following the document format and requirements. Users have expressed dislike for the system, but have admitted that the system works. There have been problems between the requirements for the PIP and annexes as viewed by Johnson Space Center and the ground operations documents that are required by Kennedy Space Center for processing payloads. These problems result in redundancy and confusion about ground processing requirements.

In the area of management effectiveness, while a single NSTS type document system would allow for adequate management controls to be applied, there would be difficulty in assuring clearly defined responsibilities. Change control for the NSTS and Space Station systems would require clear definition to assure that proper controls are applied to NSTS and Space Station separately.

The NSTS document system as it now exists is a relatively high cost system to maintain. Modifying this system to incorporate the Space Station Program requirements would be a costly process.

<u>Option 2. Use Separate Documents for NSTS and Space Station</u> - This option would utilize the existing NSTS PIP and annex system to document the integration of the Space Station logistics carriers and payloads (those that do not utilize the logistics carrier for transport to the station) to the NSTS. It is expected that the interfaces between the Space Station logistics

carrier/payloads and NSTS System will be kept to a minimum, thus allowing the documentation to be simplified.

A separate document system would be developed to cover payload interfaces and safety consideration with Space Station systems. Precedent for such an approach can be found in the Spacelab Program. This program created mission requirement for payloads document which established the integration and safety data required for payload's interfacing with the Spacelab. The proposed documentation system for the Space Station Program could be tailored to the various classes of payloads and would cover the interfaces with Space Station System such as the DMS, power, thermal, structure, and ELCSS. In addition, verification, training, safety compliance, payload requirements, mass properties, data flow, flight definition, and payload operations would be documented.

With this two document system the user would provide information to the Space Station organization responsible for the Space Station documents and this organization would then develop the integration data needed for the NSTS PIP document system.

Analysis - The use of separate documents has precedence in the Spacelab Program. The MSFC has created a document system for users that fly on the Spacelab. The NSTS PIP and Annexes are also used to document the integration of the Spacelab into the NSTS as a payload. Thus it is very feasible that a two document approach could be achieved for the Space Station Program.

There are some concerns with the friendliness of a two document system to the user. These concerns center around the need to maintain a single source/point of contact for the users. With a two document system there is a chance for redundancy in requirements and additional interfaces. However, it is possible to tailor the Space Station document to the various class of users and assure that the Space Station document would be the single point of contact for the users. The Space Station program would then work the interfaces required with the NSTS PIP and annexes.

Effective management would be achieved even though there would be two organizations involved in document preparation. Based on Spacelab experience, clear responsibilities and document scope could be established and management control over these areas could be put into effect.

The performance effectiveness of a two document system should be reasonably high due to the opportunity to streamline and tailor the documents to the Space Station Program needs. There is the potential in the Space Station document to break away from the constraints and framework exhibited by the NSTS PIP and be more innovative in formatting the Space Station document. There is concern however, that with a two document system that important data or requirements will be overlooked and not be covered in either document.

Initial consideration of the cost of a two document system would indicate potentially higher costs, however, with the opportunity to tailor the Space Station document (rather than force fit into the STS framework) the long-term costs should prove to be lower.

<u>Option 3. Use a Modified STS Document System Combined with Space Station Documentation</u> - Instead of using the NSTS PIP and annexes as they are now formatted this option would seek to modify the NSTS system to accommodate the requirements of the Space Station program and provide a singular approach to Space

Station/NSTS payload integration. The NSTS PIP would be modified to incorporate the basic and optional services required by the payload for Space Station systems and hardware, ground integration facilities and payload operations interfaces with the Space Station control centers. Included in the PIP would be Space Station flight core systems parameters. This combined document would delineate technical data supporting the payload integration process for the STS and Space Station in the areas of payload date, thermal and structural loads and models, flight operations planning and support, training and launch site support planning.

Analysis - This option is essentially a variation of option 1, which is an attempt to use the existing STS document system as is, with Space Station requirements folded into that document system framework. For this option the NSTS PIP and annex format would be modified to directly accommodate the requirements of the Space Station Program.

While such a combined document might provide the opportunity for effective management control, there may still be difficulty in establishing clear lines of responsibility between the NSTS and Space Station Programs. In fact, there is a strong opinion that the NSTS program requires a separate system, because NSTS will launch payloads other than the Space Station. A separate system may also be necessary because of the scope and complexity of both the STS and Space Station programs.

The attributes identified in a one document system (Option 1) are applicable to this option with the added possibility that the modification of the NSTS document system for Space Station requirements could incorporate improvements which would make the system more user friendly. However, these improvements would not be without impact, since the existing NSTS user community is familiar with the existing system. There would also be a cost impact to incorporate modification into the NSTS document system.

<u>Option 4. Use documentation prepared by users against guidelines provided by the Space Station Program</u> - In the previously discussed three options, the Space Station organization would prepare the documentation required for integration of payloads with the NSTS and Space Station systems with the user providing supporting information. This option would seek to establish a guideline format that would allow the user to prepare the necessary documents for payload integration. The necessary Space Station and STS background and guidance information would be documented to allow the user to independently prepare interface and safety data. The Space Station organization responsible for interfacing with the users would serve in a review capacity to assure compliance by the user with the Space Station Program guidelines. One approach to achieving this option is a "blank book" system which covers all potential areas of payload integration and processing documentation required. The user would fill in information, based on the results of analyses performed, in the appropriate sections of the book using the guidelines provided.

<u>Analysis</u> - At first look this option appears to very user friendly, since the user would deal with a standardized system which serves as a singular interface. However, it is likely that first time users will have difficulty interpreting the guidelines (difficult to make complex interfaces standardized). Misinterpretations would require users to redo their initial efforts and could result in a frustrating iterative process.

This option may prove to be difficult to effectively establish management control.

This option would be most costly to the user since he would be required to provide most of the document preparation. It would also be costly to the Space Station Program to maintain the guideline system and to interact with the user in iterative updates of the document inputs to achieve proper results.

There are concerns with achieving an acceptable performance level with a guideline system. Such concerns are: more potential for error in input; highly iterative process; and proper analysis reporting for safety items (users often are not as sensitive to safety issues as NASA).

Document Mode - The mode or media to be used in preparing, distributing or transferring the required Space Station documents was reviewed. Only two modes were considered: the existing paper system that is used on NSTS and Spacelab programs and the concept of a paperless document mode.

Analysis - Using a paper document system similar to NSTS result in an extensive array of documents due to the complexity and scope of the Space Station Program. Such a large system will be cumbersome to utilize efficiently. A paper system has proven to be flexible and able to adjust to program changes.

Electronic data base document systems are currently being established in the Space Station Program and should be used to the greatest extent practical. However, limitations of handling data bases need to be recognized. Such a system needs to be structured to impose safeguards of information transfer and to establish methods to simplify the management of complex data bases. Electronic data bases for documents should prove beneficial to cross-checking safety requirements.

Conclusions and Recommendations

The subjective evaluation of the options against the various criteria resulted in the following: Option 2 (separate Documents) was seen as the most feasible, flexible, and management effective option. All options rated about the same on cost effectiveness and safety. Proper documentation is a high, but necessary, cost burden and concerns were identified with safety reporting for Option 4, the "guideline" system. Option 4 received the highest rating for user friendliness, but with the caveat that it may prove to be a highly iterative process. Option 4 also achieved a high rating for ease of proprietary operations.

Based on the above consideration, Option 2, separate STS and Space Station document systems was seen to have the best attributes and achieved high ratings in the key areas of user friendliness, cost and management. The key features of Option 2 are: The use of the existing separate NSTS system which the Space Station Program could readily interface with; the opportunity to tailor the Space Station Program document to the various user classes; and the chance to be innovative in designing the format of the Space Station document system based on lessons learned from the STS and Spacelab programs. An approach to the Space Station Program document system is addressed in the paper "An Approach to Space Station Documentation" in Appendix D.

It is recommended that the use and development of electronic data bases for documents be expanded as practical during the development of the Space Station Program, thus reducing reliance on a paper document system.

PHYSICAL INTEGRATION/DEINTEGRATION

Payload and Logistics Module Buildup - Physical integration, in the context of user provided flight experiments/equipment for Space Station application, is defined as an early activity in overall experiment ground processing where the actual flight experiment hardware transitions from a "stand alone" support structure to a flight qualified support structure. This hardware combination will ultimately be functionally operated in the micro-gravity environment of Space Station.

Deintegration is the post flight removal of experiment hardware from the flight support element. The Space Station provided flight support element is configured as required for next flight experiment application. User's equipment is dispositioned by the user.

Options - The discussion of options considered by the Subpanel focus on the issue of physical integration occurring only at the launch site (Option 1: Centralized Physical Integration) vs. physical integration also occurring at other locations (Option 2: Decentralized Physical Integration). Centralized experiment integration would occur exclusively at the launch site and decentralized integration would occur at locations such as Science and Technology Centers or Commercial R&D Centers as well as at the launch site.

Two additional options were included to treat the special case for the location of experiment to Space Station final interface validation. These options are: Option 3 - Decentralized

Physical Integration with Final Interface Validation at Work Package Center, and Option 4 - Decentralized Physical Integration with Final Interface Validation at the launch site.

The Subpanel assessment objective was to identify an approach for Space Station that is low cost and gives high performance (utility) while being "friendly" to the user community. The "user-friendly" factors would include low user cost, fast and easy on and off of Station, and minimum travel away from user's home base. The intent is to structure Space Station facilities, equipments, and operations such that user's would have a wide envelope to operate within and still meet minimum Space Station requirements.

International Partner Planning - The Operations Task Force hosted the International Partners in a review of planning for the mature operations phase of Station. ESA and NASDA representatives both indicated plans for a decentralized approach to experiment physical integration. The significant aspects of their planning are: (1) distributed user facilities for physical integration and, (2) final experiment/support element to Space Station interface validation at the launch site in the event of shipping damage or other need for experiment interface verifications.

Assumptions - A baseline assumption is that the flight qualified support elements will be provided by the Space Station Program. Space Station provisions with these support elements will include at minimum the physical structure and mechanical attach points and may optionally include select devices and/or interfaces for services, such as, electrical power, avionics cooling, command and data, etc.

The physical integration into the flight support element occurs only after the experiment hardware or instrument package is mature in design and development. Activity in proximity of the flight support element shall not be harmful to engineering integrity or flight worthiness of Space Station provided components.

Following physical integration the essential subsequent steps to launch readiness are (1) experiment functional verification in the flight support element, (2) experiment to Space Station interface validation, (3) experiment prelaunch servicing, and (4) launch package integration. These sequential steps are illustrated in the flow chart of Figure 2-11.

PAYLOAD HARDWARE/SOFTWARE BUILDUP

Option 1. Centralized Physical Integration Site - This option focuses on a centralized capability located at the launch site for physical integration of payloads/experiments into Space Station user flight support elements, such as, module racks, attached payloads interface adapters, freeflyer carriers, and platforms. The concept is that followed during Spacelab. The Space Station Program would acquire the minimum necessary set of payload support elements in the baseline program for user accommodations. This basic set would be sized to satisfy the on-orbit complement as well as the minimum necessary set in the overall supply and return "pipeline" that accommodates support element integration through launch and subsequent return to operational inventory after landing. The quantity sizing of this operational flight inventory is based solely on total launch site integration with all flight element hardware retained at KSC. Instrument/experiment breadboarding and development at the development centers include physical integration

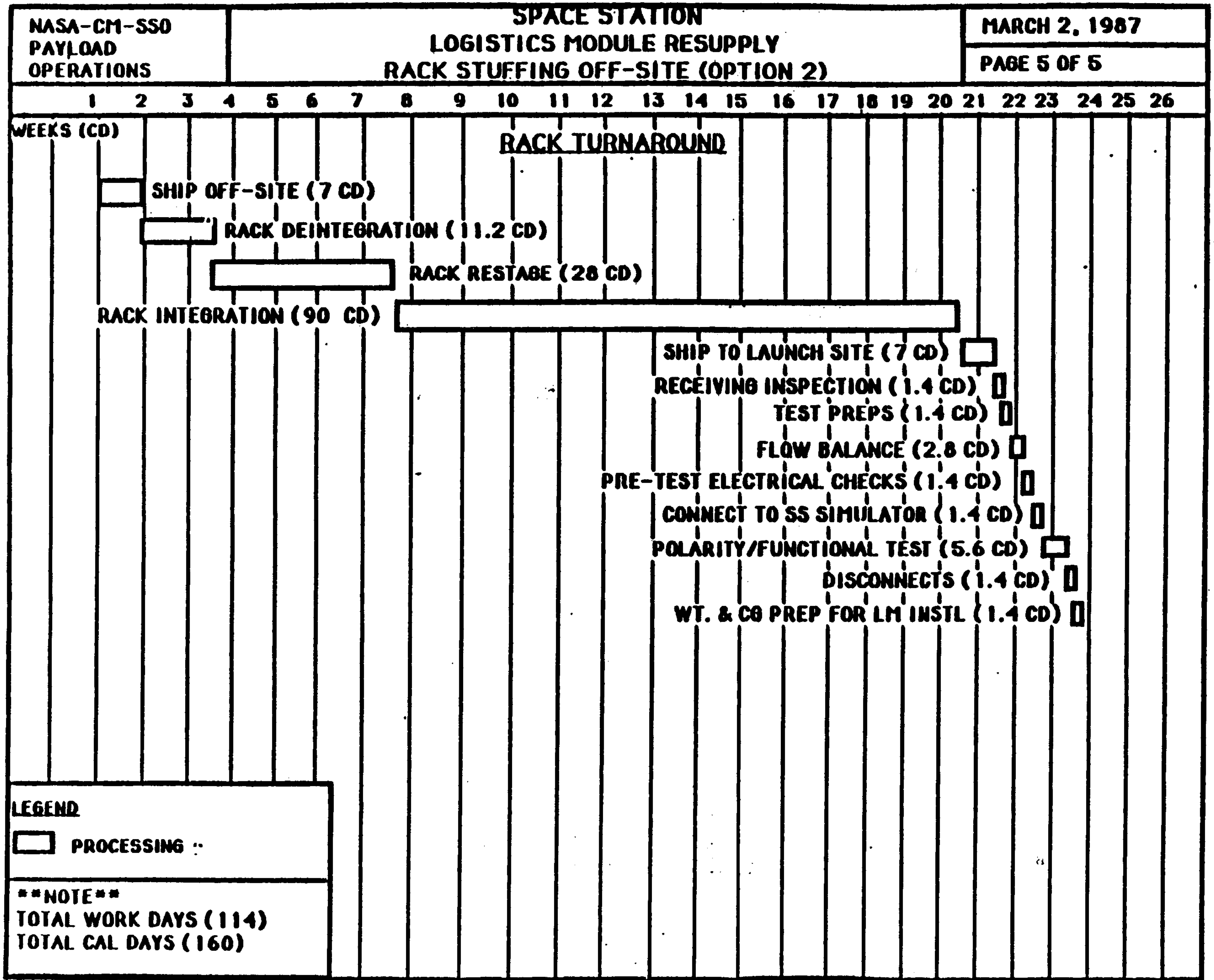


FIGURE 2-11 R[illegible]K TURNAROUND

C-2

into high fidelity ground equivalent support elements or design to flight rack Interface Control Documents (ICD's). Following delivery of the experiment to the launch site and post delivery inspections, the experiment is installed into the flight support element which has already been configured and certified in the centralized facility. Launch site personnel would perform the installation function for all items entering a rack whether representative of one or multiple experiments. The combined integrated experiment and support element would then undergo final Station interface confidence checks with a high fidelity electrical, electronic, and mechanical simulator. Following these confidence checks, the integrated support element would be placed in the appropriate launch package carrier for subsequent Orbiter installation and launch to Station.

Following post mission return to the launch site of the integrated experiment support element, the experiment is physically returned to the user provided support element. The flight support element undergoes centralized inspection and recertification and is immediately returned to the centralized operational inventory for next mission manifesting.

Analysis - This approach is feasible based on the existing Spacelab program model. Flexibility in capability to respond to new situations, such as, late changes in equipment design, late procedures updates, materials changes, etc., is rated acceptable from users viewpoint and the Spacelab experience shows the Space Station launch site centralized approach is tolerant to new situations. User friendliness was viewed only as acceptable. User concern stems from Spacelab program experience in which the experiment developer was not a part of integrating his flight hardware, even though he retained the engineering expertise for the hardware and the experimenter was required to provide temporary duty support for extended periods to accommodate the work schedule of KSC operations. Ability to transition from C/D to E in this option was rated as excellent in view of launch site accommodations for rack handling and flight interface compatibility checks by ground simulators.

Management was rated with desirable features in view of: (1) defined organizational interfaces, (2) adaptable evolving roles and responsibilities during successive phases of ground processing with accountability for those evolving roles, (4) clear accountability for actions taken. In assessing this option for Station, the experience base of the Subpanel members draws largely from the Spacelab program. In the Option 1 cost model, the user costs may be interpreted to be minimized by prudent scheduling of user arrival at the central integration launch site avoiding any unnecessary dwell time and allowing the central integration personnel to have fully arranged facility and equipment accommodations. Congestion is avoided by sizing the central facility for optimum Station capability considering its maximum capacity on orbit and the logistics resupply system capacity for experiment change-out. Positive considerations assume that the use of "telescience" will hopefully improve the Space Station cost model over the historic Spacelab cost model in that less user equipment and fewer user support personnel may be required at the integration and launch site. Because of available interfaces, performance in this option is expected to be excellent. The required functions are capable of being performed in the "centralized at launch site" approach and there is a high potential of success. The major detractants of the option are user unfriendliness and cost to the user for personnel temporary duty and extended schedules.

The safety aspects of this option were assessed highest of all options. Key features included launch site configuration control of flight hardware, quality in maintenance and servicing of equipment, and reliable and most current launch site approved operations and test procedures. Proprietary operations considerations were not a discriminator in any of the options assessed. It is generally believed proper controls and facility accommodations will be available to meet user needs.

<u>Option 2. Decentralized Physical Integration</u> - Decentralized integration is defined as payload buildup away from the launch site. This option would make Space Station racks, Payload Interface Adaptors (PIA), interface simulators, and attached payload elements available to the S&T Centers and other organizations which act as experiment development centers representing user disciplines.

S&T Centers have provided flight hardware to Spacelab and will be providing flight hardware to Space Station which will be far complex than the flight racks holding that hardware. These Centers currently do not allow Spacelab hardware procurement without Defense Contract Administrative Services (DCAS) or "in place" Quality Assurance (QA) programs at manufacturing vendors. They have provided hardware verification plans which fulfilled Spacelab Payload Mission Manager Verification Requirements for Instruments, Facilities, MPE, and ECE, JA061 requirements and both Flight and Ground Safety Plans for all payload elements for which they have had responsibility. They maintain both hardware and experiment configuration control and only perform testing of flight hardware under controlled, approved procedures under QA surveillance. They develop and deliver flight hardware to NASA program standards on their own responsibility.

Timely delivery of Space Station experiment hardware to the launch site is essential to support short term LM turnaround. Minimizing hardware handling can facilitate such delivery. Providing racks to the S&T Centers can speed up the turnaround process for hardware resupply from several aspects. Awareness of all flight rack or other mounting elements interfaces is best accomplished by providing the rack at the hardware buildup site. Allowing the user to perform fit and function of hardware in a "near" flight configuration prior to delivery for launch, is essential to understanding on orbit operations and will facilitate rapid turnaround when finally arriving at the launch site. Should anomalies occur, the Centers have the engineering expertise (womb to flight history) and the materials to correct any problems prior to delivery of the hardware. Resolution of field problems on temporary duty is costly to the user in terms of personnel support and shipments of material. Temporary duty support during the integration of experiment hardware into flight racks at the launch site proved to be extremely costly to the Development Centers (S&T) during the Spacelab era.

Integration to the rack level and to rack interfaces allows easy and speedy transition (as required for final checkout) to either the Work Package (WP), launch site, or directly into Space Station.

<u>Analysis</u> - The assessment of this option was rated highest by the panel. The primary contributors to this assessment were flexibility and user friendliness. User rating also accounted for long term costs to the user. It was acknowledged that decentralized integration would necessitate increased cost to the Space Station Program in terms of additional rack sets, simulators, other interface elements. It was also recognized that these were upfront costs which would be negligible in the

long term operational costs with respect to fidelity of building hardware to Space Station interfaces, timeliness of providing flight hardware to the launch site, and user costs. Since the developer (S&T Center) encompasses the engineering expertise pool, performance and safety were rated as equal to superior over what could be accomplished at the launch site. In fact, the strong identity for unimpaired performance is more inherent at the Development Center, whose activities must result in functioning equipment in 0-g.

Internationals have indicated that they are distributing their racks for their respective modules to their users for rack integration and interface testing, with final interface to an engineering verification module at their prime integration center. Decentralization allows the International developers to retain control of the specific rack in which they are operating but allows the flexibility of providing International racks to U.S. users as the occasion demands. The same mode of operation should be incorporated in the U.S. activities for both near and long term operations.

<u>Option 3. Decentralized Physical Integration with Final Interface Validation at Work Package Center</u> - In this option, the interface and compatibility testing of the payload element to the Space Station interface test device (simulator) after they have been physically integrated into and/or on the Space Station support elements would be performed at the appropriate Work Package (WP) element site. In this context, the Space Station support elements are defined as racks, payload interface adapters (PIA), and platforms and the WP site would be those that support WP 1 and WP 3. The distinction between this option and option 4 is the location of the payload to Space Station interface/compatibility test activities.

The flow of hardware under this option would be quite diverse. Space Station racks and PIA's would be provided to S&T Centers, if desired, for them to physically integrate the payload hardware. Space Station certified, simplified (suitcase type) Data Management System (DMS) simulators would be provided if requested that would allow the S&T Centers to do a limited interface verification. For those users not represented by an S&T Center, or who so desired, would have their payload hardware physical integration performed at the WP site. Subsequent to the payload physical integration and interface testings at the S&T and/or WP site, the total mission payload complement would be assembled at the WP site to be mated with the appropriate Space Station high fidelity simulator. During this test setup, the payload hardware to Space Station hardware interfaces and compatibility would be verified. Following this test activity, the payload complement will be delivered to the launch site for installation and verification with the Space Station carrier; e.g., LM and finally to the STS.

This option would define two WP sites to which payload hardware would flow for the testing functions. The WP 1 site would receive all payloads that would operate in the internal module; i.e., LAB module, and would maintain and operate the high-fidelity LAB module simulator required for the test activities. The WP 3 site would perform the same functions for all Space Station attached payloads and for platform payloads. The international partners would maintain and operate high fidelity simulators and perform the same functions in relation to elements of the Space Station they provided.

<u>Analysis</u> - The assessment of this option by the Subpanel was very favorable. The feasibility of this option would be well established since its approach is the basic planning for phase

C/D period. The transition to it in the operational phase would entail minimal disruptions to the ongoing program. The flexibility of this approach to respond and react to changes is enhanced compared to the other option. This is based on two essential facts: (1) the decentralization of all the activities away from one site which will provide a smaller, less structured organization which will be able to react more effectively and also less likely to become a "bottle neck" due to overload; (2) the centralization at one site of the processing for a particular class of payload, which allows the organization and people to become specialist and efficient in doing their job; i.e., they do not have to know and be able to do everything. The same factors listed above also enhances the user friendly aspects of this option. In addition, the option allows for the user to "stuff" racks, perform the level of testing he can do before getting in the big system. The users interfaces to the WP element site would be only required to define and implement the integrated test activities which would be very clear, straight forward, and provide the maximum autonomy for the user.

The overall effectiveness of this option was rated excellent. The management structure required for this option would be relatively simple since its sole function is to coordinate, if done by the user, and/or perform physical integration and integrated test activities on a class of payload hardware. The roles and interfaces of the participants would be clearly defined, thus allowing for a high degree of accountability with well defined decision points. The costs for implementing this option would most likely be higher than for the other option. This, in large part, would be due to maintaining two sites and organizations for doing the integrated test activities instead of just one. One consideration, which could reduce the cost if it could be accomplished, would be the use of the high fidelity simulators at the WP 1 and WP 3 site to support the sustaining engineering and/or new development/enhancement function. This would allow a cost sharing of the maintenance and operation of these simulators. Whether this is possible or not will be determined by the schedules and workloads of each of the two competing users of the simulators. A much more detailed study would be required to answer these questions. Another adverse cost factor for this operation is the transportation cost entailed in shipping the payload elements from the WP 1 or WP 3 test site to the launch site.

Performance under this option should be superior because it permits apportioning out the functions to where they can best be performed based on the skill levels and expertise required. It allows for letting the users do the physical integration and initial interface testing where the expertise on the payload hardware resides or conversely the WP site where the detailed knowledge of the Space Station hardware exists. The integrated test activities are performed at the site where the Space Station hardware expertise exists with the payload users tied in via the telescience network or on site as the case may be. Final Space Station carrier integration and STS integration is performed at the launch site where that expertise resides. This mix seems to utilize and optimize the knowledge bases available to the maximum extent possible. Very little or no training or transfer of knowledge would be required from one participant to the other in this option. The mixes of the functions to the appropriate skills sources will also reduce the risks involved in regard to performance and schedule and enhance the safety aspects of the program.

<u>Option 4. Decentralized Physical Integration with Final Interface Validation at Launch Site</u> - This option provides

decentralized locations for experiment physical integration in/on flight qualified support elements (as scoped in Option 2 - Decentralized Physical Integration) and adds the feature of final experiment to Space Station interface validation at the launch site.

The additional feature of this option is the planning to use the launch site Space Station simulation capability to perform integrated experiment final interface functional confidence checks prior to launch package integration and installation into the Orbiter. Users have indicated the need to provide this interface test capability at the launch site. This must be maintained to accommodate unforseen mishaps, i.e., damage to equipment in shipping transit from the S&T facility. The Space Station simulator located at the launch site will have been utilized during the assembly sequence build up phase and would continue to function during the mature operations phase. The integrated experiment will arrive at the launch site and be removed from its transportation equipment in the SSPF receiving area. Following visual inspections, the experiment package would be placed in the appropriate Space Station simulator device and functional interfaces would be verified. After completion of necessary checks, the experiment would be removed from the simulator and installed in the appropriate logistics carrier for launch package integration.

Upon completion of the mission, the experiment is returned to the SSPF where it will be removed from the logistics carrier and then shipped back to the development center.

<u>Analysis</u> - This option in the mature Space Station operations phase is rated favorably overall by the Subpanel. The approach of final interface verifications occurring at the launch site is

considered feasible due to the continued use of Space Station simulators that are baselined at the launch site for the assembly sequence phase of Space Station. User's have identified the requirement to make final checks at the launch site in the event of late changes, damage resulting from shipping, or resolution of technical problems discovered during pre-launch experiment servicing and ground processing. With the simulation and lab capability in the SSPF, this approach is rated excellant in flexibility to respond to new situations. User friendliness is rated excellant due to the large degree of autonomy afforded with S&T Center experiment development and physical integration but reliability of operation on orbit is significantly enhanced due to final checks made at the launch site. Ability to manage this option is assessed as excellant due to the ability to clearly identify technical and programmatic interfaces and accountability of operations at the S&T or launch site. In view of the current Space Station approach to launch site facilities, equipment and operations, the transition from Phase C/D to mature operations was rated by the Subpanel as excellent.

Safety is rated as low risk and receives an excellent rating. Proprietary operations considerations were not a discriminator in any of the options. Proper controls and facility accommodations will be available to meet user needs.

Conclusions and Recommendations

Option 4, Decentralized Physical Integration with Final Interface Validation at the Launch Site, was selected by the Subpanel as the preferred option. Information presented and analysis considered by the Subpanel indicated this approach was best overall for achieving Space Station Program objectives of cost effectiveness, high utility to Government and commercial users, and accommodation of International Partner planning. The significant cost considerations include cost avoidance for manpower and travel expenses for launch site physical integration as well as lower costs associated with early problem resolution at the user's development facility. Final experiment to Station interface validation at the launch site assures on orbit compatibility of experiment with Space Station systems and services.

The significant features of the recommended approach include provisions, such as, (1) shipping of flight support elements (racks, PIA's) to user facilities, (2) physical integration of experiments and their functional verification by the development team at the user's facility, (3) use of selected simulation devices at the user facility for interface functional checks, (4) provision at the launch of a master interface facility for final experiment to Space Station systems interface validation, (5) SSPF space accommodations for any required experiment post delivery repairs or late incorporation of minor modifications, (6) SSPF accommodations for experiment physical integration for experiments suited for launch site integration.

The recommendation of the Subpanel is for adoption of Option 4, Decentralized Physical Integration with Final Interface Validation at Launch Site. Planning towards this approach should be initiated with Phase C/D activity to assure best economies early and to avoid possible future organizational or systems restructuring.

LOGISTICS MODULE BUILDUP LOCATION

Logistics elements include NASA and international partners proposed elements. The international partner elements, if launched in the U.S., would follow the same processing flow as the NASA element with responsibilities and performance being in accordance with international agreement.

The logistics module, unpressurized (dry) carrier, propellant carrier, and fluids and gases carriers make up the NASA elements. The logistics module, which provides pressurized volume, is the primary vehicle for uplifting and downlifting (returning) both Space Station and payloads items.

The dry carrier, propellants carrier, and fluids and gases carriers are special purpose carriers. Processing flow of these carriers will be as required by the logistics resupply of Space Station systems. Payload users items to fly on these carriers would be recognized as part of the overall requirement and integrated into normal flow.

Two options for location of logistics module operations were evaluated. One option, any site other than launch site, would cover all locations away from launch area. Performance of logistics module operations at the launch site is the second option. Installation of the logistics module into the transport vehicle (orbiter) and prelaunch/launch logistics module test team participation at the launch site is common to both options.

Option 1. Logistics Module Processing at Site Other than Launch Site - The following are major flow operations required for Option 1:

1. Receiving inspection and handling operations required to process the logistics module shipped from post-flight deintegration area.

2. Inspection for visual problems and of areas required by design element in requirements and criteria (OMRSD).

3. Returned configuration verification to module replacement unit level such as stowage lockers is accomplished before module deintegration. Inventory within stowage lockers will be accomplished later in an offline location.

4. Deintegration and/or removal of those items not planned for reflight and those items which require some operation outside of logistics module.

5. Post-flight verification test.

6. Repair and maintenance.

7. Incorporation of design changes (modification kits).

8. Installation of module LRU's required by next flight configuration.

9. Installation of payload users items (see rack options for flow description of user items).

10. Test of module system. Interface check to payload user items where required.

11. Recertification of flight condition of module systems per system provided requirements and criteria (OMRSD). This would include any new requirements resulting from ground and flight problems, trend analysis, life cycle requirements; etc., as designated and required by sustaining engineering.

Analysis - It is feasible to prepare the module off-site, however, additional transportation, handling, and shipping would be required. The processing flow time would be increased thereby reducing flexibility to meet schedule.

Processing the module at a site other than the launch site would reduce some of the rigors associated with processing in a launch environment, such as: schedule pressures; get ready to launch pressures; and use of shop planning documentation as opposed to formal launch area documents.

Processing at an element provider site would provide the mechanism for keeping designer expertise onboard, and would provide the second set of eyes for reliability, quality, problem performance, safety, and life considerations.

Payload user elements to NASA interfaces would be increased.

The cost of maintaining logistics module processing capabilities at both sites, which would be required for final verification and installation into Orbiter and at the module processing area, would be greater.

The transition from the development phase to mature operations; Space Station Program management; safety; and ease of proprietary operations would be impacted to some lesser degree by offsite processing.

The ability of the Space Station Program to make major evolutionary program changes to incorporate research and development and new technology would be enhanced by processing at an offsite element (logistics module) provider location.

Option 2. Performance of Logistics Module Processing at Launch Site - The following are major flow operations required for Option 2:

1. Handling of logistics module within local processing facility after removal from Orbiter. Note: No shipment.

2. Inspection for visual problems and of areas required by design element in requirements and criteria (OMRSD).

3. Returned configuration verification to module replacement unit level such as stowage lockers is accomplished before module deintegration. Inventory within stowage lockers will be accomplished later in an offline location.

4. Deintegration and/or removal of those items not planned for preflight and those which require some operation outside of logistics module.

5. Post-flight verification test.

6. Repair and maintenance.

7. Incorporation of design changes (modification kits).

8. Installation of module LRU's required by next flight configuration.

9. Installation of payload users items (see rack options for flow description of user items).

10. Test of module system. Interface check to payload user items where required.

11. Recertification of flight condition of module systems per system provided requirements and criteria (OMRSD). This would include any new requirements resulting from ground and flight problems, trend analyses, life cycle requirements; etc., as designated and required by sustaining engineering.

Analysis - Utilizing the launch site processing location reduces the number of handling and shipping operations.

Processing time is reduced by the amount of time which would be required for additional shipping and handling operations.

Documentation at launch site would follow a more formal flow and therefore is less flexible with respect to changes. A "get ready to launch" environment exists and puts pressure on personnel processing hardware to meet launch goals.

The second set of eyes of quality, reliability, and design and development personnel, which is inherent in using site where item is built as opposed to operations personnel, is lost.

The number of NASA interfaces to LM users is reduced.

The number of logistics modules required to meet the processing flow is minimized because the need to provide for additional shipping and handling time involved with a remote site is not necessary.

The transition from the development flight phase; Space Station Program Management; and the ease of proprietary operations would, for long range operational life, be enhanced by processing at the launch site only, as opposed to multiple sites processing.

Conclusions and Recommendations

Logistics Module Processing - Option 2, Performance of Logistics Module Processing at Launch Site, was evaluated to be the best option for Space Station operational phase.

Flexibility, cost, and user friendly were major drivers in selection of Option 2 which was rated best in all these areas.

Close proximity to logistics holding area or spares stores areas minimizes of turnaround time. Shipments of logistics module between the launch site and another site is eliminated reducing handling and cost.

Number of interfacing locations to which users (Space Station systems and payload/experiment) would need to support is reduced.

Logistic Module Development - It is recommended that the Logistics Module Development should emphasize modularity; provisions for early and late user access; development of flexible accommodations which meet maximum user hardware fabrication tolerances;

modular data bases facilitating changes between mission flight complements; reverification of mandatory recertification requirements and criteria; and standardization of procedures.

VERIFICATION TESTING

The Verification testing options considered are:

1. Perform full-up verification testing on ground (Spacelab model) with high fidelity simulators.

2. Perform testing to rack level on ground with simulated interfaces and complete testing to the Space Station elements on-orbit (same level tests to be performed on payloads attached to Space Station and platform) (preferred option).

3. Perform all testing in orbit (no master rack or integrated ground testing).

4. Perform data system and software verification on ground, using DMS onboard the Space Station (using special links). Verify physical interfaces on ground with master gauge.

These are the options considered for the operational verification test of user experiments and payloads interface with Space Station, while they are being built, and before the equipment is put into service on Space Station. Final interface verification testing capability is currently, proposed to be at KSC. However, since there are several types of payload interfaces, including rack to pressurized module, attached payloads to Space Station truss, and payloads to platform, it may be desirable to do final verification of some of those interfaces elsewhere.

The purpose of verification testing is to demonstrate that the users flight equipment and software are compatible and effective with the Space Station and its interfaces. It is expected that user experiments and hardware will be tested during its build up by the users, to verify it does meet the specified operations and interface requirements of the Space Station Program. However, it is desirable to have a final test on the ground, with realistic Space Station interfaces, to be certain the assembly and previous verification was done right. If inadequate user hardware or software were launched, and it was found to not fit, or otherwise be unacceptable for use in Space Station then it would need to be returned, repaired, and relaunched. A ground simulation of the Space Station environment that the user will meet would save him, and Space Station, that trouble and expense. To do this final verification, the real characteristics of the Space Station side of the interface must be accurately simulated to the maximum extent feasible. The Space Station side might even be duplicated, with actual flight hardware. Testing the users equipment with this Space Station simulator demonstrates to the user what resources of power, data handling, cooling, and communication the Space Station will provide him, and their operating characteristics. It verifies whether he can physically connect to and operate with the Space Station interface. This testing gives confidence that if the user equipment operates properly with the final Space Station simulator during the interface verification test, his equipment will also operate properly on the Space Station itself. The better the simulation of Space Station, the higher the confidence. In a ground environment a perfect simulation cannot be made of either side of the interface. The Space Station simulation can be close, but the user must be aware of potential gravity variations in his equipment and compensate for them.

The final interface verification test is intended to demonstrate that the user can work with the Space Station interfaces he will meet in orbit. The user will be given all the information possible about how he functions at the Space Station interface, but the ultimate responsibility for successful operational performance on the Space Station will rest with the user.

Maximum use of telescience as a method of remote checkout and operations of payloads on Space Station by users and other verification methodologies are described in Appendix D, "Verification Considerations".

<u>Option 1. Full verification with high-fidelity simulators</u> - This option would require that after all in-process verification tests have been done, there will be a final interface test, with exact duplication of all aspects of the Space Station interface to the user. Duplication of mechanical interfaces, data, power, thermal, and communications systems would be exact. Surrounding users equipment would be duplicated or simulated for the purpose of demonstrating unexpected reactions. The exact data system conditions would be duplicated, encompassing all other users on the data bus. Power and thermal control system fluctuations would be duplicated within normal ranges. The Space Station electromagnetic environment would be duplicated, both the conductive, and to some extent, the radiative.

<u>Analysis</u> - This option is attractive because it has the best possible fidelity to the real Space Station situation the user will meet. It is the same sort of user testing that is done now in the Spacelab program before it is launched. The actual flight Spacelab is used, not a duplicate or simulator.

The major difficulty that would be encountered with this method of final verification is keeping current with all the Space Station payload configuration changes. Maintaining continuous duplicate fidelity of simulator behavior to the actual behavior of the changing configuration of payloads onboard the orbiting Space Station would require great effort and expense.

To duplicate on the ground the actual user systems and user hardware that are in orbit would be very expensive and beyond the budgets of most user programs, since users would have to produce duplicates of their fight hardware for use on the ground.

Option 2. Perform testing to rack level on ground with simulated Space Station interfaces and complete testing to the Space Station interfaces on-orbit. (Same level tests to be performed on attached payloads).

This option assumes that the users will perform adequate testing during experiment buildup, perhaps using Space Station-provided simulators, to verify that Space Station operation and interface requirements are met. Final verification would require that ground duplication of interfaces to be met on Space Station would be only as accurate as is considered cost effective. The duplication of mechanical interfaces could be very accurate. Duplication of data, power thermal, and communication systems would be to interface specification. Other adjacent users would be simulated to only a limited extent. Simulated Space Station Power and thermal control system fluctuations would stay near nominal levels. The conductive electromagnetic environment would be only partly simulated. Systems software would be duplicated. The data bus loading due to other users would be simulated.

Analysis - This verification method is considered to be feasible. With in-process expected verification tests performed, along with a reasonable final test, only the minor or subtle malfunctions would not be caught. It is believed those could be "worked around" if they did occur in-orbit.

Option 3. Perform all testing in orbit (no rack or integrated ground testing).

All racks, attached payloads, and platform payloads would be tested during the buildup process by the users at their facilities to Space Station Program specifications. Transportable "moderate quality" simulators of the Space Station structural, electrical, and data interfaces may be provided by the Space Station Programs but would not fully duplicate the actual Space Station interface. These simulators would primarily be used for verification of the payload characteristics, to preserve the safety of Space Station itself. After these tests are complete, the users would ship their payloads to the launch site for transportation to Space Station. Only after actual installation on Space Station would the user be able to check his equipment in the Space Station environment.

Analysis - In most cases, the results of this method would probably be satisfactory, with few minor malfunctions or incompatibilities found that could be worked around or fixed on-orbit. However, in some cases, the actual Space Station environment would not be what the user expected, or there would be an aspect for which he had not prepared. His equipment would then be useless and need to be returned for rework or repair.

This option presents higher risk to safety of operations of the Space Station systems. Additionally, on-orbit time may be required to detect and correct which could have been found on the ground.

This option would cost the least for the Space Station Program, but may not have the least overall cost to the U.S. taxpayers when the costs of return, repair, and relaunch after an interface failure on Space Station is considered.

Option 4 - "Perform data system and software verification on ground, using the DMS onboard the Space Station. Verify physical interfaces with ground master gauge."

After the users in-process verification tests are done a final high fidelity interface test will be done except for DMS. For the DMS an actual part of the Space Station will be utliized. The data link behavior of the new experiment to be tested can be operated with the actual flight DMS as if the experiment were already onboard Space Station. The instrument under test on the ground would appear from the DMS side as if it were just another instrument on Space Station. The instrument under ground test, would be connected through a separate, dedicated Telecommunications Data Relay Satellite System (TDRSS) communication link used as a test circuit. This special test circuit would be separately available out of TDRSS to the ground. This separate TDRSS circuit would be connected to the data port of the instrument under test on the ground. The user on the ground would use his ground control system in the normal fashion to command his experiment through all the data links he would expect to use for normal operation on Space Station, including normal TDRSS links and the DMS on Space Station. His data would then go into the special DMS data port on Space Station. The user commands and data would then take an extra jump on the separate test circuit through TDRSS, back to the ground and then into the instrument that is being put through its test program on the ground.

Analysis - This option allows use of the real flight command and data system, without simulation, for ground checkout of new experiments. The effect of system interactions and data loading could be realistically checked with the real system. It avoids simulation difficulties in an area that often gives trouble. However, providing the special data port and dedicated link on Space Station and TDRSS has high expense and difficulty. The method may not be practical in the real Space Station Operational environment due to the limitation of integrating ground tests with on-going flight operations. The alternative of high quality data system simulation on the ground is also expensive however major portions will already available via The Space Station Information Sysytem (SSIS).

Conclusions and Recommendations

The concept of Option 2, doing payload verification by testing to Space Station specifications during the process of buildup and then final test to a reasonable level on the ground, then completing the testing in orbit was rated as the most feasible to execute at reasonable cost to the Space Station Program during Space Station operations. Feasibility is good because adequate and mature simulation of the various kinds of user interfaces to Space Station will already exist, from the Space Station buildup phase.

Flexibility for user needs is good because the user can perform reasonable tests during his buildup, then any final interface tests involve only a few kinds of user interfaces to Space Station, which will remain stable. The effect of adjacent users can be reasonably simulated in the final interface test. It is considered user friendly because the Space Station interfaces are defined and predictable; the user can do whatever tests he wishes to verify his payload during buildup, as long as he meets the final interface and Space Station safety standards.

The effectiveness of transition to operational use is high and mainly a matter of stabilizing the Space Station procedures and documents to a configuration that minimizes cost and operational impact for both the users and Space Station Program. Management of final interface simulators would remain under the Space Station Program. The cost of simulator facilities would be already paid, with only some upgrade needed to optimize the balance between increasing the chance of catching user anomalies versus the cost of verification equipment. The effectiveness of verification performance will be good, commensurate with the quality of the simulation. The safety for Space Station and users will be good because the finding of safety anomalies is the object of the several reviews and the final testing will be done by experienced personnel. Ease of proprietary operation is good because the users need to reveal only as much of their payload content as is required by safety considerations.

Option 1 was considered by the panel to be excessively costly and ultimately not workable, since even high-fidelty simulation would never exactly duplicate the flight Space Station. The extreme cost of that simulation could not be justified by the few extra errors in user hardware it would catch. Moderate quality simulation, at much lower cost, that would catch almost all anomalies was considered adequate.

Option 2 was considered by the panel to be the most reasonable option for verification test. It can balance moderate cost to the Space Station Program for a reasonably high quality of verification, with reasonably low costs to the users from failures to catch subtle problems until they are found on-orbit. The cost was considered lowest for this option.

Option 3 was considered to have unacceptably high risk for the users and the Space Station.

Option 4 was considered to be impractical. It would not truly duplicate the data load of other users that will exist when each user operates on Space Station. The expense and difficulty of incorporating the independent testing circuit and the possible difficulty of inserting test data among other operational users data was thought to be greater than the extra value potentially received by finding subtle data problems by working in the real DMS instead of a simulation.

It is recommended that a user verification system like that outlined in Option 2 be adopted for operational use. Variations of this method can be made that are particularly suitable to the different types of user interfaces, such as: rack-to-module; attached payload to Space Station truss; and platform payload to platform.

LATE ACCESS/EARLY REMOVAL

Current configuration of the Logistics Module (LM) does not accommodate access to the module after integration is completed at the Processing Facility; in short after L-2 months. The only existing access is to the NSTS middeck. Pad access has been a requirement of payloads dating back to the days of Gemini. Both the NASA and NASDA Life Sciences organizations have stated a requirement for late access at the pad and early removal at landing for live and preserved biological specimens.

Background - The following data is provided to aid in analyzing the preferred option for late access/early removal. The NASDA has stated that they intend to use NASA animal transport facilities. Even if facilities are provided by the NASA Life Sciences users for containment of animals and/or plants, which control temperature, accommodate food, water, and waste, these systems will need to be maintained in a pressurized environment, require power, and an ECLSS . Use of the Orbiter middeck will not satisfy the requirement for access. Use of middeck lockers for transfer of rodents to Space Station is limited to minimally six (6) animals/locker. Space Station facilities are configured to house 72 rodents simultaneously or 12 squirrel monkeys. Transfer of 72 rodents require 12 middeck lockers with a total power requirement of approximately 450 watts. Squirrel monkeys or larger primates cannot be accommodated in a middeck locker. In addition, the transfers of animals from the middeck animal enclosure modules to Space Station animal housing facilities for single caging would be extremely time consuming and potentially hazardous.

Rack mounted animal holding facilities will have been used through three Spacelab missions before Space Station operations commence. These units are capable of maintaining animals for a period of up to 10 days. The units could be loaded as early as L-72 hours and be maintained before off-loading into the Space Station for a period of 72 hours. The ability to install existing facilities into the LM using existing SL facilities for transfer of animals would be a NASA Code E savings in excess of $2M (2 million).

Design of additional equipment (i.e., docking module) providing ECLSS, power, and pressurization while attached to the LM, may bear a weight penalty for the program.

Option 1. No Provisions for Early Access. No provisions implies total dependence on use of the Orbiter middeck and no flight of specimens greater than 350 grams or items larger than a middeck locker.

Analysis - This option has no rating for user friendliness or flexibility. Long term costs to the user and Space Station will also result. In view of the biological experiments planned on Space Station by both U.S. and International users, Option 1 must be disregarded. The biological experiments planned, which are intended to implicate the long term effect of 0-g on man in space cannot be honored. This may seriously jeopardize Space Station activities and other man-space explorations; i.e., Mars landings.

Total reliance on use of the Orbiter middeck has been considered as feasible for animals no larger than rodents. Power requirements may make this an unacceptable alternative. Safety and performance become a significant factor when transitioning the specimens from their multicaging to the Space Station facilities.

Option 2. Provide access to LM Through Design Change. Design change is defined as design change to the Logistics Module

Analysis - At this point, this would appear the most costly option to NASA and the Space Station. In the long run, because of the availability of existing holding facilities, public opinion for animal rights, and potential launch weight if installations are in co-structures, this may prove the least costly to the program. Design changes must consider safety of entry and not rely on the type of access utilized in Spacelab; i.e., suspension on a "bowswain's chair." Timely access to the

LM may also prove to be a safety critical issue for the program, both on launch and landing for other reasons; i.e., toxic wastes, contingency power, or fire suppression.

Option 3. Space Station Provides Special Carriers. The issue of early/late access can involve special carriers which must be available for varying payload uploads and downloads.

Background on Carrier Applications - A variety of wastes will be produced during Space Station operations. Preliminary analysis (Report: OSSA Space Station Waste Inventory, J. Bosley, G. Curran - Bionetics Corp., R. Maines, Nina Saint, P. Hofmann - Maines Assoc.) of wastes accumulated every 90 days during operation of only the experiments in the U.S. elements i.e., life sciences and materials processing, resulted in the following data:

Gases	600 kg	with 1100 kg peaks @ flights 8, 16, and 20
Liquids	7500 kg	
Solids	1500 kg	with 4000 kg peaks @ flights 8 and 16

This data identifies waste produced in experiments conducted on attached payloads, free-fliers, and the lab module. Primary gases include cryo fluids, argon, helium, nitrogen, and others. Examples of solids were metal shavings, bolts, fragments, syringes, animal waste, saw blades, dry/wet wipes, and vials. Liquids included items such as chemical fixatives, low level radioactive suspensions, staining solutions, cleaning fluids. Whether the station elects to vent gases, regenerate waste water or return all materials, the potential of hazardous waste exists. Efficient containment for transfer from Space Station and disposal requirements are best resolved by one organization.

For safety reasons, these wastes cannot be readily commercially transported and should therefore be disposed of at the location where they may be most conveniently off-loaded from the NSTS. In addition, containers for all wastes should be provided by Space Station to ensure proper logistics control and safety. Because it may be difficult to trace all waste accumulation for all Space Station elements, particularly in terms of routine activities; i.e., use of wipes and water, the cost of such containers and waste disposal should be dispersed among the users over the lifetime of the station.

Analysis - In accordance with guidelines for safety, carriers interfacing to NSTS must be provided by the Space Station. Their use would be coordinated through Space Station logistics, which would insure management of efficient turn around for the continuous downloading. There will be a cost for carriers; flexibility to user must be sacrificed for safety.

Option 4. Customer Provided Carriers - These are defined as carriers providing temperature control and of limited size; i.e., 5-10 cubic feet.

Analysis - Carriers intended for temperature control of unique samples are best provided by the customer who understands the requirements and can stage the logistics for their use. Customer provided carriers for items that are in conformance with pressurized container safety requirements; i.e., non-offgassing, power compatible can be accommodated in the LM and the middeck lockers. Customer provided carriers provide flexibility and are most cost effective for the Space Station

Program. The customer must also provide GSE or battery paks to accommodate any early off-loaded carriers until they are returned to the user designated required location.

DISTRIBUTION OF EARLY REMOVAL ITEMS (POST-FLIGHT)

During the Space Station operational era, the opportunity is available to transfer biological and nonbiological systems to the Space Station 0-g environment for long-term studies and sampling; to create systems both biologically, chemically, and physically; and to return such samples and systems to 1-g for extended analysis by the user. Though the systems may be altered in the 0-g environment (i.e., animal tissues and cells returned versus the live animals originally sent up), they may still require unique support and maintenance during return, landing, and post-landing operations.

Biological systems require specific support for survival and maintenance without degradation. Support may range from a pressurized atmosphere including controlled oxygen/carbon dioxide levels, water vapor, and temperature to a nonpressurized atmosphere dependent only on sustained controlled temperatures.

Examples of the former include plants and animals. Examples of the latter include refrigerated, frozen, and incubated systems as cells and tissues. Primary users include life sciences and materials processing disciplines.

Nonbiological systems may also require sustained temperature or specific gaseous-rich environments to reduce the potential of degradation during transit and return to the 1-g environment.

Option 1. Space Station Delivers All Early Removal Items. Early removal items (ERIs) include films, biologicals, products, etc., which would be transferred to Logistics at the landing site with Logistics, in turn, handling shipping and transferring to the customer.

Analysis - Handling of items such as film would be transparent to the customer. Indeed, this would be user friendly, but would result in cost to Space Station and would be an inflexible system in that this would not allow the user "on site" receipt as required. Handling of biological and chemical systems requires training and experience. In addition, the cost of shipping flight live samples or delicate materials and proprietary samples to the customer could prove excessive to the Space Station. From a performance and safety aspect, Space Station would also be held responsible for the state of the return specimens/samples.

Option 2. Space Station delivers ERI Directly to the Customer at the Landing site.

Analysis - This is a feasible option in that all handling of samples and specimens would be within their containment units. Flexibility is limited to complete customer control and responsibility. Management and performance may be jeopardized due to the customer's inability to adequately adhere to and interpret transportation regulations for shipments and to conform to required import/export regulations. The latter issues impose a level of user unfriendliness which may not be immediately perceived.

Option 3. Combination of Option 1 and Option 2. The combination of Option 1 and Option 2 implies that on a case by case basis and as negotiated, ERI would be:

- o Delivered directly to the user at the landing site
- o Shipped by Space Station directly to the user's home site
- o Delivered to the user at the landing site with assistance by Space Station for eventual shipment to the user's home site.

Analysis - The combination of the above options has been a mode of operation through the NSTS activities and has proved effective for the user. This combination allows logistics control of hardware items required for return and also assists the user in processing and returning his samples to his home site in a timely manner. Through a negotiated process, a one-on-one interaction with the user is possible in avoiding potential mistakes which could occur from inaccurate assessment of requirements from postflight processing documentation and from transport regulations.

Conclusions and Recommendations

The subjective evaluation of the proposed options against the criteria resulted in the following: Option 3, the combination of Space Station and user delivery, was rated highest in terms of flexibility, user friendliness, management, effectiveness, and safety. Option 2 (user delivery), received higher ratings for cost effectiveness and ease of proprietary operations. Option 3 received the highest overall rating and was selected. Arguments in favor are that the Space Station Program must provide logistics functions at the loading site for all Space Station payloads and the additional costs for handling and delivering, as negotiated user items requiring early removal, would represent only minor additional costs to the Space Station Program. This option would be friendly to the user since it would provide for negotiation of services which the user sees as necessary to early removal item processing. It is recommended that negotiation of services be achieved at the execution level. To effectively implement Option 3, assure cost effectiveness to the Space Station Program, provide flexibility, and clear responsibility transfer to the user, the following are recommended:

1. The user has to be responsible for loading all specimens into flight transfer units for shipment to Space Station. Maintenance of specimens at launch site, in conformance with NASA requirements for use of specimens in 0-g flights involving humans is user responsibility. The user may elect to buy services from NASA or an approved commercial contractor which would be limited to animal maintenance in terms of feeding, cage changeout, and cleaning. Veterinary care would be limited to health maintenance checks.

   Required surgical procedures would be performed by the user with NASA approval prior to any ground or flight experimental activity.

2. The user is responsible for providing transfer containment units to be used for transitioning systems from the Space Station facilities to the landing site.

   - For live systems; i.e., animals, the same units used during transfer to Space Station should be used for return. These units should be capable of temperature control and exchange air with a pressurized atmosphere through HEPA filters. Power and ECLSS must be provided by Space Station.

   - Plants, tissues, and cells maintained at ambient to +45 degrees or down to -20 degrees must be provided an external environment allowing such control along with power while on-orbit. It is assumed power is available at landing until systems are off-loaded. The user will provide ground support equipment to maintain environmental control; i.e., battery paks, blanket purges, ambient air/temperature control.

- o Maintaining and refurbishing transfer units to flight configuration and verification is user supplied.
- o Providing and maintaining logistics for use of the user provided transfer units is user responsiblility.
- o Shipment and costs of transporting hardware and specimens to the launch site are user responsibility; post-flight shipments' arrangements should be jointly negotiated with Space Station Logistics at landing. Typical shipping services include:
- o Scheduling a commercial carrier for return to the user's site
- o Administrative assistance in "export" requirements
- o Final packaging/labeling per regulations.

<u>Support Functions</u>

FLIGHT HARDWARE RECERTIFICATION

Recertification is the process by which acceptability for next use of flight hardware is certified. Recertification verifies that performance of all activities such as but not limited to inspections, tests, maintenance, servicing, calibration, replacement of limited life or failed parts and components; etc., of Space Station hardware and software have been accomplished satisfactorily.

Criteria for inspections, tests, maintenance, servicing, calibration, replacement; etc., of Space Station systems hardware and software between flight and/or on a periodic basis are one of the key factors required for success of long life operations and cost management. The criteria and procedures need to be in place for first flight. Update as changes are made and problems occur during the development flights should be accomplished in such a manner as to support the transition of Space Station from development to operational status. Emphasis in this area and coordination with logistics on sparing and reverification is an essential part to the proper selection of spares for the long life of Space Station. A separate method of providing management visibility and control of the recertification criteria and specifications is needed. The sustaining engineering organization should have responsibility for overall management of recertification with both flight and ground operations providing timely implementation and information on results of recertification and comparison trends versus problems experienced.

For international users, the NASA problem report and corrective action system will provide visibility into station problems on his provided hardware. NASA Space Station sustaining engineering will request corrective action where overall Space Station systems performance is impacted.

For U.S. provided hardware and software, the tracking and reporting on problems will be within the NASA problem report and corrective action system. Responsibility for assessing, controlling requirements, and evaluating effectiveness of recertification of Space Station system hardware is assumed to be a sustaining engineering function.

Major functions of recertification include:

- Maintain and update recertification criteria.
- Maintain and update procedures for inspection, tests, and calibrations.

- Maintain and update historical records as required by specification and requirements documents and quality and reliability and safety documents where applicable.

- Verify that records indicate required tests, inspections, maintenance, calibration, replacements, rework, modifications; etc., have been accomplished.

- Establish and maintain standard operation procedures for recertification.

- Initiate and maintain certification records.

Three locations for performing recertification were considered. Sustaining engineering would manage and control criteria and specifications for recertification under all options. Payload provider retains responsibility to certify his hardware for reflight and or reuse in same manner as on initial or new hardware deliveries.

Option 1. Launch Center performs Recertification. All documentation, verifications, tracking and reporting, records of certification are responsibility of launch site.

Launch center certifies recertification status at flight readiness reviews.

Space Station sustaining engineering organizations provide changes in criteria and specifications needed for certification.

Analysis - This option provides a central source for documents, problem reports, test reports, data packages; etc., needed for recertification.

The most experienced test personnel (during operational phase) will be at launch center.

Recertification before higher level integration is a constraint to most milestones and status needs to be known for work planning impact assessment.

Launch operations personnel are more subject to immediate processing flow schedule priorities than independent integration personnel.

Option 2. Commercial Integrator Performs Recertification. All documentation, verifications, tracking and reporting, records of certification are responsibility of commercial integrator.

Commercial integrator presents and documents status of certification to Space Station organization.

Space Station organization reports certification status at integration and flight readiness reviews.

Commercial integrator responds to and implements approved changes to recertification.

Analysis - An organization independent of launch pressures performs the function.

Data, records, reports; etc., would be duplicated to extent necessary for NASA traceability. Contractual directions needed to effect changes and increases certification interfaces.

Option 3. Payload Integrator (i.e., S&T Center, International Partner, etc.) recertifies all program-provided flight hardware just prior to installing experiment hardware. All documentation, verifications, tracking and reporting, records of certification are responsibility of integrator.

Integrator certifies hardware ready for flight or identifies open verifications at time of delivery to the Launch site.

Integrator performs or negotiates with launch center performance of any open verification items after delivery.

Launch center verifies performance of open items it accepts.

Integrator certifies recertification status at flight readiness reviews.

Analysis - An organization independent of launch pressures performs the function.

This option increases locations where certification status has to be visible for processing flow. Certification problems experienced in launch area are better known by launch personnel.

Conclusions and Recommendations - Option 1 (Launch Center Recertification) was selected as the best option. Option 3 (Distributed Integrator Recertification) was evaluated to be the least desirable, because timely management and control would be more difficult. The one major factor in selection of launch center option for recertification is that records, hardware, problems experience are more concentrated in the launch center during operational phase. Additionally, the Sustaining Engineering organization manages, evaluates and controls recertification where ever implementation is located.

USER SUPPORT FACILITIES

User support facilities are defined as facilities located at the launch or landing site areas to support payloads pre and postflight processing activities. Facilities addressed are for multiple purposes. The NASDA has indicated requirements for facility space for final integration and checkout of their Experiment Logistics Module (ELM), plus animal handling facilities and phytotrons. U.S. users in the Materials processing and Life Sciences disciplines (Code E) will require facilities supporting pre/post-flight operations involving biologicals (animals, plants, tissues) and crew baselining.

A crew Baseline Data Collection Facility (BDCF), approximately 5000 square feet will be required at the launch and the landing sites (Dryden-Ames Research Center and Kennedy Space Center). BDCFs with their complement of equipment must be in place 120 days prior to launch and must be available immediately at crew landing. Deconditioning, (dependent on the body function), can occur within 10-20 minutes after reintroduction to 1-g. Current Life Sciences planning is to closely analyze all mission crew physiological changes in an effort to determine the viability of the long-term Humans in Space program. In short, a BDCF would be a long-term use facility.

Similarly, the science community addressing functions in nonhuman systems, will require facilities for immediate post-flight analysis and testing of live specimens. NASA , during NSTS operations, established a precedent that such specimens conform to defined microbiological requirements preflight. Animals must be maintained and cared for under very stringent procedures as defined by the American Association for Accreditation of Laboratory Animal Care (AALAC), as evidence that NASA associated animal activities are conducted with utmost concern for humane care and treatment. Facilities currently used for Spacelab/NSTS activities involving animals, tissues, and plants are sized to accommodate pre/post-launch and early access/removal activities for Space Station. Because of the long duration (45-90 days), ground controls should be conducted at the appropriate S&T Center (Ames Research Center).

It is assumed that NASA will impose the same requirements for NASDA and/or ESA biological specimens as those placed on their U.S. experimenters, since the crew interface is at issue. This must be implemented if the Internationals use the NASA animal transport facilities as they have indicated. This also implies sequencing animal experiments by the Japanese and U.S. experimenters due to transporter availability. Total animal loads at a ground facility pre and post-launch should not exceed that observed for Spacelab.

Other potential preflight operations for all sciences (life sciences and materials) which require unique support would include sterilization (autoclaving, ethylene oxidation, and irradiation), system evacuation and pressurization, and incubation. These capabilities could potentially be procured off site.

To address the long-term use of facilities it may be best to consider "discipline" facility use, regardless of the activity, whether NSTS Spacelab, Space Station, ELV's, or Aerospace plane. In a discipline multi use mode the logistics for scheduling use of such facilities when available for multiple activities is foremost. Secondly, the availability of contractor, off-site facilities for continuing support will be dependent on the ability of the contractor to show a substantial profit margin.

No clear choice among the options considered for user support facilities emerged from the evaluation process because of requirement variables. A description and assessment of each option follows.

Option 1. User Contracts with Off-launch Site facilities for support - This option allows the user to contract for a facility in which he may perform any prelaunch activities or to contract for services; i.e., sterilization/cleaning activities cited. If NASA dictates this must be the mode of operation, there would have to be some assurance that such facilities and/or services exist within the launch area. Additionally, this implies that hardware must be moved from the off-site area to the Launch Processing Facility (LPF). The latter activity places an added cost on the user or potentially on NASA, depending who transfers equipment from off-site to the launch processing facility.

Analysis - The off-site facility for the BDCF equates to no facility at all because of the degradation in performance; i.e., the requirement for rapid crew access post-landing. This may also be true for the animal handling facilities in view of the stringent AALAC requirements which limit access by the general public to such facilities. A secured area for the animals may be required during the Space Station activities as was required during Spacelab. Off-site facilities may in fact result in added cost to NASA, may result in difficulties due to certification requirements for specimens and facilities. The option does not allow the flexibility necessary for late/early access and contingency delays. In turn, safety and performance may be severely jeopardized by use of off-site facilities for biological specimens. The option is only viable for hardware activities occuring well in advance of a launch.

Option 2. Facility Provided at Launch Site at Rental Fee. This option is representative of the Hangar L facility at KSC and BDCF and Flight Receival Facility at Ames-Dryden used during Spacelab activities.

Analysis - This option allows flexibility because of the nearness to the launch/landing site. Transition is viable, based on Spacelab experiences. The option eliminates the potential that a commercial facility may simply not continue to exist for the operational lifetime of Space Station. It eliminates any contract or legal obligation NASA may face in stating that the user must find a facility off-site; i.e., if there were potentially multiple contenders to offer services. It would allow easier configuration for a dedicated user; i.e., the BDCF or animal handling. It also assures maintenance of NASA requirements; i.e., AALAC under Government control and surveillance. For the animal handling capabilities, this is feasible: such facilities do exist and support Spacelab activities.

Option 3. Trailer Lot Hookups at Launch Site. This option involves setting up a trailer-lot facility with power hook-ups. The user brings his trailer and support equipment to the site. The option is particularly viable for proprietary operations involving late stowage, pad access, and/or resupply in a contingency mode. The option is viable for "stand alone" hardware check-out and for science related activities as plants/phytotrons and insect maintenance. The limitations, in terms of environmental standards must be recognized.

Trailers may be interpreted to provide flexibility; they are user-friendly dependent on the specific applications.

3.0 LOGISTICS

3.1 EXECUTIVE SUMMARY

The provision of logistics support to the operational Space Station represents one of the major cost drivers of the operational era and is the most sensitive to the adequacy of the design consideration given during the Phase C/D activities. The Logistics Subpanel has addressed the full spectrum of logistics issues from design to mature operations and across all program elements, including the institutional support elements necessary for the thirty year estimated life of the program. During the course of its deliberations, the subpanel reviewed and commented on the Work Package requests for proposals (RFPs).

In addition to the briefings supplied to the Task Force in general, we have attempted to gather information from throughout the Space Station Program and the logistics community at large. The subpanel would like to express its appreciation to all those who took the time to share their experience and expertise with us. Our ability to contribute to this endeavor was significantly enhanced by those from outside the Task Force who participated. The subpanel would also like to acknowledge the outstanding work that has been done to date by those in the program. An enterprise such as the Task Force will always concentrate on the things yet to be done. It is appropriate to recognize at the beginning that many dedicated people have labored hard to bring the program to this point. Our task is to seek to find ways to enhance their efforts to the end that the Space Station Program is better served by us all.

Those from the logistics community who read the report will likely say: "I told you so", while those associated with the program planning to date will find some food for thought. The subpanel suggests that there remains a significant challenge for the program in providing the emphasis in designing for supportability if the baselined requirements for reliability and maintainability are to be realized. The RFPs do not represent a consistent set of design requirements. If they are not supplemented to correct this deficiency, the Space Station system will be more costly to operate and maintain than it should be, and will have less than the desired experiment operations capability.

The subpanel has recommended several changes in approach to the program which, if implemented, should enhance the design effort. A Phase C/D management scheme is presented. Additional facilities for warehousing and repair are proposed and a suggestion for the management of maintenance and resupply/return is discussed. The subpanel hopes the proposals outlined in the summary that follows prove helpful to the program.

SUMMARY OF FINDINGS

- Request For Proposals. Phase C/D
  - All Work Package proposals need to have a common Logistics emphasis for design emphasis
  - Logistics Support Analysis is a start - if it is consistent across Work Packages and integrable
- Logistics Operations Center (LOC)
  - Establish immediately as the Program Office organization

- LOC to integrate acquisition logistics and operational logistics capability development
- LOC to include on-site intermediate & depot capability and management
- Phases out original equipment manufacturers (OEMS)
- Incorporates Automated Test Equipment with OEM provided test equipment
- Ensures flight recertification testing of ORU's
- Monitors maintenance, operations and upgrades to Space Station critical institutional systems.
- Manages and participates in strategic, tactical and execution planning
- Manages common items
- Monitors transportation traffic control
- Reports to Associate Administrator of Space Station
- Maintains a LOC capability development plan and implementation

o Logistics Carrier Prepacking

- Work area required in LOC

o Integrated Logistics Working Group (ILWG)

- Revitalize the ILWG
- Needs dynamic chairperson
- Program Office charter via NASA Management Instruction (NMI)
- Secretariat function by Payload Ground Operations Contractor and/or Program Support Contractor
- Membership from Work Package (WP) Centers and Kennedy Space Center

- Supported by WP contractors as appropriate
- Manages resupply/return requirements determination
- Manages on-orbit storage requirements determination--not adequately managed today
- Ensures acquisition and operational logistics requirements are met and related contract provisions are fulfilled.

o Inventory/Logistics Management System

- Interfaces with Kennedy Inventory Management System (KIMS). KIMS is incomplete for Space Station today, does not include on-orbit storage
- Interfaces with TMIS
- Interfaces with CAD/CAM/CAE/CAL's
- Space Station inventory management must cover all ground and orbital items.

o Customer and International Users

- Coordinate requirements for logistics support through ILWG
- Includes servicing interfaces for logistical goods and services

o Maintenance Paradox

- Maintenance man-hours typically decrease as complexity lessens
- Space Station design requirement is an anomaly

o Space Station Warehousing

- Additional $30M facility required
- Current Space Station estimate is 50K line items; SSOTF estimate is 300K line items
- Inventory buildup phasing depends on block design phasing

- o Technical Documentation
  - Acquire documentation to avoid OEM dependency
- o Availability/Reliability
  - Incentivize contractor to deliver highly reliable system elements

3.2 CONCEPT DESCRIPTION

3.2.1 Introduction

A logistics support concept for any system is largely a matter of system design. While some aspects of logistics support in the operational phase of the Space Station Program lend themselves to variations in approach, the basic scope, character and limitations of the logistics support concept are a result of decisions made during the design phase of the program. Equally as important, are the decisions that are not made. The omission of design requirements addressing logistics support issues will lead to a system that is as unsupportable as one predicated on inappropriate system design decisions.

The task of the Logistics Subpanel -- to envision the fully operational Space Station support system in the year 2010 -- was made more challenging by the fact that the design decisions which characterize the supportability of a system have not yet been made in the Space Station Program. To propose an operational logistics support approach is, consequently, a risky business. However, it affords the subpanel the opportunity to assume that the proper attention has been given to supportability issues at the appropriate times, from beginning to end, in the design process. Notwithstanding the peril of these assumptions, the subpanel has ventured into the future and attempted to describe the salient aspects of a logistics support approach which will satisfy the program constraints as we understand them.

In the course of our deliberations we have suggested approaches different than those currently contemplated by the program to accomplish several logistics functions. The approaches suggested by the subpanel, and our concerns in key areas, are summarized here.

Overview

The Space Station operation era logistics support will be characterized by the human, material and information resources and associated activities required to transport material to and from orbit, repair and maintain the on-orbit hardware and repair and maintain the ground systems. The maintenance of program hardware and the resupply/return of consumable supplies, experiment hardware, maintenance and repair materials, tools and manpower and the transfer of crew persons will constitute a major portion -- at least fifty percent -- of the operational era costs according to recent Space Station Cost Commitment Team findings.

To manage the operational logistics task, the Logistics Operations Center (LOC) is proposed. Reporting to the Program Office NASA Headquarters and located at KSC, the LOC provides the execution level integration to assure logistics support to the Space Station and provides strategic, tactical and execution level planning support to the appropriate levels of management. An on-site intermediate/depot level repair facility at KSC is proposed to perform failure analysis using automated test equipment (ATE), to manage the repair process and to perform recertification testing before returning hardware to orbit. A uniform approach to the maintenance and upgrade of the institutional systems which support the Space Station is suggested as appropriate, with the LOC serving in a program oversight capacity. The facilities and data management required by this approach are proposed to be located at the ground operations center. Data entry and access will be widely distributed.

Recommended Changes in Approach.

Integration of Acquisition Phase Logistics with Logistics Operational Capability Development - The necessity to resolve on-orbit maintenance and resupply/return requirements at the strategic/tactical level and the multi-center integration of logistics support requirements led the Logistics Subpanel to propose the creation of a headquarters Logistics Office at the Program Office level and the Logistics Operations Center (LOC) located at the ground operations center. The functions and roles of these two organizations for the operations phase of the Space Station Program are presented in the discussion which follows.

The recommendation concerns modifying the management approach to the Phase C/D logistics design activities (Acquisition Logistics) and the logistics operational capability development effort. As currently structured, the management of Phase C/D logistics activities has been delegated to the individual Work Package centers. The Integrated Logistics Working Group (ILWG) developed the Phase B program and policy documentation for logistics, but the translation into the Phase C/D Requests for Proposals was not accomplished in a consistent fashion.

The task of operational logistics capability development has not been clearly defined or delegated. The integration of Work Package requirements with operational logistics capability planning has been diligently pursued; however, the priority for this activity has not been sufficiently high on the list of the Work Package centers to meet the needs. Indeed, one would expect the Work Package centers to be more concerned with developing their hardware, and thus the dilemma. Figure 3-1 displays the various facets of the logistics support development process. It is the subpanels observation that only the Assets portion of the program is being pursued and that the Organization and System portions of the program require a comparable level of attention.

The Logistics Subpanel recommends the LOC be created immediately as a function of the Program Office. In order to perform the execution level integration of Phase C/D logistics activities and transition them into a complete operational logistics capability, the structure shown in Figure 3-2 is proposed. The LOC manager would report to both the Program Office manager for Systems Engineering and Integration (SE&I) and the Program Office manager of Utilization and Operations. Operations center personnel would be teamed with contractor support from the SE&I's Program Support Contractor (PSC), staff from the operations center's Payload Ground Operations Contractor (PGOC) and a major aerospace company that has previously been involved with the logistics integration of a large scale program to accomplish the task. Using the logistics integration staff to define the RFP requirements for analysis and integration, the PSC and PGOC personnel would be used to monitor package contractors' performance and to incorporate the resulting design decisions into a comprehensive comprehensive LOC capability development plan. In this manner,

SS PROGRAM	PHASE B	PHASE C	PHASE D	IACO/TRANSITION	MATURE OPERATIONS
LOGISTICS PROGRAM	ESTABLISH CONCEPTS/STRATEGY	OBTAIN SUPPORTABLE DESIGN	DEFINE/ACQUIRE SUPPORT	VALIDATE SUPPORT	MAINTAIN SUPPORT
A. ORGANIZATION	1. CONCEPT 2. DEVELOPMENT PLAN 3. BUDGET BASELINE	1. COMPATIBILITY REVIEW 2. FUNCTIONS AND RESPONSIBILITY BASELINE 3. STAFFING PLAN	1. CHARTER 2. STAFFING 3. OPERATING PROCEDURES	1. VERIFICATION 2. BUDGET TRANSFER 3. RESPONSIBILITY TRANSFER	1. ON-GOING OPERATIONS
B. SYSTEM	1. SYSTEM DESCRIPTION 2. ACQUISITION PLAN 3. BUDGET BASELINE	1. SYSTEM ARCHITECTURE 2. DATA BASE SPECIFICATION 3. ADPE REQUIREMENTS 4. DATA ELEMENT DICTIONARY	1. ADPE PROCUREMENT 2. SOFTWARE DEVELOPMENT 3. CHANGE CONTROL PROCEDURES 4. FILE LOAD 5. DATA VERIFICATION	1. VERIFICATION 2. BUDGET TRANSFER 3. SYSTEM ACCEPTANCE	1. ON-GOING SYSTEM USE AND MAINTENANCE
C. ASSETS	1. LOGISTICS CONCEPTS 2. ALLOCATIONS 3. STD ANALYSIS CRITERIA/METHOD OLOGY 4. BUDGET BASELINE 5. ILS PLAN	1. ALLOCATION VERIFICATION 2. REQUIREMENT BASELINES 3. STD SPECIFICATIONS/PR OCEDURES	1. ALLOCATION VERIFICATION 2. ACQUIRE ASSETS 3. ASSET BASELINES 4. STD CHANGE CONTROL PROCEDURES	1. VERIFICATION 2. BUDGET TRANSFER 3. ASSET TRANSFER	1. ON-GOING ASSET USE AND MAINTENANCE/ REPLENISHMENT

Figure 3-1. Major Logistics Focus by Program Phase

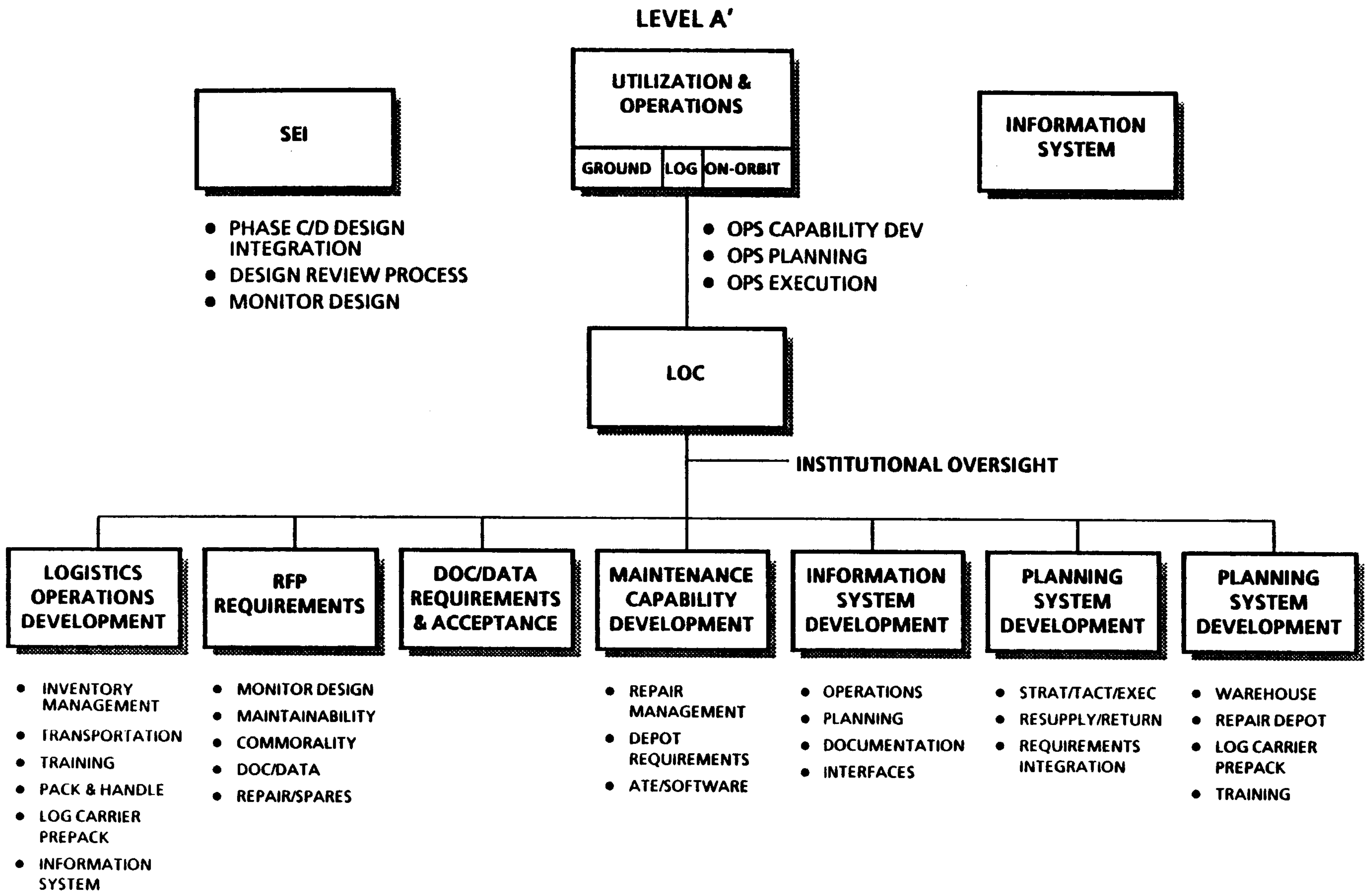


Figure 3-2. Management Structure

the consistent application of logistics design criteria across the Work Packages can be enhanced and the capability to support hardware can be solidly based on the scheduled flow of that hardware and technical systems through the operations center to orbit. As the assembly and verification phase of the program comes to an end, the logistics integration contractor and the PSC participation can be concluded and the NASA/PGOC team would be well prepared to provide the long term logistics support to the program. This orderly flow of responsibility also avoids the disfunctional impacts associated with logistics responsibility transfer that have been experienced within the Space Shuttle Program.

<u>Repair Depot</u>

The long term supportability of the Space Station will depend to a large degree on how effectively hardware returned from orbit can be repaired and maintained on the ground. In examining the current support approaches proposed in the Work Package RFP's and discussing long term support issues with personnel in the Space Shuttle and Air Force reconnaissance programs, the Logistics Subpanel concluded that an on-site intermediate/depot repair facility should be included in the current program planning.

The use of automated test equipment to analyze failure modes and to recertify repaired equipment prior to return to orbit provides a synergistic savings to the program. The need to acquire the technical documentation necessary to maintain, repair and reacquire the Space Station hardware has been strongly recommended to the Task Force. The need to plan, from the beginning, to provide on-site repair capability and to phase out the original equipment manufacturer (OEM) in most cases has also been strongly recommended. It is recognized that there will be some hardware for which the retention of the OEM as the repair source will be the best decision. This will be the exception, however. The subpanel recommends the addition of an on-site depot repair facility at KSC that incorporates these features, to support the maintenance of Space Station hardware.

Log Carrier Prepack.

The reconfiguration of the Space Station Processing Facility to serve as an experiment verification and checkout facility will provide an excellent user support facility. The ground processing flow, however, should not be encumbered with the routine packing of non-experiment materials destined for orbit. The Logistics Subpanel recommends that a logistics carrier prepacking area be included in the proposed Space Station logistics facility. The off-line prepacking of racks and drawers for installation in the pressurized logistics carrier as well as the preparation of the nonhazardous unpressurized logistics carriers will ease the pressure for on-line ground processing and will be a compatible addition to the tasks already performed on the logistics facility.

Key Areas of Concern

Maintenance Paradox. In the process of reviewing the Work Package RFPs, the Logistics Subpanel concluded that the requirements for reliability and maintainability were not consistently applied to all the RFPs and that the criteria stated was extremely ambitious. The subpanel sought to examine the maintenance philosophy and to compare the current Space Station approach with other comparable systems. Figure 3-3

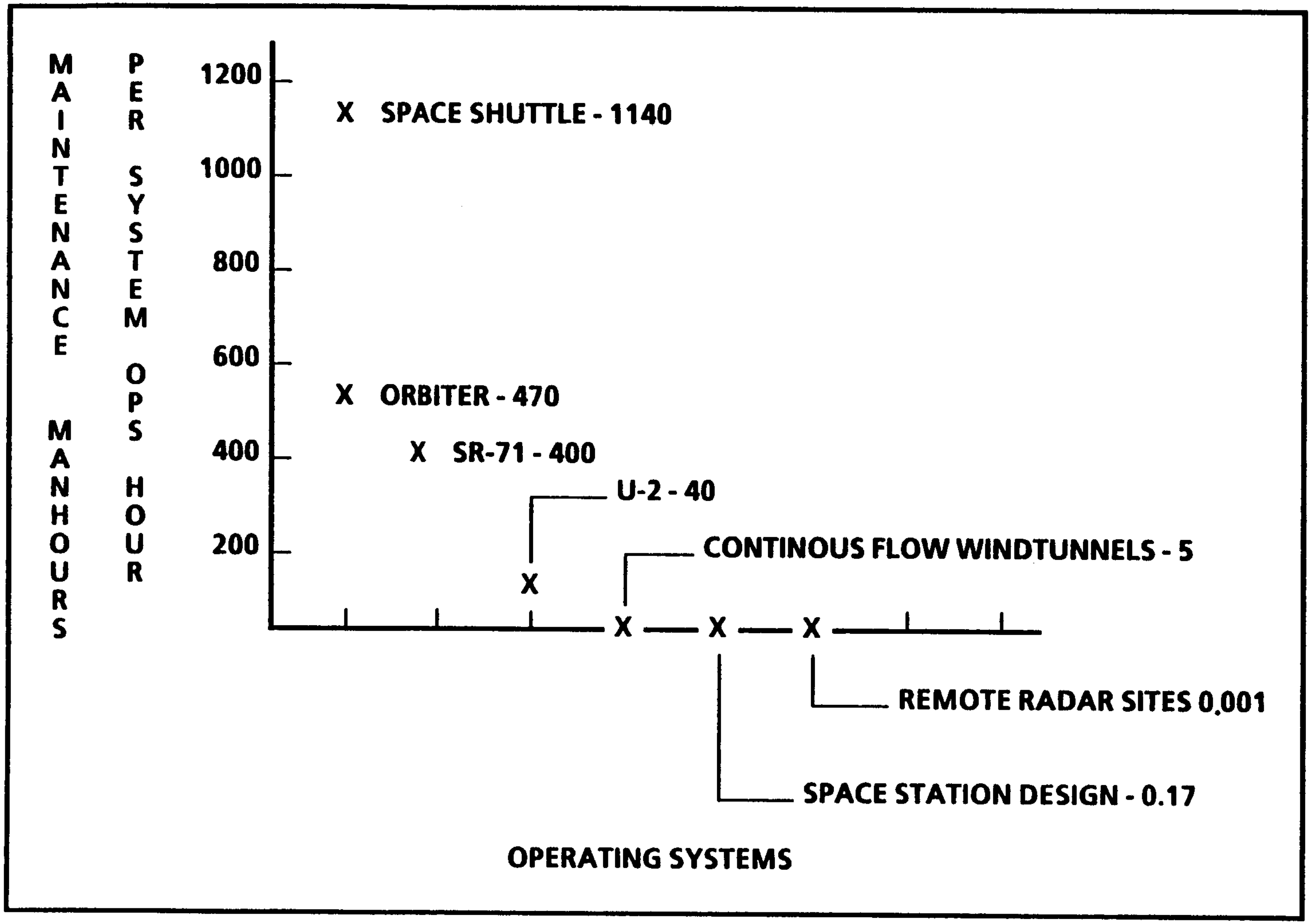


Figure 3-3. Space Station Maintenance Paradox

displays the maintenance man-hours per system operating hour for the systems examined. The paradox lies in the fact that maintenance man-hours per system operating hour decreases as system complexity decreases, yet the Space Station design is very complex and is allotted fewer maintenance man-hours per system operating hour.

In achieving the 0.001 maintenance man-hours per system operating hour for the remote radar sites, the Air Force used a number of techniques to focus on reliability and maintainability as design requirements. Proposal evaluation criteria, requirements to demonstrate reliability during design, award fee evaluation criteria and performance bonuses were all employed to get the contractor to focus on delivering a very reliable product that required a minimum of maintenance.

Another aspect of the paradox which needs closer examination is the trade-off between experiment operations and on-orbit repair. The philosophy followed by the Air Force in achieving the low maintenance man-hour posture is to only remove and replace failed components. Most repair is done at a depot facility; there is no attempt to perform major repair at the remote site. There are, however, combinations of circumstances for which it is economical to perform repair on-orbit. Mr. Robert Shiskho of JPL points out in a position paper written for the subpanel that the key decision factors are the "prices" one associates with parameters such as crewtime and delivery to orbit. The issues of "real cost", imputed cost and opportunity cost need to be addressed as applied to the Space Station maintenance philosophy.

A further manifestation of the subpanel's concern is addressed by David Lowry, Boeing Aerospace Company, and Thomas Feaster, NASA KSC, in their Space Congress presentation entitled, " Regaining Space Leadership Through the Control of Life Cycle Cost". Their discussion points out that the Department of Defense and commercial aircraft development efforts typically spend forty percent of the life cycle cost in design, development and production and sixty percent in operations. Whereas in the Space Shuttle Program, fourteen percent of the life cycle cost was spent in design, development and production and eighty six percent spent in operations. Even when the subtleties of the NASA budget process are accounted for, the message is clear: the energy spent during design on behalf of high reliability and low maintainability pays back handsomely.

The Logistics Subpanel suggests that the program requirements for reliability and maintainability should be reviewed for compatibility with the state-of-the art in system design and with the assumptions concerning the cost of current program design requirements. After a position has been established, a clear, concise and consistent description of the NASA design expectation should be provided to the Work Package contractors. Consideration should also, be given to innovative approaches to encourage the contractors to enhance the reliability and maintainability of their designs.

<u>Resupply Return</u>. The current state of resupply/return planning places the Space Station Program in great peril. The existing projections of under support are approximately 35,000 pounds a year of up mass and 150,000 pounds a year of down mass. Equally as disturbing is the apparent lack of assignment of the management of this critical aspect of the program. The management of resupply/return requirements was assigned to the

Integrated Logistics Working Group(ILWG). The ILWG has since become inactive, not having met since August, 1986. The management of resupply/return capability development appears not to be organizationally assigned. The subpanel could not find a group actively pursuing the resolution of this operational dilemma. The over subscription of Space Shuttle based resupply/return capability and the degradation in Space Shuttle availability as a transportation medium for the Space Station call for an aggressive review of resupply/return planning and management.

The Logistics Subpanel recommends that the Integrated Logistics Working Group be revitalized and their assignment to manage resupply/return requirements be vigorously pursued. Further, that the Space Station Program reassess the realities of the degrading availability of Space Shuttle and aggressively examine all expendable launch vehicle alternatives for accomplishing resupply/return. In addition, the management of resupply/return capability development should be clearly assigned and the long term management of resupply/return should be considered for delegation to the LOC to facilitate the synergistic management of maintenance, resupply/return and the logistics infrastructure that support the program.

<u>On-Orbit Storage</u> - In reviewing the allocations of on-orbit weight and volume for various activities (JSC 30000 Section 6, Rev. A) , the Logistics Subpanel could not find allocations for on-orbit storage. The requirements document calls for the incorporation of storage in the element designs but gives no allocation of weight or volume. All of the schemes for the management of resupply/return presented to the Subpanel called for extensive on-orbit storage. However, there is no apparent assignment of management responsibility for this critical Space

Station resource. The Logistics Subpanel recommends that this assignment be given to the ILWG as a synergistic addition to their resupply/return requirements management role.

<u>RFP Inconsistencies</u> - Since the review of the Work Package RFP's was completed, we have not, as a group, had the opportunity to look at the revised RFPs to ensure the fidelity of data items and data item delivery schedules. However, the review in the Fall of 1986 revealed inconsistencies in across-the-board data requirements, (see Table 3-1) a characteristic that will compound the work required in integration of Work Package products. The attempt to create a common content document for use in RFP preparation was an excellent step. Unfortunately, the translation of the common content document into individual RFP requirements was not uniform. As a result the requirements for system Availability, Reliability, and Maintainability are not consistent across the Work Packages. The long term cost and supportability of the integrated Space Station will be heavily dependent on the consistency of logistics design across the Work Packages.

The subpanel recommends the RFP's be reviewed for consistency of data and design requirements, and that inconsistencies receive appropriate resolution through the Program Office action. (See Table 3-2).

3.2.2 Assumptions

These assumptions have been segregated into three categories strategic, tactical and execution. This segregation is consistent with the following SSOTF "criteria for assignment of functions":

DATA REQUIREMENT	WP1	WP2	WP3	WP4	PSC
1. Configuration Management Plan	CM 01 60 Days after CSD Rid written	No DRS with RFP	MD 07 with proposal	CM 01 with proposal	No DRS with RFP
2. Commonality Plan	SE 03 5 Weeks after CSD Rid written	No DRS with RFP	None Rid written	SE 10 with proposal	No DRS with RFP
3. Maintainability Plan	LS 02 30 Days after CSD Rid written	No DRS with RFP	Sep 01 at PDR Rid written	None Rid written	No DRS with RFP
4. Integrated Logistics Support Plan *(includes LSA Plan as appendix)*	LS 01 Schedule/ outline with proposal no LSAP required 2 RIDs required	No DRS with RFP	OPD 09 schedule/ outline with proposal Rid written	LS 01 30 Days prior to PDR Rid written	No DRS with RFP
5. System Engineering and Integration Plan	SE 01 2 Weeks after CSD Rid written	No DRS with RFP	SE 02 at PDR, Rid required	SE 01 with proposal	No DRS with RFP

TABLE 3-1 RFP LOGISTICS DATA REQUIREMENTS

RECOMMENDATIONS FOR RFP LOGISTICS DATA REQUIREMENTS

1. Require initial submission with proposal (including PSC)

2. Negotiate NASA comments prior to contract award

3. Require revised submission 30 days after CSD

4. Establish minimum program wide data requirements content

5. Develop review criteria for each submission

6. Centrally approve (Level A') the RID package for each submission (i.e. the baseline to negotiate comments with contractor)

7. Centrally (A') verify that the RID package has been negotiated in an acceptable manner prior to authorizing contract award

8. Provide on-going oversight (A') of plan implementations

TABLE 3-2 REVIEW OF DATA AND DESIGN REQUIREMENTS

- <u>Strategic</u> - Those functions concerned primarily with establishing and coordinating the objectives and policies of the organization. These objectives and policies affect a broad range of customers and institutional activities.

- <u>Tactical</u> - Those functions concerned primarily with using the established objectives and policies to produce plans and directions for their accomplishment.

- <u>Execution</u> - Those functions whose products and activities result in either an institutional end product or products and activities accomplishing the details of a plan in support of a specific end product.

<u>Strategic Assumptions</u>

1. By 2010 A.D., the operational phase has matured to the full up operational station.

2. Growth/evolution phase is now in process.

3. Users are NASA, U.S. industry, academic, DoD, internationals and private citizens.

4. NASA provides any off-line Space Station user with support/logistics as negotiated, budgeted and funded by the user. Support is provided by the operations center and reimbursed by the user.

5. NASA is still an integral part of the management/execution scheme.

6. Associate Administrators for programs still exist at NASA Headquarters; the Associate Administrator for Space Station operations is located at Headquarters.

7. The traditional roles for NASA centers remain the same. KSC has become the agency's focal point for space operations. There are operations contractors for both the STS and the Space Station, and new systems are expected to follow suit.

8. New starts include Space Stations 2 and 3, Mars Mission, Lunar Station and STS II.

9. Industry is a "participant" in some programs, i.e., in partnership with NASA.

10. Internationals and DOD are participants on Space Station.

Tactical

1. The prime Space Station logistics functions are ground and on-orbit maintenance and resupply/return.

2. The Space Station Program elements include two U.S. modules, four nodes, truss structure, co-orbiting and polar platforms, photovoltaic and solar dynamic power systems, a satellite servicing facility, a mobile service center, two international modules, and five different logistics carrier types. These systems are comprised of state-of-the art space qualified hardware and include all the subsystems necessary to sustain life and on-orbit operations.

3. Three maintenance levels have been implemented: organizational (on-orbit and ground), intermediate (ground repair/modification) and depot (modification, repair, fabrication and checkout).

4. Organizationally, "Logistics" is on the same level as "Operations" and "Systems, Integration and Engineering".

5. A high priority small sample return system is operational, e.g., parachute recovery by a C-131, unmanned recovery capsule or remotely piloted vehicle. The Crew Emergency Return Vehicle also supports this activity.

6. A Logistics Operations Center (LOC) manages integrated logistics support for the Space Station Program.

7. The Space Station inventory management system is a subset of the Logistics Information System and includes the management of assets on the ground and on orbit.

8. On-Orbit Replaceable Units are verified operational by operations center personnel prior to shipment to the Space Station.

9. The resupply interval is 45 days.

10. Engineering and maintenance technical data is adequate for inhouse support to ground and on-orbit Space Station systems, including support equipment.

11. Integrated, relational data base products are available for logistics trend analysis and corrective action.

12. The Logistics Operations Center has implemented a fully automated warehouse which utilizes bar-coding and other "smart" identification tags.

13. Logistics management responsibility transfer (LMRT) to the Logistics Operations Center was initiated during Phase C/D and completed on a system-by-system basis within one year after orbital deployment.

14. Industry still exists in customer/contractor relationships in all programs.

15. Medium and heavy lift expendable launch vehicles are an integral part of space transportation services.

16. The 1990-2015 program dilemma associated with an inability to support the annual up mass and down mass requirements has been resolved. The management of resupply/return is a primary function of the Logistics Operations Center.

17. Crew rescue vehicles are part of the U.S. space transportation services fleet.

18. The on-orbit maintenance concept of "Remove and Replace at the ORU/LRU level" was designed in during Phase C/D and has been proven.

<u>Execution</u>

1. Source, Maintenance and Recoverability (SMR) codes are used to procure, maintain, and dispose of material.

2. Spares have been acquired to provide the best system availability for the optimum funding level.

3. Maintenance - After an ORU has been received at the repair location the nominal turn-around-time (TAT) for ORU repair is:

   - Intermediate level - 14 days
   - Depot Level at the LOC - 30 days
   - Depot level within the U.S. - 60 days.
   - Depot level outside the U.S., i.e., international - 90 days.

4. Fly-in maintenance crews augment on-orbit maintenance. The fly-in maintenance crews consist of normally ground-based maintenance personnel.

5. Material Management

   - There are approximately 300,000 line items in the Space Station inventory.

   - The initial provisioning for new items covers 24 months after the first planned use.

   - The inventory management system accommodates the partner-participants.

6. Cannibalization is used only to correct an on-orbit life-threatening situation.

7. National Stock Numbers for all parts are identified by the Federal Supply Code for manufacturers and manufacturers' part number.

8. Average Space Station ORU characteristics:

   Weight: 16.1 pounds

   Size: 1.0 cubic foot

   Cost: $20k/pound installed in orbit

   Cost base: 1986 dollars

   Cost /ORU: $322k

   10 SRUs: ORU

   20 piece parts/SRU

   On-orbit storage requirements: TBD

9. A nominal cost of one man year's effort (50K per year, 84 $) is needed to keep an OEM's door open. This amount is considered an overhead tax for a plant contact, updated drawings, operational test equipment, etc. This cost does not include any actual repair costs.

10. An economic discard criteria of spending no more than 65% of replacement cost of an ORU is the guide for

repair/discard. Discard by orbital deboost and reentry burn is an option applied when return capacity is exceeded, on-orbit stowage capacity is maxed out and non-toxic burn products result.

11. Serialized control for all ORUs permits precise configuration control and "bad actor" corrective action.

12. The Viking Lunar Lander Oven at KSC is available for refurbishment and reuse for Space Station; ORU recertification and additional facilities for vibration and thermal-vacuum testing have been added.

Anticipated New Technology and Innovations.

The following technology enhancements have been assumed as applicable to the logistics support efforts in the year 2010.

CAD/CAM/CAE Interface with LIS

1. Computer aided design is routine

2. Logistics information system interfaces with the CAD/CAE data bases provide a CALS capability.

3. Repair procedures are automated with touch screen and voice recognition features.

Artificial Intelligence (AI)

1. Artificial intelligence is in the process of maturing.

2. Breakthroughs have occurred which aid in applying this technology to repair diagnostics.

Machine Vision (MV)

1. Machine vision is an extension of AI.

2. Optomechanical sensors substitute for human optical and tactile sensors.

Automatic Fault Isolation and Self Healing

1. AI and MV augment failure identification.
2. Self repair is automated to a low level of capability

3.2.3 Major Functions

3.2.3.1 Maintenance - Maintenance is a primary task for the operational Space Station logistics system. The scope of activities involved and the breadth of interfaces necessary to integrate maintenance activities with other activities led the panel to address a structure for maintenance management. Table 3-3 shows the interfaces for on-orbit and ground maintenance. Historically the management of these program elements has been fragmented and distributed across several Centers. In order to support the strategic and tactical planning process and to effectively execute on-orbit maintenance, these program elements must be managed in a different fashion.

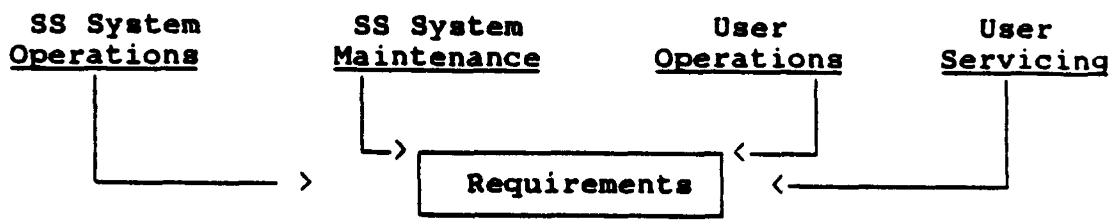
Figure 3-4 addresses the complexity associated with the resolution of resupply/return requirements and the management fragmentation of the resources necessary to satisfy those requirements. The resolution of requirements priorities is clearly a strategic/tactical task which must be accomplished in the rarefied environment of the Tactical Operations Control Board (TOCB).

The management structure necessary to ensure the effective and efficient management of Space Station Maintenance and resupply/return must cope with the diversity of integration and management interfaces. It must be capable of integrating strategic, tactical and execution level of planning. It must identify accountability for Space Station performance and it

TABLE 3-3

MAINTENANCE ELEMENT INTERFACES

- ON ORBIT INTERFACES
  - SUSTAINING ENGINEERING
    - CONFIGURATION MANAGEMENT
    - MODIFICATION MANAGEMENT
  - LOGISTICS
    - INVENTORY MANAGEMENT
    - REPAIR MANAGEMENT
    - STORAGE MANAGEMENT
    - TECHNICAL DOCUMENTATION MANAGEMENT
  - ON-ORBIT OPERATIONS
    - ON-ORBIT CONFIGURATION MANAGEMENT
    - CREW ACTIVITY PLANNING
- GROUND INTERFACES
  - DISTRIBUTED GSE/ATE/INTEGRATION FACILITIES
  - SYSTEMS WITH INSTITUTIONAL IDENTITY
    - WAREHOUSING
    - SIMULATORS
    - TRAINERS
    - TEST BEDS
  - PROGRAM AND INSTITUTIONAL FUNDING



- o Requirements resolution is a strategic/tactical task.
- o Resource management is fragmented
- o Payload capacity to and from orbit is oversubscribed

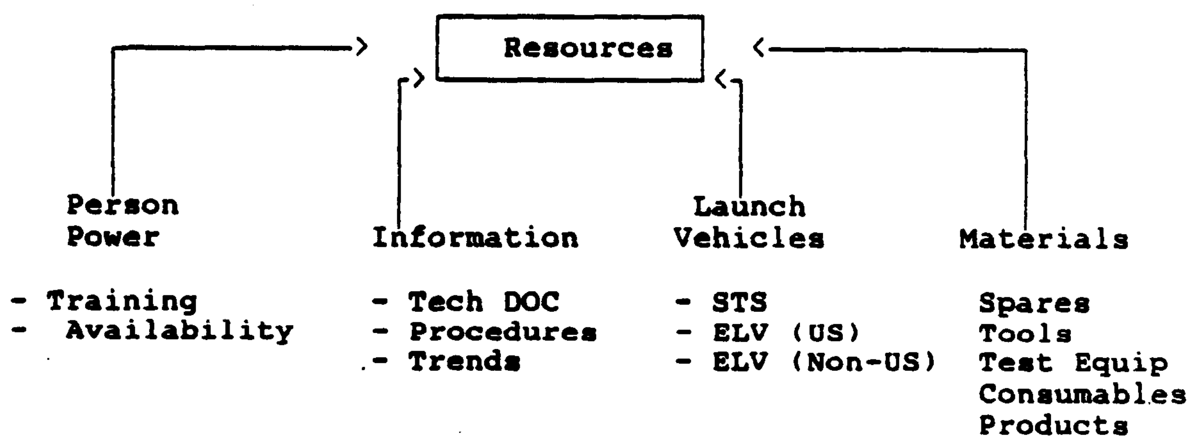


FIGURE 3-4 RESUPPLY / RETURN

must manage the systemic processes and issues which cross institutional and management level boundaries. The Headquarters and operations center structure proposed is shown in Figure 3-5. The Program Office would provide the strategic and tactical integration across requirements and integrate the planning requirements across ground, logistics, and on-orbit operations. The Logistics Operations Center, located at the ground operations center, would provide the day-to-day management of Space Station logistics support. It would provide technical logistics support to the TOCB process and would manage Maintenance both on-orbit and on the ground and resupply/return.

The management roles are shown in Table 3-4 and Table 3-5.

The establishment of the dedicated Headquarters logistics function and the Logistics Operations Center will provide the continuity of strategic, tactical, and execution logistics planning and actual execution necessary for effective Logistics support to the program.

ON-ORBIT MAINTENANCE

The successful planning and execution of on-orbit maintenance for the Space Station will be one of the most challenging operations era tasks. The synthesis of flight increment (see discussion under Anticipated Environment) maintenance and modification plans and their integration into the strategic, tactical and execution planning process will require the integration of Sustaining Engineering technical documentation, material/tools/training, repair management, and resupply/return management requirements with the operational constraints imposed by the Space Station Support Center and Payload Operations Integration Center. The following discussion

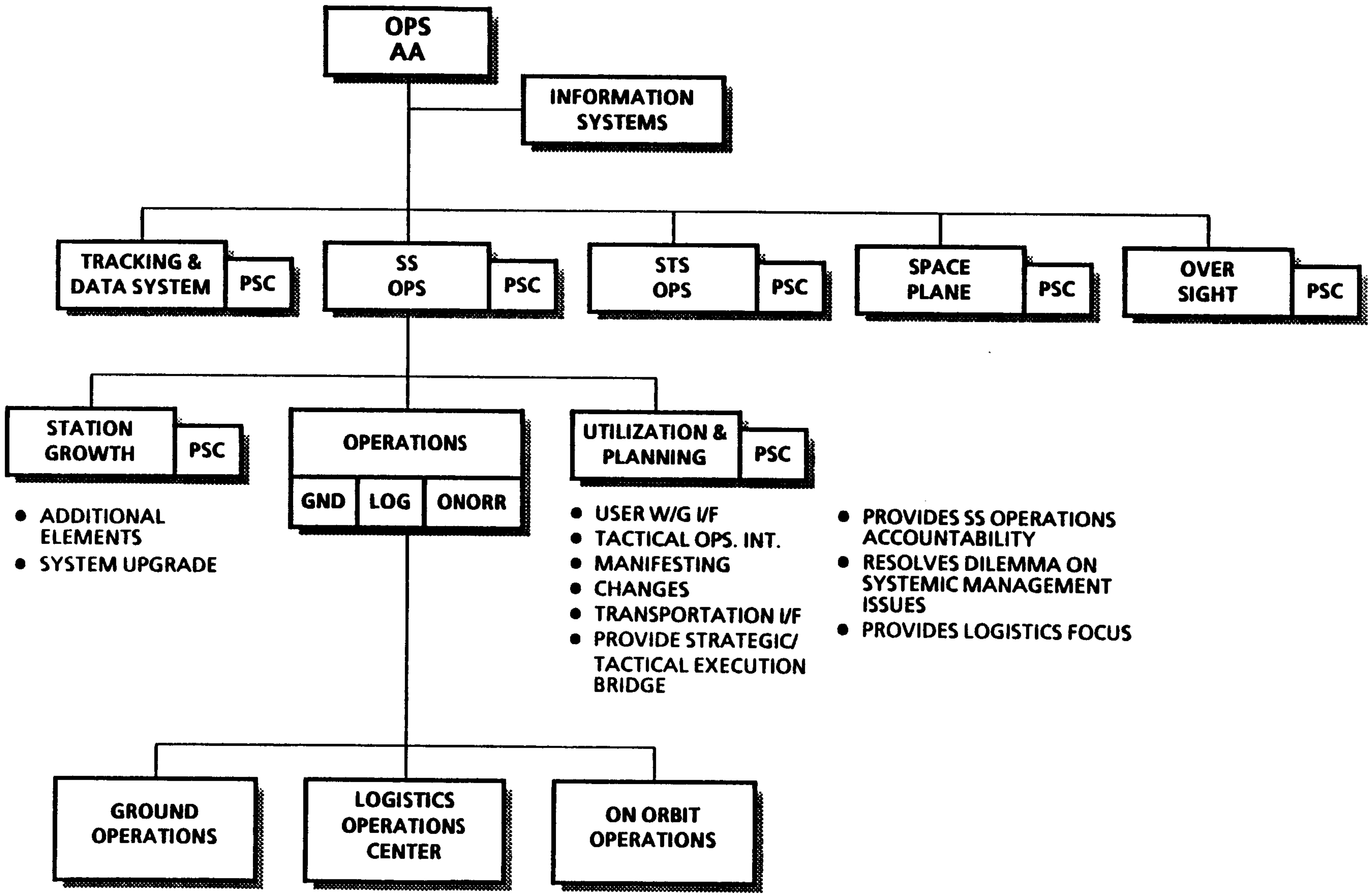


Figure 3-5. Headquarters and Operations Center Organizational Structure

TABLE 3-4

PROGRAM OFFICE LOGISTICS MANAGEMENT ROLES

- ESTABLISHES AND MAINTAINS SPACE STATION PROGRAM LOGISTICS POLICY PROCEDURES, SPECIFICATIONS, AND STANDARDS
- REPORTS DIRECTLY TO SS OPERATIONS FOR SS PERFORMANCE
- INTEGRATES TOCB DECISIONS INTO GROUND, LOGISTICS AND ON-ORBIT TACTICAL/EXECUTION PLANNING REQUIREMENTS.
- GENERATES LOGISTICS, GROUND AND ON-ORBIT STRATEGIC PLANS
- APPROVES LOGISTICS GROUND, AND ON-ORBIT TACTICAL AND EXECUTION PLANS
- MANAGES RESUPPLY/RETURN
- MANAGES ON-ORBIT AND GROUND MAINTENANCE
- MANAGES BUDGET FOR SPACE STATION PROGRAM LOGISTICS ACTIVITIES
- INVOLVES CENTER PERSONNEL THROUGH TDY ASSIGNMENTS
- PROVIDES PERFORMANCE APPRAISAL INPUTS FOR LOGISTICS, GROUND, AND ON-ORBIT OPERATIONS MANAGERS

TABLE 3-5

LOGISTICS OPERATIONS CENTER MANAGEMENT ROLES

- DEVELOPS STRATEGIC PLANNING INPUTS FOR THE PROGRAM OFFICE
- DEVELOPS TACTICAL AND EXECUTION LOGISTICS PLANS FOR GROUND AND ON-ORBIT SUPPORT
- EXECUTES RESUPPLY/RETURN FUNCTION
- EXECUTES MAINTENANCE, REPLENISHMENT AND USER LOGISTICS SUPPORT FUNCTIONS
- MANAGES LOGISTICS OPERATIONS AT THE OPERATIONS CENTER
- MANAGES THE LOGISTICS INFORMATION SYSTEM
- MANAGES BUDGET FOR ASSIGNED HARDWARE,SOFTWARE AND CONSUMABLES
- MONITORS/MANAGES REPAIR CYCLES FOR GSE, ORU'S, ATE AND SRU'S
- MONITORS TRANSPORTATION STATUS AND CHANGES SHIPPING PRIORITIES

addresses the proposed approach to on-orbit maintenance planning, the operational environment expected and a description of on-orbit maintenance execution.

Strategic Planning Concept

The Logistics Operations Center (LOC) provides technical input to the Space Station Users Board (SSUB) in support of the development of the five year Consolidated Utilization Plan (CUP). The LOC annually provides the SSUB with a strategic (24-60 month) maintenance and modification requirement projection. Tactical planning approval status is shown on this projection for maintenance and modification requirements in the twenty-four (24) to thirty-six (36) month time frame. Tactical planning approval prerequisites and, where applicable, resupply/return and evolution mass and volume requirements are identified in the projection.

The SSUB integrates the LOC strategic planning requirements with the strategic planning input received from the SSSC, POIC and the ground operations center. This strategic projection identifies the gross man-hour, mass and volume requirements of each flight increment. The SSUB integrates the inputs received to prepare the CUP. This integration process verifies that all proposed events comply with strategic planning prerequisites; program man-hour, mass and volume units are not exceeded; and event priorities are established. An approved budget and an acceptable procurement schedule, if applicable, are minimum strategic planning approval prerequisites. Thus, the strategic planning process represents the allocation of critical orbital resources (man-hours, mass and volume) in a prioritized manner which identifies the impact of the decisions made and affords an opportunity to explore alternatives.

Tactical Planning Concept

Semiannually, the Space Station Tactical Operations Control Board (TOCB) issues a Space Station Tactical Operations Plan (TOP). This plan addresses the major events scheduled for accomplishment during each flight increment in the next twelve (12) to thirty-six (36) months. Thus, the TOP includes the tactical planning window (18-36 month time frame) and overlaps the execution planning window.

The TOP establishes a man-hour allocation for the major events in each flight increment. Each man-hour allocation is segregated into an IVA and EVA component. In addition to an event man-hour allocation, the TOP establishes an event mass and volume allocation for the resupply/return. The TOP includes a major sequence profile for each flight increment. The man-hour requirements for each event are identified on the event sequence profile. The resupply and return profiles also identify applicable mass and volume requirements. In addition, the event sequence profiles cite Space Station Execution Operations Plan (EOP) event approval prerequisites. The TOP shows the EOP approval status of events and event sequence profiles in each flight increment in the next twenty-four (24) to thirty-six (36) months.

The LOC semiannually provides the TOCB a tactical (18-36 month) maintenance and modification event sequence profile. Execution planning approval status is shown on this profile for maintenance and modification requirements in the next twelve (12) to eighteen (18) months. Execution planning approval prerequisites, and where applicable, resupply/return mass and volume requirements are also identified in the profiles.

The TOCB integrates the input received from the LOC with inputs received from the SSSC, the POIC and the Operations Center to prepare the TOP. This integration process verifies that all proposed profiles comply with tactical planning prerequisites; event man-hour, mass and volume limits are not exceeded; and event priorities are reconciled. Identification of payload integration requirements, definition of the on-orbit event execution steps and associated man-hour requirements, hardware delivery schedules consistent with payload integration requirements, and the delivery of on-orbit event execution procedures are typical execution planning approval prerequisites. Thus, the tactical planning process represents a prioritization of critical orbital resources (man-hours, mass and volume) and a verification of execution planning prerequisites in a manner which identifies the impact of the decisions made and affords an opportunity to explore alternatives.

Execution Planning Concept

Quarterly, the TOCB issues a Space Station Execution Operations Plan (EOP). This plan addresses all events scheduled for accomplishment during each Transfer Period and Flight Segment in the next eighteen (18) months. Thus, the EOP includes the execution planning window and overlaps the current execution period (0-3 month time frame).

The LOC forwards maintenance and modification execution event planning and verification data to the TOCB quarterly. This data shows execution event verification status for maintenance and modification requirements in the next three (3) to eighteen (18) months. Execution event verification is a mandatory execution event approval prerequisite.

The TOCB integrates the LOC, SSSC, POIC execution event data with data received from the Operations Center. After all data is integrated, the TOCB issues the EOP. The EOP shows the actual execution approval status of each planned execution event. Thus, the execution planning process represents a gateway through which an event must pass to verify that the event can be safely accomplished on-orbit and to accommodate priority realignments.

ANTICIPATED ENVIRONMENT (2010 AD)

Space Station operations are executed in a series of repetitive 45 day cycles throughout the useful life of the Space Station. Each 45 day cycle is composed of three segments. One segment is a 7-10 day transfer period during which the Space Shuttle or other carrier/vehicle is docked at the Space Station. The second segment is a 22-25 day operations and maintenance segment during which the Space Shuttle is not docked at the Space Station. The third segment is a 7-10 day period in preparation for return of the Space Shuttle.

The Space Station is in mature operations. Major reliability problems have been solved. Design modifications have been installed to reduce the on-orbit maintenance workload experienced during the early operational years. Validated data bases exist to justify all on-orbit "in-place" consumable replenishments/replacements which are minimal.

On-orbit "Repair-in-Place" and "Repair Off-Line" maintenance actions are performed only in response to safety related emergency conditions. On-orbit maintenance of Space Station

Elements/Systems/Equipment consists of one or more of the four following types of maintenance: 1) Periodic maintenance (preventive), 2) Condition-Monitored Maintenance (preventive), 3) On-Condition Maintenance (corrective), and 4) modification. These terms are defined below.

a. Preventive Maintenance

Periodic Maintenance: The replacement of an item with an identical item on a fixed schedule. The fixed schedule is based on validated historical data. This type of maintenance is required for mission critical and safety items and is scheduled for accomplishment during transfer periods.

Condition Monitored Maintenance: The replacement of an item with an identical item on a schedule determined by the continuous analysis of operational performance data. This type of maintenance is required for safety items and highly desirable for mission items as well as other items. Maintenance is scheduled for accomplishment during flight increments.

b. Corrective Maintenance

On-Condition Maintenance: The unscheduled replacement of an item, after failure, with an identical item. This type of maintenance is not applicable to safety nor mission critical items. On-Condition maintenance can be scheduled for accomplishment during either the transfer periods or flight increments.

c. Modification: The scheduled replacement of an item with an item of a different configuration (new or modified). This type of maintenance is scheduled for accomplishment during transfer period for mission and safety items. Modification to other items are scheduled for accomplishment during transfer periods.

Due to 1) the availability of additional manpower, 2) the reduction of an on-orbit storage requirement, 3) the elimination of the risk of installing spares of the wrong configuration, and 4) the impact on flight increment operations, modernizations are normally made and tested during transfer periods instead of flight increments.

ON-ORBIT EXECUTION DESCRIPTION

On-orbit maintenance execution for Space Station hardware requires the existence of logistics systems, organizations, and capabilities along with compatible Space Station hardware. The systems, facilities and capabilities cannot be acquired without a detailed baseline on-orbit maintenance scenario. The following discussion provides an example to a level of detail required to support acquisition of the logistics systems, organizations and capabilities.

The SSSC transmits a 10-day on-orbit event schedule to the Space Station daily. The event schedule includes all operations and maintenance events authorized for accomplishment during the 10-day period. The Space Station crew can adjust when an event is performed, but they cannot add an event to the schedule i.e., all events must be entered on the event schedule by the SSSC. The SSSC acts as the single point of contact with the Space Station for all matters related to the planning, scheduling and execution of emergency corrective maintenance.

The SSSC maintains an on-orbit event completion file and an on-orbit event deferral file. Maintenance event completion and deferral information is transmitted to the LOC by the SSSC. The LOC updates the appropriate LOC files to reflect this completion and deferral information.

The LOC identifies the on-orbit manpower, skills, material and technical information needed to perform each maintenance requirement on a transfer period or flight increment and forwards the resulting maintenance list to SSSC. The LOC identifies material needed to accomplish on-orbit transfer period or flight increment maintenance requirements or to replenish material used during previously completed on-orbit maintenance events and relays this in formation into the inventory management system. The inventory management system then provides the manifest status of this material to the LOC. The LOC adjusts the maintenance requirement schedule to reflect material shortfalls or requests a Space Transportation System manifest priority adjustment. Resulting maintenance schedule revisions are forwarded to the SSSC, after manifest approval. The master orbital hardware maintenance requirements file is linked to a configuration status accounting file, an on-orbit maintenance procedure file, an on-orbit inventory management file, a ground inventory management file, a modification requirements file, and a maintenance history file. The maintenance history file includes on-orbit maintenance event completion, material usage, manpower utilization, procedure utilization, maintenance event deferral and maintenance event deferral reason information.

The LOC coordinates the maintenance of an on-orbit data file which contains the procedures needed to accomplish the maintenance requirements on the flight increment schedules.

The LOC also coordinates the maintenance of an on-orbit data file which contains the operating and casualty procedures used by the Space Station crew. To support procedures files maintenance, the LOC coordinates the development, verification and/or routine transmission of maintenance procedures needed to support on-orbit emergency corrective maintenance.

The LOC's on-orbit flight increment maintenance requirements file has two sections. One section, the Active Maintenance section, contains all maintenance requirements included on the 10-day operations and maintenance event schedule issued by the SSSC and is accessed by either event number or maintenance requirement number. The second section, the Maintenance Backlog section, contains all maintenance requirements for the next 120 days which have not been assigned an event number by the SSSC, and it is accessed by date or maintenance requirement number.

A planning and estimating (P&E) record exists for each maintenance requirements file. This P&E record contains the major steps to accomplish each maintenance requirement, the manpower and skill level, the tools and test equipment, the material and the maintenance procedure number(s) needed to perform each step.

This file is replicated on-orbit. The LOC transmits weekly additions, deletions and changes to the maintenance backlog section of this file. The LOC does not change data in the Active Maintenance section of this file. The Space Station crew, alone, changes data in the Active Maintenance section of this file to show that a maintenance requirement is either completed or deferred. The LOC identifies any recommended changes to the Active Job section of this file to the SSSC which in turn transmits the recommendations to the Space Station crew.

In developing the P&E record for each maintenance requirement, the LOC verifies the on-orbit availability of the skill level, material (tools, parts and test equipment) and technical data (maintenance procedures and drawings). Skill level shortfalls are treated as replacement crew training requirements. Material shortfalls are treated as transportation manifest and inventory management system demands, and technical data shortfalls are treated as TMIS development requirements.

Once a maintenance requirement appears on the 10-day on-orbit event schedule, the Space Station crew uses the P&E record to query the on-orbit inventory management system to determine the on-orbit location of the tools, parts and test equipment needed to accomplish the maintenance requirement. This location data is copied onto the P&E record. Similarly the Space Station crew queries TMIS and copies the needed maintenance procedure as a trailer record to the appropriate step in the P&E record. These copy transaction are voice activated and/or key stroked. Any material or technical data deficiency is communicated to the SSSC. The SSSC coordinates resolution of these deficiencies with the LOC.

The P&E record and the technical data trailer record are down-loaded onto a portable maintenance aiding device. This maintenance aiding device has, for example, an optical scanner, a microphone, a key pad and a video display. The Space Station crew obtains the material needed to perform the maintenance event from its on-orbit storage location.
Using the optical scanner, the crew member scans the material removed and its storage container. If the item scanned is not

on the P&E record, a suitable response is provided to the crew member.

The validated material is then taken to the area where the maintenance event will be performed. Since the on-orbit material storage location is close to the on-orbit location of the equipment the material supports, the time required to transport this material is minimal. Using the maintenance aiding device for procedural guidance, the installed material is isolated and removed, the replacement material is installed, and a functional test is performed. Procedural deviations are voice or key pad entered into the maintenance aid device. The removed material is scanned and placed in the return mass container identified on the P&E record. The scanner is used to read the bar code or other label on the container and thereby identify the on-orbit disposition of the removed material.

The crew member transfers the information on the maintenance aiding device to a maintenance event completion record in an on-orbit operations and maintenance event completion file. This record is transmitted to the SSSC. The SSSC closes the maintenance event and transmits the maintenance event completion record to the LOC.

If the maintenance event involves installing a modification (configuration change), the P&E record for the maintenance event will include steps which: 1) remove obsolete material (parts, tools, and test equipment) and put them in down mass containers, 2) place new material in the designated on-orbit locations, and 3) purge obsolete and add new maintenance procedures to on-orbit technical data files.

GROUND MAINTENANCE

INTRODUCTION

A number of issues were examined by the panel related to the maintenance task to be accomplished on the ground. The trade off between original equipment manufacturer (OEM) support versus the role of a depot repair facility in the repair of on-orbit hardware, the operational dependence of the Space Station Program on systems historically viewed as institutional assets, the wide distribution of GSE that will require repair support and the relationship between repair management and resupply/return management were the major subjects addressed.

REPAIR OF FLIGHT HARDWARE

The repair of failed flight hardware will represent a significant portion of the ground maintenance effort. Logistics Support Analysis (LSA) during the Phase C/D design effort should provide a detailed repair level analysis. The planned mix of repair among OEMs, third parties and on-site capability should be examined. The analysis of probable losses of OEM repair capability should also be part of this analysis and a plan to recover from or prevent these losses should be identified. The continued use of the development prime contractor as an agent for this repair in all likelihood will be prohibitively expensive as has been demonstrated by the Space Shuttle program. In addition to the development contractor overhead as a cost burden, the long term support from the original equipment manufacturer is an expensive proposition as well. The maintenance of a repair capability for items no longer manufactured is also very costly.

In a recent study of Orbiter hardware it was estimated to cost $16-17M to keep the doors open for three years at seventeen

Orbiter suppliers, or approximately $300,000 per year per supplier. It is estimated that approximately three hundred suppliers of Orbiter hardware may have to be supported in this fashion.The current estimate of Space Station Orbital Replaceable Units (ORU's) is four to five thousand units. This estimate includes provision for all four Work Packages. For comparison purposes the Space Shuttle Orbiter has approximately 3800 Line Replaceable Units (LRUs) and the KSC Launch Processing System (LPS) has approximately 3500 LRUs. If the Space Station experience were to be comparable with that of the Space Shuttle in this regard, approximately $100M a year would be spent to just keep repair capability available at the OEMS. The results of the Space Shuttle program study point to the need for an on-or-near site depot repair facility to provide repair support at a reasonable cost.

In his discussion paper to the SSOTF, Mr. Lorenz Simpkins of KSC recommends:

> "...Specify and purchase all documentation...Plan for the assumption of the maintenance of the system - use OEM until you have established an in-house capability...Develop test systems with both Automated Test Equipment (ATE) and Artificial Intelligence (AI) concepts in order to capture knowledge/expertise..."

In its 1986 annual report the Aerospace Safety Advisory Panel recommended the following to the Space Shuttle program:

"3.Establish control of the pipeline for the repair of Line Replaceable Units (LRUs), in particular, as well as for other components. This will probably include the need for a repair depot on-site at KSC. Although it will be necessary to return certain sensitive units to the manufacturer for repair, the number of such units should be kept to a minimum."

The Logistics Subpanel recommends that the Space Station Program locate a depot level repair facility with state-of-the-art Automated Test Equipment (ATE) on-or-near site at the ground operations center under the management direction of the Logistics Operations Center. The payback in reduced repair cost over the life of the program and the availability of repair capability for a thirty-year period will more than offset the initial investment. In addition to the repair function, the Space Station Program will require the recertification of repaired ORUs prior to their return to orbit. The same automated test equipment and software used to perform failure analysis in the repair process can be used to recertify ORU performance prior to return to orbit. The addition environmental retesting required should also be considered as a task for the repair facility.
The management and process control and tracking of the repair process and the gathering of maintenance trend data should be automated and incorporated as part of the Logistics Information System.

To support this depot repair capability, it will be essential to acquire a complete technical data package during the Phase C/D acquisition. Every person involved in repair and maintenance management who made input to the SSOTF strongly advised the purchase of technical data, repair and maintenance manuals and the drawings necessary to enable reprocurement as part of the original acquisition effort. The acquisition of these technical data after hardware delivery has proven to be extremely expensive. The current estimate to acquire the necessary technical data and maintenance manuals for Space Shuttle Orbiter support is $23M.

The development of execution level resupply/return plans for each Space Station operations increment will require the integration of material acquisition, on-orbit maintenance requirements, repair management and logistics carrier processing. The inclusion of repair management in the responsibilities of the LOC is essential to provide close integration of repair performance with resupply/return requirements and provide the necessary interface for repair and maintenance management.

The timing of the transfer of the responsibility for repair and maintenance management has been a subject of great debate. The Work Package requests for proposals assigned this role to the development contractor through IOC, IOC being defined as after the successful launch and deployment of the platforms. In the view of the Logistics Subpanel, there is no merit in leaving this responsibility with the development contractor for ten years after the hardware has been deployed in orbit which the current plan would call for. The more effective approach to a timely transition of management roles is to integrate the acquisition logistics task with the operational logistics planning and capability development. By involving the ultimate operator in the Phase C/D activities, a positive logistics presence will be felt during design by putting the "loggie elbows on the drawing board." At the same time, the capability to provide operational logistics capability is not developed in a vacuum but with a real time awareness of the design process. Through the use of the Program Office for this logistics integration function, the capability to repair and maintain ORUs would be in place at the time the hardware is assembled and verified, and the management responsibility transfer could be easily accomplished within a year of on-orbit deployment.

MAINTENANCE OF INSTITUTIONAL SYSTEMS

Historically, institutional capability has been developed, upgraded and replaced as part of a center's participation in the current manned space program. Simulators, trainers, computer mainframes, warehousing, special carriers and various test and evaluation capabilities have been put in place with program funding and have taken on an institutional flavor. These systems have become integral, in some cases, to the determination of center roles and responsibilities and therefore are considered institutional assets in many minds. In the case of the Space Station Program, many such existing systems will be required in addition to those that will be added as part of the development program. The ability to conduct Space Station operations over the thirty-year life of the program will depend on the long term maintenance and replacement of these systems. The Space Station represents a far more comprehensive commitment to institutional support than has heretofore been required by an Agency program.

The panel recommends that the Program Office be given a maintenance management role that includes the oversight of the support given to any system without which Space Station operations cannot continue or the loss of which would seriously degrade station operational capability. The oversight would include the review of maintenance and replacement planning for these systems and a review of the program and institutional funding that is proposed and allocated to support these systems. It would be inappropriate in this context for the Space Station Program to micromanage a center's institutional planning. However, the oversight of all the assets necessary to conduct Space Station operations over the life of the program is a prudent exercise of management responsibility.

GROUND SUPPORT EQUIPMENT

With the repair and maintenance capability of the LOC established, the repair and maintenance of ground support equipment can be accommodated in the same facilities. The requirement to acquire technical documentation, to provide for complete Logistics Support Analysis (LSA) and to anticipate long term support issues is just as important for ground support equipment as it is for on-orbit hardware. The successful long term support to the on-orbit hardware and operations activity will depend on the prudent and diligent support of the ground equipment infrastructure and the assets necessary to maintain and repair it.

3.2.3.2 MATERIAL MANAGEMENT

DESCRIPTION

Material management is the process by which serviceable material is provided through provisioning, replenishing, distributing, storing, and repairing in order to support space station and user operations. The objective is to provide the best operational availability from specific resources or a specific operational availability from an optimal mix of resources.

MATERIAL.

Material consists of reparable and nonreparable spare parts, end items, support equipment, modification kits, and consumable space station supplies.

THE PIPELINE.

When an end item of equipment, subassembly, or recoverable spare fails, it is removed and replaced with a serviceable item, or it is removed, repaired, and replaced (see the Concept of On-orbit maintenance in section 3.2.3.1). The failed component is transported to a maintenance activity either on-orbit (extremely limited) or on-ground where it is repaired or condemned. If repaired, the component is transported to a storage facility or directly to the user. If condemned, a new item is procured to replace it. Ideally, this supply pipeline functions smoothly so that no breaks occur. The Space Station represents a unique challenge for the supply pipeline concept. The constrained transportation to orbit associated with Space Station operations will require a careful integration of repair turn around times, procurement activity and resupply/return planning. See Figure 3-6 for the Pipeline Process.

CUSTOMERS.

Customers of the material supply system are on-orbit space station operators or users who need the spare part or end item to replace a failed item, to change out an item before it fails, or to perform minor repairs on-board the Space Station. Serviceable material is also provided to on-ground users for storage in a warehouse facility for future use, and to the maintenance activity for the repair of ground support equipment, orbital support equipment and returned on-orbit hardware.

STORAGE FACILITIES.

Facilities are required to receive, store, and issue material from warehouses located at KSC, other Centers, contractor

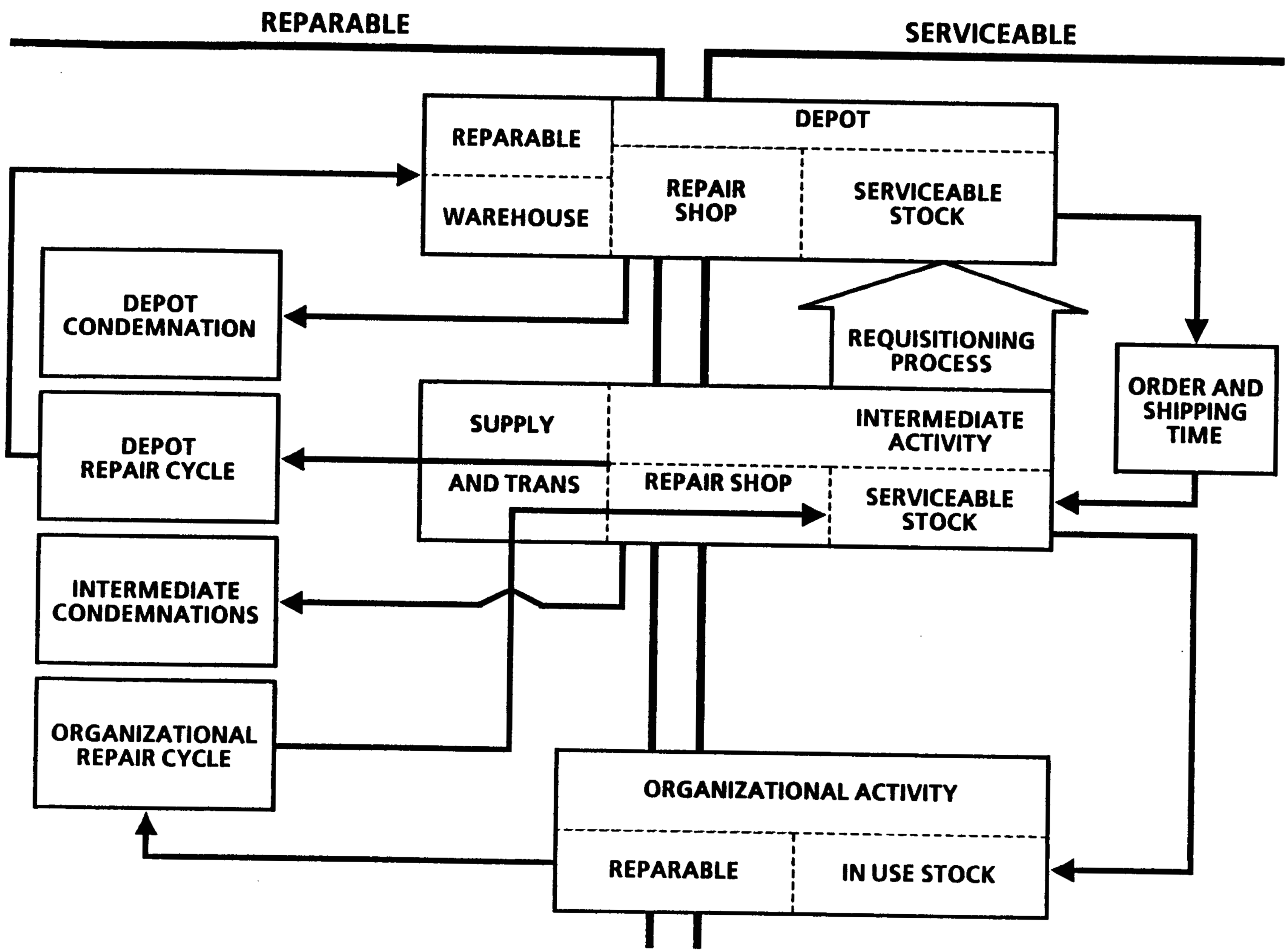


FIGURE 3-6 THE PIPELINE PROCESS

facilities, user facilities,and on-orbit. Storage areas are also needed in on-ground maintenance facilities. On-orbit storage facilities are needed for spare parts held to replace critical systems ORUS for preventive or corrective maintenance and for consumable material needed to perform maintenance and minor repairs. Additional storage facilities are needed for temporary holding at material receipt points such as launch site payload integration areas.

SPARES REQUIREMENTS DETERMINATION

The range and quantities of spare ORUs and LRUs will be projected to provide the best system availability for a specific funding level or to minimize funds required for a desired system operational availability. Spares requirements will be projected item by item, by groups of items or by class codes for bulk items to determine what and when to buy and repair for purposes of budgeting, and scheduling, initiating, and executing buy/repair processes. Actual supply system performance and system availability data will be tracked and monitored for trend analyses and system calibration.

INVENTORY MANAGEMENT SYSTEMS.

The existing Kennedy Inventory Management system (KIMS) performs some, but not all, of the necessary inventory management functions. This system should be either expanded to encompass on-orbit inventory, distribution, maintenance, and procurement functions, or designed to interface with other systems performing these functions. Existing systems will be utilized, where practical. The Problem Reports and Corrective Action system (PRACA), for example, could be used to track performance data.

DATA FILES.

Historical item data will be retained for trend analyses, for adjusting item information, and to provide an audit trail. Examples of the data include unit cost, repair cost, failure/demand rates, repair cycle times, lead times, transportation times, condemnation rates, next higher assemblies, item criticality, and Source, Maintainability and Recoverability codes.

ASSET VISIBILITY.

The location of all assets for each item managed by NASA will be tracked worldwide and spacewide. The location of material will be entered into and maintained current in an automated data system both on the ground and on-orbit. The estimated number of line items is 300,000. See the white paper, "Space Station Line Items Estimate", for details. Serial number tracking will be performed for all items used on-orbit and for all other critical items.

SYSTEMS IMPLEMENTATION.

Systems to perform the functions described above must be designed and funded so that they are in place and operational before the end of Phase C/D. TMIS should provide for the additional systems and interfaces. In addition, the management system, inventory management functions, initial spares, ground support equipment, storage, maintenance, and distribution activities must be in place and operational by the end of Phase C/D.

MANAGEMENT STRUCTURE.

a) Day-to-day logistics data systems operation should be centrally managed at the LOC. The Program Office role is to ensure systems compatibility and consistency of data formats and files, among all Centers and compliance with Logistics Information System standards regardless of the location where the systems are to be operated.

b) Program Office budget formulation will be supported by all participating centers with A responsible for consolidation and verification of budget inputs from the centers for spare parts, maintenance requirements, and ground support equipment. The budget will be reviewed, validated and submitted to the Administrator through Level A.

c) The LOC will provide implementation of material management processes and spares management for common items. These common items include items for the common GSE. Item Managers will be identified for the common GSE and will support the equipment at all locations within the program. Item managers at participating centers initiate procurement actions, track critical items, negotiate repair quantities, and schedule repairs with maintenance activities, both in-house and on contract.

DEVELOPMENT PROGRAM RECOMMENDATIONS

a) In reviewing the Space Station Program Definition and Requirements Document, Section 6: Function and Resource Allocation (JSC 30000 Sec.6 Rev.A) we found a lack of volume and mass allocation for on-orbit storage. While section 2.3 of the document calls for storage allocations, none are called out in the resource allocation tables. In our opinion, on-orbit storage volume and mass requirements are not adequately perceived, are not being managed and may turn out to be as critical a problem as resupply/return capacity. The determination of on-orbit storage requirements should be delegated to the Integrated Logistics Working Group under the Program Office management so as to be integrated with their resupply/return requirements definition task.

b) In meetings with Phase B contractors and Work Package logistics managers we derived an estimate for the number of line items that would be found in the Space Station inventory. Our estimate, documented in an enclosed white paper, is 313,000 line items. The draft KSC Facilities and Equipment Requirements Document available to the Logistics subpanel based the storage requirements on an estimate of only 60,000 line items. In our opinion, the facility requirements for storage, handling and repair are under-perceived and should be reviewed prior to further commitment to facility planning, storage, handling, and repair.

3.2.3.3 TRANSPORTATION

INTRODUCTION

The ground transportation requirements for the operational Space Station Program were not judged to be demanding. The development program will require some unique transportation capability during the assembly and verification phase, but the operational phase requirements should be comparable to the current demands placed on the Space Shuttle program. It is recognized, however, that the reconfiguration of the Space Station Processing Facility (SSPF) at KSC to support experiment processing may drive out unique transportation requirements for evolutionary activities.

TRANSPORTATION DESCRIPTION

The Space Station Transportation System is comprised of earthside and space segments. This system uses a range of vehicles chosen to offer economical, efficient, and priority movement of human, material, consumable, experimental, and manufacturing products within the transportation network. These resources support U.S. Government and commercial operators/users and international partners. The LOCs Transportation Manager plans, communicates, coordinates, implements, and monitors terrestrial shipments of resources from integration centers, technology centers, customers, and vendors; the Transportation Manager's line management is headed up by the Traffic Controller who resides in the LOC. The Traffic Controller is responsible for real-time shipment requests, arrivals on dock, and shipment schedule changes. Duties include achieving shipment arrival deadlines set by other Space Station line organizations to assure timely and effective on-orbit Space Station support. Variations in established shipping schedules and their perturbations are analyzed and alternate solutions to needs are developed through considerations of priority shipping modes, alternate sourcing, and other alternatives of fulfilling resource requirements. An important element of the terrestrial transportation network is the KSC transportation node, a depot for truck, rail, and air shipments, both U.S. and international. Customs Service processing at this depot facilitates international material shipments, permitting direct arrivals from international sites to be expeditiously processed for integration into space transportation segment cargos. The KSC Receiving and Shipping

C-3

Section processes arriving material to the Space Station Logistics Support Facility for storage, load integration, off-line payload integration and checkout, or movement to other ground support or operations facilities for other purposes. Status of inbound and outbound shipments in the Receiving and Shipping Section is maintained in the LOC via computer/ telephone.

SCHEDULING

Ground segment transportation schedules pivot about the 45-day resupply cycle and the recoveries of returning material nominally 7 to 10 days after resupply launches. The 45-day resupply flight cycle is treated as an inviolate planning factor to assure the best possible support of on-orbit missions and operations. More than 10 years of Space Station operation have allowed increasing flexibility in resupply frequency. Continuing reliability improvements of installed systems yield increasing resupply and return cargo capacity for experiment and manufacturing materials and products. Thus, while Space Station operations support requirements are decreasing, user requirements are expanding to optimize use of up and down cargo capacity. Crewmember rotations are nominally at 90-day intervals. While the Shuttle is the primary space transportation vehicle for Space Station support, the variety of expendables, partially reusable and reusable vehicles play an increasing role. Periodically, fly-in maintenance crews bring all needed resources to accomplish periodic maintenance and modernization of Space Station systems. This innovation was made possible by the enhancement trends in systems hardware, firmware, and software. Exceptional requirements for systems components occur infrequently, necessitating priority shipments via the most efficient or available vehicle for the task; e.g., an expendable or the aerospace plane. On rare occasion, other countries' vehicles are used to fill out-of-schedule resupply/return needs, primarily in support of the international partners' Space Station activities.

LOAD PLANNING

Resupply and return load-plans are initially computer-generated based on firm and projected requirements for station and user material. These requirements derive from periodic component change-outs and predicted failures of other components based on performance trend analysis. Also included are requirements for user experiments and manufacturing materials and on-board housekeeping materials. As actual requirements continually flow into the data base from the condition monitoring and transmission systems incorporated within installed Space Station and user systems, resupply load-plans for systems support are firmed up. Cargo preparation and loading flow times, based on trials and experience, are factored into the automated manifesting routine, with management margins to add confidence in the routine's schedules. Material stowage patterns are included in the automated manifesting program to minimize need for human interference with this sophisticated expert system; factored in are packaged item physical characteristics of weight, volume, stress sensitivities, and environmental control requirements. Items to be used immediately are placed in the cargo container for quick access upon arrival at the Space Station, and the efficient, rapid shifting of cargo items for this accommodation is done in accordance with specific, detailed instructions provided to the handler through the manifesting program. The duration of prelaunch cargo manipulation periods is vehicle dependent, dictated by vehicle preflight servicing and checkout requirements. Major cargo changes are possible up to within minutes of launch or takeoff of the transatmospheric vehicle the "Orient Express", within less than a day for the Shuttle and other vehicles.

ON-ORBIT MOVEMENT

Space-based orbital maneuvering vehicles (OMV) are proving to be extremely useful for shifting resource containers from launch vehicles to the Space Station and back to return vehicles. This capability is used primarily for cargo transfer from expendable and partially reusable vehicles and the aerospace plane, and for shuttling between the station and the Orbiter. While OMV's are mainly used for servicing free-flyers and co-orbiting platforms and for manipulating new station modules and other exterior modifications, there is a sufficient quantity of these versatile craft to perform the shuttling activities. Orbital transfer vehicles (OTV) derived from the OMV are nearing the test and evaluation phase. The OTV will be crucial to recovery of valuable but unserviceable communications and weather satellites in geosynchronous orbits. Once brought back to LEO station environs, repairs can be affected on these satellites and they can be replaced in geosynchronous locations by OTVs. Additional OTV applications for lunar-base and geo-shack buildup and for resupply are planned to begin in the 2017-2020 era of space resource exploitation and exploration.

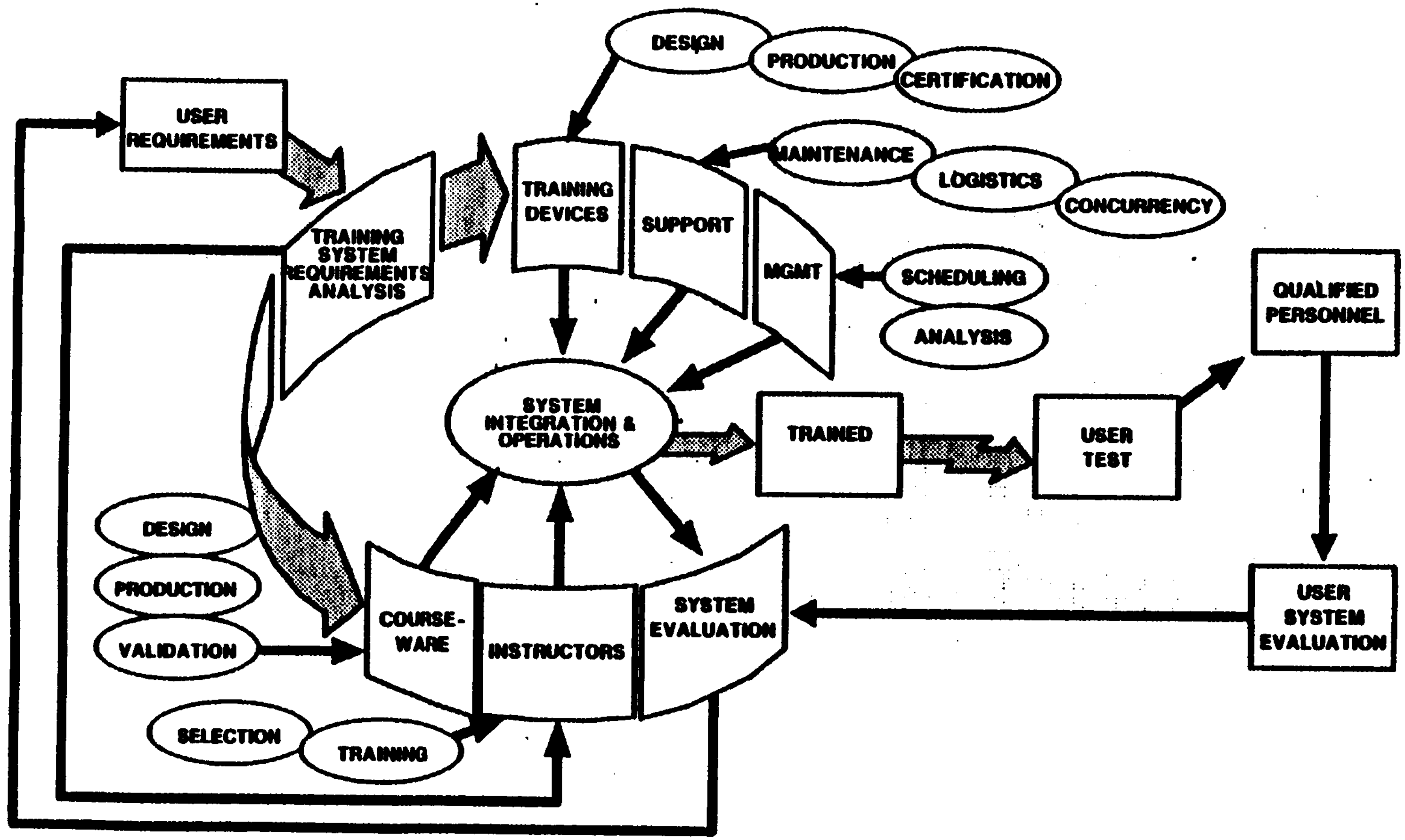
3.2.3.4 TRAINING

The basic concept for Space Station training as discussed in section four of the Panel 1 report has been considered as an approach to build upon for application to ground operations and logistics activities. The expansion to include ground operations skills development as discussed in the training plans for the Shuttle Processing Contractor and the Payloads Ground Operations Contractor will complete the scope of training to be considered. The generic development of managers and the maintenance of engineering skills should also be included in Space Station training discussions, particularly as applied to the contractor work force.

A comprehensive Space Station training system requirements analysis should be undertaken before assuming the manpower and resources intensive role model provided by the STS. It is expected that crewpersons will not fly many missions due to health concerns and career growth pressures. The training program will therefore have to respond to a large turnover of personnel with repeat crewpersons essentially starting all over. The application of the current STS role model to the Space Station crew rotation, as discussed in the Panel 1 report, will require a prohibitive investment in training development and maintenance.

The Space Station Training Coordination Board (STCB) as proposed by Panel 1 should be strengthened to become a firm program management element. A rotating chairmanship will not provide the necessary management direction to ensure the consistent quality in training required to sustain the program. Rather, the Program Office chairmanship is recommended for consistency and continuity. However, the systems approach to training development and delivery, as discussed by United Airlines during their January 15,1987 briefing to the Task Force, (Figure 3-7) does have the desired program structure.

TOTAL TRAINING SYSTEM



UNITED PREPARED TO DO ALL OR ANY PART

UNITED AIRLINES
SERVICES CORPORATION

FIGURE 3-7 TOTAL TRAINING SYSTEM

3.2.3.5 PACKING AND HANDLING

DESCRIPTION

Packing and handling are those processes by which material is prepared for transportation. In the case of transportation to and from orbit, the packing must protect the material from damage during the launch and reentry phases. The vibration, thermal and vacuum environments that material are subjected to can be severe for both the Space Shuttle and Expendable Launch Vehicles. In the case of ground transportation, the hazards to material can be severe even in local on-site moves. Packing and handling specifications are part of the technical documentation developed during the Phase C/D activities or are provided by the specific user design agent. In some cases material will have to be repacked between ground transportation and transportation to orbit.

MANAGEMENT

The packing and handling function will be integrated by the logistics operations manager with the efforts of inventory management, maintenance management and resupply/return management. The timely preparation of material for shipment to and from orbit, to and from the repair process and locally at the operations center is essential to maintaining processing schedules. A logistics operations manager is responsible. Automated tracking of material through the packing and handling function would be performed by an appropriate module of the Logistics Information System.

LOGISTICS CARRIER PREPACKING

A significant portion of the material transported to and from orbit will not require the verification and checkout process discussed in Section 5.3. These items which represent 30 to 50 percent of the cargo transported are the non-experiment hardware, user, system and crew consumables and the materials and tools associated with maintenance and modification activities. Since the processing of these materials will not require an extensive interface with the ground data management system or any on-board interface verification, they can be prepacked in the logistics facility and installed in/on the logistics carriers as part of the processing activity. By prepacking at the rack or drawer level, on-line processing time for these materials can be minimized. Hazardous fuels and fluids carriers will have to be processed off-line for safety reasons and will be loaded in/on the STS or ELV independently.

For those items which will be returned from orbit for repair or reuse, the packing design must facilitate on-orbit storage and require a minimum of crew handling time as the material arrives and leaves the Space Station. The integration of this requirement into the overall on-orbit storage approach will be a key design task.

3.2.3.6 FACILITIES

INTRODUCTION

The facilities required to support the logistics functions at the operations center fall in three main categories, warehousing including space for offices and training activities, repair and maintenance facilities and a logistics carrier prepacking and unpacking facility. For the purposes of this discussion, it is assumed that the facilities to support logistics functions at distributed integration and operations sites are provided by the site managers or institutions involved.

WAREHOUSING

The Space Station logistics warehouse will be a fully automated "lights out" facility. Through the use of automated store and issue equipment and the use of smart tags and similar technologies, the need for warehouse handling personnel will be minimized. More conventional staffing will be required for the receipt, inspection, packing, shipping and material service center functions.

Several Space Station Program unique storage requirements were identified. The planned thirty-year program life and the anticipated flow of specialized experiment hardware will require a capability to store special shipping containers and pallets. Experiment rack shipping containers, special containers to support the shipping of Space Station systems, consumables, and fluids are proposed as a program supplied item. Users are expected to have similar requirements to support servicing in addition to containers for ground and to and from orbit transportation . There may also be a requirement to store experiment racks between the time they are shipped from the integration center and the scheduled need date at the operations center.

Two approaches were employed to size the warehousing requirement. The analysis is presented in white paper, "Space Station Line Items Estimate" by Ray Norman. Both cases produced an estimate of 300,000 line items of inventory. This finding has been forwarded to Space Station Program management for their consideration since it represents a factor of five increase in the estimate that is currently anticipated by the program.

REPAIR AND MAINTENANCE

As previously discussed under ground maintenance, the majority of repair of Space Station system ORUs and operations center ground systems LRUs will be accomplished in an on-or-near site depot maintenance facility. This facility will have the capability, using automated test equipment, to analyze ORU failure modes and isolate the failed SRUs and/or piece parts. In addition, this same equipment will be used in the return to orbit recertification testing activity.

The scope of required repair capabilities is very broad. The current concept of self-sufficiency would demand that the operations contractor have a variety of repair capabilities. It is suggested that there may be a synergistic set of repair capabilities that would support the Space Station and the Space Shuttle programs as well as the operations center institutional support requirements. The following is a list of capabilities anticipated as Space Station Program requirements:

- ELECTRONIC REPAIR AND REMANUFACTURE
- ELECTRICAL FABRICATION
- GAS AND FLUID SAMPLING AND ANALYSIS
- PROOF LOADING
- CLEAN ROOMS/LAMINAR FLOW BENCHES
- SEWING AND FABRIC REPAIR
- PNEUMATIC REPAIR

PAINTING AND COATINGS APPLICATION
CHEMICAL PROCESSING
FOOD PROCESSING
ENVIRONMENTAL TESTING
RECERTIFICATION TESTING
WASTE PROCESSING
HYDROSTATIC TESTING

LOGISTICS CARRIER PREPACKING

As discussed in Section 3.2.3.6, Packing and Handling, the prepacking of non-experiment hardware and consumables is proposed as a logistics facility function to facilitate ground processing. The hazardous fuels and fluids processing is assumed to be accommodated through the use of existing operations center capabilities. The prepacking of logistics carrier drawers and racks will require additional facility capability over current program plans. A clean room environment is viewed as a requirement for prepacking racks and drawers destined for the pressurized logistics carrier. The cleanliness quality of this clean room is assumed comparable with the experiment processing facilities.

FACILITIES COST AND PHASING

The Space Shuttle Logistics Facility has been used as a model for cost estimating purposes. For estimating purposes we have also assumed that the warehousing, repair, and prepacking facilities could be co-located. The estimated amounts are:

Description	Million Dollars	Man Years
Construction of Facilities	$ 30.	
Warehouse Equipment	15.	
Test Equipment & Software	30.	
Operational Manyears (MYR)		460
Senior manager 20		
Middle manager 40		
Technician 400		
Repair 200		
Material Mgt 150		
Procurement 50		

The warehousing capability should be in place to support initial assembly and checkout activities. This would require that the facility be available one year prior to first launch. Two years are estimated for construction and equipment installation and check out. A total of five years is the norm for new COF projects. The phasing of the repair capability is proposed to be consistent with the assumption of the repair and maintenance management role by the LOC at ORU launch plus one year. Thus the test and repair equipment acquisition, installation, checkout and certification will be driven by the launch package schedule. It is estimated that eighteen months to two years will be required to install, check out and certify the repair and test equipment. Acquisition lead times were not estimated and are additive. Logistics carrier prepacking and unpacking capability must be in place with the onset of resupply and return missions.

3.2.3.7 TECHNICAL DOCUMENTATION

Technical data or documentation is the paper, audio-visual, optical or magnetically stored information which is used in system assembly, checkout, operating and maintenance instructions, inspection and calibration procedures, overhaul procedures, modification instructions, time compliance and technical instruction, modification kits instructions, drawings and specifications and reprocurement information that are necessary for the performance of Space Station system operations.

The data will be developed by the Work Packages and their contractors during Phase C/D as a result of needs definition through the Logistics Support Analysis process. That process will also identify appropriate formats and media for the various data applications described earlier.

The development of the documentation occurs in conjunction with hardware and software/firmware design and development, with the verification complete before or no later than the first need date. Since trained technical documentation users are required at the need date, the related technical documentation must be ready in advance of the operational need date by the amount of time required to develop training materials, coordinate and checkout training facilities and equipment, train instructors and conduct necessary qualification and certification training.

We would require that the training and certification process be tested using the verified technical documentation to ensure adequacy and accuracy. This training verification is referred to as Personal Reliability Programs, Standboards, etc.

The technical documentation data base will be a partitioned resident of the TMIS integrated system. Updating technical documentation will be a joint function of all users and monitors, with Sustaining Engineering assigned overall responsibility. Logistics Engineering and Configuration Management have coordination responsibility on proposed revisions. Accomplishment of this coordination and an approval process will assure requisite interfaces with the operations, training, supply and procurement disciplines to permit their actions necessary to stay current for optimum Space Station success.

Through development of systems design, documentation for maintenance processes is derived with assembly and integration process documentation. After development contractor derivation and commitment to the assigned media, the documentation is validated by the PGOC and/or integration contractor for process completeness, accuracy and effectiveness. A Government verification process will be demonstrated by representative users prior to acceptance by the LOC.

Technical data and documentation verification and acceptance will be complete before the first element launch, as a part of the Phase C/D process. After acceptance by the LOC, the complete data package(s) will be transferred to the Space Station documentation repository/TMIS and be available for the Logistics Information System for use.

One of the recent ('87) techniques described in the AIAA proceedings and manufacturers' wish lists are the portable or battery powered, no hands, heads up, helmet projection procedure/drawing instruction for extra vehicular activity. One can envision an astronaut who, by voice command, can cause a video picture to be projected in his helmet. Also, by voice command, he makes a drawing isometric rotate, enlarge or reduce in an in-helmet overlay of the actual picture of the device that he is working on at the time.

One can extend this thinking to the 2010 astronaut who can have a direct projection of this optical image on the retina. Even the very simplest applications will be voice activated and have touch screens employed at repair work sites at the LOC and on-orbit in the SS.

3.2.3.8 <u>User Support</u>

Space Station logistics support requirements for the user in the 2010 timeframe are based on the definition of users. Users can be participants, customers, international partners, principal investigators (PIs), and other U.S. government agency partners.

This section addresses the logistics support requirements of the international partners, and will touch on the other users mentioned above. The assumptions used in this section are:

1. Users are participants

2. Customers are participants

3. Partners are the internationals and other U.S. government agencies.

INTERNATIONAL PARTNER SUPPORT

All three international partners have indicated that it is too early to define their total logistics support requirements for the year 2010. However, the Japanese did present their resupply/return requirements and capabilities for the year 2010 as follows:

Resupply 100 tons/yr (15-30 tons/yr for JEM)
Retrieval 20 tons/yr (5-10 tons/yr for JEM)
Therefore: 10/20 tons/yr stays up on JEM
Estimates up to 25 tons/yr of garbage
Estimate resupply capability of H2 is 40tons/yr (4 Launches-include logistics module(s) of 10 tons)
Advanced H2 proposed has capacity for resupply of 60-120 tons/yr proposed

In general, the International partners have indicated a desire for facilities at KSC. These facilities would include storage, prelaunch/post-launch recovery processing, warehousing, and office space. If the Arienne 5 (ESA) and H-2 (Japan) vehicles are available in the 2010 time frame, then ESA and Japan will probably use the co-located launch and operational centers in French Guiana and TKSC, Japan. Most logistics support such as storage, prelaunch, post recovery, warehousing, and office space would be located at the appropriate international launch site.

Operations and logistics will be the major cost elements in the year 2010. ESA and, even more so, Japan have indicated their desire for complete autonomy for their modules and platforms in the Space Station Program. They assume this would keep their costs down and minimize the exchange of funds among countries. Therefore, both Japan and ESA would like to have their logistics and operations functions based in their respective countries. All partners and users availing themselves of the Space Shuttle, however, will have to use the facilities at KSC for processing their elements. Partners may want or need to use facilities at other locations as well, for example, the power test facility at NASA-Lewis so that partners could verify their power systems prelaunch/post-recovery performance.

Canada will depend heavily on NASA expertise for their operational logistics support, partly because of cost and partly because of the relatively small size of the Canadian Space Station organization. The bulk of NASA logistics support for Canada would be at KSC with some logistics support possible for the interaction between JSC's movable platform and truss and Canada's mobile servicing system (MSS). Acquisition logistics support for the Canadian MSS will be done in Canada to provide procurements of spare parts, tools and technical documentation.

It is also probable that NASA, ESA, Japan, and all other experimenters will need to interact with Canada's logistics organization, especially if their payloads/experiments are external and use the Canadian arm for positioning and servicing.

If either ESA or Japan can offer the Canadians a better pricing structure than NASAs for launch services, the Canadians can offset the higher costs of ground/air/sea transportation to ESA or Japanese launch sites. The Canadians would then use ESA/Japanese launch services, and be tied into logistics support from ESA or Japan.

For the international partners, logistics support will be negotiated and included in international top level agreements dealing with program element contributions and requirements on both parts. Such intergovernmental agreements often use annexes to top-level program documents to define variance in the program requirements as negotiated between the parties affected. Waivers of requirements may be granted to internationals on an as required basis. An issue for early consideration is the need for standardized interfaces with the LOC managed Space Station support systems. Standardized interfaces will ensure appropriate user support systems development, smooth functioning of logistics systems, and maximized support efficiency.

Forums that could support logistics interface definition would be working groups such as the International Operations Working Group (IOWG), International Cooperation Working Group (ICWG), and ILWG. Some agreements can be formalized through authorized working groups speaking for both NASA and the participant. If use of NASA facilities at KSC or elsewhere is planned or desired by any of these users, negotiations with NASA Level A, the Program Office and appropriate NASA centers is necessary early in the program to minimize schedule and cost perturbations to the Program and the users' efforts. Other logistics element planning, development and emplacement must occur parallel with NASA Space Station Program logistics milestones. Issues could be settled by the Program Coordination Committee (PCC).

OTHER USER SUPPORT

Participants may include Universities, principal investigators (PI), industry, DOD, other government agencies, and internationals other than ESA, Canada and Japan. Participants would require the same NASA logistics support as discussed above. However, as an alternative, they could ship their payloads/experiments to KSC ready to launch. Any logistics support required will be negotiated on a case-by-case.

DOD experiments would be located on the U.S. portion of the Space Station and DOD will provide the primary operations and logistics support. When security is pertinent, the DOD would be expected to use KSC/CCAFS facilities.

Also desired are facilities and logistics support at KSC and other landing sites for Life Sciences programs which would permit early/late access to the logistics carriers. The capabilities and equipment to support this activity would include staging areas, controlled environments, test equipment, means of transportation to and from the launch site, payload installation/removal, handling, storage, office space and, in some cases, data analysis. Logistics support is also required for "Quick Sample Return" and "Emergency Crew Return". The support required for these scenarios would include coordination with other U.S. government agencies such as the U.S. Navy for recovery, special handling facilities and transportation.

If Universities, PI's and U.S. Industry locate their experiments in the Japanese or ESA module, they must interact with Japan's or ESA's Program Office for their logistics support needs. In one scenario, these experiments would be located in either the JEM or ESA Module and launched by the U.S. from KSC. Another scenario would be U. S. experiments located in the JFM or ESA modules and launched by H-2 or Arienne 5. This scenario would significantly complicate the U.S. experimenter's logistics support options, with little or no control by the U. S. experimenters at the International launch sites. Other international experimenters might contract with ESA or Japan for their logistics support, particularly for ESA or JEM hosted payloads.

3.2.3.9 RESUPPLY/RETURN

Resupply/return is not a classical logistics function. It is a combination of such functions which require joint management because of the unique transportation bottleneck that the Space Shuttle presents to the Space Station Program. The major resupply/return tasks are described in Table 3-6.

One of the most disturbing findings of the Logistics Subpanel was the lack of resupply/return requirements management on the part of the Space Station Program and the current inability of the program to support the requirements known at this time. The current requirements exceed the Space Shuttle/Logistics Carrier capability by approximately 35,000 pounds upmass and 150,000 pounds downmass annually. The credibility of the requirements estimates is admittedly low. Many of the requirements should be more appropriately considered as "user desirements". A "desirement" being defined as a requirement on the part of someone who has no funding or approved program. The other major exacerbation is the degrading availability of the Space Shuttle as an on-orbit delivery vehicle. In recent reports both the Aerospace Safety Advisory Panel and the Shuttle Processing Contract Review Team recommended reductions in flight rate below the sixteen per year that the Space Station operations planning assumes. The current resupply/return analysis assumes eight dedicated shuttle flights a year. Any reduction in the availability of the Space Shuttle will have obvious consequences.

TABLE 3-6

- o Strategic,tactical and execution level planning of mass and volume for materials necessary to support a given increment

- o On-orbit storage planning and inventory management to support a given increment

- o Logistics carrier load planning and inventory management

- o Launch vehicle/logistics carrier utilization management

- o Orchestration of the preparation/acquisition/delivery of the necessary materials, technical documentation and training to support a given increment

The Logistics Subpanel recommends that the Integrated Logistics Working Group be revitalized and their assignment to manage resupply/return requirements be vigorously pursued. Further, that the Space Station Program reassess the realities of the degrading availability of Space Shuttle and aggressively examine expendable launch vehicle alternatives for accomplishing resupply/return. In addition the long term management of resupply/return should be considered for delegation to the LOC to facilitate the synergistic management of maintenance, resupply/return and the logistics infrastructure that support the program.

3.3 OTHER OPTIONS

INTRODUCTION

The Logistics subpanel, early in its' deliberations, examined alternative approaches for support required in major logistics functional areas. This was, by no means, an exhaustive review of all logistics functions, but covered those areas where selection of one approach over other potential approaches had the greatest impact on the organization and planning of Space Station support. The categories reviewed are identified in Table 3-7.

TABLE 3-7

L1 - ILS Planning/Management

L2 - Maintenance Scheduling
- L2A - Orbital Hardware Supported On-Orbit
- L2B - Orbital Hardware Supported On-Ground
- L2C - Ground Equipment Supported on-Ground

L3 - Maintenance Execution
- L3A - On-Orbit
- L3B - On-Ground

L4 - User Autonomy/International Participation On-Orbit and On-Ground

L5 - Transportation to Orbit

L6 - Evolution

L7 - Original Equipment Manufacturers Support Strategy

Within each functional category, support subfunctions were identified and defined. Each panel member scored each subfunction on a scale of 1 to 5 (with 1 being the least acceptable alternative and 5 the most acceptable) for each of the following elements:

1. FEASIBILITY - "Doable," capable of being carried out to completion.

2. FLEXIBILITY - Capable of responding to new situations, i.e. space station growth and evolution to a new configuration; does not (necessarily) have to be scrapped or junked to viably adapt.

3. USER FRIENDLY - Provides easy training for and use to a journey level person with average intellect and motor sensory skill/perception.

4. EFFECTIVENESS:

   a. Transition - How easy is it to go from Phase C/D to Phase E (Operational)?

   b. Management - Does this option lend itself to "effective" management skills, tools?

   c. Cost - What is the relative life cycle cost of one option compared to other options for the function or subfunction?

   d. Performance - Is it capable of doing the function in a timely and sufficient (all that is required) manner?

5. SAFETY - What is the relative risk of bodily harm or hardware/firmware/software damage?

6. TERMINATION - Can this option be terminated/ eliminated/phased out without terminating the total station/ having cataclysmic effects?

Functional interdependences were considered and conflicts were resolved. The panel collectively agreed on a single value for each subfunction and element, and a total score was tallied for each subfunction. Table 3-8 displays the scores for each subfunction and scoring element.

All subfunctions were reviewed in terms of the ultimate objective of optimum Space station support. The key criterion for evaluating support in all of these areas is achieving the highest possible operational availability of each Space Station system and of the Space Station as an entity for the smallest possible expenditure of resources. The preferred alternative in each of the functional categories was the alternative that provided the most effective support from the most realistic combination of resources.

L1 INTEGRATED LOGISTICS SUPPORT (ILS) PLANNING AND MANAGEMENT

The primary ILS alternatives concern the approach to be taken in management structure. Is the most effective management centralized, distributed across performing organizations, or allocated functionally to different management levels? Our analysis showed that either of the two extremes is disfunctional and that an appropriate allocation of functions across management levels and performing organizations provides the most effective results. We also concluded that the Phase C/D effort should consist of highly centralized policy formulation and management of logistics planning across all Work Packages with a migration of logistics support implementation to the launch site occurring as the program moves through the assembly/checkout phase into on-orbit, ground supported operations.

During mature operations, central policy formulation and strategic planning should take place at Level A/the Program Office. The Headquarters function of Level A is responsible for broad policy guidance. The Program Office is responsible for central tactical planning and policy implementation guidance. Implementation planning and execution is performed on-site at the operations center by people involved with event flows. Controls over execution of support operations are extended by the Program Office to the operating levels in the form of standards, procedures, and specifications to promote optimum Space Station performance and safety, with minimum redundant efforts and unnecessary expenditure of resources, i.e., through an optimum support posture.

Realistically, none of these three levels of ILS management works alone. Each works with and through the others, striving to accomplish tasks synergistically. To illustrate, a five-to-thirty-year strategic view of Space Station Integrated Logistics Support (ILS) developed through Level A/The Program Office Program Management would be used as the blueprint for year-to-year tactical planning; which in turn sets the broad guidelines for implementation planning and the subsequent execution of event plans and flows. Upon completion of a plan segment, feedback by ILS element among levels permits status quo continuance or adjustments in future plans and support efforts at each level. With new baselines established from the feedback, reappraisal and adjustment, the logistics management process comes full circle.

L2 MAINTENANCE SCHEDULING

L2A ORBITAL HARDWARE SUPPORTED ON ORBIT

The logistics subpanel examined five alternate scenarios for scheduling on-orbit maintenance of flight hardware: continuous, periodic, dry-dock, fly-in, and hybrid. A schema of periodically scheduled maintenance events is realistic in combination with the minimum necessary, continuously scheduled maintenance. Occasionally, scheduled and opportunistic inspections may uncover a need to "deactivate" station elements for major repairs on structures and/or system segments. Major modifications might be accomplished in a similar mode. A minimum of necessary station keeping functions would be carried out during these "dry dock" periods. Such downtime must be viewed as essential, rehabilitation/enhancement activity. Therefore, emphasis must be on ensuring necessary resource availability at the start of dry-dock or fly-in to minimize downtime while optimizing planned task accomplishment. To facilitate maximum crew work on mission objectives, a fly-in maintenance team concept could be the ideal, if the state-of-the-design and manufacturing arts could support it through extremely high mean-time-between-failures and easy maintenance. Realistically, however, such teams would be required so frequently to support systems with currently expected reliabilities that this concept is now economically untenable. With technological evolution leading to orders of magnitude improvements in systems reliabilities and maintainability, however, the fly-in maintenance team mode could become a viable concept.

A positive, necessary step in an evolutionary direction of operating condition monitoring is Phase C development of a performance and maintenance database/information management/ trend analysis system, developed and implemented during and after Phase D. With the resulting trends to guide the program, evolution can efficiently lead to higher and higher equipment reliabilities and proportionately decreasing on-orbit maintenance requirements.

L2B/C ORBITAL HARDWARE AND GROUND SUPPORT EQUIPMENT SUPPORTED ON THE GROUND

While a continuous maintenance program is desirable for workload smoothing, periodic requirements must be added. Therefore, a hybrid maintenance management plan is recommended which combines continuous and periodic scheduling. A pure "on-demand" maintenance scheduling approach for orbital hardware and ground support equipment is ill-advised due to a higher risk of equipment damage and/or personnel injury at times of on-orbit equipment and ground support equipment failure. Also, on-demand maintenance spikes would be accentuated by linkage to launch and recovery periods, i.e., reparable returning from orbit would saturate the maintenance capacity, and ground support equipment needing repairs during prelaunch, post-launch and recovery periods would similarly cause activity peaks and inactivity valleys. This would cause increased maintenance expenses for unplanned maintenance setup costs and inefficient use of maintenance personnel. A reasonable effort should be made to smooth out such requirements to optimize maintenance resources allocations for ground support of orbital equipment and ground support equipment.

L3A ON-ORBIT MAINTENANCE EXECUTION

Five alternatives were examined: 1) repair in place; 2) remove the failed ORU, repair it, and reinstall it (a viable option for non-mission essential, nonhazardous item failures); 3) remove, install a serviceable spare and repair the malfunctioning unit off-line on-orbit; 4) remove, install serviceable spare and return the malfunctioning unit to Earth for repair on the ground; and 5) a hybrid combining all of the above. The hybrid approach is appropriate so that the maintenance execution concept varies depending upon ORU or SRU supportability characteristics. The Phase C/D Logistics Support Analysis will be rigorously conducted to determine the overall best maintenance execution option for each item.

Obviously, at least some on-orbit repair capability appears logical from American and Russian manned space flight experience to date. Frequently-failing items will have to be repaired or spares will have to be positioned on orbit. A pool of spares is desirable for critical/frequent failure items to minimize the time equipment is unavailable to perform a needed function. Some items may require spares to be positioned on-orbit as well as a capability to repair them on-orbit. Other items failing less frequently may lend themselves to on-orbit or to ground repair. In such instances, logistics support analysis (LSA) related trade studies will show mission, economic, and efficiency benefits of chosen options. Trade studies will be based upon factors such as unit cost, repair frequency, repair resources cost, unit weight (extrapolated to cost-to-orbit-and-return), mission criticality, and reparability (ease of repair). These early, predictive data will then be refined as significant quantities of on-orbit and ground maintenance and on-orbit systems performance data become available for further analysis. Changes in maintenance execution modes will be reasonable to continue to improve efficiencies of performing on-orbit systems maintenance.

L3B ON-GROUND MAINTENANCE EXECUTION

The following modes were examined for earthside maintenance execution for both orbital and ground support equipment: 1) repair in place; 2) remove the failed ORU, repair it, and reinstall it (non-essential/noncritical ORUs); 3) remove, install a serviceable spare, and repair the failed item on-line, or discard, if it is beyond economical repair (reparables can be fixed or discarded at government and/or vendor locations); and 4) remove, install a serviceable spare, and repair the failed item off-line, or discard, if it is beyond economical repair; 5) remove, repair off site, and replace, 6) a realistic combination or hybrid of the above implementation modes, depending on each item's characteristics.

Again, a combination of modes is preferred depending upon equipment/item characteristics. Each type of equipment will be subjected to LSA, and a plan for its maintenance tailored to its characteristics. Systems must be designed during Phase C/D to provide optimal maintenance and supportability.

L4 USER AUTONOMY AND INTERNATIONAL PARTICIPATION

The Logistics Subpanel looked at degrees of user autonomy possible, from self-sufficiency to total NASA support, in order to derive desired support approaches for the range of U. S. and non-U. S. users. Regardless of points of origin, users' maintenance facilities, technical data, supply support, transportation, and other ILS system interfaces must be compatible with the NASA Space Station logistics system. We selected a position in which NASA negotiates with the user for support to be provided by the user and support to be provided by the NASA logistics system. Precise definition of what the support entails is a part of the negotiation process. For example, the user may provide on-orbit operations and maintenance requirements for his systems and equipment, and NASA may provide associated procedures, communications with ground stations, and a standard technical data display. Storage, office and maintenance facilities, and on-ground maintenance of selected on-orbit and ground support equipment can be negotiated on a case-by-case basis, if the user desires NASA support. Resupply and return may be provided partially or entirely by NASA. Space Station systems familiarization training, however, must be performed under NASA auspices for NASA and user personnel. NASA Space Station cadre personnel should attend user familiarization training on user systems and equipment, and user personnel should similarly learn Space Station systems, to facilitate operational responses.

L5 TRANSPORTATION TO ORBIT

Though choice of earth-to-orbit and orbit-to-Space Station vehicles is not a logistics decision, logistics requirements are pertinent to those vehicle designers and decision-makers. Crucial logistics factors include initial on-orbit spares, repair materials, tools and equipment, and maintenance/ servicing consumables plus subsequent resupply and return manifests of logistics items, for the Space Station and vehicles to be maintained/serviced on-orbit. The JPL cost model, MESSOC, provides a key tool for management application in defining the logistics requirements, and, therefore, space transportation vehicle/manifest needs.

A combination of STS and ELV launch support appears to be the most practical combination from the logistics perspective. With ELV support, the capacity for transporting logistics cargo weight and volume is expanded, and the cost per mass unit is decreased. Support provided by foreign launch vehicles is dependent upon the development of these vehicles by foreign users of the Space Station and coordination with NASA operations.

L6 EVOLUTION

The alternatives for Space Station evolution implementation range from continuous incremental changes to block modifications, i.e., mods, for step function improvements in systems capability. The approach taken has dramatic implications for logistics support. A constantly changing Space Station systems configuration requires the constant revision of logistics support analysis, continuing investments in initial spares and the documentation and equipment to repair them, and the continual updating of training material and operational procedures to accommodate the revised system configuration. Block changes, on the other hand, afford the opportunity for synergistic planning, scheduling and execution and consolidate the configuration changes into manageable groups.

Our analysis pointed out that block mods should predominate over continuous design changes, though there will be a need for both. Incremental changes between block modes should be limited to those associated with safety of station equipment and personnel. The urge to improve system performance or upgrade to overcome minor shortfalls in predicted performance should be avoided in favor of a stable Space Station systems configuration primarily changed through block mods that all operational elements can use in planning for long-term support.

L7 ORIGINAL EQUIPMENT MANUFACTURER (OEM) SUPPORT STRATEGY

Over the planned thirty year Space Station life, what role or roles should OEMs play? The answer depends partially upon the expected length of useful component life and reliability, i.e., numbers of failures during the life of an OEM item. An item's life should be planned from initial installation through its final use, including its support. For many items, predicted reliabilities are calculated with sufficient certainty to be a valid basis for lifetime spares acquisition. For some items, initial spares should be bought on less certain reliability calculations and follow-on spares procurement can be made on actual usage factors. For a highly reliable item, initial spares can be purchased for the program's life on an insurance basis and with no retention of vendor support. In any case, OEMs should not be counted on beyond initial spares procurement, due to the vagaries of time and economics. If follow-on spare buys are expected to be necessary, we should purchase a complete reprocurement data package i.e., Level III drawings ("as-built") and engineering descriptions of sufficient detail and clarity to permit bidders to accurately estimate manufacturing costs upon which proposals can be based. One should always guard against re-identified items, having the true manufacturer for all items as a contractual, auditable requirement. Up-front purchasing of reprocurement data is cheaper, usually by two-to-three times, than subsequent purchases of this data. This significant cost differential occurs when reverse engineering is necessary, after original drawings and data are lost. "If in doubt, buy the data!" is a cost-effective motto. Both follow-on procurement and "dual vendor sourcing" of frequently used spares are cheaper, if reprocurement of as-built data or data rights are purchased during acquisition.

The role of OEMs also depends upon the extent to which NASA intends to perform the management function for Space Station spares, or to allow contractors to continue to manage the items they have produced. NASA should take over the management of these items from the point of initial procurement to allow standardization of data required from contractors as well as integrated data base design for configuration management, historical tracking and requirements projections. This management will also reduce unnecessary procurements and costly modifications because item modifications will be performed only with NASA approval/direction and procurement quantities will be determined by NASA controlled systems.

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L1 ILS Planning/MGT											
1. centralized	5	1	4	2	4	5	4	5	3	33	
2. distributed	1	3	2	2	1	1	3	4	3	20	
3. hybrid	4	5	4	5	4	4	5	5	3	39	

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL M	REMARKS
				TRANS-ITION	MGMT	COST	PERF				
L2 Maintenance Scheduling											given design state-of-art
A. Orbital hardware maintenance (On-orbit)											
1. continuous	2	3	3	3	2	2	3	2	2	22	hybrid
2. dry-dock	2	2	3	2	3	2	2	3	3	22	hybrid
3. periodic	3	3	3	3	3	3	3	3	4	28	preferred
4. hybrid	5	4	5	4	3	4	5	5	5	40	of 1&2 recommend
Fly-in-<u>only</u>	1	1	2	2	3	3	2	2	3	19	out years

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L2 Maintenance Scheduling											
B. Orbital Hardware Maintenance											
(On Ground)											
1. continuous	3	5	4	5	4	3	5	5	1	35	keep operational
2. periodic	3	2	4	5	4	3	5	5	1	32	hard time
3. on-demand	1	2	2	3	1	2	1	1	3	16	fly to failure not good idea
4. linked to up/down mass orbital equipment	2	1	3	4	4	3	2	2	1	22	all linked to up & down

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L2 Maintenance Scheduling											
C. Ground Support Equipment											
1. continuous	3	5	4	5	4	3	5	5	1	35	
2. periodic	5	5	5	4	3	3	4	4	3	36	
3. linked to pre/post launch processing requirements	4	2	3	4	2	3	2	3	3	27	
4. on-demand	4	1	1	5	3	3	1	2	3	23	operate to failure

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L3 Maintenance Execution											
A. On-orbit											
1. repair in place	3	4	2	5	5	2	3	1	5	30	Expensive Acquisition
2. remove/repair/replace											Lower operational cost
a. organizational repair only	3	3	3	3	2	4	2	3	4	27	Allow <u>some</u> on-orbit maintenance
b. organizational and intermediate repair	3	4	3	2	3	3	2	3	3	26	rather than trying to return everything to the ground to be repaired.
3. remove/install spare item/repair spare item on orbit											Minimal maint. is more
a. organizational repair only	4	4	4	3	4	2	4	4	4	33	desirable than extensive repair
b. organizational and intermediate repair only	3	4	3	2	3	3	2	3	3	26	facilities because of cost, tools, space availability
4. remove/install spare item/return item to earth for repair	3	1	5	1	2	1	2	2	1	18	Also want a pool of spares to minimumize the time equipment is unavailable to perform a needed function.
5. Hybrid	5	5	4	3	4	4	5	5	3	38	Optimum cost-benefit

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L3 Maintenance Execution											
B. Ground Support											Hybrid is most desirable. Off site maint. of ground equip is more acceptable than of on-orbit equip. probably because timing is less critical in repairing ground equip.
1. repair in place	5	4	5	3	5	3	1	3	3	32	
2. remove/repair/replace	3	4	3	1	4	2	2	3	3	25	
3. remove NLA/install NLA spare/repair NLA on-site	3	3	3	2	3	1	4	3	3	25	
4. remove NLA/install NLA spare/repair NLA off-site	4	2	4	4	2	4	4	3	3	30	
5. remove/repair off-site/replace	2	1	2	5	1	5	3	3	3	26	
6. hybrid	5	5	5	4	4	3	5	3	3	37	

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L4 User autonomy and international participation											
A. On Orbit											
1. self sufficient	3	3	4	3	2	1	3	3	4	26	
2. defined (partial NASA) support	5	5	5	4	3	3	5	4	3	37	
3. Total support	3	2	3	4	5	5	4	5	1	32	

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L4 User autonomy and international Participants											
B. Ground Support											
1. self sufficient	4	4	4	2	3	2	4	3	1	27	
2. defined support	5	5	5	4	5	3	5	5	3	40	
3. total support	4	2	3	4	2	3	3	4	1	26	

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L5 Transportation to orbit											
1. STS only	3	1	3	3	3	3	3	3	3	25	
2. STS and ELV	5	4	4	5	4	4	4	4	3	37	
3. International fleet (hybrid)	1	5	5	3	3	5	5	2	3	32	
4. other											

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL M	REMARKS
				TRANS-ITION	MGMT	COST	PERF				
L6 Evolution											
1. continous	1	1	1	2	1	2	4	3	2	17	
2. block modifications	3	2	5	5	5	4	3	1	3	31	
3. hybrid	4	3	3	3	3	5	5	4	4	34	

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L7 OEM Support Strategy											
A. Flight Hardware											
1. continue all OEMs, i.e., "Marching Army"	5	4	5	1	4	1	4	4	1	29	costly to transfer; out-year procurement challenge
2. add parallel OEMs, i.e., second sources (at IOC)	1	4	5	1	1	1	5	5	1	24	costly
3. terminate all OEMs ASAP; get all data, manufacturing rights; create an organic capability.	1	5	5	5	5	1	5	3	1	31	need data costly dependability
4. hybrid	5	5	5	3	5	5	5	5	5	43	

LOGISTICS OPTION AREAS FUNCTIONS SUBFUNCTIONS	FEASIBILITY	FLEXIBILITY	USER FRIENDLY	EFFECTIVENESS				SAFETY	TERMINATION	TOTAL	REMARKS
				TRANS-ITION	MGMT	COST	PERF			M	
L7 OEM Support Strategy											
B. Ground Support Equipment											
1. continuous	5	4	5	1	4	1	4	4	1	29	
2. second source	1	4	5	1	1	1	5	5	1	24	
3. terminate/Gov't source	5	5	5	3	5	5	5	5	5	43	

3.4 WHITE PAPERS

3.4.1 Space Station Line Items Estimate

RAYMOND L. NORMAN JR.
APRIL 3, 1987

The following projections for the number of line items anticipated in the Space Station inventory have been derived through several estimating techniques.

Space Station Operations Task Force Estimate:

The first estimate of the range of inventory line items is one derived through deliberations of experienced logistics professionals and the use of a simple questionnaire to Work Package and other respondents who represent potential users of the SS inventory system.

Work Package Estimates

The WP contacts are indicated in Table 3-9. These personnel represent a portion of the SS Integrated Logistics Working Group as it existed in November '86 to March '87. These contacts are responsible for the logistics function and represent an extensive background in the field as the Government/user and in some cases years of industry experience as well.

SPACE STATION OPERATIONS TASK FORCE
RANGE OF INVENTORY ESTIMATES FOR 2010 A.D.
(LINE ITEMS X 1000)

WP	CENTER	CONTACT/PHONE		LOW		MEAN		HI		REMARKS
			TOTAL	217		313		403		
			SUBTOT	161	56	218	95	275	128	
				F	G	F	G	F	G	F=FLIGHT G=GSE
WP1	MSFC	K.PURUSHOTHAM 824-0250		30	10	35	15	40	20	BEST ROM AVAILABLE
WP2	JSC	C.HOWARD 525-3824		30	10	35	15	40	20	PROBABLY HIGH. ACCEPTABLE FOR NOW
WP3	GSFC	D.VANDERTUIG 888-8990		7	3	15	5	20	10	NONE
WP4	LeRC	J.EWASHINKA 297-5292		7	3	15	5	20	10	UNDER REVIEW PMAD IMPACT TBD
COM.GSE		DESIGN ENGR		-	(10)	-	(15)	-	(20)	(NOT INCLUDED)
INTERNATIONAL	JPN			30	10	35	15	40	20	
INTERNATIONAL	CAN			2	1	3	2	7	3	
INTERNATIONAL	ESA			30	10	35	15	40	20	
PLATFORMS (COP)				15	5	20	10	30	10	
DOD		MAJ. WOOLARD		7	3	20	10	30	10	VERY LOW ESTIMATE 60-75K ESTIMATED
EXPERIMENTER/PI		TBD		2	1	3	2	5	3	
INDUSTRY				1	-	2	1	3	2	

NOTE: PREPARED BY R.NORMAN, PANEL 2 LOGISTICS SUBCOMMITTE, 867-4670, 853-9035. 16 MAR 87
INPUTS SOLICITED FOR NEXT REVISION WHICH WILL INCLUDE ORU, SRU, PIECE PARTS.

FIGURE 3-9

Common GSE

Common GSE was not included in the first iteration of this estimate. A non-additive number is given as a rough order estimate. These numbers represent the best guess of the KSC SS GSE point of contact (A. Anderson). It is believed that 10% of the forecasted $1B will become officially labeled "common" and managed by KSC. The question remains from the operational logistics organization's perspective and more properly from the Program Office policy standpoint"...will there be an Item Manager or Commodity Manager for this GSE?" A policy recommendation is suggested that there be an item manager concept established at KSC today for this future equipment and that a coordination/memo of understanding be promulgated between the other centers anticipating the use of the common GSE.

International Participants

No official interface with the international participants has been initiated on this subject. The LeRC representative was used as a sounding board for these projections. However, the projections themselves were based on Spacelab experience for JPN and ESA. The STS RMS experience was used for the Canadian projection.

Co-orbiting Platforms

The COP projections are based on a 50% relation with a more complicated WP; e.g. WP1.

DOD

We believe that there will be a significant DOD impact in the outyears. However, under todays DOD posture, such a large projection does not fit with public information. Should the SS become a more viable DOD platform for certain experiments then this number would grow. The DOD representative indicated a high estimate of 60-75K line items.

Experimenter/Principle Investigator

There undoubtedly will be special cases were PIs will want and NASA will agree to stock store and issue unique items for use. A simple example of this is a very high purity gas or unique gas; e.g. argon, which will be needed for a PI while he is here. Since there is either a long procurement time or difficulty in locating sources of these lab quality resources there will be a requirement for continuous stocking of a limited but unique inventory. This inventory will be replaced with different lines as the nature of the experiments change.

Industry

Just as there will be a need for unique PI items of supply, industry will also want uniques material. The mechanisms for reimbursements of these items to the Government will be covered in Program Implementation Plans or other agreements.

Independent Estimate

A separate rough order of magnitude line item projection was independently made by Boeing Company representatives. (Mr. Douglas Ballander, BAC, working on NAS 10-11238, 867-7430)

These representatives suggested that for SS alone there would be 4408 repairable ORUs which would require six SRUs per ORU to be stocked and there would be 36.5 unique pieceparts per SRU. This arithmetic projection is

Number of ORUs	4,408
X 6 SRU/ORU	26,484
X 36.5 parts/SRU	965,352
Subtotal	996,208
X Stockage Factor	30%

For a grand total of 298,862. A 4.7% variance is determined when compared with the 313,000 line items projected with the SSOTF logistics. Subpanel projects that these estimates are for the number of line items only. It expresses our belief as to the RANGE of inventory. It does not describe the DEPTH. We believe that the depth will be somewhat more than other programs due to the thirty-year life time.

3.4.2 Maintenance of A Complex, Distributed System - LPS

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Background

The Launch Processing System (LPS), which was first installed in 1977, comprises three major subsystems; the Checkout, Control and Monitor Subsystem (CCMS), Central Data Subsystem

(CDS), and Record and Playback Subsystem (RPS) which support the Space Transportation System (STS) pre/post-flight maintenance and checkout, prelaunch testing, and launch operations at KSC and VAFB. The LPS operations concept involves automated checkout and launch procedures, processing of significant "change" data, and on-line test data analysis.

LPS contains numerous simple and complex, analog, digital and hybrid electronic and electromechanical devices (e.g. computers, peripherals, Line Replaceable Units (LRUs) and Shop Replaceable Units (SRUs)). The elements of LPS are maintained in a classical manner as described in one of the following three categories:

Organizational Level

Maintenance performed on vehicle subsystems and related support equipment in direct support of the turnaround flow. It includes scheduled and unscheduled maintenance actions required to inspect, service, calibrate, replace, repair and modify in place, and reverify (sub) systems and associated components.

Intermediate Level

Maintenance that is performed in direct support of organizational level maintenance and involves disposition, repair, service, modification, calibration, and verification of items removed during organizational maintenance. Automatic Test Equipment, bench setups and Minimum System Configurations are used in this level of maintenance.

Depot Level

Maintenance that is performed by designated maintenance sources (e.g., manufacturers, USAF air logistics centers, NASA centers, etc.). It normally consists of maintenance that required test equipment, facilities, or skills which are not economically available to the intermediate level (e.g., repairing modifying, overhauling, reclaiming, or rebuilding parts, assemblies, subassemblies, components and items, manufacturing of unavailable parts and providing technical assistance to the organizational and intermediate levels.

Routine organizational level maintenance includes scheduled preventive maintenance routines and corrective maintenance required to restore systems and equipment to an operational status. Routine Organizational Level Maintenance is performed by maintenance personnel assigned to each set/subset of CCMS equipment. Corrective maintenance requires problem isolation to the LRU level, removal and replacement with a verified spare, and system retest. Selected troubleshooting and problem isolation below the LRU level is performed, when justified, by technical and/or operational requirements.

Hardware Interface Modules (HIMs) located in the LC39 areas require special consideration due to the diversified locations and multiple set configurations possible. Organizational level maintenance for HIMs is consolidated and implemented as a separate group. A mobile crew utilizes dedicated radio-equipped vehicles to provide maintenance and operational support as required.

Logistics and intermediate level maintenance support is conducted from two areas. The Intermediate Level Maintenance Facility (ILMF), located in the Central Instrumentation Facility (CIF) at KSC, provides Intermediate and Depot level maintenance for all LPS equipment, equipment fabrication and modification, and on-call maintenance functions. MSC 12 provides Logistics support to the ILMF and coordination with MSC 34, which supports the LC39 areas.

The ILMF is a designated R&QA Hardware Dispositioning Area (HDA). LRUs received at the ILMF, with the required paperwork, are logged into the Production Tracking System and dispositioned per Source, Maintenance and Recoverability (SMR) Codes. Barcodes are affixed to the paperwork and to the LRU/SRU if not already attached.

Designated LRUs, utilized in classified operations, are tested, repaired, and verified in a secure area. The secure Minimum Peripheral Test Set (SMPTS) provides a secure area for maintaining "hot spares" for use within any control room, and an area for off-line maintenance of failed peripherals. Intermediate level maintenance on equipment, unique to secure areas, is performed in this area, including color-change procedures on LRUs leaving the secure areas. In addition, selected Intermediate level maintenance on other equipment is performed as required. Maintenance data collection and work control, in the SMPTS, are the same as in unsecured areas.

SRU maintenance is performed in direct support of LRU maintenance in the ILMF with the primary objective of LRU turnaround back to usable spares. It includes dispositioning, bench calibration, troubleshooting, repair and verification.

LRU and SRU, maintenance requirements are documented and included in the appropriate IDMM/IDMMSS. Repairable SRUs, requiring separate testing and verification, are acted on in the same manner as an LRU. A separate work order is opened for each action on an LRU or SRU.

Over the years, the decision to be self sufficient in Maintenance and Logistics Support has proven to be the best choice for a long term program. Many Original Equipment Manufacturers (OEM) are either out of business or no longer support the product. Expertise and documentation are gone or unusable. Due to the above reasons, LPS Maintenance has assumed more and more, not only, the Intermediate Level Maintenance role but also that of Depot level maintenance.

To compensate for expertise loss, both by the OEMs and by our SPC, we are making extensive use of Automated Test Equipment (ATE) and in the future, Artificial Intelligence (AI) systems to capture the experts knowledge. Mandatory documentation has been a requirement through out our maintenance processes.

<u>In Work and The Future</u>

We are currently developing a position on the use of ATE for Shuttle LRUs. The use of ATE for testing will allow one type of machine to do testing of multiple types of LRUs thus eliminating the costly process of replacing obsolete OEM test fixtures. The same critical factors of expertise, documentation and repair costs are again the drivers for this decision.

In future systems, NASA has to acknowledge and fund the inclusion of Integrated Diagnostics, Testability and Maintainability at the inception of a new project. It is not enough to build a highly reliable or redundant system to accomplish its assigned task. Systems still fail sometime during their useful life and we, the Maintainers <u>must</u> determine the cause and repair the LRU/SRU or resolve the cause to a solution. When one does a cost analysis of up front costs (est. 40%) for testability versus life cycle costs of maintenance support at all levels, it becomes very clear that it is far better to include our needs up front.

<u>Recommendations for New Systems</u>

- Specify and Purchase <u>all</u> documentation

- Specify all the elements that make up Integrated Diagnostics and Testability

- Plan for the assumption of the Maintenance of the system - use OEM until you have established an in-house capability

- Develop test systems with both ATE and AI concepts in order to capture knowledge/expertise

- Provision lifetime spares during the system manufacturing stage to improve supply, testing and reduce cost

- Do a good job of <u>planning</u> and <u>budgeting</u> at the earliest part of system conception

Summary

Maintenance of sophisticated systems require intelligent planning at conception, NASA must begin making that commitment.

3.4.3 A Review Of Air Force Reconnaissance Programs

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APRIL 7, 1987

At the suggestion of senior NASA management, members of the the panel visited the Headquarters of the Strategic Air Command (SAC)and reviewed the current approach to logistics acquisition and support for several types of reconnaissance aircraft. The intent was to examine the techniques applied to small fleet sizes and to look for parallels that might be applied to the Space Station Program.

The reconnaissance aircraft divide into two types, those that are modified versions of commercial aircraft and those specially designed for unique missions. The approach to acquisition and logistics support varies significantly for the two types. The modified aircraft are acquired through the normal Department of Defense acquisition process. The logistics support for these aircraft draws heavily on the established Air Force Depot Maintenance System with mission peculiar equipment support handled on a case by case basis. In general, the special design aircraft were not acquired by the Air Force but were assigned to the Air Force later in the operating lifetime of the aircraft. As a result, the approach to long term logistics was not predicated on having a world-wide operating base for support. By the time the aircraft were assigned to the Air Force, the pattern of total support by the development contractor was established. The final mitigating factor is the Department of Defense requirement to have an organic (in-house) front line support capability in time of hostilities.

The large depot system of support and the unique nature of some aspects of the reconnaissance mission combine to make comparisons with the Space Station difficult. There were, however, some very valuable lessons learned which are applicable to the Space Station and if incorporated in the acquisition and design activities will result in cost savings and enhancements in support.

USE OF STANDARD HARDWARE,SOFTWARE AND FIRMWARE

The use of standard state-of-the-art hardware was strongly advised. There is a substantial penalty in cost and supportability associated with "exotic" hardware. In addition, a list of standard hardware was recommended. The Air Force has experienced multiple design agents for equipment and the resulting duplication of inventory and support assets that results from each designer having the freedom to specify his favorite piece of gear. As a result, they have developed a lists of equipment already in the inventory. The designer of a new system must use the equipment already in the inventory or justify new items as mission essential.

The application of this approach to the Space Station would require the focused management of hardware,software and firmware design. The Air Force experience indicates, however, that there is a substantial savings in the magnitude of the resulting support assets required which will reduce logistics cost and reduce the scope of the configuration management job. The proposal to centrally manage the acquisition of common GSE would thus appear to have great merit. The thrust for program-wide commonality and standardization should be vigorously pursued to optimize supportability and reduce operating costs.

DESIGN APPROACHES DO MAKE A DIFFERENCE

The variations in supportability across the reconnaissance aircraft types are significant and result from the differences in design approach. The ratio of maintenance man-hours to system operating man-hours varied by a factor of ten and was a factor of a hundred, minimum, larger than the current estimates for the Space Station. The message is very clear! You get what you design for! The current Space Station maintenance man-hour allocations call for an improvement of two orders of magnitude in reliability and or maintainability(R&M) over that experienced by the reconnaissance aircraft. The requirement for close attention to (R&M) during the design cannot be over emphasized. In addition it will be imperative that the (R&M) design requirements be uniformly applied across the Work Packages if a consistent support posture is to be achieved.

BUILT IN TEST EQUIPMENT (BITE)

One of the maintenance man-hour reduction techniques to be applied in the Space Station Program is the use of built in test equipment (BITE). This will minimize the time a crewperson must spend in determining the cause of failure in a piece of equipment and if the replacement ORU is functioning properly. The Air Force has experienced reliability problems in BITE which have resulted in higher than predicted repair costs. The key issue is who pays when the BITE says you have a failure, the ORU is subsequently examined by the manufacturer and he says there is nothing wrong and ships it back. The program has thus incurred the cost of removal, replacement and shipping, which in our case can be from orbit. The suggestion from the Air Force is that if the BITE gives a false indication of failure which results in a remove and replace action, that the manufacturer be contractually responsible for his own cost and that the fee structure should meaningfully recognize this action as poor performance.

BUSINESS STRATEGY

It was suggested that the Space Station Program will need a long term business strategy that is supportive of the logistics support strategy. The contractual and management mechanisms for coordinating the residual support from prime contractors,the operations contractors and the original equipment manufacturers continuing to support the program need to be well thought out and provide incentives for each party to perform well. The vagaries of the NASA budget process need to be anticipated to smooth variations in support posture.

DATA ACQUISITION

Emphatically, SAC systems support experts stated the requirement to buy all technical/engineering data or data rights during full-scale engineering and development. The data should be deliverable in government specified format(s), validated by the development contractors and verified under government auspices as to technical accuracy, completeness and usability before final government acceptance. Drawings and schematics must be suitable for use in component/assembly reprocurement, i.e., Level III drawings, "as built," complete in technical detail and fully legible, so that a non-OEM vendor can produce the required item without re-engineering or reverse engineering. This level of technical integrity is also required in the technical documentation to be used for maintaining hardware, software and firmware, to eliminate or at least reduce to the absolute minimum any program dependency on OEMS for technical guidance during the operational phase. Acquiring only data rights, in lieu of actual data, must be reserved for only those relatively few specific items for which there is no foreseen need to subsequently support, modify or replace in kind. In such cases, having purchased the rights to technical/engineering data ensures future data acquisition capability in the event of unexpected need.

This concept is much preferred over the idea of acquiring technical/engineering data piece meal when needed over the program life. In the case of the Space Station, not having items of data ready to apply when needed could be safety or mission critical, even disastrous, and undoubtedly much more expensive than up-front acquisition.

<u>MAINTENANCE DATA GATHERING</u>

It is clear from the Air Force experience that there is a dubious payback to current systems support posture for the cost of maintenance data gathering. It is clear that the design of new aircraft does benefit from the knowledge gained through maintenance data gathering on operating systems. It would appear that the Space Shuttle program missed a golden opportunity to provide an experience base for Space Station designers when the development of a maintenance data gathering system was not pursued.

The suggestion offered was that regardless of the approach taken the system needs to be automated, user friendly and that it should provide an immediate information payback to the current system maintainer in order to gain his support for data input discipline.

OPERATIONS CONTRACTOR APPROACH

After discussing the approaches taken by the Air Force in providing logistics support for the various aircraft and missions involved in reconnaissance several conclusions have been reached. If the Space Station Program elects the option of a downstream operations center contractor with expertise to support sustaining engineering as well as the broad based logistics support the program will require, we must decide and implement an appropriate operational strategy during the Phase C/D period. The operations contractor should be part of the design process. If we do not involve them up front, we will have to use a combination of operations and development contractor expertise managed by the operations civil service center personnel. This approach would require a migration of management responsibility from the development centers to the operations center, a task we have not accomplished well in the past.

The other conclusion reached is that the particular approach selected, while important, is less important than the timing of the decision. The compelling need is to select a support approach early in the design process and to insure that the design process includes supportability decisions that are consistent with the support approach selected. In the case of Space Station, the design discipline must extend across all four of the Work Packages and include all elements if a unified support posture is to be achieved.

Clearly, the person who should be the most concerned about this issue today is the person who will be accountable for Space Station operational performance. That person needs to be identified immediately and given the wherewithal to deal with these issues.

4.0 SUSTAINING ENGINEERING/CONFIGURATION MANAGEMENT

4.1 INTRODUCTION

Sustaining Engineering and Configuration Management are critical activities required during the Space Station mature operations phase. These two activities are closely interrelated and will be required and conducted during all phases of the mature operations: (1) ground processing operations, (2) on-orbit flight operations, and (3) upload and download flight operations. For the purpose of this report, mature operations for sustaining engineering/configuration management is defined as the phase after development and after initial operations when major redesign activities have stabilized.

As a general definition, sustaining engineering is maintaining a design that fulfills original design intent and is compatible with intended operational use. Problems are resolved to keep the hardware/software systems in an operational status. Operational performance is enhanced through product improvement redesign for more cost effective and efficient operations. Approved changes in design and requirements are incorporated as part of system evolution. Sustaining engineering excludes major upgrading of existing systems or the acquisition of new systems if more than incidental research and development is required, but supports new development to gain the expertise necessary to operationally sustain new systems.

Configuration management is defined as the discipline of applying technical and administrative direction and surveillance to identify and document items under configuration control, to control changes to these items, to record change processing and implementation status (configuration status accounting), and to verify compliance with requirements (auditing).

4.2 SUMMARY

Sustaining engineering is an assigned role of the Space Station Program and is an ongoing operational function performed under the Integrated Operations Management system of the Space Station Program. Two basic levels of management for the sustaining engineering efforts are identified: 1) the tactical planning level and 2) the execution level. Tactical level engineering integration and configuration control is performed as a centralized organizational function at the NASA Headquarters level. The executional management functions are performed at the NASA operation centers receiving direction and technical requirements from the tactical management system located at NASA Headquarters.

4.2.1 Flight Systems

The executional responsibilities for sustaining engineering of the Space Station flight systems and interfaces are centralized at the launch center. The centralized function performs the responsibilities for supporting the flight systems during ground processing, upload/download operation, and on-orbit operations. Considering that the on-orbit operations are "remoted" to the ground and that the other operations are primarily occurring at the launch center, locating the sustaining engineering responsibilities at the launch center has considerable merit. A significant exception to the foregoing concept is to provide for a separate organizational concept at a separate flight operations center for the sustaining functions (except commonality) of the Space Station platforms (except commonality) pending the programmatic concept in organizationally separating the platform operations from the manned operations of the Space Station.

Internationals and users perform their own sustaining engineering functions within established Space Station program policies, guidelines, and criteria which are initiated at the strategic level and further defined at the tactical and execution levels. Safety issues and interfaces are controlled by the Space Station Program. For users a payload integration organization (user integration) is established under Space Station operations to coordinate the engineering integration and interfacing function between users and the Space Station sustaining engineering organizations at the tactical and execution levels. The technical analysis of compatibility with the Space Station is performed as an integral function of the centralized sustaining engineering task at the launch center.

The Space Station consists of flight elements designed and developed by NASA, Internationals, and users. Each of these elements will be responsible for the sustaining engineering of the hardware and software provided for that element of space station operations. NASA has the overall responsibility of performing the analysis to ensure the compatibility of user/International designs and performance. Each user will be required to design to a standard Space Station user interface. The user/Internationals must establish compatible management procedures which will assist NASA in accomplishing Space Station integration. All elements must work with and participate in established methods of controlling hardware/software interfaces, i.e. Interface Control Documents (ICD's). The Space Station engineering integration function is a NASA sustaining engineering activity that will integrate all Space Station hardware/software design into an integrated operational station. The engineering activity will encompass system analyses, (e.g., hazards, thermal loads, stress, mass, dynamics...), resource allocation between International elements and NASA elements, and NASA safety certification of engineering changes (this includes all user hardware/software modifications and International modifications).

An established method of controlling hardware and software design interfaces will be used by NASA during mature operations. Where design interface exists between the Space Station flight systems and an International module, Interface Control Documents (ICD'S) will document this design. The ICD's will be baselined jointly by the affected Internationals and the Space Station. All proposed changes to these ICD's will be jointly processed and jointly approved by the Space Station operations and Internationals involved. Interface Revision Notices (IRN's) will be used to document proposed and approved changes to joint NASA/International/users ICD's. These ICD's will show standard interfaces to which the Space Station is designed and which the Internationals/users will be expected to meet. Exceptions to the standard interfaces will require interface changes which, as approved by the Space Station operations, will require peculiar ICD's between the Space Station and user instrument. These peculiar interfaces must be designed for removal and return to the standard interface design upon mission completion of the affected user instruments. Both the standard Space Station/user ICD's and the peculiar Space Station/user ICD's will be baselined and controlled using established ICD change processing methods.

4.2.2 Space Station Dedicated Support Systems

The Space Station support systems receive tactical direction and technical requirements from the NASA Headquarters level and the execution responsibilities are performed at the operations centers. The distributed support systems which are located and utilized across the NASA centers are assigned to the lead operations center to perform the sustaining engineering. The sustaining engineering for commonality in support systems is also assigned to the lead operations center. Unique systems dedicated to ground processing or flight operations are assigned to the launch center and flight operations centers, respectively.

4.2.3 Multi-Program Support System

The multi-program support systems perform their own sustaining engineering outside the Space Station Program. The multi-program support systems include NASA programs such as: transportation systems including NSTS, satellites such as TDRSS, NASA institutional systems . . . . The support of these systems to the Space Station Program are initially agreed to at the strategic level and further interface relationships are established at the tactical and execution levels. Normally the Space Station Program performs within the standards and criteria of these support systems to a joint agreement to preclude unilateral changes impacting the Space Station Program. NASA Space Station operations will perform the technical coordination and integration between the users/Internationals and the multi-program support systems.

4.2.4 Engineering Change Processing

Inherent in sustaining engineering responsibilities is the change processing methodology. The methodology can be divided into functions and interfaces. The flight element change processing methodology requires engineering change definition, a review and evaluation process, change approval, and the actual change implementation plan. The NASA configuration management system will provide for an engineering change identification, evaluation, approval and implementation system which will control all changes to the Space Station and the Space Station dedicated support systems during the operational phase. Internationals and users of the Space Station must have internal management systems which are similar with NASA's change processing methodology and compatible where interface controls are necessary. The primary configuration control responsibility is at NASA Headquarters; delegated authority to the operations centers is a NASA Headquarters option.

Space Station change methodology and rationale for Space Station changes during mature operations is:

- To minimize all engineering changes. During mature operations the only authorized changes will be those approved for design improvement, i.e. to correct a component/system failure and minor enhancements to improve operational efficiency. Major upgrades and evolution/growth designs are considered as separate development programs and are only operationally sustained after turnover to mature operations.

- To permit design of engineering changes only to those elements who have been assigned sustaining engineering responsibilities as authorized by the Space Station Program.

- To approve all changes to the hardware/software configuration which must be incorporated on flight systems and interfaces.

- To flight certify all changes, including those required by Internationals/users, which must be integrated into Space Station hardware/software either on-orbit or prior to launch. Users will be encouraged to have design maturity prior to experiment delivery and integration into Space Station elements/systems.

4.2.5 Real-Time Support

Real-time support will be provided on an on-call basis to monitor critical operations and to perform failure analysis of critically failed components/systems. For on-orbit and up/down load operations, a small scale integration function will exist around-the-clock to coordinate the on-call support as required, to track problems, integrate problem resolution, and to identify areas where engineering support is required.

4.2.6 Transition Phase

A concerted plan between Space Station operation and development organizations must define transition requirements for the mature operations phase. This plan must be established early in the development phase to ensure an efficient turnover to mature operations. The recommended concept is to have operational representatives involved during the early development phase and an engineering core in-place approximately three years prior to turnover. The turnover will occur in increments and on a system-by-system basis depending on design maturity and complexity. A decision milestone prior to the three years is necessary to determine the turnover status and establish the turnover date. This is applicable to complex systems; the time is shorter for less complex systems or when turnovers have minimal impacts in transitioning to mature operations. Design maturity during initial operations will determine turnover date and, hence, mature operations.

4.3 FUNCTIONAL DESCRIPTIONS

Configuration management and sustaining engineering activities are interrelated and support each other in the sustaining operations of the space station. Figure 4-1 shows the basic functions of Sustaining Engineering/Configuration Management and typical inputs and products. This section of the report will further describe the functions of sustaining engineering and configuration management.

Inputs

- o Program, Plans, Budgets, Directives
- o Operational Plans, Schedules
- o Assessments and Impacts
  - Engineering Change
  - Analysis Requests
- o Failure Reports
- o Performance Data
- o Completion Notices
  - Installation
  - Verification
- o Certification Recommendations
- o Customer Design/Performance Data

Configuration Management

Configuration Identification
Configuration Control
Auditing
Accounting

Sustaining Engineering

Engineering Integration
System Analysis
Design Engineering
Documentation

Products

- o CCB Directives
  - Change Approvals
  - Contracts
- o Technical Requirements
  - Test and Checkout
  - Maintenance
  - Verification
- o Engineering Release
  - Design and Reviews
  - Procurement
  - Mod Kit Definition
- o Real-time Support
  - Problem Resolution
  - Critical Operations
- o Certification for Flight
- o Configuration Status
- o System Analysis Results
- o Risk Assessments
- o Costs and Schedules

SUSTAINING ENGINEERING/CONFIGURATION MANAGEMENT

EXTERNAL INTERFACES

Figure 4-1

4.3.1 Sustaining Engineering Functional Descriptions

In discussing sustaining engineering functional descriptions, a top level listing includes the following:

1. Planning and Management
2. Systems Analysis
3. Design Engineering
4. Engineering Integration and Verification
5. Documentation

Each of these five functional descriptions are outlined in Appendix E and discussed as follows:

Planning and Management

The functions of planning and management for sustaining engineering address the cost, schedule, and performance impact for accomplishing sustaining engineering activities, for selecting one approach for an activity, and then following the results of this activity on a periodic basis. These functions cover budget management, contract management, and resources management (cost and manpower). Management functions for Advanced Technology Programs when assigned to the Space Station operations will be included. The functions will provide for Space Station evolution/growth management wherein the sustaining engineering organization must plan, manage, and implement an approach for Space Station design changes and methods for permitting a systematic growth in the design of the Space Station. Some outputs from the planning and management functions are plans, schedules, budget requests, evaluation of proposed MOU changes, contract changes, and management directives. These functions will continue the use of management information systems, which were initiated during the Space Station development phase.

Systems Analysis

Systems analysis is a key sustaining engineering function. A primary portion of sustaining engineering analyses will be turned over by the Space Station Work Package contractors to the operations sustaining engineering organization. System analyses will document the results of the development phase and describe in total the Space Station design including Space Station unique ground support equipment and models, test beds and simulators. Also turned over will be engineering drawings and parts lists which completely describe the hardware and software configurations of end items provided during the development phase. This data base will be provided to the operations sustaining engineering organization at the start of mature operations. Examples of analyses in this data base are:

- Systems Performance Analyses
- Mass Properties Analyses
- Failure Mode and Effects Analyses
- Stress Analyses
- Thermal Analyses
- Vibration Analyses
- EMI Analyses
- Sneak Circuit Analyses
- Hazards Analyses
- Safety Analyses

Any proposed configuration change to controlled end-items must be assessed for impacts to program costs and schedules, to feasibility, availability, commonality, maintainability, operability, and safety aspects of the Space Station.

An important system analysis function of sustaining engineering is flight certification engineering analysis. During mature operations, every design change to the Space Station flight systems must be flight certified by NASA. In most cases, the sustaining engineering organization will, given a proposed change design concept, conduct an engineering design analysis as to the change's overall affect on the Space Station if that change is incorporated. The analysis would be updated throughout the design cycle of the change until the change modification kit is verified and accepted for change incorporation. At the acceptance review for that change, the updated flight certification analysis is part of the review. Safety issues of a change are reviewed during the preliminary or critical design reviews. If a safety concern had existed for this change, it would be eliminated or resolved during the change design finalization. If not, the change would be disapproved. Ideally, the change should be disapproved prior to detailed design in order to save engineering design effort. For this reason, safety considerations must be considered early in the design change process. The flight certification process directly involves the Internationals and the users. Any user must have his experiment flight certified by the NASA sustaining engineering organization prior to flight. User documentation published by NASA will define these requirements. In a like manner, Internationals must have their flight incorporated design changes certified by NASA sustaining engineering. Changes incorporated prior to launch will be safety and flight certified by NASA as a part of certification of the complete International module or end item (to be accomplished during the Space Station development phase). During mature operations, flight certification will be accomplished on an individual engineering change basis. The Space Station operations organization will manage the flight certification process during the operational phase.

The Space Station sustaining engineering activity must work closely with the International's sustaining engineering personnel responsible for International Space Station hardware and software. Interface Control Documents (ICD's) will be used to control the design between U.S. provided hardware and International provided hardware. The International agency will accomplish sustaining engineering within its management system unless interface design is affected or Space Station requirements such as contamination, safety, materials, ... are not met. When a nominal requirement cannot be met, the International sustaining engineering organization will submit a design waiver to the Space Station requirement listing the proposed waiver requirement, what will be met in lieu of existing design standards, and a justification of why the waived condition is acceptable for the time period listed in the waiver. Design improvements or problem fixes proposed by Internationals which do not affect the above criteria will be approved and implemented by the International except NASA will approve flight certification recommendations which is required for all design modifications to be incorporated in the operational Space Station.

The Space Station sustaining engineering function also interfaces directly with many users providing Space Station payloads (experiments). Users will be required to meet the requirements of Space Station accommodations. Interfaces will include design/performance data reporting and resource usage agreements. The users must submit sufficient payload data for the Space Station flight certification to the sustaining engineering organization. In some instances, the user may request a change to the Space Station design to accommodate a specific experiment. If approved, NASA sustaining engineering and the user must coordinate closely on the interface analysis and design. Changes to this design, must be coordinated and shall be designed to be returnable to the original configuration after the experiment mission.

Design Engineering

As a major part of sustaining engineering, design engineering will perform conceptual, preliminary, and detailed design for space station flight hardware/software and associated ground support equipment. The design engineering function will inherit from the Space Station development phase a large quantity of engineering data, such as, drawings, specifications, program-level requirements documents, operations and maintenance documents, ... Most of this data will be maintained by sustaining engineering throughout mature operations as changes are approved to the Space Station and ground support systems. These data will be revised accordingly to provide an up-to-date design configuration. If an evolution/growth change is authorized to the Space Station, the design engineering data base is the initial baseline for the evolution/growth design. The design of an evolution/growth change is outside the scope of operational sustaining engineering until the design becomes operational.

The design engineering function is vitally concerned with interface design. Interface design is controlled by NASA's system of Interface Control Documents (ICD's). These documents list the interface design between hardware/software elements, and are approved by both interfacing agencies responsible for the hardware or software. Once approved, ICD'S cannot be changed unless all approval parties agree to the change. Interface Revision Notices (IRN's) are used to document preliminary and finally approved changes to ICD's.

The preparation of modification kit instructions is a responsibility of design engineering. For each modification kit, instructions are required to explain how the change is to be incorporated on-orbit or at the launch site. Instructions for installing the modification kit detail parts in the logistics carrier is included. Return parts and/or tools must be stored/mounted in the logistics carrier for return to earth. Depending on the complexity of the change, detailed design may be required for upload and download of parts included in the modification kit. Test and verification requirements must be included in the mod kit and test procedures for verifying that the changed hardware/software is operating satisfactorily. In summary, modification kit instructions integrate the engineering change into one package which totally and completely describes the change, how to verify the change, both on the ground and on orbit, and how to install the change (with flight procedure detail).

Sustaining engineering is concerned with component failures, maintainability analyses, and failure analyses. All failures must be analyzed and recurring control actions taken as required. Failure analysis may determine that a design change is required or additional spares must be procured. Maintenance requirements could be affected and must be revised as required.

Sustaining engineering must conduct design reviews. The design and development of any Space Station complex engineering change will require accomplishment of NASA's system of design reviews from Preliminary Design Review (PDR), Critical Design Review (CDR), Design Certification Review (DCR) and finally, Flight Acceptance Review (FAR). Engineering changes may not require all of these reviews or several changes can be covered at a single review. The intent of these reviews must be covered during engineering change design development and acceptance. Affected users and Internationals will participate in these design reviews. Upon completion of design for a change, and incorporation of the change into any flight/ground subsystem/system, design engineering will prepare revisions of the affected drawings, specifications, ... to an "as built" configuration. Completion notices of verification, installation and checkout will update the data bases indicating final closeout of a change.

If Space Station design changes require test articles or additional support equipment, a sustaining engineering function is to identify the items and justify the utilization for engineering change verification. Upon change approval these items must be designed and procured or manufactured. Design specifications and other documentation will be supplied by sustaining engineering.

Engineering Integration and Verification

Sustaining engineering must closely integrate both systems analysis and design engineering. For any proposed engineering change, engineering must be totally integrated to determine all hardware and software affected by the change. If affected, design changes must be made to these items as well. The integration function must carefully review a proposed change and determine if ground systems, transportation systems, and ground data communications, software systems, Internationals, users, ... are affected. Impacts to change all affected systems must be included and submitted in the engineering change proposal for NASA approval. Change assessments must be obtained from Flight Operations, Ground Processing, Logistics and Safety, Reliability and Quality Assurance (SR&QA).

Each proposed engineering change must be reviewed to determine how it will be verified. Verification test planning includes test objectives and requirements, evaluation criteria, procedures, test plans, training requirements, logistics requirements, and schedules. Any hardware or software required for verification must be identified, justified, designed and manufactured or procured. The manufacturing and procurement functions must be supported by sustaining engineers who are familiar with the engineering change. Any software change must be verified and validated in the hardware/software integration facility. Integrated test plans and requirements will be developed for prelaunch verification the final installation, and checkout of the modification.

All sustaining engineering functions will be required to support both flight and ground operations to resolve anomalies or to monitor systems performance or test results. If a critical operation or test is to be conducted, real-time sustaining engineering support will be provided as required for operations. Routine sustaining engineering support will be provided by engineering integration functions which will coordinate engineering expertise as required. For mature operations, a high level of real-time engineering support will not be required during routine operations.

Documentation

There will be a large amount of documentation required to accomplish Space Station sustaining engineering. Requirements documents, ICD's, and engineering drawings must be kept up-to-date in an electronic data base. These data will be provided to mature operations by organizations involved in the development phase. Configuration status and accounting reports will be a part of sustaining engineering documentation. Mass Property Reports, Performance and Trend Prediction Reports and Engineering Analyses will be required and kept up-to-date. Flight certification reports and the latest status of this activity will be maintained. Other documentation will include commonality items and the status of their development. SR&QA Documentation will include Critical Items Lists, Failure Mode & Effects Analyses, ALERTS, Safety Assurance Analyses, Hazards Analyses, and Inspection Reports. The required documentation electronic data base will be obtained and/or prepared, and maintained in order to accomplish Space Station sustaining engineering. To the maximum extent possible this documentation will be computerized and made available to all Internationals and users. Data access to the

Internationals' and users' data bases will also be made available. It is imperative for mature operations of the Space Station, that the development phase documentation be transferred for maintenance and control by the operations organizations. Electronically, an overall goal is to minimize the required Space Station program documentation under maintenance and control. The operations sustaining engineering function will continue to minimize the active program documentation required for Space Station sustaining engineering throughout the mature operations. Historical documentation will be archived and accessible when required.

4.3.2 Configuration Management Functional Descriptions

Configuration management is a support function that provides management discipline and surveillance to the space station configuration. For Space Station mature operations an effective management and communications system for controlling and documenting changes is required to ensure continued operations support. Configuration management utilizes sustaining engineering to accomplish its objectives.

For each proposed engineering change, configuration management determines the organizations and elements which are affected by the change. Sustaining engineering must determine what subsystems are affected and what disciplines are affected, such as verification, software, reliability, maintainability, ... A major area of responsibility is document maintenance. The control documents which configuration management has under baseline control are engineering documents, such as, specification, ICD's, and engineering analyses. Configuration management must ensure that the Space Station engineering data base (engineering drawings and parts lists) is maintained accurately by sustaining engineering.

Configuration management has four functions: 1) configuration identification, 2) configuration control, 3) configuration verification (auditing), and 4) accounting. Each of these functions is outlined in Appendix F and discussed as follows.

Configuration Identification

For Space Station, the identification of configuration end items will have been accomplished during the development phase and will be given to mature operations organizations. New end items to be controlled may be added to this list when required and justified as part of an approved engineering change.

Configuration Control

The configuration control function will process proposed changes to the Space Station and will support systems designs. The change control system permits evaluation of each change by affected organizations and provides for a final decision on the change when evaluation is complete. As changes are approved, affected control documentation is also updated, and the change implementing organization is directed to accomplish the change. Real-time status of change processing will be accomplished from change request receipt to change incorporation in the hardware/software end item.

The approval of engineering changes is controlled by NASA by delegating approval authority to the appropriate NASA manager. For example, the Space Station flight hardware and each support system will have separate NASA managers. These managers will have defined engineering change approval authority. If interface changes between systems are proposed, the NASA managers responsible for both systems will have joint change approval authority. For changes affecting International or user interfaces, a joint change processing methodology will be agreed to by the affected parties and this methodology will identify the managers with change approval authority. In a similar manner, contractors under contract to NASA will have certain change approval authority for hardware/software assigned to their control. For the Space Station flight hardware and software, engineering change approval authority is normally assigned to NASA managers only.

Verification (Auditing)

Audits will be performed to verify that the configuration management procedures and implementation practices are being followed by the program elements and organizations. Reviews will be conducted to assure that modifications and changes are being implemented in accordance with configuration change directives and that the as-built configuration is identical to the as-designed configuration. Corrective action will be identified and recommended to configuration management.

Accounting

The configuration accounting function not only closes out each configuration change, it also updates each controlled document affected by the change. Also, engineering release records are revised to show the new configuration on the engineering drawings and parts lists. Configuration accounting also provides a status of all change requests, control board directives, proposals, and change dispositions. Included in configuration accounting is the status of the modification kits and instructions required to incorporate an approved change.

4.4 OPERATIONAL CONCEPTS

This section of the report describes concepts for organization, transition to mature operations, change processing methodology, and selected special topics as they relate to sustaining engineering and configuration management.

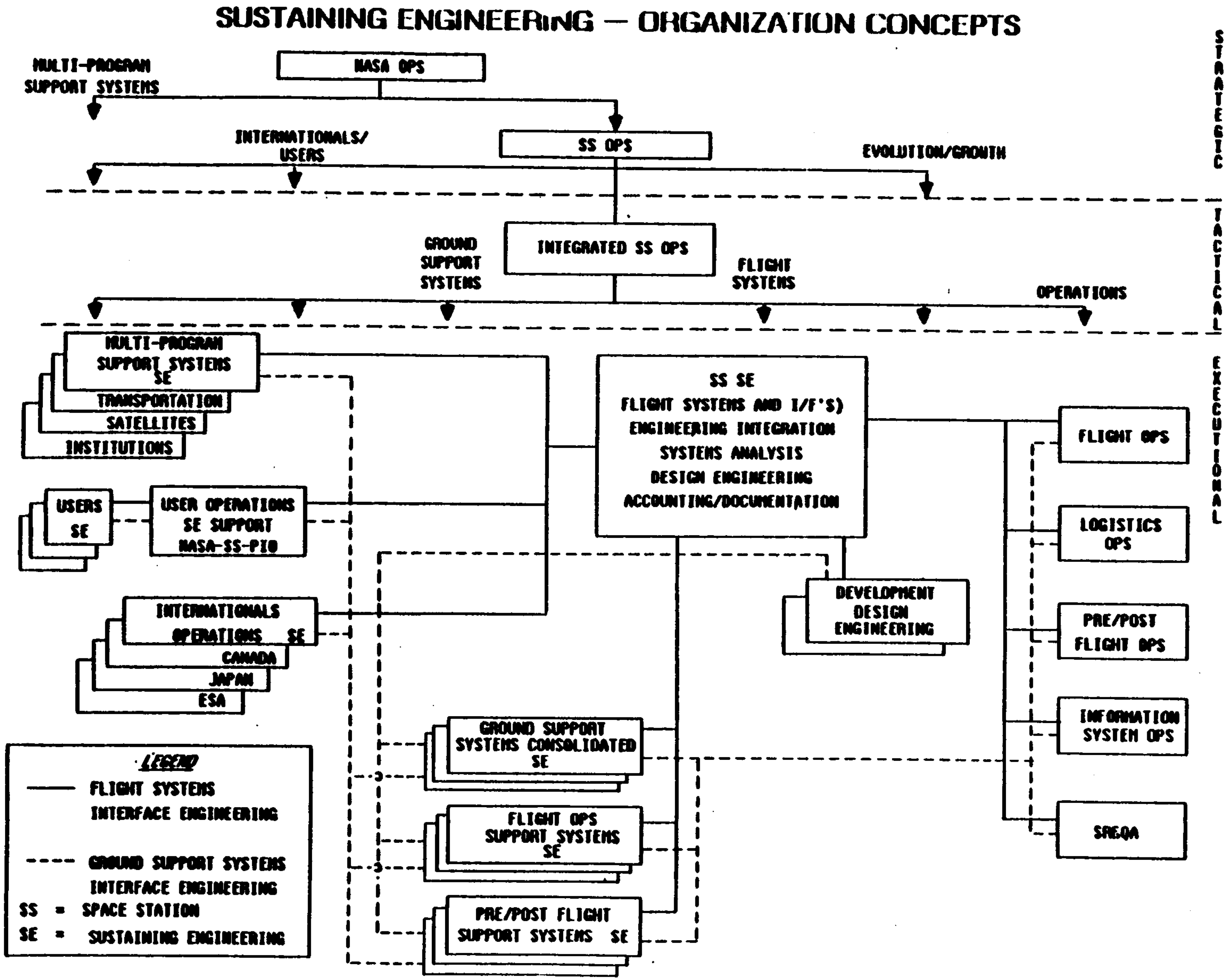
4.4.1 Organizational Concepts

The following concepts describe organizational roles and relationships for sustaining engineering and the controlling levels of configuration management for mature operations. The operations centers perform the execution functions and support the tactical planning and requirement activities at NASA Headquarters. Operations centers are inclusive of the launch center and the flight operation centers for manned space station, space station platforms, and payload operations centers whether combined or separated organizationally.

Sustaining Engineering

Figure 4-2 shows the basic organizational concept for sustaining engineering.

Integrated Space Station Operations. At a centralized NASA Headquarters level, tactical planning, budgeting, and engineering integration are performed. Incremental manifests are defined and engineering requirements are established to support the forthcoming increments. Inputs from the Internationals, users, multi-program support systems, evolution/growth programs, and from the operations centers are assessed and integrated into operational plans and requirements including approved configuration management requirements and directives affecting physical and functional interfaces to the space station flight systems and support systems for all phases of the mission increments (ground


SUSTAINING ENGINEERING — ORGANIZATION CONCEPTS
STRATEGIC
TACTICAL
EXECUTIONAL
NASA OPS
MULTI-PROGRAM SUPPORT SYSTEMS
INTERNATIONALS/ USERS
SS OPS
EVOLUTION/GROWTH
INTEGRATED SS OPS
GROUND SUPPORT SYSTEMS
FLIGHT SYSTEMS
OPERATIONS
MULTI-PROGRAM SUPPORT SYSTEMS SE
TRANSPORTATION
SATELLITES
INSTITUTIONS
USERS SE
USER OPERATIONS SE SUPPORT NASA-SS-PIO
INTERNATIONALS OPERATIONS SE
CANADA
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FLIGHT SYSTEMS AND I/F'S)
ENGINEERING INTEGRATION
SYSTEMS ANALYSIS
DESIGN ENGINEERING
ACCOUNTING/DOCUMENTATION
DEVELOPMENT DESIGN ENGINEERING
FLIGHT OPS
LOGISTICS OPS
PRE/POST FLIGHT OPS
INFORMATION SYSTEM OPS
SR&QA
GROUND SUPPORT SYSTEMS CONSOLIDATED SE
FLIGHT OPS SUPPORT SYSTEMS SE
PRE/POST FLIGHT SUPPORT SYSTEMS SE
LEGEND
FLIGHT SYSTEMS INTERFACE ENGINEERING
GROUND SUPPORT SYSTEMS INTERFACE ENGINEERING
SS = SPACE STATION
SE = SUSTAINING ENGINEERING

Figure 4-2

processing, upload/download, and on-orbit processes). An engineering analysis and assessment as to the feasibility and supportability of the increment planning is performed by the operations centers. Requirements to/from users are integrated and coordinated by a NASA Space Station Payload Integration Organization.

The Space Station sustaining engineering organizations at the operations centers will accomplish the major functions of sustaining engineering under the centralized management and control system at NASA Headquarters. This provides a singular management interface to the Internationals and to the users. This also provides a single approach to maintenance of the Space Station engineering data base (EDB) throughout mature operations. A standard system will be provided for processing engineering changes and updating affected Space Station documentation. The operations centers provide the technical support and analysis required for the tactical planning. Major design changes to Space Station hardware/software are evaluated and approved at this level and are included in the tactical planning for the Space Station operation. The request for major redesigns is normally initiated at the operations centers; upon approval, the design effort is assigned to the evolution/growth design developer who will proceed with the redesign under operations control. Evolution/growth programs which are strategically planned at the Space Station Program level is performed separate from the integrated Space Station operations; however, the operations centers will support these programs from an operations perspective.

<u>Space Station Flight Systems and Interfaces</u>. A centralized function responsible for the sustaining engineering of the flight systems and its interfaces is defined at the executional level and is located at the launch center. Staffing with sufficient engineering expertise exists to perform engineering integration,

systems analysis, and design engineering to maintain/sustain the flight systems during ground processing, upload/download, and on-orbit operations.

The engineering integration functions are primarily "project management" organized (for example, manned modules, logistics modules, support system interfaces, international and user interfaces, ...) to provide interfacing and coordinating capabilities to other organizational elements including coordination of real-time support. Requirements from the tactical level at Headquarters are normally received and coordinated with the other sustaining engineering organizations.

System engineering to perform such tasks as failure and performance analysis, modification designs, and engineering assessments are organizationally pooled and led by sub-system managers in individual system disciplines (for example, flight software, environmental control systems, communications, structures, . . .). In the presence of evolution/growth development for the Space Station, major design engineering efforts will be selectively assigned to the evolution/growth contractor but responsive to Space Station operations control and integration; an "on-call" capability will exist between sustaining engineering and the evolution/growth activities for expertise and major design support. Evolution/growth engineering representatives will be assigned as contact coordinators to the sustaining engineering organization. "In-house" design engineering will contain the capability to perform small-scale modifications and enhancements.

Within the Space Station Program, there exists unique flight elements and systems which merit having separate sustaining engineering organizations (excepting commonality and interfaces). Two significant examples are the Space Station platforms and EVA systems. Because of their uniqueness and minimal interfaces, separate sustaining engineering groups in these areas located at the corresponding operations centers is advantageous.

Development Design Engineering. Evolution/growth programs are separate and functionally removed from the Integrated Space Station operations. To have access to this resource of expertise and to develop the sustaining expertise for the evolution/growth systems, a relationship needs to exist between development and operations organizations. This interconnected relationship consists of two parts; 1) evolution/growth development and 2) design support to Space Station operations.

For evolution/growth activities space station operations will support by providing operational design perspectives and at the same time develop the necessary engineering expertise to sustain the evolution/growth designs after they become operational. For major designs to sustain the Space Station, an "on-call" capability shall exist; for these designs the developer shall be responsive to the requirements of the design as defined by Space Station operations.

The rationale for a separate organization is to minimize interference with the mission of Space Station sustaining engineering and vice versa for the development programs. To control the possible overlap between these two organizations, the development organization and the sustaining engineering organization, special design control features would be established. The control features would result in interfacing agreements that define the interfaces for the organization responsible for the operational design changes and the organization responsible for development hardware/software design. Copies of released design changes would be provided via the engineering electronic data base to the development organization by the sustaining engineering organization. The design concepts developed by the development organization would be coordinated with the sustaining engineers.

Additional agreements would be established between these organizations to assure NASA that successful Space Station sustaining engineering and follow-up development activity would be mutually compatible with mature operations.

Space Station Support Systems. Space Station dedicated support systems can be categorized as follows:

1. Support systems unique to flight operations (command/control stations, flight data processing, communications).

2. Support systems, unique to pre/post flight operations (servicers, handling equipment, test equipment).

3. Distributive systems which reach across centers including systems having commonality in function and design. (simulators, trainers, SSE, TMIS)

In all three categories, the executional functions of sustaining engineering is performed at the operations centers. Tactical planning and requirements are received from NASA Headquarters. For categories 1 and 2, the sustaining functions are performed locally at the flight operations center(s) and the launch center, respectively.

For category 3, lead operations centers are assigned the responsibility to perform the sustaining engineering functions for the individual distributed systems and the common designs. Organizationally these functions may be combined with other sustaining engineering functions being performed at the same operations center. The sustaining efforts for simulators and trainers which are similar to the flight systems maintains an engineering exchange with the flight systems sustaining engineering to retain flight-type configurations.

The sustaining engineering for SSE should be assigned to an operations center as a consolidated function; field engineering functions will be required because of its distributive nature. TMIS can be sustained in the same manner; however, if the concept of TMIS management goes across other NASA programs then TMIS will be sustained in a manner similar to other multi-program support systems.

User Operations Support (PIO Functions). The user operations support role is a Payload Integration Organization (PIO) function under Space Station operations performing integration and coordination responsibilities between the Space Station and users at tactical and execution levels. The users perform sustaining engineering on their own instruments and support systems within operating envelopes, standard ICD's and safety standards provided by Space Station operations via PIO functions. The PIO coordinates with the user and acquires user design and performance data and ensures that the users are within the Space Station standards. Specified data is required by Space Station sustaining engineering to maintain the overall Space Station configuration and performance. Space Station sustaining engineering will perform the technical risk assessment, design compatibility analysis, and flight certification review. If the standards are exceeded or if the user has unique requirements, the Space Station sustaining engineering function will perform the necessary analysis, assessments, and approvals prior to incorporating the unique requirements.

International Operations. The Internationals will perform sustaining engineering on their hardware/software within operating envelopes, ICD's, and safety standards established by Space Station operations. The Internationals will also perform engineering integration functions with their users and provide or make accessible their integrated design/resource data to Space Station operations. This data will be utilized by Space Station sustaining engineering to maintain the overall space station configuration and performance. The International sustaining function includes their support systems. NASA may assume responsibility for sustaining engineering only in cases of negotiated agreements. Safety requirements will be analyzed, assessed, and approved by Space Station operations.

The interfacing sustaining engineering functions with Space Station operations is performed at the tactical and executional levels. To perform this function, engineering integration representation to support tactical planning and execution is minimally required in the U.S.

Multi-Program Support Systems. Commitments of support are normally agreed to at the strategic planning level under the Space Station program. Tactical planning is performed at the Space Station operations level at NASA Headquarters and the execution at the operation centers.

The multi-program support systems perform sustaining engineering on their own systems outside the Space Station Program. Safety standards and standard ICD's including operating envelopes are provided to space station operations by joint agreement. Space Station sustaining engineering provides integrated engineering data on design/resources to the multi-program support systems. The Space Station operational sustaining engineering organization will interface directly with the other NASA Programs. The interface design for hardware and software belonging to these programs and interfacing with Space Station Program hardware and software will be documented on Interface Control Documents (ICD's) and approved by both interfacing programs. This design is then kept under configuration control. Any proposed change initiated by either program which affects that design must be coordinated with the interfacing program. If both programs agree, each program then implements the change within their organization to jointly agreed directives. If new hardware/software is required by any program and an interface design exists with the Space Station Program hardware/software, an ICD must be baselined and controlled to document the interface design for both programs. Inherent in the ICD systems, is the requirement on both organizations to annotate the ICD design shown on engineering drawings so that the interfacing program's concurrence is obtained prior to the initiator program incorporating that change in their hardware and/or software.

Operations. Space Station operations are defined as flight operations, Pre/Post Flight Operations, Logistics, Information Systems, and SR&QA.

The sustaining engineering interfacing functions with operations are described at primarily the execution level. These functions occur at the operations centers (flight operations center(s) and launch center).

Technical requirements are provided by sustaining engineering for implementation into operational procedures. These include test and checkout, maintenance, and verification requirements. For mature operations, these requirements are normally limited to approved changes associated with modifications and enhancements. A feedback system from operations includes the data which verifies that the requirements have been met or completed.

Real-time support by sustaining engineering is provided on an "on-call" basis for critical operations or failure analysis support. The engineering integration function coordinates this support with operations. Failure reports are provided by operations to the sustaining engineering organizations who performs the analysis, integrate the problem resolution, and recommend to operations the integrated solution.

The upload/download operations are complex and requires considerable mass properties analysis, flight dynamics assessment and configuration definition which is supported by configuration management and sustaining engineering functions. The standards, criteria, and requirement envelopes will be provided by sustaining engineering via computer aided analysis and inputted by operations using approved manifest and flight certified hardware data. When using a fully automated system for mature operations, the computer models and programs are then maintained and controlled by sustaining engineering and configuration management. The integrated payload data, mass properties and configuration, are then provided to the transportation systems such as STS or ELV's for their overall compatibility analysis.

Configuration Management

A major activity required for the Space Station operational phase is configuration management. This activity works closely with the sustaining engineering organization but is separately managed. A key function of configuration management will consist of engineering change processing. In order to control these changes and to assure acceptable approval of these changes, NASA will establish configuration change approval levels. These levels are listed in Figure 4-3. The control levels listed in the first column of Figure 4-3 are generally relatable to NASA organizational levels.

Configuration Control Boards. Levels I and II relate to Space Station organizational levels A and the Program Office (or equivalent). Level III is the resident manager's level at the operations centers; for flight systems, this is delegated as an option from Level II. Level IV is the project element or contractor control level and may be delegated by Level III to the sustaining engineering organization at the operations centers. Each level documents the criteria which an engineering change

Figure 4-3

CONFIGUREMENT MANAGEMENT

<u>Control Level Management System/Control</u>

I. Space Station Program

- o Program Plans, Policies, and Directives
- o Memoranda of Agreements and Understanding
  - Internationals
  - Commercials
  - Evolution/Growth

II. Integrated Space Station Operations

- o Budget and Cost Allocations
- o Management Requirements and Responsibility Allocation
- o Design/Performance Requirements and Standards
- o Interface Requirements
- o SR and QA Requirements
- o Commonality Requirements
- o Information System Requirements
- o Acceptance and Certification Requirements
- o Level I Requirements and Traceability
- o User Integration Requirements
- o Integrated Baseline Configuration

III. Space Station Operations Centers

- o Level I and II Requirements and Traceability
- o Specific Requirements and Specifications
  - Design/Performance
  - Interfaces (ICD's)
  - Verification
- o Internal Baseline Configuration as delegated from Level II

IV Project Element Operations

- o Level I, II, and III Requirements and Traceability
- o Detailed Specifications
- o Engineering Releases

affects. The change must be approved at that level. For example, changes affecting the international module to Space Station flight system interfaces would affect the level controls at Level II as shown on Figure 4-3. Therefore a proposed change would be coordinated with the Internationals, change impacts would be developed and consolidated, and all the change data would be forwarded to Level II for a joint disposition with the affected International. Again, referring to Figure 4-3, during mature operations, it is expected that Levels I and II will retain approval authority for all engineering changes affecting the Space Station flight systems. Change approval authority to ground support systems hardware/software will be delegated to Levels III and IV at the various NASA operation centers. These levels are usually the Program Manager at Level III and Project Managers at Level IV. During mature operations, these two levels may be combined into one level which would be Level III which relates to Level C in the Space Station development phase. Each approval level receives its change approval authority from the next higher level. If a manager does not desire to delegate any change approval authority to the sub-tier managers, then he is the approval authority for his level and the next lower level. Level IV is the final level which is delegated to sustaining engineering for the Space Station. During mature operations, this delegation will be for engineering drawing changes which affect the drawings, parts lists, and other similar documentation, but does not affect hardware or software. The approval authority for hardware/software changes will be delegated to sustaining engineering for identified ground support systems, but if the change affects an external interface the approval level will be Level III or higher.

Another ground rule which assists in understanding the control levels is that any level can disapprove a change which affects the controls at any other level. This means a Level III Manager can disapprove a Level I change. The Level II manager, which receives copies of Level III control board directives, can review the disapproval decision and require additional justification. If the Level II manager is strongly for approval, he may direct that the Level III manager approve the change. This would rarely occur and is mentioned only for clarifying how the system works. If the disapproved change is an interface change, and it is strongly required by the interfacing manager, the interfacing manager usually has the change redefined or proposes the change be implemented by another means. In this case, a new change request is processed to the Level III manager who disapproved the first Level I change. In many cases, the rewritten change or the new method of implementing it, is sufficient for the manager to accept the change and approve it.

Documentation. A key function for configuration management during the operational phase is maintenance of the Space Station Electronic Engineering Data Base (EDB). Maintenance of the EDB will primarily consist of keeping the following computerized programs up-to-date:

Change Processing Status - Records receipt of all change requests, and tracks the status of these requests through the change flow to CCBD approval and final contractual direction.

Control Documentation Record - Maintains all Space Station control documents, such as specifications, ICD's, ACD's and BCD's, and released approved changes to these documents by releasing change pages which incorporate the document change. Maintains in computerized storage a baselined record of all program controlled documents.

Modification Kit Status - Tracks the development of mod kits from CCBD approval through design, manufacture, preparation of modification kit for delivery, checkout of kit at launch site, installation in Logistics Module, launch, and incorporation on-orbit, verification, and inspection of final change. Verification and installation completion notices will be released and distributed for each modification kit installation.

Engineering Release Records - Provides the status of all engineering drawings, parts lists, and engineering orders for all Space Station Program hardware engineering drawings. Prints configuration record of each end item at any point in time.

Engineering Drawing Computerized File - This file provides and stores copies of all Space Station engineering drawings. These drawings are updated as they are changed. These drawings may be accessed by any Space Station Program participant on-the-ground or on-orbit.

Other computerized records may be required, and established on a case-by-case basis.

4.4.2 Change Processing Methodology

Configuration management requires the application of good management practice to all required actions from change request through change incorporation. An effective change processing methodology must assure:

- Comprehensive impact analysis
- Control of cost and schedule impacts
- Optimum implementation
- Coordinated implementation
- Accurate configuration records
- Supportability

The most visible and usually the most criticized aspect of change processing is configuration control. Consequently, today's environment demands an automated change processing system with an efficient Configuration Control Board (CCB) operation.

The configuration management system must provide for an engineering change identification, evaluation, approval and implementation system which will control all changes to the Space Station and the dedicated support systems during mature operations. Internationals and users of the Space Station must have internal management systems which are similar with NASA's change processing methodology and compatible where interface controls are necessary. Procedural methods for the overall change process system are required and must be documented for all participants to adapt and function within the proper standardized procedures.

Configuration Control Board (CCB). The CCB is the focal point for program change management and is responsible for the total assessment of change impact. It also directs implementation for changes. Typical CCB membership should include sustaining engineering, operations, SR&QA, logistics, program management, configuration management, manufacturing, test, and others as required. The CCB membership should assure complete change analysis and evaluation by all involved. All members may not be required for every meeting, but there should always be a core group present. Alternate members should be assigned whenever possible. The CCB chairman makes the final decisions and should be either the program manager or the configuration management manager.

CCB effectiveness can be maximized and meeting time minimized by:

- Distribution of change requests and agenda prior to meeting
- Change impact analysis by each member prior to meeting

- o Attendance by member or alternate
- o Availability of necessary technical documentation
- o Preparation of complete CCB directive
- o Preparation and distribution of minutes
- o Preparation and distribution of change status reports

For maximum efficiency a recorder is present at each CCB meeting.

Change impact analysis is the single most important CCB function because it is the source of data for all other activities. Faulty analysis can have wide ranging inputs on performance, cost, and schedule. A comprehensive impact analysis requires homework and input by the CCB members. A preliminary analysis by engineering may be necessary prior to the development of the final analysis. The use of analysis checklists are helpful. The results of the analysis is documented.

It is the responsibility of the configuration management organization to either accomplish or assure others accomplish the following for hardware/software changes:

- o Change request documentation
- o Request processing and recording
- o Approval/disapproval
- o Incorporation in configuration documentation
- o Incorporation in products
- o Verification of incorporation

The requirements and objectives of change management are the same for hardware and software. However, the methods have to change because of a higher rate of changes that can be worked mostly internal to the software organization. Delegation may be necessary to the software organization under specified criteria and control. A software member then would be included on the CCB.

Computerized Data Systems

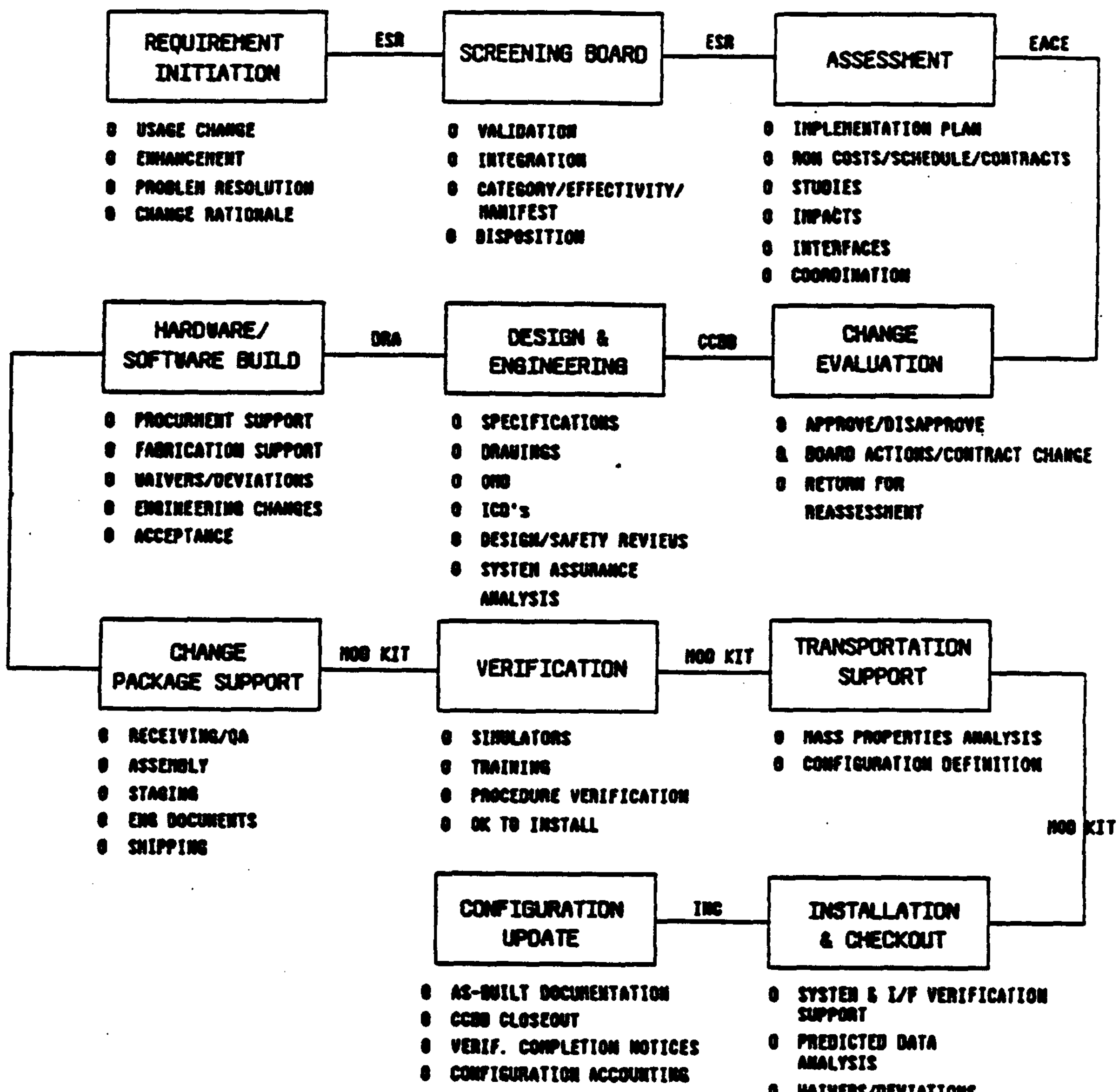
CAD/CAM and automation present challenges for change management because of the real-time change capability and dispersed data bases. Timely change coordination and verification of change incorporation becomes more difficult. To meet these challenges it is necessary that CM be established as the data base controller with impound capability. Maximum automation of change processing, change analysis, and CCB operation should be implemented. Extensive terminal coverage for CCB members and management should be provided. Computer aided inspection/auditing is utilized to verify change incorporation.

Change Integration

The typical flow for an engineering change during mature operations covers the elements participating in the various functions required to assure an acceptable processing of the change from receipt through final incorporation. Figure 4-4 shows a generic function flow of change processing. Appendix G further describes in detail the process of changes. A key part of this functional flow is change integration. Change integration is a responsibility of configuration management with assistance from the sustaining engineering organization. Change integration is the activity which totally and completely describes a proposed change, thereby identifying all hardware and software affected by the change and the organizations required to implement the change if it is approved. When a change is initially received, the configuration management organization makes a distribution to all organizations affected by the change. These organizations are listed on the

SUSTAINING ENGINEERING
GENERIC FUNCTIONAL FLOW

CHANGE PROCESSING



NOTE:
FUNCTIONS ARE DEPENDENT ON REQUIREMENTS

Figure 4-4

change request, but if not, the configuration management personnel can readily determine who is affected by noting the control documentation affected by the change request. For example, if an ICD is affected, the organization approving that ICD will receive copies of all change requests affecting that ICD. The configuration management personnel must be familiar with what approval level is affected and thereby what change control board will have approval authority for that change. In addition to the change distribution determined by configuration management, a copy of the change goes to the sustaining engineering organization. This organization accomplishes engineering integration of the change request by determining all hardware and software end items affected by the change. If this determination identifies organizations responsible for hardware/software items affected by the change and not included on the distribution list for the change, sustaining engineering informs configuration management to provide copies to the new organizations.

Engineering Support

An engineering change request is forwarded to NASA sustaining engineering for technical assessment of the change concept, cost and/or schedule impact. If the change is approved, sustaining engineering will design the change, oversee the manufacture of the design, test and verify the hardware and software, and prepare a modification kit for change incorporation on-orbit. Upon change incorporation, the engineering data base will be revised to reflect the new configuration.

Change Impacts

All organizations affected by a change request must identify the impact for implementing that change. When all impacts are received, the change request is ready for inclusion on the next scheduled change control board agenda. If the change is approved, all affected organizations, as determined by the change integration process, will be directed to implement the change by actions assigned and listed on the change control board directive.

Risk Evaluation

For each engineering change considered, a program risk evaluation is accomplished to cover all program impacts to costs, schedules, hardware, software, facilities, and to identify non SSP affects. Changes affecting users and/or Internationals must be approved/concurred in by these agencies prior to SSP approval. The NASA change processing system is structured to accomplish joint agency approval or disapproval for each change when required.

Screening Board

A screening authority is included in the change processing flow to consolidate similar changes and establish validity to changes prior to further processing. This authority performs initial integration of the change to identify the systems affected by the proposed change. Besides affected systems the screening functions looks at validation affects, change category and effectivity, manifest requirements, and criticality. NASA change screening authorities will be established and must have access to other screening authorities for changes which may require joint dispositions by other affected systems.

Every change processing system has the capability to expedite engineering change approval and subsequent incorporation. Normally this is performed as a function of the screening board. Expeditious action depends on the complexity of the change, but the change evaluation process can be reduced to rapid review and a meeting with the appropriate NASA manager. Rapid incorporation of a change is dependent upon when it is required and if the design and parts required are not complex. Incorporation can occur "real-time" or within a short space of time.

Verification

An activity associated with configuration management is the functional verification of products (modifications). After completion of the development phase, mature operations begins with a baseline (engineering design data base). The only modification that will change that baseline configuration is an approved configuration change. Changes can be divided into two classifications by need: 1) A design improvement, 2) A design fix change, or failure fix. The approved changes are incorporated by modification kits. Modification kits will include 1) hardware and/or software changes and supporting documentation or 2) documentation changes only, such as, a change in performance criteria. The functional verification of modifications will utilize test fixtures and simulators as developed during the development phase to validate a Space Station modification. In cases of approved complex engineering changes, sustaining engineering may need to develop a test fixture, model, or simulator which will be used to verify the engineering change during ground processing. The requirements for a change must be included during change evaluation of the change proposal in order that all change aspects, including cost and complexity, are covered prior to change approval.

Audit/Accounting

The function of configuration audit/accounting assures that each design change (after approval) goes through satisfactory design reviews, is verified by simulators, test beds, models, ... and/or tests, and is inspected to verify the "as-designed" change equals the "as-built" change or deviations/waivers between the two are documented and approved by the responsible and affected organizations. After change incorporation, tests and/or inspections are required to verify adequate incorporation of the change. The configuration audit cycle is statused for each change at each milestone completion. The complete cycle ends with change incorporation acceptance, and a Incorporation Notice Closure (INC) to the configuration accounting function which closes the change and updates the affected portions of the engineering data base which were affected.

Changes to Commonality Items

A key process for configuration management during mature operations is change processing for commonality items. Rigid configuration control procedures will be established during the development phase for changes to common items. These procedures will have assured that all changes to the items were coordinated with all users of the items prior to change approval. The procedures will require for each common item developed, an interface drawing showing the common item interfaces, such as electrical and mechanical connections, item mounting arrangement, performance data. . . The interface drawing will be approved by all common item users and baselined for configuration control. The baselined interface drawing will control the interfaces of the item so that users can design interfacing hardware at the same time that the common item developer composes his internal design. The developer completes the manufacturing and testing of the first unit prior to considering the baseline of the completely designed common item. After baselining the complete design, all proposed changes to the item are coordinated will all users of the item prior to change approval and incorporation.

4.4.3 Transition Concepts

The mature operations concepts showed that the Space Station and its dedicated support systems will have the execution of sustaining engineering located at the operations centers. The major and most complex transition will be the transfer of responsibilities for the flight systems to the launch center. For mature operations, the support systems, with some exceptions, will already be located and being sustained at the operation centers. This section of the report will concentrate on the transfer of engineering expertise and capabilities for complex flight systems, keeping in mind that these concepts can also be applied to the support systems.

Transition Plans

For mature operations to occur and be successful, transition plans and requirements must be established early in the development phase. The guidelines, criteria, and requirements for mature operations are established by Space Station operations. Each of the Work Package Centers and the operations centers must develop the implementation plans in concert with each other. These plans must cover the roles and responsibilities for civil service organizations and their supporting contractors and define tools, equipment, facilities, software, data bases, documentation. . . which are to be transferred both physically and/or in-place to the operations organizations and centers. Other criteria in these plans will include management plans, evolution/growth relationships, safety, Logistics, Information Systems . . . and the interrelationships associated with mature operations.

Sources of Engineering Expertise

Various sources of engineering expertise, civil service and contractor personnel, will evolve during the development phase. Pending definitions of evolution/growth programs, a significant number of engineering personnel with space station expertise will no longer be required after the development phase and completion of contracts. Rather than losing this expertise to other programs, the transfer of experienced personnel into operations organizations is an important aspect to mature operations.

During the development phase the Systems Engineering and Integration (SE&I) organization with its contractor will have distributed elements at the Work Package locations which includes the launch center and flight operations centers. The SE&I function will develop considerable engineering expertise and knowledge which will provide a substantial engineering base (civil service and contractor) for mature operations. This base contains mostly integrated engineering requirements expertise.

The Work Package Design centers and their contractors will have evolved an engineering base of Space Station expertise which, again, may be lost to other programs if not involved in Space Station evolution. The expertise base has strong design and engineering analysis capabilities.

Significant knowledge and expertise will be gained at the operations centers during the prelaunch and on-orbit assembly and checkout as part of the development phase. Substantial engineering expertise is gained in the prelaunch installation, test, and checkout of modifications implemented and user instrument integration after delivery of flight hardware/software to the launch center. This expertise will be retained into mature operations.

Types of Sustaining Engineering

The engineering required during the later stages of the development phase can generally be categorized into the following three types:

Type	Location	Description
I	Launch Center	Implementation of modifications and payload integration
II	Development Centers	Design and Analysis
III	Development Centers	Payload Integration Analysis

Type I-Modification Implementation and Payload Integration. As the final stage in the modification process and payload integration prior to launch, modification kits and payloads are delivered to the launch center to be installed, verified, and checked out. The launch center by definition is a centralized location where all hardware is processed prior to launch. The day-to-day relationship with space station hardware and user equipment will require field engineering changes at the launch center. These changes will be identified and defined by the launch center and certified by the development center.

Type II - Design and Analysis. The development centers are responsible for the design and related engineering analysis of modifications to the Space Station. Depending on the complexity of the modifications, more than one development center may be involved in the design/analysis. The analysis of the design is required to ascertain compatibility with the Space Station.

Type III - Payload Integration Analysis - Prior to payloads being certified to fly on the space station, an engineering analysis is required to certify that the payload is compatible with the space station for the upload/download and on-orbit operations. The analysis performed is nearly identical to that required for Type II.

Transition Stages

In the transition from the development phase to mature operations, four stages or milestones are identifiable. Each stage is a gradual buildup of engineering capability in preparation for the concept of centralizing the sustaining engineering for flight systems including the integration of payloads during mature operations. Figure 4-5 shows these stages relative to the Space Station program.

Stage I - Development and Assembly Phase. The transition functions for stage I are as follows:

- Development and definition of transition plans and requirements
- Participation in requirement reviews
- Initial representatives in-residence (initially by civil service and later by contractor)
- Participation in design reviews
- Establish ROM schedules for turnover in late development and assembly phase
- Finalize detailed plans by each operation center approximately four years prior to mature operations
- Operations contract established at mid-development phase
- Engineering Types I, II, and III performed by developers except after delivery Type I is performed at launch center.

TRANSITION CONCEPT

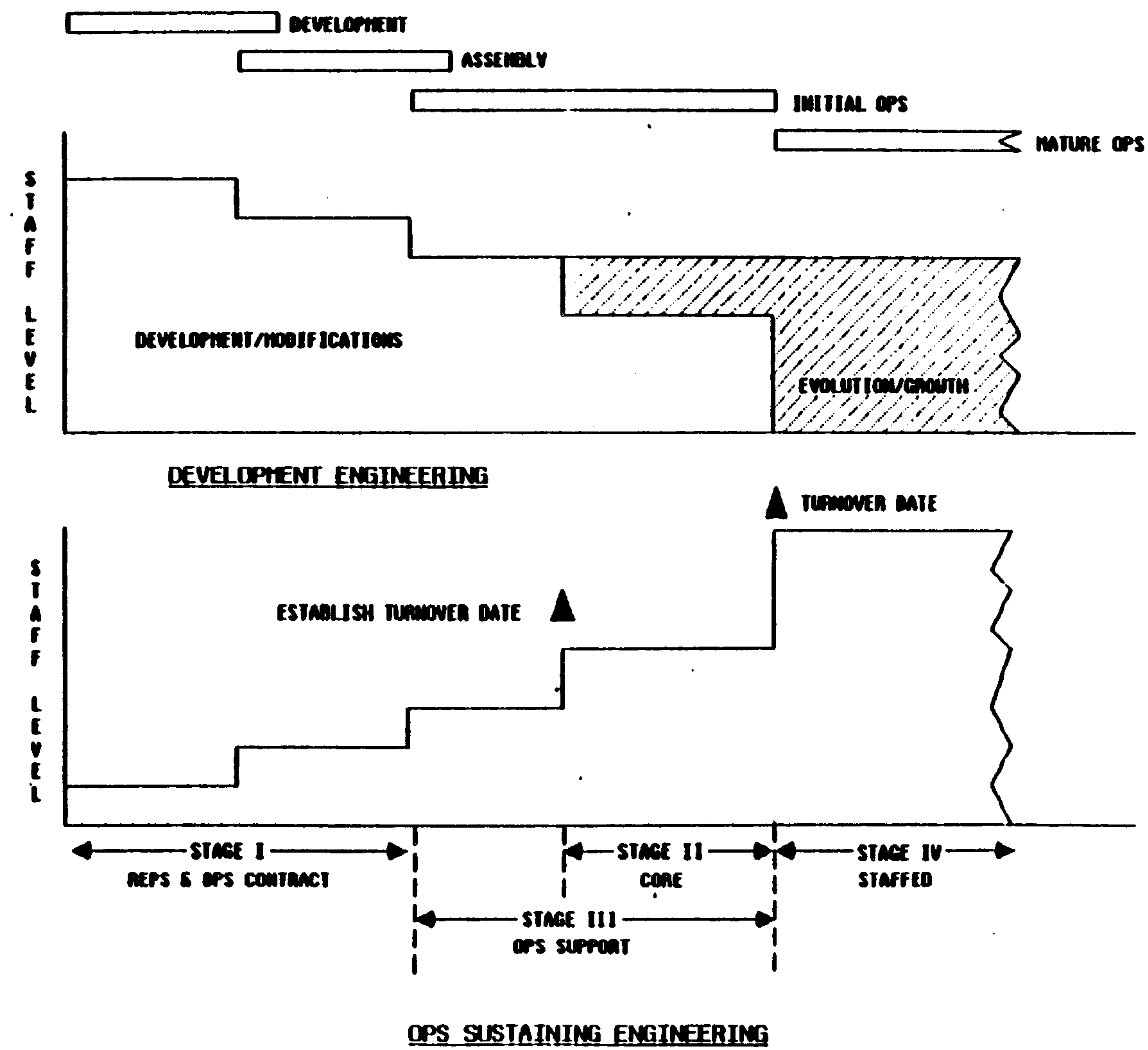


Figure 4-5

Stage II - 3 Years Prior to Mature Operations. This stage may overlap into Stage I or III depending on the turnover date. The transition functions are as follows:

- o Civil service and operation contractor core of engineers established and represented for each system and subsystem
- o Core has defined roles and responsibilities in support to developers such as system and user analysis
- o Engineering Type I performed at launch center and Types II and III performed by developers

Stage III - Initial Operations/Post Assembly Phase. Initial operations is a variable time span depending on maturity of design and status of operational expertise. The transition functions are as follow:

- o Build-up towards full staff and organization
- o Engineering Type I performed at launch center and Types II and III performed by developers
- o Minor changes/modifications performed by operations with certification approvals by developers
- o Turnover of less complex systems consisting primarily of support systems with support from developers
- o Stages II and III are totally overlapped for complex systems and can be defined as a singular stage whereby initial operations may be longer than 3 years

Stage IV - Mature Operations. Mature operations begins when operational expertise is in-place and design has matured. The transition functions are as follows:

- o Full staff and organization in-place with civil service-to-contractor engineer ratio of 1-to-12 (minimum)
- o Final turnover of responsibilities
- o Support from developer (where still active in evolution/growth) on an "on-call" basis

- o Support by operations to evolution/growth activities
- o Types I, II, and III of engineering performed at the launch center (Flight Systems)

Engineering Expertise Development

The transition phase overlaps the development phase and initial operations. The length of the transition phase will vary depending on the complexity of the systems and turnover requirements. It is recommended that the transition phase with an engineering core begin 3 years prior to mature operations. This will provide 3 years for the operational organizations to perform detailed planning and establish detailed procedures for all operational phase activities prior to its start. The 3 year transition phase is needed for a new contractor to prepare for and gain expertise from the individual Work Package (WP) contractors in order to be ready to perform sustaining engineering at the start of the mature operational phase.

Once the sustaining engineering organization is established and/or contracted the entire transition phase will be oriented towards preparing for mature operations. This preparation will be accomplished by interfacing with the development Work Package contractors and the Program Support contractor to develop a Space Station design expertise.

The sustaining engineering organization will develop Space Station design expertise by a combination of the following activities:

1. On-the-job training in working closely with Work Package contractor counterparts.
2. Studying and reviewing Space Station program control documentation such as specifications, ICD's, and engineering drawings.

3. Training classes on the Space Station design taught by the Work Package contractors.

4. Studying and reviewing engineering design analyses, test results, failure mode & effects analyses, and design knowledge capture data as a support role to the Work Package development activities.

5. Participating in design reviews, acceptance reviews, mission simulations, and other activities occurring during the design and development phase.

A key function for the transition phase is the maintenance of the Space Station engineering data base. Although this maintenance will be the responsibility of the Work Package contractors during the transition phase, the operational sustaining engineering organization will review this data base, assess changes and become capable of maintaining the engineering baseline when mature operations begin. The transitional phase will focus on transferring the maintenance responsibility of the engineering data base, engineering drawing files, and historical design analyses which documented design alternatives considered by the Work Package contractors and the rationale for selecting the most optimum alternative. By studying these analyses, an organization other than the Work Package design and development contractor will be able to achieve design authority and be responsible for Sustaining Engineering of Space Station hardware and software during mature operations.

Turnover Reviews

NASA will determine the progress made by the sustaining engineering organization in gaining the design knowledge of the Space Station. This will primarily be accomplished by periodic status reviews throughout the transition phase and culminate in a turnover review for each Space Station Program hardware/software end item. The Space Station development phase is managed by dividing all Space Station hardware and software into specific identifiable end items. To determine the state of readiness of each end item for mature operations, NASA shall conduct a turnover review for each item. At this review the responsible Work Package contractor will present the design and hardware status of each end item and its readiness for mature operations. The sustaining engineering organization will present the status of his expertise on the item and the adequacy of the engineering data base of the item to be transferred. Open items and remaining actions are presented at the review and agreement is made as to responsibility of closure. On an end item basis there will be many turnover reviews; however, one review may cover many end items, especially in the case of non-complex GSE or software end items. For items already existing in orbit, the review must identify the complete configuration of the item, including approved waivers which permitted design departures. In rare cases, action may be taken to to inspect the item on-orbit and provide a description of the area in question to the turnover review authority. It is expected that the non-complex designed items will have a turnover review early in the transition phase while the more complex items will have their reviews later. The number of end items will require the turnover reviews to be conducted incrementally.

Upon completion of all of the turnover reviews and upon closeout of all actions assigned at these reviews, the Space Station hardware and software will be ready for mature operations. The turnover reviews will establish a mutually agreeable status of the hardware and software end items at mature operations and the capability of the operations sustaining engineering organization to receive the engineering design authority for the Space Station. The reviews may also cover other aspects of mature operations readiness, such as, spares status, logistics status, . . ., as determined by NASA.

Configuration Management Transition

The configuration management (CM) activity is interrelated closely to sustaining engineering activities during mature operations. A transition phase is needed at the end of the development phase for a configuration management organization to assume responsibility for the configuration management functions. The turnover of this responsibility shall occur in a manner similar to and in conjunction with the turnover of the sustaining engineering responsibility. At the completion of reviews for all end items, the total CM responsibility will be transferred to the new configuration management organization. In a similar manner as sustaining engineering, configuration management will submit plans and procedures to NASA for approval. Upon NASA approval, the configuration management organization will be ready to start mature operations. Another area of responsibility which the configuration management organization must assume is the generation of various status reports, which include change processing status, document change status, change approval, mod kit status, and change incorporation status, ... All of these status reporting responsibilities are transferred from the Work Package contractors to the new configuration management organization when agreed to by NASA and the two elements involved. This transfer may be accomplished on a report-by-report basis or a one time basis, whichever is mutually agreeable. The requirement being that the new configuration management organization will have received all of the development phase configuration management responsibilities for implementation at the beginning of mature operations.

4.4.4 Special Topics

4.4.4.1 Tools and Facilities

To facilitate the sustaining engineering functions, design/development tools used as simulators, test beds, analysis models. . . will be provided or made accessible to the operational sustaining engineering organizations. During the transition phase these items and agreements for access will be defined. The transition plans and agreements must include those tools and facilities which require physical relocation. In cases where the sustaining engineering organization is the primary user, the tools and facilities will be located at that site. These tools will be required by sustaining engineering for modification verification, analysis, training, anomaly investigations, and information storage and retrieval.

For sustaining engineering to adequately and properly perform its function, certain tools and physical space is required. These requirements will be identified and briefly described.

Tools and facilities required can be categorized into four areas: analytical, functional, informational and production.

Analytical. The prime analytical tools required are computer models. These are required to support engineering analysis of performance including upload/download characteristics. The computer models will be used to analytically determine mass properties, thermal, dynamics, stress and other parameters. They are also needed to perform software analysis related to changes or upgrades in the SSE.

Functional. Functional tools are needed to verify planned modifications prior to implementation and for training installation crews and/or developing step-by-step installation and checkout procedures. These tools include test beds, test fixtures, trainers, and simulators. Facility space is needed to accommodate these tools and also to provide an area for hardware and software integration [Multisystems Integration Facility] (MSIF). Modification and performance/design verification including training and failure simulations will be conducted in this area. This facility is shared with operations. Software data may be electronically transmitted for verification in this facility.

Information Systems. Information systems and performance monitoring facilities are needed to support a wide variety of sustaining engineering functions. For example, access to engineering documentation and configuration/failure status is a function that requires TMIS support. Performance monitoring facilities are needed to monitor real-time data and accumulated or compiled data. These are provided as either a remote or local capability and would be similar to todays HOSC or MER type functions.

Production. Software production facilities and small scale manufacturing facilities are required to produce software changes and hardware modification kits and mock-ups . For producing design drawings and related documents, CAD/CAE systems compatible with TMIS is required. Also, office space for sustaining engineering personnel will be needed.

4.4.4.2 Interface Control Documents (ICD's)

ICD's are used to document the interface design between two or more elements furnished by two or more design agencies. Both agencies approve the design and sign the final ICD. At this point, the design is baselined.

Proposed changes to the ICD design are submitted by preliminary interface revision notices (IRN's) to the appropriate change boards. The preliminary IRN's should be coordinated with both interfacing agencies to assure that the IRN design is technically feasible. The IRN design should also be coordinated with NASA and other affected agencies.

After the proposed change is completely evaluated, the chairman of the change board approves or disapproves the change. If approved, the change board directive documents the approval. The directive is not released until an approval directive is received from the interfacing change board. The second directive is referenced on the first and the CCBD is released. The CCBD directs the design agency to change his hardware/software design to comply with the IRN.

The interfacing CCBD also directs the interfacing agency to comply with the IRN. Upon approval of the IRN's against an ICD, the ICD is updated to a new revision which incorporates all of the approved IRN's.

ICD's should be baselined as soon as possible after the Preliminary Design Review (PDR) for the hardware. The preliminary design should include preliminary interface design which should be finalized after all interfacing elements have approved it. When approved, the ICD drafting can begin. Upon completion of ICD preparation, the ICD can be coordinated and approved by all affected agencies. It is then baselined and placed under configuration change control. All subsequent design changes which affect the ICD must be proposed by preliminary IRN and approved prior to release of design changes.

All physical and functional interfaces are documented in ICD's. Physical interfaces are mechanical, electrical, environmental, dynamic and envelopes. Functional interfaces include procedural and operational, i.e. torque requirements for tightening fasteners on a cover which must be accomplished in a specific sequence.

Electrical pin functions would be a functional interface. Operational constraints will also be included in these ICD's.

ICD's are required between interfacing design agencies, i.e., two contractors or NASA and ESA. If the same agency is responsible for both hardware items which have a physical interface, then engineering drawings are sufficient for controlling the interface design.

In some cases, the Space Station will provide standard or one-sided ICD's, specifically where interfaced systems vary or change often and are noncritical to safety. The utilization of standard ICD's is cost effective by reducing maintenance of ICD's; performance can be maintained with effective planning of standards and criteria. This concept is particularly applicable to user racks, logistics carriers, and stowage containers. An example of this ICD would be the documenting of standard interfaces for the users. These ICD's would show the design of the Space Station which would accommodate user experiment connections, such as electrical connections, mechanical attach points, fluid connections, . . . Only the Space Station side of the interface would be shown. As long as a user meets the requirements of this one-sided ICD, the Space Station design would not be changed; the user still would be required to provide design and performance data to the interface. If one user required a change to this standard interface, he would coordinate his requirement with the sustaining engineering element and if feasible, a new interface would be designed to accommodate this user. A new or unique ICD would be initiated showing this design and would be approved by both the Space Station Program and the affected user. The new ICD would then be subject to configuration control. This ICD would be effective for the Space Station/user from joint approval through the end of the experiment mission. At that time the Space Station hardware must be changed and returned to match the original one-sided ICD interface.

Since the user to Space Station interface must be returned to the standard interface, care must be maintained in designing peculiar user interfaces so this can be readily accomplished. When using standard ICD's, the Space Station Program would still be required to assess and analyze the compatibility of the user design and performance with the Space Station.

4.4.4.3 Maintaining Expertise

Sustaining engineering is an ongoing function and an assigned task for the Space Station Program. Sustaining the operations requires day-to-day performance analysis, solving potential problems prior to outright failures, and ensuring contingency planning is kept up-to-date. Trainers and simulators are excellent tools for developing contingency plans and for the training of operators, flight crews, and engineers. As a method for maintaining engineering expertise, sustaining engineering shall have the responsibility of developing induced failures in trainers and simulators in the training of personnel.

Sustaining engineering will also be involved in the evolution/growth design programs in a support role. An operations perspective is provided in the review of the evolution/growth designs. Sustaining engineering will also review and/or perform the technical risk factor assessments and analyze the impacts on the existing space station systems. Besides a means of maintaining expertise, involvement in evolution/growth also provides the mechanism for developing the expertise necessary to perform the sustaining functions when the evolution/growth designs become operational.

Advanced technology programs also provides an opportunity to maintain and advance expertise for sustaining engineering. Selected programs shall be allowed in the sustaining engineering organization for special studies and assessments for potential adaptability to the Space Station. Careful selection is required to ensure these programs remain as a secondary function to the sustaining engineering's primary role of sustaining the Space Station.

4.4.4.4 Rack Staging

Rack staging is the process of configuring flight racks with Space Station hardware and components to accommodate user instruments. In the Spacelab Program the hardware consisted of passive and active components. Passive components included standard storage containers, hand rails, support struts, attach points, and cooling cover plates. Active components included remote acquisition units (multiplexers), intercom units, TV systems, heat exchangers, fire suppression systems, and cooling ducts. For each mission, configuration drawings and physical reconfiguration of the racks were required at substantial costs to the design agency and the launch center.

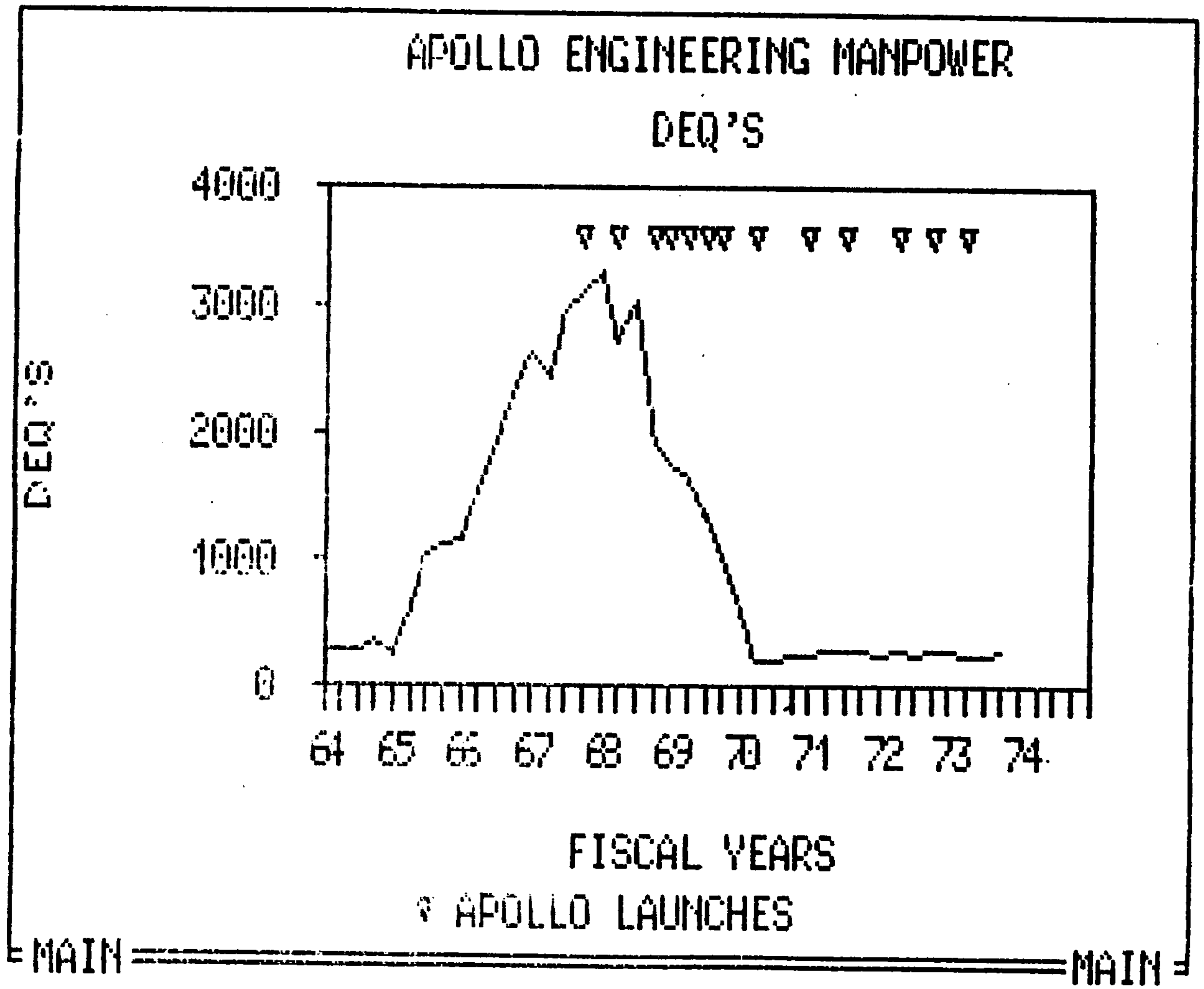
Considering that the Space Station Program is planning on at least six sets of racks (10 per set), substantial cost savings in sustaining engineering and ground processing can be realized by standardizing all racks and reducing or eliminating the active components in the racks. Active components should be designed to be external to the racks (such as placed in permanently located subsystem racks). Standard interfaces should be defined for user accommodation. The foregoing is based on the shipment of racks off-site to other locations whereby with active components installed, additional maintenance and sustaining costs can be expected by the Space Station Program.

In summary, the design of the racks should be standardized for user accommodation with minimal Space Station active components required internally, particularly if the racks are shipped to other locations.

4.4.4.5 Estimating Techniques

There are many factors that affect the manpower required to perform sustaining engineering. For example, the number of approved changes in evolving requirements, number of product performance improvements, and the operational enhancement redesigns that required for more cost effective operations all impact sustaining engineering manpower. These type of factors are not accurately predictable. However, we can use past program experiences to develop cost estimating relationships that will give some guidance in what to expect for Space Station sustaining engineering costs.

The basic approach is to determine sustaining engineering manpower on an annual basis as a percentage of total development engineering manpower for a given system or program and apply that percentage as a predictor for future programs. In reviewing Apollo statistics, it was determined that for Kennedy Space Center ground systems, the annual sustaining engineering manpower was 2.6% of the total engineering development manpower for those same systems (See Figure 4-6). The sustaining level for ground systems began after the seventh Apollo launch. For Shuttle Kennedy Space Center ground systems the factor is 2.7% (See Figure 4-7), with sustaining beginning after the 14th Shuttle launch. This excludes LPS. For systems with heavy software applications, the estimating factor increases substantially. Based on CITE/OFS statistics, the sustaining engineering annual percentage increases to 6.6%. The equipment and material cost required to implement the sustaining modification is equivalent to an additional 50% of this sustaining engineering manpower cost.


APOLLO ENGINEERING MANPOWER
DEQ'S
4000
3000
2000
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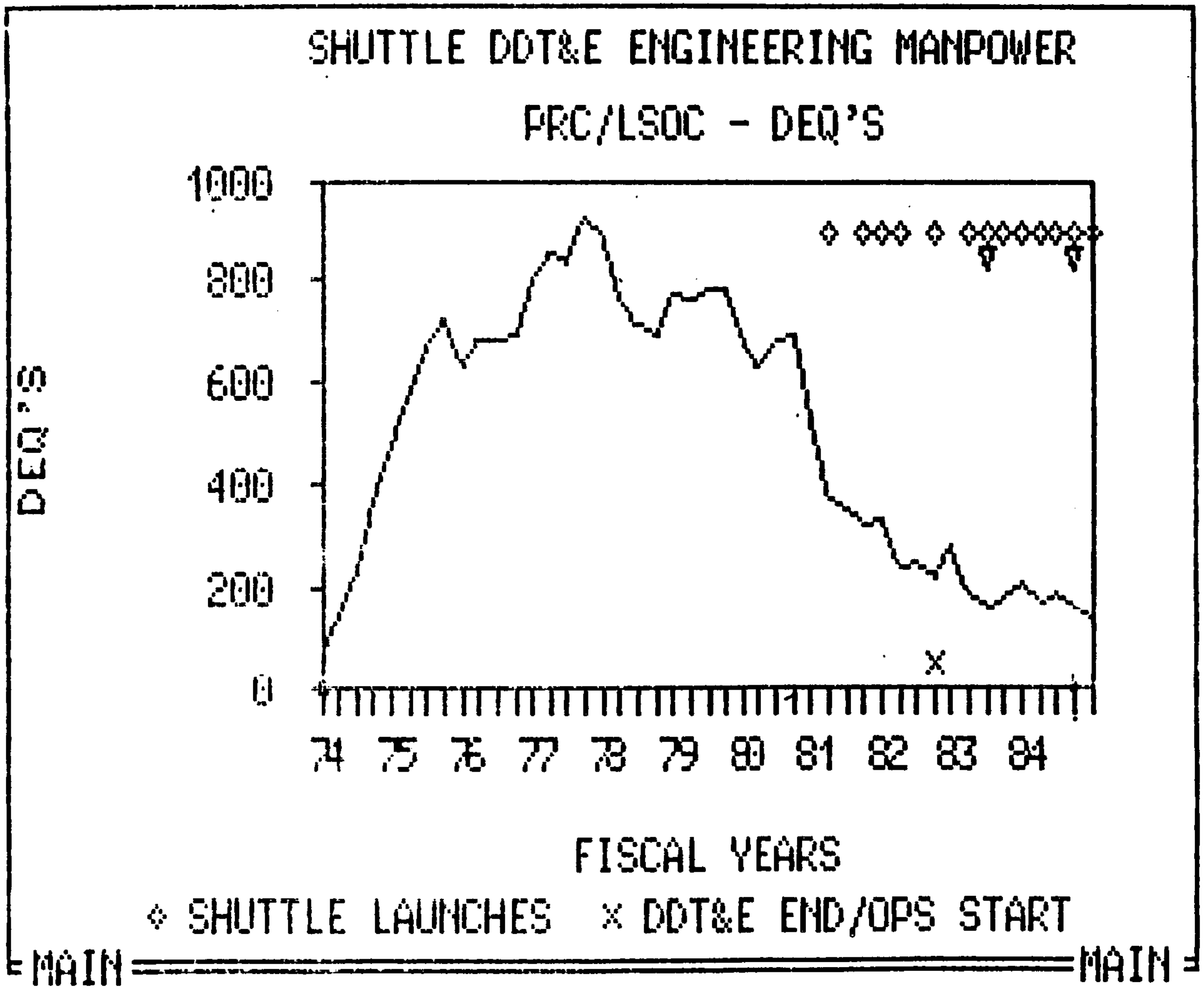
0
DEQ'S
64 65 66 67 68 69 70 71 72 73 74
FISCAL YEARS
APOLLO LAUNCHES
MAIN
MAIN

Figure 4-6


SHUTTLE DDT&E ENGINEERING MANPOWER
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1000
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400
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74 75 76 77 78 79 80 81 82 83 84
FISCAL YEARS
◊ SHUTTLE LAUNCHES × DDT&E END/OPS START
MAIN
MAIN

Figure 4-7

With these factors from past programs, the Kennedy Space Center sustaining engineering manpower and materials cost for Space Station mature operations can be estimated based on the engineering manpower budgeted for Space Station development. Taking the 2.7% and 6.6% estimating factors as predictors for the annual sustaining engineering manpower and applying it to the most recent cost commitment development manpower estimates results in a sustaining engineering manpower level of about 100 man-years per year. This means that based on past Apollo and Shuttle sustaining engineering manpower data it should require about 100 direct equivalents per year for the sustaining engineering of Kennedy Space Center developed systems for Space Station. Since Apollo and Shuttle were much larger development programs for Kennedy Space Center than Space Station (roughly five times the man-years), there may be some economies of scale not realized for Space Station. In that case the 100 man-years would be low. However, since there is already a base of engineering support providing sustaining engineering for the same types of systems (payload and shuttle) as for Space Station, the increase required for sustaining Space Station systems may be less and tend to offset the economies of scale handicap.

This analysis is only for Kennedy Space Center systems, but the approach could be applied to other NASA systems. However, it may be difficult to determine estimating relationships for flight systems since historically mature operations have not been achieved. And even though Kennedy Space Center estimating relationships may be applied to other NASA support systems, it probably would not be appropriate for higher criticality flight systems. Further study and analysis is needed to better estimate sustaining engineering manpower and cost projection for Space Station mature operations.

4.5 OPTION EVALUATION

Option areas can be categorized into three (3) major areas with suboptions defined in each of the major categories:

1. Centralization and Autonomy

   - Space Station Flight Systems
   - Internationals
   - Users
   - Support Systems

2. Risk Acceptance and Planning

   - Prelaunch verification
   - Contingency planning

3. Design Factors

   - Automation
   - Evolution
   - Supportability and Maintenance
   - Commonality

4.5.1 Centralization and Autonomy

A centralized management operations system for configuration management control of the Space Station flight systems and its interfaces with other systems is essential and thereby a basic premise in analyzing various options.

Minimum controls and requirements by a centralized configuration control of interfaces with the Space Station flight systems include:

1. Direct interface accommodation involving physical and functional areas.
2. Factors affecting the safety of the Space Station and crew.
3. Environmental controls which include contamination, RF radiation, thermal, vibration, acoustical, and others.
4. Commonality of hardware and software.
5. Specified resource data access to other interfacing organizations including design and performance data.

The option evaluation of centralized, consolidated, and distributive systems for sustaining engineering functions and configuration management is heavily weighted by commonality of hardware and software. The effectiveness of costs, configuration management systems, and sustaining engineering, are considerably improved in areas of high commonality by centralization and consolidation. Duplication of engineering efforts in distributed areas and enclaves drives cost effectiveness to lower levels. Configuration management controls from centralized and consolidated management systems provides for effective management controls of common hardware and software. There is the tendency where uniqueness exists with minimal interfaces that greater autonomy is allowed with minimum controls from centralized systems.

Space Station Flight Systems Options. Option 1. Space Station Work Package centers perform sustaining engineering and Space Station operations management controls interfaces between elements and distributive systems.

Option 2. Space Station evolution/growth contractor performs sustaining engineering from a centralized system under the management of Space Station operations.

Option 3. Space Station operations perform sustaining engineering with contractor directed support from evolution/growth Contractor. Configuration control management is performed by Space Station operations.

Option 1) Work Package Center Concept - This option is more typical and historical in the method of performing sustaining engineering within NASA Space programs. The major programs were short-lived in comparison to the life span of space station in its operational phase and did not progress to the mature operations phases as planned for the Space Station.

The effectiveness of management is considered low in that this option relies on developers and development centers to perform sustaining engineering more from the perspective of development motives rather than an operations viewpoint. A heavy reliance on the expertise of the developer in defining the rationale and accommodations for changes and enhancements to Space Station operations management can and does result in many changes not essential or mandatory to operations. The efficiency of working across interfaces involves the integration of many management systems of Work Package design centers and developers. The development of evolutionary, growth and new programs lessens the motivation in sustaining the operations of the space station. Transition costs and planning are minimal due to initial technical expertise and design knowledge depth.

Option 2) Combined Evolution/Growth and Sustaining Engineering - A single contractor managed by operations to perform both sustaining engineering and evolution/growth development requires in-residence time at the Work Package contractor's locations during the development phase. This is necessary to develop design skills and knowledge to perform sustaining engineering during mature operations. It also affords the opportunity for input to design from the operations perspective while in-residence training takes place.

The phase-in from Work Package contractor to OPS contractor will take place gradually, maturing at the beginning of the mature operations phase. The operating contractor should be on contract during the development phase about three years prior to final turnover of responsibility. This is necessary to improve the initial depth of technical expertise and design knowledge.

Using the evolution/growth contractor to perform sustaining engineering on a centralized basis allows greater flexibility in shifting resources and greater consolidation of duplicate engineering capability. Interface issues are more easily resolved and the evolution/growth contractor is fully involved and aware of sustaining changes affecting growth development. Placing management of their contract under operations will help prevent the development perspective from resulting in numerous sustaining engineering changes not essential or mandatory to operations. However, it is not as effective as a separate contractor responsible only for sustaining engineering with a few evolution/growth representatives contract directed to support the sustaining effort (See Option 3).

Another advantage of this option is the readily available resources to accommodate large sustaining design tasks. This is a benefit derived from combining growth development and sustaining engineering resources. However, there could be some dilution of interest in sustaining engineering due to evolution/growth projects.

Transition costs and planning in going from the design and development phase to mature operations may be significant since considerable development expertise will have to be transferred to the evolution/growth contractor prior to mature operations. Transition may be made more difficult if growth does not start until after mature operations begins. However, if the evolution/growth contractor is in place several years before mature operations begin, it would facilitate transition for the purpose of assuming sustaining engineering responsibility from the prime developers. It is assumed that the growth contractor will be one or more (but not all) of the prime development contractors.

A centralized system for the users to work with on day-to-day issues will enhance the operations perspective and facilitate the resolutions of interface issues at lower management levels.

<u>Option 3) Centralized Sustaining Engineering with Evolution/Growth linkage</u> - A single operations contractor for sustaining engineering with a small team of evolution/growth contractors representatives assigned for support and liaison is similar to Option 2 except that evolution/growth development responsibility is a separate contract. If major design is required, the OPS contractor can utilize the evolution/growth contractor on an on-call basis. The growth development contractor is assumed to be a Work Package development contractor(s).

This option requires the same transition plan as described for Option 3. It will entail significant up-front transition costs and planning but should prove cost effective over the long term because of reduced dependance on high cost development support.

A level of expertise and capability is retained within the Space Station operations centralized system to perform engineering integration, overall station analysis and assessments. A design engineering capability is retained to perform routine design changes to sustain/maintain the Space Station operational status. Major design efforts would be contracted to the evolution/growth development contractor. This would especially be effective for major block engineering changes. Utilizing evolution/growth contractor representatives as part of the sustaining engineering contract team will also keep the growth contractor fully involved and aware of ongoing sustaining changes and analysis.

In consideration of the long term operation phase and initial transition, this is the recommended option. It has the advantage of providing a separate management system and teams dedicated to operational sustaining engineering. Also, it eliminates the possibility of growth development work being partially funded by sustaining engineering budgets. Major development work will be a separate contract and must be fully funded on its own. Sustaining engineering will be dedicated to maintaining an established capability by correcting service revealed deficiencies and improving systems performance, whereas, evolution/growth will be developing new capabilities funded by newly approved budgets.

OPTION AREA: SPACE STATION FLIGHT SYSTEMS

	Option 1	Option 2	Option 3
	Work Package Centers	Combined with Evolution/Growth	Centralized With Separate Evolution/Growth Lingage
Feasibility	5	3	4
Flexibility	2	4	4
User Friendly	1	4	4
Mgmt Effective	2	4	4
Cost Effective	2	3	4
Performance	3	4	5
Safety	2	5	4
Total	17	27	29

Internationals

Option 1. Full partnership role in space station operations.

Option 2. Separate allocation with space station operations controlling interfaces and safety.

Option 1) Full Partnership - In a shared partnership role management effectiveness is significantly low; changes affecting the space station require more mutually reached approvals and a sharing in the decision processes. Cost restraints from each partner may have restrictive impacts on the other partner where enhancements or improvements may be involved. The amount of commonality in designed hardware and software (foreign contracted) is expected to be low which further diminishes the rationale in a full partnership role.

Option 2) User Role - Option 2 is the preferred option. Each partner has a greater autonomous role within the allowance of safety and interface controls from space station operations management. Each party has greater flexibility in the changes made to their respective elements. Management effectiveness is greater within the realm of each partner's responsibility.

OPTION AREA - INTERNATIONALS

	Option 1 Partnership	Option 2 User Role
Feasibility	2	5
Flexibility	2	4
User Friendly	4	3
Management Effective	2	5
Cost Effective	2	5
Performance	2	4
Safety	4	4
Total	18	30

Users

Option 1. User interfaces controlled by their own management with minimum Space Station constraints.

Option 2. User interfaces controlled by a NASA user support group.

Option 1) Autonomous - Option one leaves a lot to be desired because of impediments it presents to standardizing Space Station payload interfaces. It creates an environment of payload driven interfaces that could result in considerable customizing. Overall Space Station performance would not be as effectively managed. Even though it is desirable to be as attractive to potential payload customers as possible, consideration must be given to minimizing Space Station interface changes for the economic and performance benefit to all payload customers. Also, a more standardized approach to interfaces facilitate performance and safety integrity.

Option 2) Controlled - Option two optimizes the balance between user unique interface requirements and Space Station standards by establishing a NASA user support group with participation from the user community. This approach establishes a single area of contact within NASA and affords the means for an integrated resolution of interface conflicts. This results in improved understanding of Space Station operating standards and constraints. Overall performance of Space Station and standard interfaces will be more efficiently maintained for user utilization.

OPTION AREA - USER AUTONOMY

	Option 1 Autonomous	Option 2 Controlled
Feasibility	3	4
Flexibility	4	3
User Friendly	4	3
Management Effective	2	4
Cost Effective	2	4
Performance	2	4
Safety	2	4
Total	19	26

Space Station Support Systems. Support systems for Space Station include all unique systems required to support in-flight operations and prelaunch and post landing processing. This includes such systems and equipment as command and control stations, handling GSE, servicers, automated checkout systems, training, simulators, SSE, TIMS, and others.

There are basically three options in performing operations sustaining engineering for Space Station support systems: 1) Use developers, 2) Centralize under one SE contractor, 3) Distribute unique systems to appropriate operations centers and centralize common/distributive systems under the flight systems SE contractor or appropriate operations center.

Option 1 is clearly not recommended for the same reasons that were identified for not retaining the prime developers for SE of the Space Station flight systems. Those reasons were primarily related to higher SE costs over the long run, development mentality driving unnecessary operational changes, and management inefficiency created by multiple SE contractors.

Option 2 is not considered practical due to the large diversity of systems and transitional impacts between established operations centers.

Option 3 would centralize SE of only those systems with high commonality and wide distributions under the centralized flight systems SE contractor. This would include such systems as SSE and TMIS. Unique systems such as servicers, handling GSE, simulators, training, GDMS; etc., should be sustained by the operations center having predominant use. For example, GDMS sustaining engineering would be performed by the Kennedy Space Center payload ground operations contractor. Advantages of implementing Option three are: provides SE support closest to the location of predominant use, thereby improving response time to changes and better lead-time support; more efficient manpower utilization-minimum duplication; and minimum transition impacts. Therefore, Option 3 is the recommended approach for Space Station support systems.

OPTION AREA: SPACE STATION SUPPORT SYSTEMS

	Option 1 Distributed	Option 2 Centralized	Option 3 Mixed
Feasibility	2	1	4
Flexibility	2	3	4
User Friendly	1	4	3
Management Effective	2	4	3
Cost Effective	1	2	4
Performance	3	2	4
Safety	3	3	4
Total	14	19	26

4.5.2 Risk Acceptance and Planning

There are two areas of risk acceptance and planning that need to be reviewed and options considered as they relate to sustaining engineering during the operational life of the Space Station. They are: Prelaunch Verification and Contingency Planning.

Prelaunch Verification. There are two basic Prelaunch Verification options involving levels of risk and planning that affect sustaining engineering. One option requires extensive prelaunch verification that includes a thorough flight hardware checkout at the launch site prior to launch. The other option is described as "ship and shoot" and requires minimum checkout and verification once the hardware has left the developers location.

Option 1) Thorough Prelaunch Verification - Thorough prelaunch verification necessitates a higher initial investment in verification equipment such as simulators, test sets, and models as well as more available facility space. However, from a sustaining engineering viewpoint, it should be cost effective over the long term since a larger number of deficiencies or discrepancies would be identified prior to placing hardware or software in service, thereby minimizing costly on-orbit sustaining engineering changes. Also, the availability of ample verification equipment and software would facilitate future on-orbit sustaining engineering enhancements and other modifications. Another benefit of this approach is the lower risk involved in achieving the desired results of specific changes since a more thorough evaluation prior to launch is afforded. Also, it would be more advantageous in providing real time engineering and operational support required for problem resolutions. Planning accuracy would be improved as a result of the ground capability to better verify timeliness and procedures and train personnel required to implement modifications. Over the life of the Space Station, the greater initial ground time and hardware investment should be more than offset by the savings of expensive on-orbit time and on-orbit trial and error lessons.

Option 2) "Ship and Shoot" - This option, described as ship and shoot, would obviously lower initial prelaunch investment cost, but would incur a greater risk of required follow-up effort after launch. The one time cost saving on verification hardware/software and facility space on the front end of the program seems ineffective in terms of the increased cost potential over 30 years of station operation due to inefficiency of implementing sustaining engineering changes. The utilization of simulators, test sets, and models not only to comprehensively verify baseline program elements prior to launch, but to verify future modifications appears to make the ship-and-shoot option with no thorough prelaunch verification a poor choice from a long term sustaining engineering viewpoint. A relative comparison of these two options is shown as follows:

OPTION AREA: PRELAUNCH VERIFICATION

	Option 1 Through Verification	Option 2 Ship and Shoot
Feasibility	5	3
Flexibility	5	2
User Friendly	1	5
Management Effective	5	1
Cost Effective	4	2
Performance	4	2
Safety	4	2
Total	28	17

Contingency Planning. Basically, there are two extremes in approaching contingency planning. There is the one option of detail plans and procedures and the other option of real time adaptation to whatever anomaly situation may occur.

Option 1) Planned - Detail planning and preparation for contingencies requires a higher level of sustaining engineering effort. A thorough analysis of failures and hazards must be made on all changes and provided to operations and safety personnel for review and planning. A group of engineers separate from the designers, but within the sustaining engineering function, would be required for this option. The slightly higher cost incurred would well be worth the lower risk produced by an approach that is well documented analytically with proper backup procedures that minimize impacts due to anomalous performance. The need for deviation waivers would be minimized.

Option 2) Adaptation - Option two would concentrate more on adapting to anomalous performance in real-time. Even though less effort would be expended on front-end planning, there would be a greater need for involvement of engineering on a real-time basis during critical operations as opposed to a less intense on-call approach. Therefore, there would probably be insignificant engineering cost savings, but there would be a higher risk to operations. Also, with less rigorous planning for contingencies, the potential for documentation and configuration problems due to more real time changes would increase. These two options are rated as follows:

OPTION AREA: CONTINGENCY PLANNING

	Option 1 Planned	Option 2 Adaptation
Feasibility	5	1
Flexibility	2	4
User Friendly	2	4
Management Effective	5	1
Cost Effective	4	2
Performance	4	2
Safety	5	1
Total	27	15

Design Factors. There are certain design factor options that affect the sustaining engineering functions for Space Station and for flight and ground support systems. These factors are: Automation, Evolution/Growth, Supportability/Maintenance, and Commonality.

Automation. To appreciate the effect automation may have on sustaining engineering it is instructive to look at the extremes of a highly automated operations verses a manual operation with no automation. Highly automated operations imply technically complex systems with a high degree of design sophistication involving robotics and other advanced technology. This requires a higher engineering skill level resulting in higher costs for sustaining engineering, even though there could be a very significant cost reduction to operations because of less dependence on the human element. Also, there would be an improvement in safety especially where a non-human mechanical means of accomplishing hazardous operations could be utilized. Conversely, a manual operation with a high dependence on man would simplify many systems resulting in a lower sustaining engineering skill level. It should be noted that even in the case of a highly automated robotic operations, consideration is not given to the total elimination of man's presence which would open up a wide array of different trade-offs.

The approach here is to examine the effect on sustaining engineering for the long term with highly automated systems and less dependence on man, even though he is still present, verses a non-automated system with high dependence on man. The most beneficial approach considering both extremes is to automate to the extent only of protecting man from the more risky procedures and to the extent that systems can be developed that would not overly complicate long term engineering and maintenance support. Appendix H describes an approach used by Ocean Systems Engineering.

OPTION AREA: AUTOMATION

	Option 1 Automate	Option 2 Manual
Feasibility	5	1
Flexibility	2	5
User Friendly	2	3
Management Effective	3	2
Cost Effective	5	1
Performance	4	2
Safety	2	4
Total	23	18

Evolution/Growth

Two approaches toward the growth and evolution of the Space Station are: 1) plan well in advance by factoring it into the design and by appropriate scarring during the fabrication, or 2) adapting to whatever growth evolves at whatever time.

A well planned scheme for the evolution and growth of the Station has many advantages for sustaining engineering. It minimizes modification design and implementation impacts and provides for a better managed approach for making enhancement changes. Knowing what growth is planned allows sustaining engineering to implement changes without creating problems for that growth. As a consequence, this results in lower cost, better reliability and more accurate change assessments during mature operations.

If the second approach of adapting to growth as it materializes is used, it will require a higher sustaining effort because of the necessity to redo or undo modifications that impede growth. Also, sustaining engineering will be more developer dependent. The final results for sustaining engineering will be higher cost, less reliability and less accurate configuration data.

OPTION AREA: EVOLUTION/GROWTH

	Option 1 Planned	Option 2 Adaptation
Feasibility	2	5
Flexibility	2	5
User Friendly	5	1
Management Effective	5	1
Cost Effective	5	1
Performance	5	1
Safety	4	2
Total	28	16

Commonality

Commonality of hardware and software where feasible can serve to reduce sustaining engineering cost by allowing the consolidation of resources. Commonality to the Orbital Replacement Unit (ORU) level is already a key driver in the SSP design. Further benefit can be realized by achieving commonality in flight and ground support systems. For example, simulators and checkout systems will be required to support both flight and ground functions.

If a large degree of commonality is developed in systems such as Taverns and Ground Data Management System (GDMS) it would allow for consolidation of operations functions such as sustaining engineering and logistics. Commonality could also be extended to include GSE, models, trainers, control centers, and data bases. A high level of commonality would offer significant opportunity for consolidation during the operations era with a corresponding reduction in cost.

The alternate approach is independent development with no push for commonality. Unique systems and equipment will be the result with minimum opportunity to consolidate operations functions.

OPTION AREA: COMMONALITY

	Option 1 Commonality	Option 2 Independent Design
Feasibility	3	5
Flexibility	5	1
User Friendly	4	2
Mgmt Effective	5	1
Cost Effective	5	1
Performance	5	1
Safety	4	2
Total	31	13

Supportability/Maintainability

An important supportability/maintenance factor to sustaining engineering is the level of diagnostic capability. A high level of diagnostic capability offers better analyses of trends that may lead to problems or failures and consequently results in a more effective sustaining engineering and maintenance effort. Potential problems can be detected and corrected either by maintenance procedures or engineering changes before operational impacts are incurred. An important consideration in implementing a high level diagnostic capability is not to overly complicate the systems and hardware to be diagnosed. This could exaggerate the very condition that one is attempting to improve. To minimize this effect it is important that to the extent possible diagnostic components be separate and portable while only sensors and minimum diagnostics be incorporated into the operating hardware. (Ref. Appendix H, An overall review of the development of teleoperated systems and sustaining engineering programs in the Deepwater Industry).

The other option is, to provide very little diagnostic capability which would save initial cost, but would increase cost and risk over the long term because of less effective sustaining engineering and maintenance effort and more operational impacts. Even though, there are less components to fail or give erroneous data with this approach, a better approach is to maximize the portability of diagnostic components and retain a high level of diagnostic capability while preserving system reliability.

OPTION AREA: SUPPORTABILITY/MAINTAINABILITY

	Option 1 High Diagnostics	Option 2 Low Diagnostics
Feasibility	2	4
Flexibility	5	1
User Friendly	4	2
Mgmt Effective	5	1
Cost Effective	4	2
Performance	5	1
Safety	4	2
Total	29	13

APPENDIX A

SUSTAINING ENGINEERING

FUNCTIONAL DESCRIPTION OUTLINE
Appendix A

SUSTAINING ENGINEERING

FUNCTIONAL DESCRIPTION OUTLINE

This section is an outline definition of the sustaining engineering functions necessary to support operations of the Space Station Program. These functions are replicable to any area of sustaining engineering organizations. The scope of this effort is flight hardware and software, ground systems hardware and software, ground support equipment and ground processing software, and support to customer integration. The sustaining engineering functional area includes:

Performing the analysis and engineering necessary to maintain and enhance the Space Station Program orbital and ground support program elements.

Designing, building, and supporting the installation and integration of approved modifications to the program elements.

Developing and maintaining integration and verification requirements for flight systems, ground systems, and the interfaces to customer systems, transportation systems, and institutional tracking, data relay, and ground data communications systems.

Performing the day-to-day management of approved program configurations and supporting the overall Configuration Management and control program.

FUNCTION OUTLINE:

1. Planning and Management

2. Systems Analysis

3. Design Engineering

4. Engineering Integration and Verification

5. Documentation

SUB FUNCTIONS:

1. Planning and Management
   A. Planning and Scheduling

   B. Budget Management

   C. Contract Management

   D. Resource Management
   E. Manage Station System Advanced Technology Programs - As Assigned

   F. Evolution and Growth Management - (Space Station Impacts)

2. Systems Analysis
   A. Flight Certification Engineering Analysis (from customer recommendations and station/platform system

modifications and enhancements)

B. Systems Performance Analyses - Conduct Trend Analyses and Evaluate Test Data

C. Provide Analyses of System Performance Degradations

D. Identify Requirements for Operational Performance Enhancements

E. Failure Analyses

F. Mass Properties Analyses and Configuration Analysis

G. Support the Feasibility and Supportability Analyses of Proposed Enhancements and Modifications

H. Technical Risk Assessments - for flight and ground support hardware and software systems

1. Criticality Assessments
2. Failure Mode and Effects Analyses
3. Single Point Failure Analysis
4. Safety and Hazard Analyses and Assessments
5. End-to-End Analysis
6. Sneak Circuit Analysis
7. Control Logic Reviews
8. Feasibility
9. Availability
10. Commonality
11. Maintainability
12. Operability
13. Cost
14. Schedule

I. Environmental Analysis and Control

1. Vibration Analysis
2. Acoustical Analysis
3. Thermal Loads Analysis
4. RFI Analysis
5. Load Stress Analysis

3. Design Engineering
   A. Design and Engineering of Flight Systems and Ground Support Systems Enhancements/Modifications
      1. Conceptual, Preliminary, and Detailed Design Products (includes documentation, analyses, and reviews.)
      2. Integrated Design Reviews
      3. Specifications, Drawings, Requirements
      4. Design Criteria
      5. Design Verification Requirements
      6. O&M Documentation
      7. Installation/Modification Requirements
      8. Preparation and Maintenance of "As-Built" Drawings, Specifications and S/W Source Code Listings
      9. Systems Reconfiguration and Installation Requirements. Also Includes Payload Installation/Removal Requirements. Includes Schematics, Installation/Removal Instructions and Software Products.
      10. Transportation Configuration Design

   B. Design of Test Article Hardware, Software, and Ground Support Equipment

4. Engineering Integration and Verification
   A. Modification Enhancement Hardware and Software Integration and Implementation
      1. Flight Systems

2. Ground Systems

3. Customer Systems to Flight/Ground Systems

4. Flight/Ground Systems to Transportation Systems

5. Flight/Ground Systems to Institutional Tracking, Data Relay, and Ground Data Communications Systems

B. Customer to System/Subsystem Integration, Verification, and Compatibility Assessments

C. Verification Testing Planning

1. Test Objectives and Requirements
2. Evaluation Criteria
3. Test Procedures and Plan
4. Training
5. Scheduling

D. Support to Verification Testing (testing performed by operations)

E. Customer-System Interface Engineering. Includes Customer-System Interface Designs as Required

F. "Build" Process

1. Make or Buy Decisions
2. Procurement Support
   a. Hardware
   b. Software
   c. Materials
   d. Services

G. Real-Time Engineering Support to Operations
1. Engineering for Anomaly Resolution
2. Systems Performance Monitoring
3. Engineering for Critical Operations

H. Integrate and Coordinate Evaluations, Assessments, Analysis, and Anomaly Resolution

5. Documentation

A. Maintain and Update Flight Hardware ICD's

B. Maintain and Update Flight S/W Source Code Listings

C. Maintain and Update Ground-Flight Systems ICD's

D. Maintain and Update Ground System S/W Source Code Listings

E. Maintain and Update Architecture Control Documents (ACDs)

F. Design Documentation

G. Configuration Status and Updates (Data Base Products)

H. Mass Property Documentation

I. Performance Trend and Prediction Reports

J. Design Review Packages

K. Analysis Reports

L. Flight Certification Status

M. Commonality Identification and Status

N. Access Requirements to Customers, Space Station Elements, and Support Systems

O. Updates to Controlled Documentation is Approved by Configuration Management

APPENDIX B

CONFIGURATION MANAGEMENT

FUNCTIONAL DESCRIPTION OUTLINE

CONFIGURATION MANAGEMENT

FUNCTIONAL DESCRIPTION OUTLINE

This section is an outline description of the configuration management Functions required to support the Space Station Program. These functions are replicable to any level of configuration management Systems.

Day to day activities are a mixture.

Very Top-Level function can be strategic - i.e., Bilateral Agreements to change the Fundamental Configuration of the Space Station Flight or Support Systems.

FUNCTION OUTLINE:

1. Configuration Identification

2. Configuration Control

3. Configuration Verification (Auditing)

4. Configuration Accounting

SUBFUNCTIONS:

1. Configuration Identification

   A. Selecting End Items of Hardware and Software to Come Under Configuration Control

   B. Develop and Maintain Baseline Identification of H/W and S/W Under Configuration Control

   C. Develop and Maintain Engineering Documentation
      1. Prepare and Maintain H/W & S/W Specifications, Drawings, and S/W Source Code Listings
      2. H/W & S/W Engineering Documentation and Computer Program Media Records and Releases

2. Configuration Control

   A. Controlling H/W & S/W Such That Demonstrated Physical Status and Performance Satisfy Mission, Safety, and Security Requirements

   B. Managing Changes to the Baseline System Through a Formal Review and Approval Process Prior to Directing H/W & S/W Changes

   C. Closing Out Configuration Change Directives Upon Completion of the Configuration Verification and Configuration Accounting Processes

3. Configuration Verification (Auditing)

   A. Conduct Reviews to Assure that the Design of the Changes to the Baseline Configuration Satisfies Approved Requirements (Mission, Safety, & Security)

   B. Conduct Reviews, Tests, Inspections, etc., to Assure that H/W or S/W End Items Conform to the Released Design Documentation

   C. Conduct Reviews, Tests, Inspections, etc., to Assure that the Modifications Have Been Incorporated in Accordance with the Configuration Change Directive (i.e., Verify "As-Built" is the Same as "As-Designed")

   D. Conduct Periodic Reviews and Audits to Verify that the Change Control Process is Effective

4. Configuration Accounting

   A. Establish and Maintain a Data Collection and Storage System Which Provides for Tracking and Auditing the Change Control Documentation. These Include Change Requests, Disposition Actions for Change Requests, and Verification Reports

   B. Provide Approved Inputs to the System(s) Containing the Identification of the Baseline Systems

   C. Manage Program Configuration Data Base(s)

Sustaining Engineering and Configuration Control Scenarios/Schemes for the Space Station Program Operational Era

Glenn R. Parker

INTRODUCTION

After the Space Station Program (SSP) becomes fully operational, the methods by which the engineering changes associated with SSP maintenance, modifications, upgrades, and overall evolution are handled and managed will be similar to those methods that are implemented during the SSP Design, Development, Test, and Evaluation (DDT&E) phase, but the management scheme for these methods/functions should be different than that employed for the early DDT&E phase of the program. Required management and operational response time, efficiency, and cost effectiveness will dictate that an evolution in sustaining engineering and change management schemes take place that will allow such systems to be operationally oriented and streamlined in order for the program to cope efficiently with the multifaceted scenarios that will exist during the SSP operational era. These scenarios will probably be different than those faced early in the program due to the increased complexity in SSP subsystems/ systems, operations, and interrelationships/ interdependence with other program/agency elements. This treatise will describe typical engineering change scenarios that might occur during the SSP operational era, and will also describe operational change management and sustaining engineering schemes that could be utilized to handle these scenarios.

ENGINEERING CHANGE SCENARIO DESCRIPTION

For the purposes of this paper, two typical engineering change scenarios that might occur during the SSP operational era are considered. It is realized that other scenarios may exist which will be different than those described herein, or that a combination of scenarios may exist that embodies some elements of those described herein. However, these two scenarios are felt to be representative of the boundary conditions that will exist for such changes that may occur during this era. The two chosen scenarios are:

(1) An engineering change that affects multi program/agency elements such as the Space Station Program elements, International elements that are a part of the SSP, National Space Transportation System (NSTS) elements (e.g., Orbiter), and other program/agency elements such as users (customers), the Tracking Date Relay Satellite System (TDRSS), and/or the Global Positioning System (GPS). Examples of such changes are:(a) A change to

the basic station electrical power scheme involving wiring size changes, electrical frequency changes, load carrying capabilities, etc., (b) changes in data rate/channel requirements, high resolution video requirements, or uplink/downlink data requirements, and (c) a requirement for Orbiter control of the Station Remote Manipulator System. Such changes would not only affect U. S. Space Station Element subsystems/systems, but could affect international element, customer, Orbiter, TDRSS, and/or GPS subsystems/systems, dependent upon the example considered.

(2) An engineering change that affects only the U.S. supplied elements of the SSP and does not involve any other supplied elements of the SSP or any other elements of various programs/agencies. An example of such a change might be a change involving the addition/upgrade of a work/maintenance bench in the U.S. Laboratory or Habitation Module.

For each of these scenarios, a proposed operational era engineering change management and sustaining engineering scheme will be presented and described.

OPERATIONAL CHANGE MANAGEMENT AND SUSTAINING ENGINEERING SCHEME

Typically, early phases of any program utilize a change management and sustaining engineering scheme that involves the program manager, the program's project managers, a configuration management team, a systems engineering and integration (SE&I) team, project systems engineering experts, and a distributed change evaluation process to evaluate, disposition, and implement program/project change requests (CR's). The program/ project managers usually have all of the approval/disapproval authority for the purposes of dispositioning such CR's, and operations personnel are usually only a part of the submittal and/or the change evaluation/ implementation process. As such, operations personnel have very little control over their own destiny, and operational considerations, including cost, often are not properly considered during the change control/management process. During the operational era of the SSP, and other programs, a change management and sustaining engineering scheme should evolve to one that is primarily controlled by operations personnel via a single Program Operations Manager, who is in charge of both flight and ground operations for the program(s). The appeal route for such a scheme would be from the Program Operations Managers to an Associate Administrator for Operations. A proposed top-level organizational structure for such a scheme is depicted in Figure 1. Such a structure would replace the normal structures that exist during the early phases of various programs. The operational era structure would make a change management and sustaining engineering scheme more operationally controlled and oriented, in tune with operational needs, more streamlined, and, hopefully, more cost effective.

In a program`s operational era, it would be desirable if all programs could evolve their organizational structure, change management schemes, and sustaining engineering schemes along such a philosophy to facilitate inter-program compatibility.

With such a philosophy in place, an engineering change and/or sustaining engineering effort that affected the SSP only would be supported by the "generic" change management and sustaining engineering scheme shown in Figure 2. An example of such a change, as previously mentioned, might be an addition of an/or upgrade to a work/maintenance bench in the U.S.A. supplied Laboratory or Habitation Modules.

If a change affected multiple programs, such as the SSP, the NSTS program, and the Canadian (International) program, the "generic" change management and sustaining engineering scheme would be expanded, as shown in Figure 3, to encompass the three programs. An example of such a change would be one that required a modification to allow for control of the Space Station Manipulator Arm (MRMS) from the Orbiter Aft Flight Deck.

Finally, if a change affected all programs that may be interrelated with the SSP, during the operational era, the "generic" change management and sustaining engineering scheme would be further expanded, as shown in Figure 4.

The only differences between the three schemes are the number of participants involved and the magnitude of the required integration effort among the various involved programs. However, the same basic eleven step process would be followed for all of the depicted schemes. In order to describe the basic eleven step process of these change management and sustaining engineering schemes, the example depicted by Figure 3 is chosen. This example was chosen because it adequately depicted the complexity associated with multi-program interrelationships, while at the same time remaining simple enough in scope to allow the reader to relate to the "generic" scheme. In describing the basic eleven step process, it should not be assumed that all changes must go through the entire process. Some changes, such as 'quick turn changes' or changes to basic customer`s hardware/software, may be able to skip some steps. These factors would be considered on a case-by-case basis. However, what follows, is a basic description of the eleven step process for the change example chosen.

OPERATIONAL CHANGE MANAGEMENT
AND SUSTAINING ENGINEERING SCHEME
STEP DESCRIPTION

STEP #1 - Requirement Initiation - An engineering change could be initiated by anyone from any program/agency at any level. Such a change request could be in the from of a Program/Project Change Request (CR), an Engineering Support Request (ESR),

Engineering Change Proposal (ECP), or any other program equivalent. For the purpose of this paper, a generic term, "Change Request (CR)", will be used to describe such changes.
When the CR enters the system, a requirements initiation team would receive it and perform the following functions:

A. The team would determine whether the change affected the usage of the station and/or operations, whether the change represented an enhancement to present station design, or whether the change was needed to resolve a problem on board the station. It would also determine if one or more programs/agencies were affected by the CR.

B. The team would determine the criticality of the change.

C. The team would assess the change rationale and insure that the originator had included enough information with the CR (e.g. design concepts, etc.) to allow for a future impact assessment.

D. The team would prepare and forward an Engineering Support Request (ESR), or equivalent, that reflected the original CR. The ESR would be forwarded to the appropriate screening boards, where Step #2 of the process would begin.

STEP #2 - Screening Board - The screening boards would be chaired by the Program Operations Managers or designate and supported by various operations discipline and SE&I discipline personnel such as logistics personnel, customer (user) representatives, engineering personnel, operations personnel, manifest personnel, safety reliability and quality assurance (SR & QA) personnel, etc. Each program/agency affected by the change would have a similar arrangement. The purpose of the screening boards would be to initially screen the change and provide for a preliminary disposition in order to keep unwanted changes from choking the full assessment process. Upon receiving the ESR, the screening boards would perform the following functions:

A. The screening boards would perform an initial validation of the ESR to determine if the change paper contained enough information for an assessment, if the change rationale and criticality assessments were proper, and if the change`s effect on their programs design/operations were properly assessed. Each screening board, via its SE&I personnel, would perform an initial integration task to insure that the above tasks were accomplished and that an integrated assessment existed across all affected programs/agencies.
B. The screening boards would determine the changes category (i.e. mandatory, highly desirable, etc.), its effectivity (e.g. one or more orbiters), and would perform an initial determination of how the change would be manifested for launch or by which flight it would be implemented. Again, each screening board`s SE&I support would insure that an integrated assessment

existed across all affected programs/agencies. In addition,the screening boards manifesting personnel would work with any other SSP/NSTS manifesting experts (e.g., a Tactical Operations Control Board) to properly coordinate manifesting.

C. Finally, each screening board would provide their initial disposition of the change. The dispositions would take one of two forms: (1) Approval for further full assessment of the change by a change assessment team, or (2) Disapproval of the change, which would result in no further action regarding the change. Any disagreement between dispositions of any of the affected screening boards would result in a conflict resolution appeal to the Associate Administrator for Operations. Such an appeal route would also be available to the CR originator. If all of the screening boards approved the ESR for further assessment, or if the Associate Administrator for Operations, directed approval, then the ESR would be forwarded to an Assessment Team for each affected program/agency and Step #3 of the process would begin.

<u>Step #3 - Assessment</u> - An assessment team for each effected program/agency would perform the following functions:

A. The teams would develop an implementation plan and schedule for the change.

B. The teams would determine the Rough Order of Magnitude (ROM) costs for the change and assess the required contract changes for their programs.

C. The teams would initiate and complete any required studies that might result because of the change.

D. The teams would determine any other impacts resulting from the change (e.g., weight impacts, launch slip impacts, etc.).

E. The teams would assess the interfaces affected by the change and prepare appropriate ICD/IRD changes.

F. Each team, via its SE&I personnel, would coordinate with each other to insure that an integrated assessment would be achieved.

G. Upon completing an integrated assessment, the teams would forward the assessment in the form of an Engineering Analysis and Cost Assessment (EACE), or equivalent, to a Joint Change Evaluation Board, which would begin Step #4 of the process.

<u>Step #4 - Joint Change Evaluation Board</u> - A Joint Change Evaluation Board would receive the EACE for consideration. This board would be chaired by the SSP Program Operations Manager and supported by similar operations managers from all other affected

programs/agencies, each with an equal vote. The functions of this board would be:

A. The Board would either approve or disapprove the change. If the Board disapproved the change, no further action on the change would occur, unless a subsequent appeal to the Associate Administrator for Operations reversed the decision. Upon Board approval of the change, a joint Change Control Board Directive (CCBD) would be issued to the Design and Engineering Organizations of the affected programs/agencies, and Step #5 would begin.

B. In considering the change, the Board might also issue further actions regarding the change or as a result of the change. The Board could also return the change back to the respective Assessment Teams for further reassessment.

C. The Board would also issue Contract Change Authorizations (CCA's) to the involved contractors of each affected program/agency, and would notify the affected manifesting/logistics personnel of the decision so that proper manifesting/logistics planning could begin.

Step #5 - Design and Engineering - Each program/agency Design and Engineering organization would receive their respective CCBD's, and begin the normal activities for implementing the change. These activities would include:

a. defining the detailed design requirements and specifications,

b. preparing drawings and/or implementation instructions,

c. defining detailed verification and test requirements,

d. supporting the preparation of test procedures and/or analyses,

e. updating various affected ICD's/IRD's/ACD's/BCD's
f. conducting appropriate design and safety reviews, and

g. performing appropriate assurance analyses.

Each program's/agency's SE&I staff would be responsible for integrating their own activities and coordinating with the other affected SE&I staffs in order to assure an integrated approach to the design and engineering effort. From this effort, Document Release Authorizations (DRA's), or equivalent, would be released to each program's/'agency's manufacturing personnel to begin Step #6 of the process.

Step #6 - Hardware/Software Build - Each program's/agency's manufacturing team would begin the process of actually building the hardware/software associated with the change modification. These efforts would include:

A. support for the procurement of the piece parts and/or software code from the vendors (subcontractors/contractors),

B. the support required for the actual fabrication of each program's/agency's hardware portion of the modification, and the support required for the building of software programs required by any program/agency,

C. the processing of any waivers/deviations required to the original design, including coordination between each program/agency by their respective SE&I personnel,

D. the processing of engineering changes to the original modification design, to facilitate the manufacturing process, by each affected program/agency, along with appropriate integration of these changes by the affected SE&I personnel, and

E. the factory verification support from each program/agency for their portion of the modification, including development through final acceptance verification and certification. Such verification would also include an integrated certification and acceptance verification for the end-to-end system affected by the modification using actual flight hardware/software and/or simulators as required. Such verification would be coordinated and integrated by each program's/agency's SE&I personnel.

Once this step is complete, each program/agency would ship their portion of the mod-kit to the launch site, where the final phase of this scheme would begin with Step #7.
Step #7 - Change Package Support - Each program/agency would have engineering and management support personnel located at the launch site to help perform this step, which would include the following functions: (NOTE: The actual hands-on work at the launch site would be performed in accordance with established methods of operating.)

A. the shipping, receiving and quality assurance (QA) inspection for each program's/agency's portion of the mod-kit,

B. the final assembly and staging for each portion of the mod-kit along with stand-alone power-on-testing that would be required, and

C. the preparation of any final engineering documentation associated with any portion of the mod-kit required for final installation and integrated testing.

Once this step is complete, the mod-kit portions would be turned over to the SSP launch site personnel for the beginning of Step #8.

Step #8 - Verification - SSP launch site personnel would receive each program's/agency's portion of the mod-kit and, off-line from the NSTS processing, integrate the mod-kit into a total on-orbit configuration using actual flight hardware and appropriate simulators. This would be done to accomplish both single and multiple launch package integration and verification to assure that the mod-kit will operate as designed with station/orbiter hardware/software that is already on-orbit. In addition, such verification could augment crew training and be used to verify on-orbit flight procedures. Once this step is complete, Space Station personnel could begin Step #9 of the process.

Step #9 - Transportation Support - Space Station personnel would prepare a configuration definition and mass property analysis for installing various portions of the mod-kit in the Orbiter Aft Flight Deck, Orbiter Payload Bay, and/or the SSP Logistics elements. Close coordination between the SSP and NSTS SE&I, Logistics, and Ground/Flight Operations personnel would be required to assure that orbiter mods were properly scheduled, logistics elements were properly manifested, that the Orbiter Payload Bay and/or Aft Flight Deck was properly manifested, and that on-orbit station installation and checkout operations were properly scheduled. Once these function were completed, Step #10 of the process would begin.

Step #10 - Installation and Checkout - Each affected program/agency would begin the task of supporting and/or installing/manifesting, as appropriate, portions of the mod-kit into their affected hardware/software subsystems/systems. Actual hands-on work would be accomplished by established methods of operating. installations would be followed by appropriate support for final verification and checkout of the affected subsystems/systems. This installation/checkout could occur on the ground and/or on-orbit, and would be followed by an analysis of predicted data and the processing of any final waivers/deviations by each affected program/agency. At the completion of this task, "installation complete (INC)" notices would be given to each affected program's/agency's configuration management and verification personnel teams to begin Step #11f the process.

Step #11 Configuration Update - Each program's/agency's configuration management and verification personnel teams would accomplish the final step of this process, which would include:

A. updating all drawings and documentation to the as-build configuration,

B. providing CCBD closeout documentation,

C. completing verification completion notices, or equivalent, (VCN's) and updating the appropriate verification data bases,

D. performing any other required configuration accounting actions required by each affected program/agency.

The completion of the step would complete the entire change management and sustaining engineering effort for such a change.

SUMMARY

This paper has attempted to deal with one aspect of the sustaining engineering effort required for the SSP and other interrelated programs during the SSP operational era - the "Change Management/Implementation Process". The proposed change management scheme is but one way that such a scheme could evolve, but it is felt that such an evolution, or a similar one, will be necessary if the SSP is to cope with the operational complexities that will exist during this era.

5.0 TRANSPORTATION SERVICES/RESCUE

5.1 INTRODUCTION

After the Space Station Program (SSP) becomes operational, the transportation and services aspect of the SSP will be one of the most costly and labor intensive portions of the Space Station support systems. The methods utilized by the transportation and services operations associated with the SSP will have to be considerably different than those implemented for the SSP Design, Development, Test, and Evaluation (DDT&E) phase. Required management and operational response time, efficiency, and cost effectiveness will dictate that an evolution in operational and management techniques take place in order to be user friendly yet managerially effective during the operational phase.

During the DDT&E phase, the National Space Transportation System (NSTS) will be devoted almost exclusively to the establishment of the major architecture of the Space Station. Once the Space Station is constructed, manned, and declared operational, the operation of a Space Station Program during the next twenty years will require utilizing the resources of the entire repertoire of Space Transportation systems both in the United States as well as those of the International Partners in order to have a cost effective, viable program. This section describes the capabilities and options that may be available for transportation services and rescue during the SSP time frame.

5.1.1 Transportation Services/Rescue

The transportation systems to support the Space Station subsequent to 2000 will require a robust fleet of space vehicles. The findings and recommendations of the NASA mixed fleet study team released on January 12, 1987, (Branscome, special programs), stated that a mixed fleet is required to support the Space Station because the NASA launch capability is not robust even with a high expendable launch vehicle option.

Ground Rules and Assumptions

- o The Space Shuttle (STS) and/or its replacement (Shuttle II) is operational
- o The Space Station is fully operational
- o Maximum Space Station crew size is 18 members
- o Crew Rescue Vehicles have a capacity for up to 6 members each
- o There will be sufficient crew rescue capability for all station members at all times
- o Space Station support is provided by domestic space transportation systems and could be supplemented with foreign space vehicles as necessary
- o A minimum of one orbital maneuvering vehicle (OMV) will be based at the Space Station
- o The propulsion unit of the OMV will be serviced routinely at a ground based facility (and therefore routinely require transport to the ground and back to the station)
- o The cold gas system of the OMV short range vehicle will be serviced at the station
- o The possibility of returning an unpressurized Logistics module using a non-Station Shuttle mission exists

Existing Shuttle System Vehicle Overview

The Space Shuttle consists of a reusable delta-wing spaceplane called the orbiter with two solid-propellant rocket boosters, which are recovered and also reused, and an expendable external tank containing cryogenic propellants for the orbiter's main engines. The tank contains separate compartments for liquid hydrogen and liquid oxygen.

At launch, the orbiter's three liquid-fueled rockets and the solid rockets generate 7 million pounds of maximum thrust. As the Space Shuttle reaches an altitude of about 31 miles, the spent solid rockets are detached and parachute into the ocean for recovery and reuse. The orbiter and tank continue toward low Earth orbit. When the orbiter's main engines cut off, the external tank is jettisoned to impact in a remote ocean area. The orbiter with its crew and payload accelerates into orbit to carry out an operational mission. When the mission has been completed, the orbiter re-enters the atmosphere and returns to Earth. Touchdown speed is above 210 miles per hour.

The assembled Shuttle vehicle is approximately 184 feet long and 76 feet high. The orbiter measures about 122 feet long and has a wingspan of around 78 feet. Its payload bay is 60 feet long and 15 feet wide.

The capability of the Space Shuttle has been revised after the 51-L accident and is shown below.

Orbital Capabilities:

Up weight - 39,500 lbs.

Down weight - 21,500 lbs

Shuttle Growth Vehicles

Because of the decreasing launch weight capability of the STS with current solid rocket boosters (SRB), improvements in performance is desired. While this can be accomplished with improved, next generation solid rocket boosters, another effective way to accomplish this is to replace the SRBs with liquid rocket boosters (LRBs). Some of the potential advantages of LRBs compared to SRBs include thrust termination capability and performance flexibility such as increased payload capability, throttling, thrust tailoring, and engine out capability. LRBs potentially offer higher reliability and improved ground processing including safer handling and potentially faster turnaround. They also offer more acceptable environmental conditions (i.e., no acid rain) and may lend themselves more readily to design modifications, inspection, and testing.

Candidate LRB replacements are shown in Figure 5-1. Each of these offer significant performance improvements over the existing system, and generally have Low Earth Orbit delivery capabilities of about 100,000 pounds.

Use of existing F-1 engine designs from the Saturn V program, with some modifications, is one LRB option. This approach would require about a 5 year development program, but has a high potential payload growth capability with low DDT&E required. As envisioned, each LRB would have two engines, stand about 150 feet high, and is just over 15 feet in diameter. Another option is the SSME35 LRB with 4 engines each. This low DDT&E, low development risk program would require about a 5 year development program, and has a wide range of applications. This booster is also about 150 feet high, but about 20 feet in

Ground Operational Support Systems
Ground Support Systems

pre post flight operations

SHUTTLE GROWTH OPTIONS

CANDIDATE LRB REPLACEMENTS FOR SRB

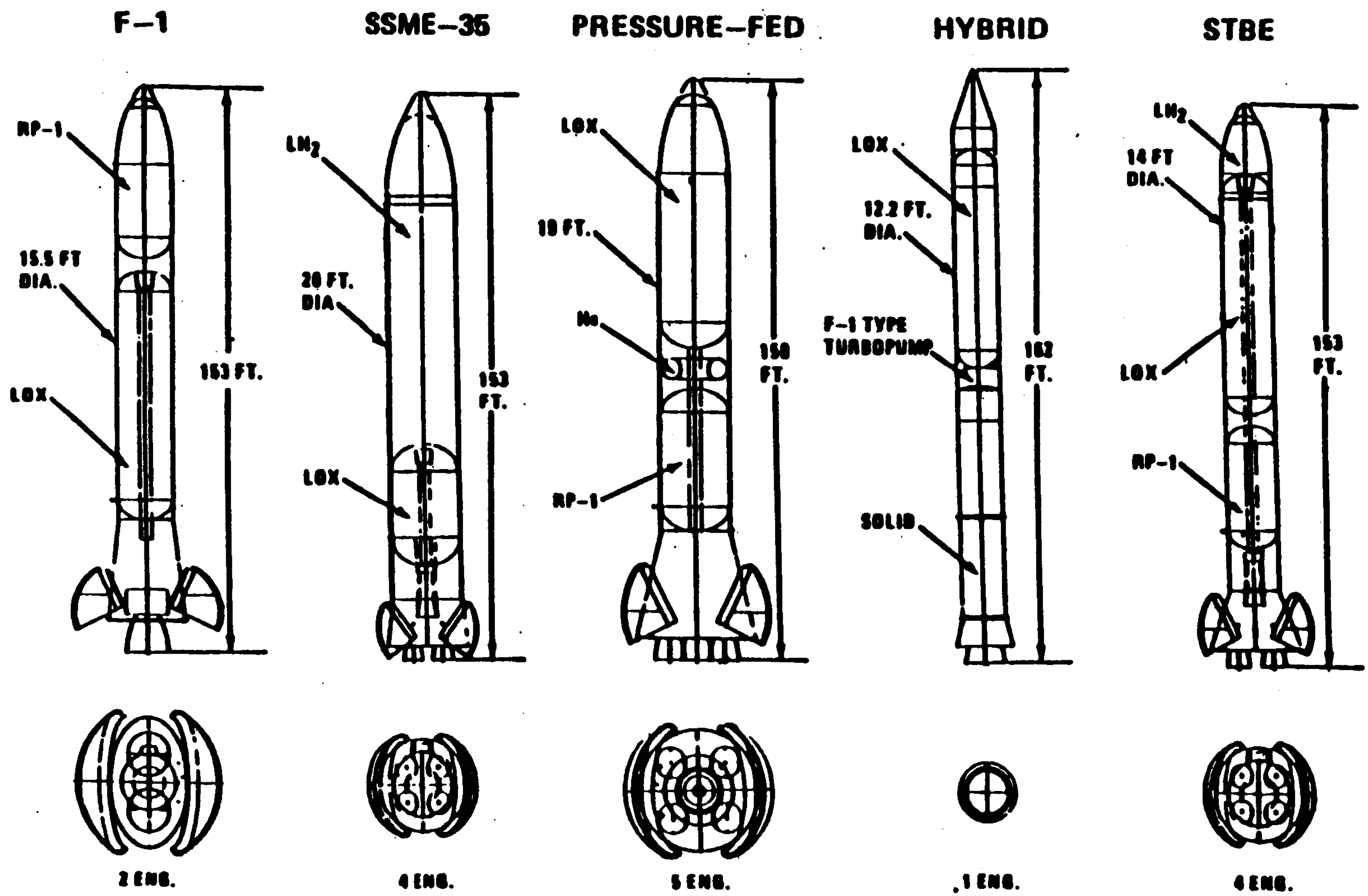


Figure 5-1

diameter. Another option is the 5-engine pressure-fed booster. It is about 160 feet high, 19 feet in diameter, and has a 6-9 year development requirement with relatively high DDT&E. Because of the high pressure, the thick tank walls make it amenable to water recovery. Another option is the hybrid booster, which has solid fuel and liquid oxidizer. Since it is an unproven concept, the feasibility has not been verified and a 10-year development time is forecast.

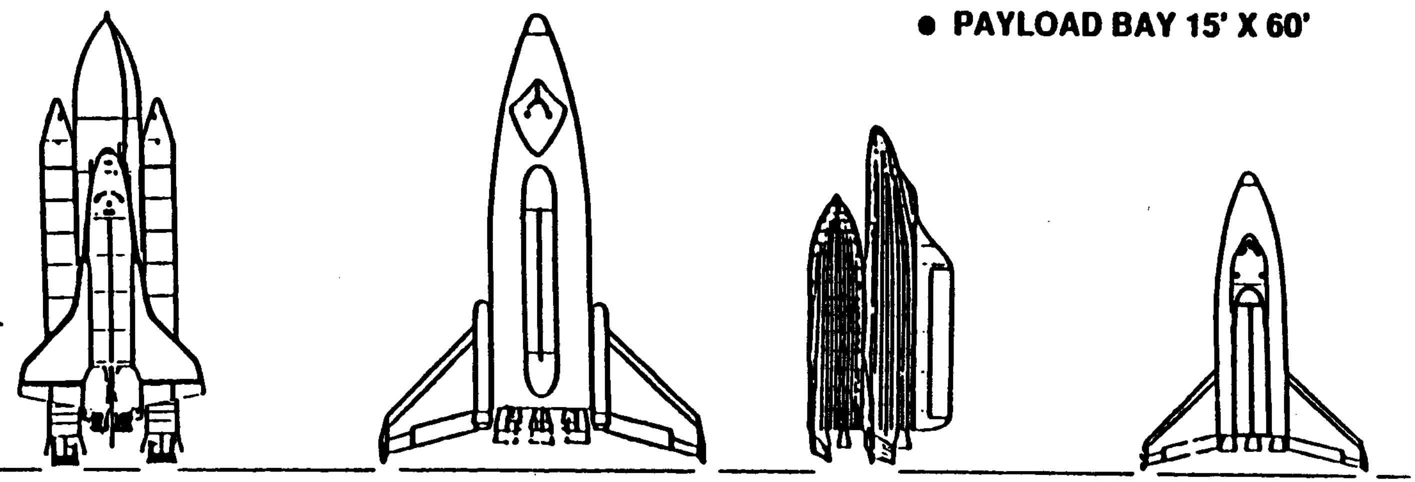
While additional payload capability, if needed, could be attained with improved solids or new LRBs, integration of LRBs into the STS configuration and launch facilities is a major consideration. The impact is probably largest with the pressure fed boosters because of the increased diameter required. Studies and experiments are needed to confirm viable means for water recovery and reuse of pump-fed propulsion systems, and the utility of on-pad or ascent shutdown capability needs to be better understood. System studies and supporting technology efforts can provide a better basis for decisions and selection of approach. Use of LRBs for the Shuttle might best be preceded by verification with Shuttle Derived Vehicles (SDVs) because of safety considerations.

Shuttle II

Subsequent to 2000, the current STS will need replacing because of system lifetime and the need for a newer, higher technology, and more efficient vehicle. There are now many concepts for this "Shuttle II" including Single Stage to Orbit (SSTO) with the SRBs, two-stage, and Advanced SSTO. Examples of these concepts are shown in Figure 5-2. All concepts have delivery capabilities comparable to the present Shuttle system, or about 40,000 pounds to the Space Station orbit. Desires for this

SHUTTLE II CONCEPTS COMPARED TO SPACE SHUTTLE

- ALL VEHICLES LIFT 40Klb. TO SPACE STATION
- PAYLOAD BAY 15' X 60'



SYSTEM	STS	SSTO+SRB	TWO-STAGE	ADVANCED SSTO
GROSS Wt, KLB	4600	2930	2620	1050
DRY Wt, Klb	610	260	220	56
DRY WEIGHT REDUCTION *	0	15%	15%	60%

* COMPARED TO SHUTTLE TECHNOLOGY

Figure 5-2

next generation Space Shuttle include low cost per flight, total reusability, all-weather capability (within reason), robust surfaces, large performance margins, small ground crew requirements, quick turnaround, minimal payload handling, and amenability to non-NASA operations. Some higher technology developments include advanced materials and structures, durable TPS and hot structures, and cooled materials. Other design features may include a detachable payload canister and axially separable internal tanks. Advanced performance technologies for weight reduction may include lightweight structures (carbon-carbon, new metal matrix materials), high performance, light weight rocket engines (using composite materials and high performance pumps, bearing, and preburners), lightweight subsystems (using advanced avionics, fiber optics, AI, and expert systems), and advanced configurations and control (such as adaptive GN&C and fault tolerant electronics). A possible evolutionary path for Shuttle II development from expendable SDVs, recoverable SDVs, and reusable winged boosters.

<u>Domestic Cargo Vehicles - Expendable Vehicles</u>.

<u>Titan IV</u> - The Air Force has been authorized to proceed with the development and procurement of 23 new Titan 4 launch vehicles to meet their requirements for assured access to space. (See Figure 5-3.) The first launch of the IUS upperstage version is 1989, with the Centaur version beginning in 1990.

The Titan 4, or Titan 34D7, is the latest addition to the family of Titan launch vehicles. The Titan III has successfully completed 129 operational launches since 1967 for a 97 percent success rate. The Titan 4 is an improved version of the Titan 34D space launch system, with stretched first and second stages, seven-segment solid rocket motors, a 16.7-foot

Titan IV Configuration

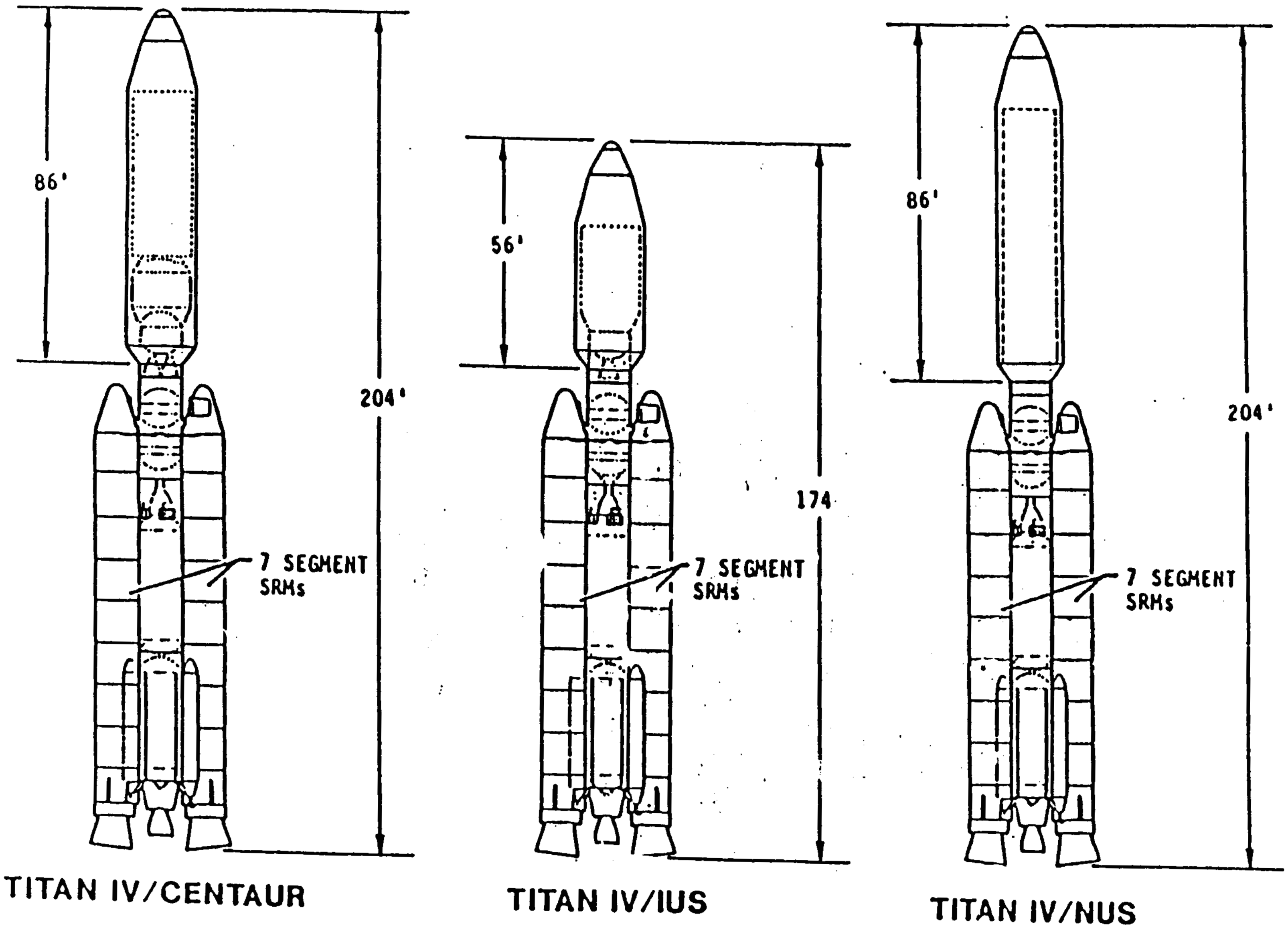


Figure 5-3

diameter payload fairing, and a Centaur G-prime or IUS upper stage. Overall length of the system is 204 feet. The keyload capability to 220 n.m. at 28.50 is approximately 20,000 lbs.

Delta Vehicles - The Delta is called the workhorse of the space program. This vehicle has successfully transported over 150 scientific, weather, communications, and applications satellites into space. Also, the Delta launch vehicle has been selected as the Medium Launch Vehicle (MLV) for the Air Force deploying the Global Positioning Satellite system.

First launched in May 1960, the Delta has been continuously upgraded over the years. Today it stands 116 feet tall. Its first stage is augmented by nine Caster IV strap-on solid propellant motors, six of which ignite at liftoff and three after the first six burn out. The average first-stage thrust with the main engines and six solid propellant motors burning is 718,000 pounds. Delta has liquid-fueled first and second stages and a solid-propellant third stage.

The configuration of the Delta rocket for the MLV program will be an upgrade from the present vehicle. The vehicle will be lengthened and high performance solid propellant will be used. The capability of the Delta rocket to low Earth orbit will be TBD with an eight foot diameter payload fairing.

Atlas/Centaur Vehicles - The Atlas/Centaur is NASA's standard launch vehicle for intermediate payloads. It is used for the launch of Earth orbital, geosynchronous, and interplanetary missions.

Centaur was the nation's first high energy, liquid-hydrogen, liquid-oxygen propelled launch vehicle stage. Since 1966, both the Atlas booster and the Centaur second stage have undergone many improvements. At present, the combined stages can place 12,000 pounds in low Earth orbit.

An Atlas/Centaur stands approximately 131 feet tall. At liftoff, the Atlas booster develops over 431,000 pounds of thrust. The Centaur second stage develops 30,000 pounds of thrust in vacuum.

Shuttle Derived Vehicles - Shuttle Derived Vehicles (SDVs) are launch vehicles that utilize existing components from the Space Shuttle but have a payload compartment instead of an Orbiter. While these components are sometimes necessarily modified because of different load paths, they are essentially the same proven systems. SDVs have been studied in some form since the mid-1970s, both by in-house NASA and contracted studies. Concepts include both expendable and reusable main engine versions, the latter using a Propulsion/Avionics Module, and if development started now, could be ready for launch in the early 1990s. Early versions of SDVs generally include the same solid rocket boosters as the present Shuttle system, but if liquid boosters are used for Shuttle performance enhancement, these can easily be adapted to the SDVs. Liquids generally offer benefits over solids for performance, flexibility, operational simplicity, and environmental impact.

SDVs, because they do not carry the Orbiter, have more payload capability than the Shuttle. Depending upon the configuration, payload capacities generally range from 75,000 to 200,000 pounds to Low Earth Orbit.

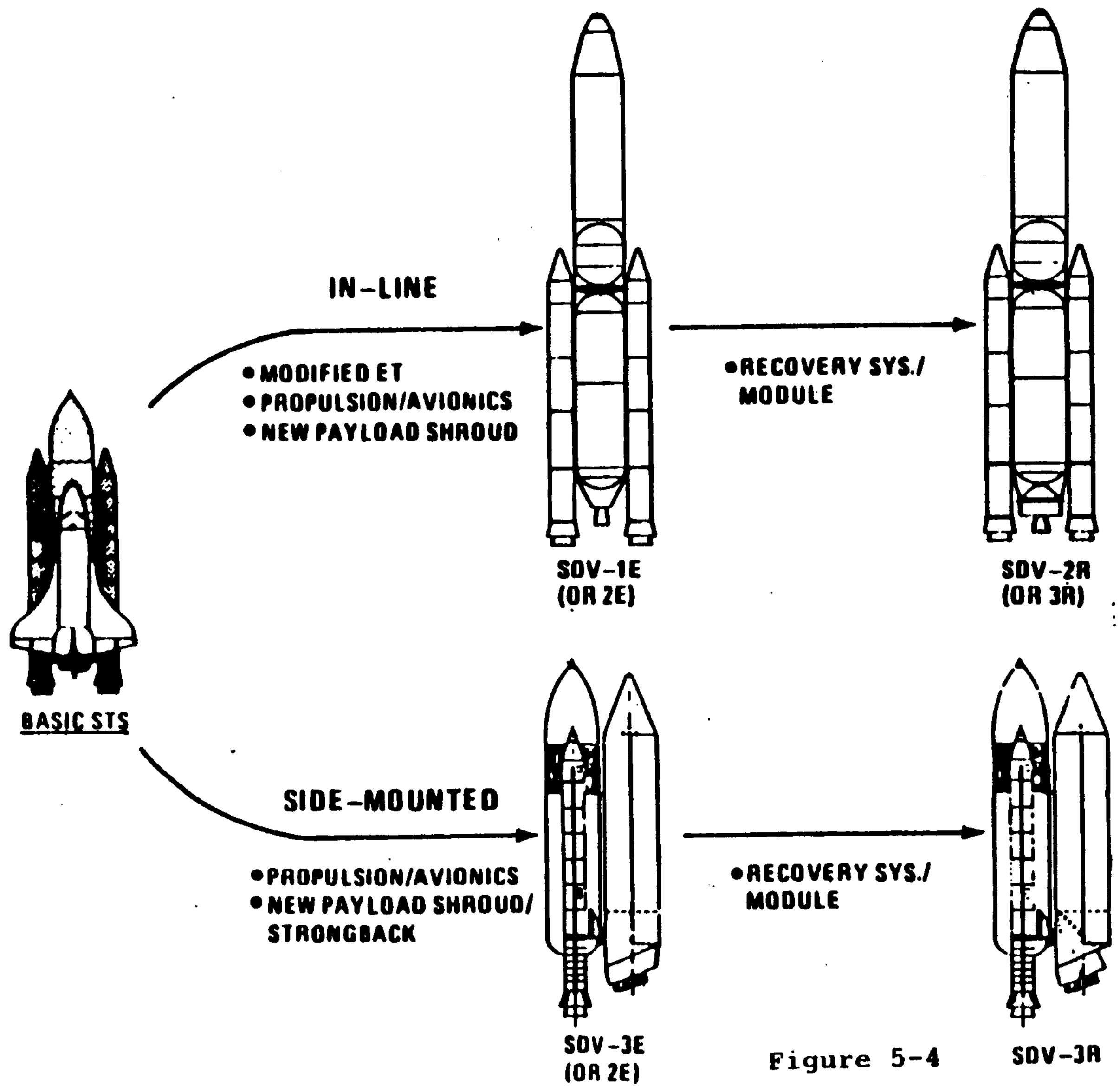
One of the main advantages of SDVs is that many factors are common with the STS. If the 15' x 60' payload size is maintained, many facilities such as assembly buildings, transporters, launch pads, and test and verification sites can be shared. Tanks, integration hardware, and transportation modes are the same. Many major hardware elements such as engines, thrust structure, nozzles, and payload fairings are the same as well as others such as avionics systems and cryolines, valves, and insulation. The operations processes of assembly, transportation, launch and orbital sequences are the same or similar.

Two basic SDV configurations, the side mount and the in-line, are most often considered. Each of these has variations that lead to a family of vehicles covering a wide performance range. Figure 5-4 shows the evolutionary flow from the STS to both types of SDVs, with further development to a reusable main propulsion system.

Studies are currently underway to investigate the feasibility of P/A Module, where main propulsion and avionics systems are packaged together in a reusable pod, for use in SDV and possibly other launch systems. The development of advanced precision recovery systems for high cost components, such as the P/A Module, is being considered to reduce launch costs considerably. Such systems would allow minimal touchdown damage and decrease refurbishment and integration times, particularly if the system can accommodate land touchdown and avoid the salt water corrosion problems associated with ocean splashdown.

<u>Side Mount</u> - The side mount SDV is identical to the STS, except the Orbiter is replaced with a "side mounted" payload carrier. The payload size may range from 15' x 60' (STS size) to

SHUTTLE DERIVED LAUNCH VEHICLE CONCEPTS
PROGRAM OPTIONS



COMMON FACTORS W/STS

FACILITIES

- ASSEMBLY BUILDINGS
- TRANSPORTERS
- LAUNCH PADS
- R&D, TEST & VERIFICATION SITES

STAGES

- TANKS
- INTEGRATION HARDWARE
- TRANSPORTATION MODES

MAJOR ELEMENTS

- ENGINES
- THRUST STRUCTURE
- NOZZLES
- PAYLOAD FAIRINGS

COMPONENTS

- AVIONICS
- CRYOLINES, VALVES, INSULATION

OPERATIONS

- ASSEMBLY
- TRANSPORTATION
- LAUNCH
- ORBITAL

Figure 5-4

25' x 90'. If the STS size payload is maintained, few Kennedy Space Center facility modifications are required. Since OPF activities are no longer needed, the flow is actually simplified. Payloads would be integrated vertically on the pad as most are now, with no modifications needed to the RSS or MLP. A larger payload would require new or modified payload processing facilities, as well as off-line payload integration or changes to launch pad RSS and POR.

The Side mount SDV, users STS SRBs, ET, and SSMEs unchanged. In the reusable version, engines and avionics are combined into a Propulsion/Avionics (P/A) Module which is recovered and refurbished for further use. If a 25' diameter shroud is used, special 15' foot cradles can be developed to adapt for STS payloads.

Performance from ETR to a 28.5 degree Low Earth Orbit ranges from about 100,000 lbs for a two-engine reusable version to over 150,000 for the three-engine expendable version.

The major advantage of the side mount over the in-line version is that it requires a minimum change to the present STS facilities. Once the payload carrier is developed, it could enter the processing flow with a minimum impact. Compared to the in-line configuration, performance is slightly lower because of the off-center thrust of the main engines and the asymmetric aerodynamic shape.

<u>Inline SDV</u> - The Inline SDV configuration has the payload carrier mounted on top of ("in-line" with) the External Tank, with the main propulsion engines under the tank. Standard SRBs are attached to the ET in the usual manner. The ET is modified

somewhat. The hydrogen tank and intertank structure are unchanged, but the LOX tank aft ring is inverted and the LH2 tank forward dome is used on the forward end of the LOX tank. This is necessary to support the payload atop the ET. On the aft end of the ET, the insulation for aerodynamic heating is no longer necessary, but new thrust structure for the main engines is required. The payload shroud is new hardware, and is jettisoned inflight after maximum dynamic pressure. As with the side mount configuration, payloads can range from 15' x 60' to 25' x 90'. Payload adapters can be used for STS-sized payloads in the larger diameter version. Because of the cleaner aerodynamic shape and the on-center thrust, weight placement capability is higher than the side mount with the same number of engines.

Performance ranges form about 80,000 pounds in the single engine expendable version to over 200,000 pounds for the three engine expendable. Reusable engine versions (with a P/A Module) range from about 140,000 pounds to 180,000 pounds for two and three main engines, respectively. A performance summary comparing both side mount and inline SDVs is shown in Figure 5-4.

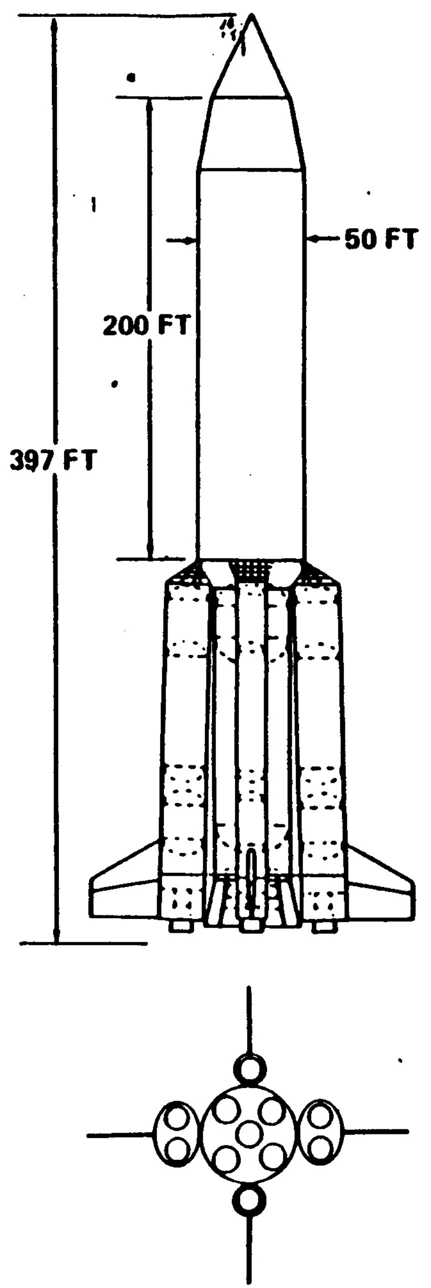
Launch site facility modifications are somewhat more extensive than with the side mount. Payload integration will be done away from the pad (possibly in the VAB), and payload access at the pad is not possible without special equipment. Because of the payload height and location, modifications to the payload umbilicals is necessary, as well as service tower and lightning mast extension. The MLPs are not presently configured with a flame exit hole at the main engine location, so a modification is necessary here or else suffer a performance loss with an altitude start of the SSMEs.

Heavy Lift Launch Vehicles - A large Heavy Lift Launch Vehicle (HLLV) designed to deliver 300 - 400,000 pounds to Low Earth Orbit may be required to meet national needs for 1995 and beyond, and may have applications in the operational era of the Space Station. The vehicle, shown in Figure 5-5, can accommodate payload envelopes up to 50 feet in diameter by 200 feet in length. Payloads utilizing this capability may be Space Station elements (particularly in the growth configuration), commercial space facilities, or advanced military systems.

Design requirements of this vehicle include reusability of the more expensive components such as avionics and propulsion systems, rapid launch turnaround time, minimum hardware inventory, stage and component flexibility and commonality, and low operational costs. All ascent propulsion systems utilize liquid propellants and overall launch vehicle stack height is minimized while maintaining a reasonable vehicle diameter.

This configuration is a parallel burn two-stage vehicle which used LOX/JP4 boosters consisting of four tank sets or substages, two 246-inch diameter and two 171-inch diameter. The larger sub-stages have two 1/6 million pounds thrust advanced main engines and the smaller substages have one engine each, for a total of six booster engines. The second stage is 396 inches in diameter and has five two-position nozzle engines. All first and second stage engines are ground ignited and flown in parallel burn until booster staging.

Cargo Return Vehicles - All of the launch vehicles, except for the Shuttle system, has only the capability to launch payloads to orbit. The need to return payloads back to Earth from the Space Station is a major requirement. The current Space Shuttle system has a mismatch of about 15,500 pounds in its



HEAVY LIFT LAUNCH VEHICLE

Performance

ETR ~ 400 K Each

WTR ~ 300 K Each

- o Reusable Propulsion & Avionics
- o New Launch Facilities Required

Figure 5-5

ability to return payloads versus launch them to orbit. The use of the Shuttle alone will cause a backlog of payloads to be returned to Earth. The driving factor for the productivity of the Space Station will become the down weight capability of the transportation system. Concepts need additional development and emphasis for the Space Station program to enable use of an efficient transportation system.

The Cargo Return Vehicle concept is based on the CERV design but without the manned features. The vehicle would be reusable with low refurbishment costs. The vehicle will be able to meet time critical payload requirements which will be a key factor to the user community. A proposed design is shown in Figure 5-6.

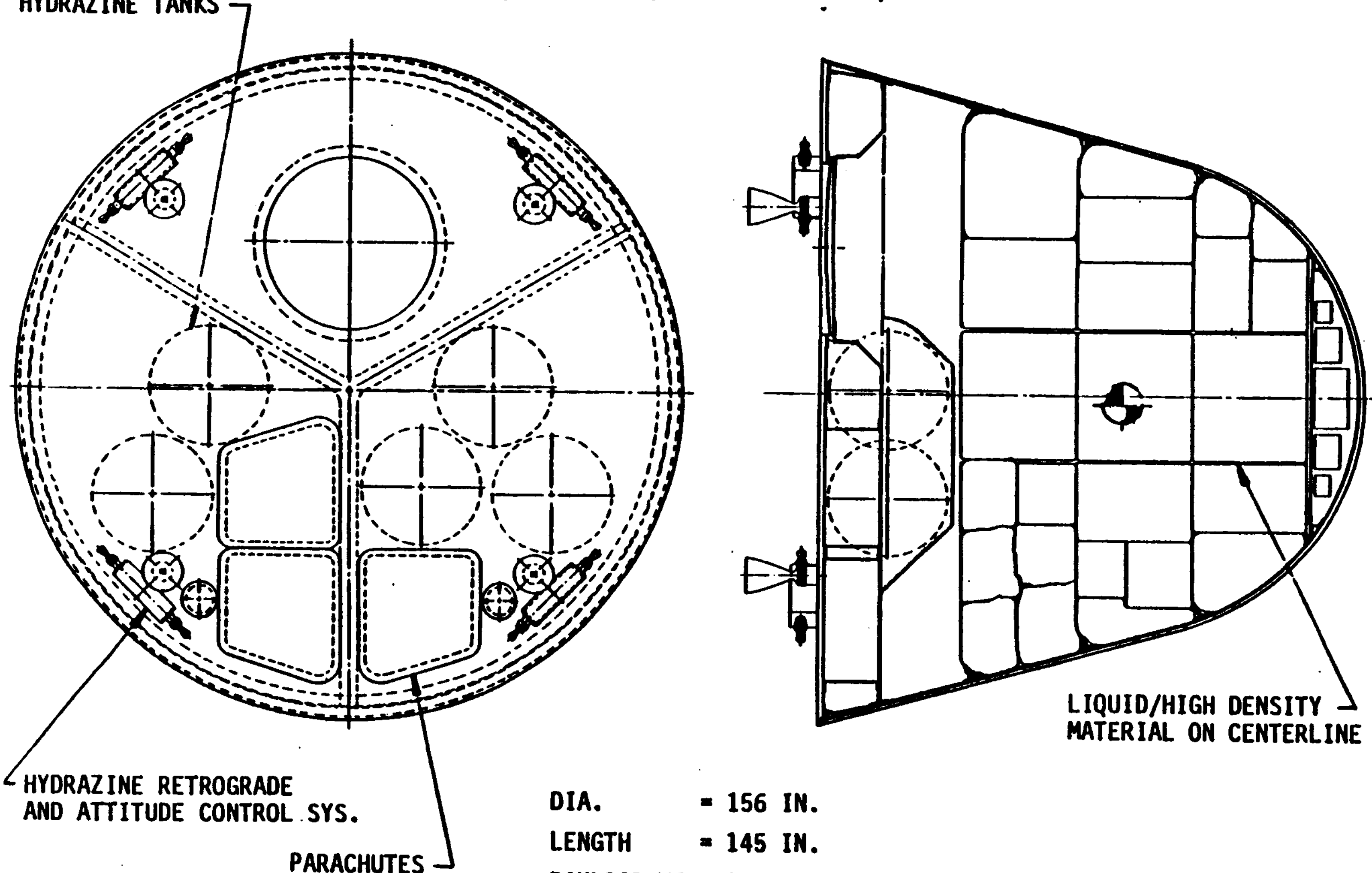
<u>Foreign Space Transportation Systems</u> - In spite of the operation of the reusable U. S. Space Shuttle, the era of conventional expendable launch vehicles is not over and a new generation of classic launch vehicles, Japan's H-11 rocket and Europe's Ariane 5, is being developed. The foreign launch vehicle programs have also started towards development of reusable orbiter type vehicles for manned space operations. Figures 5-7 and 5-8 shows future foreign development launch vehicles.

<u>European Space Agency (ESA)</u>

<u>Overview</u>. The European Space Agency's eleven member-states met in early 1985 to define their objectives for the next decade. They settled on three: an autonomous capacity to work in space; the construction of a small, reusable shuttle; and the development

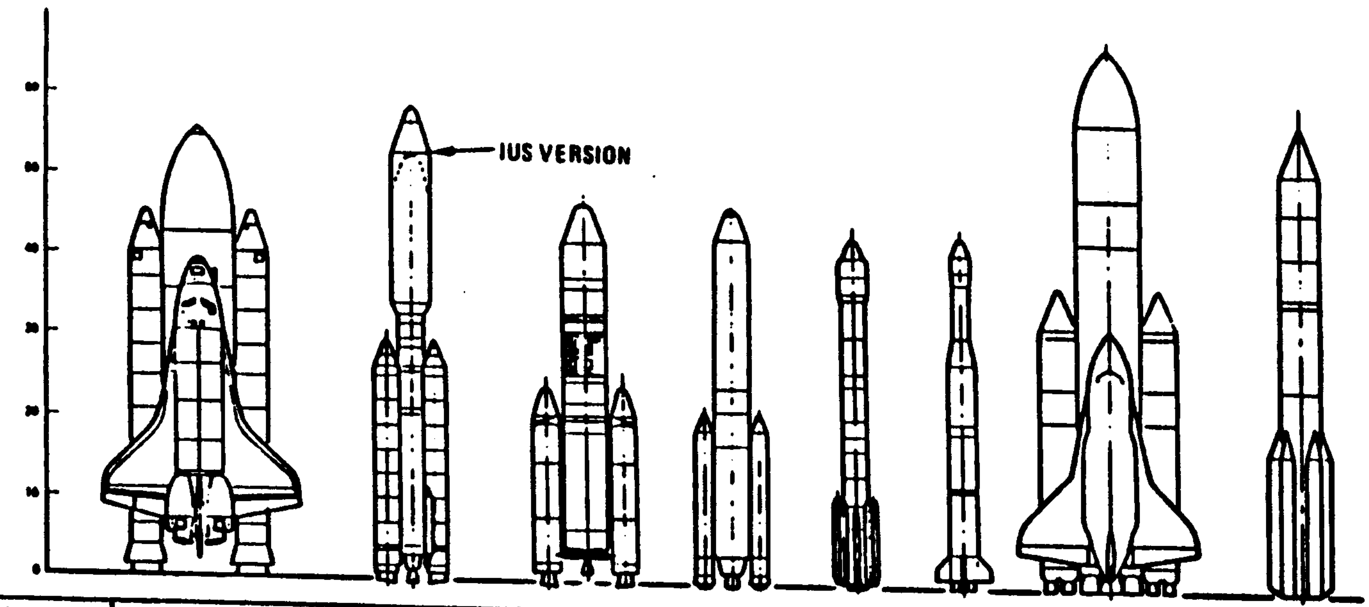
LOGISTICS VEHICLE

(BASED ON 13 FT DIA CERV)
(OFF-SET CG, LIFTING REENTRY)



DIA.	= 156 IN.
LENGTH	= 145 IN.
PAYLOAD WT	= 10,000 LBS
TOTAL WT.	= 16,000 LBS

Figure 5-6

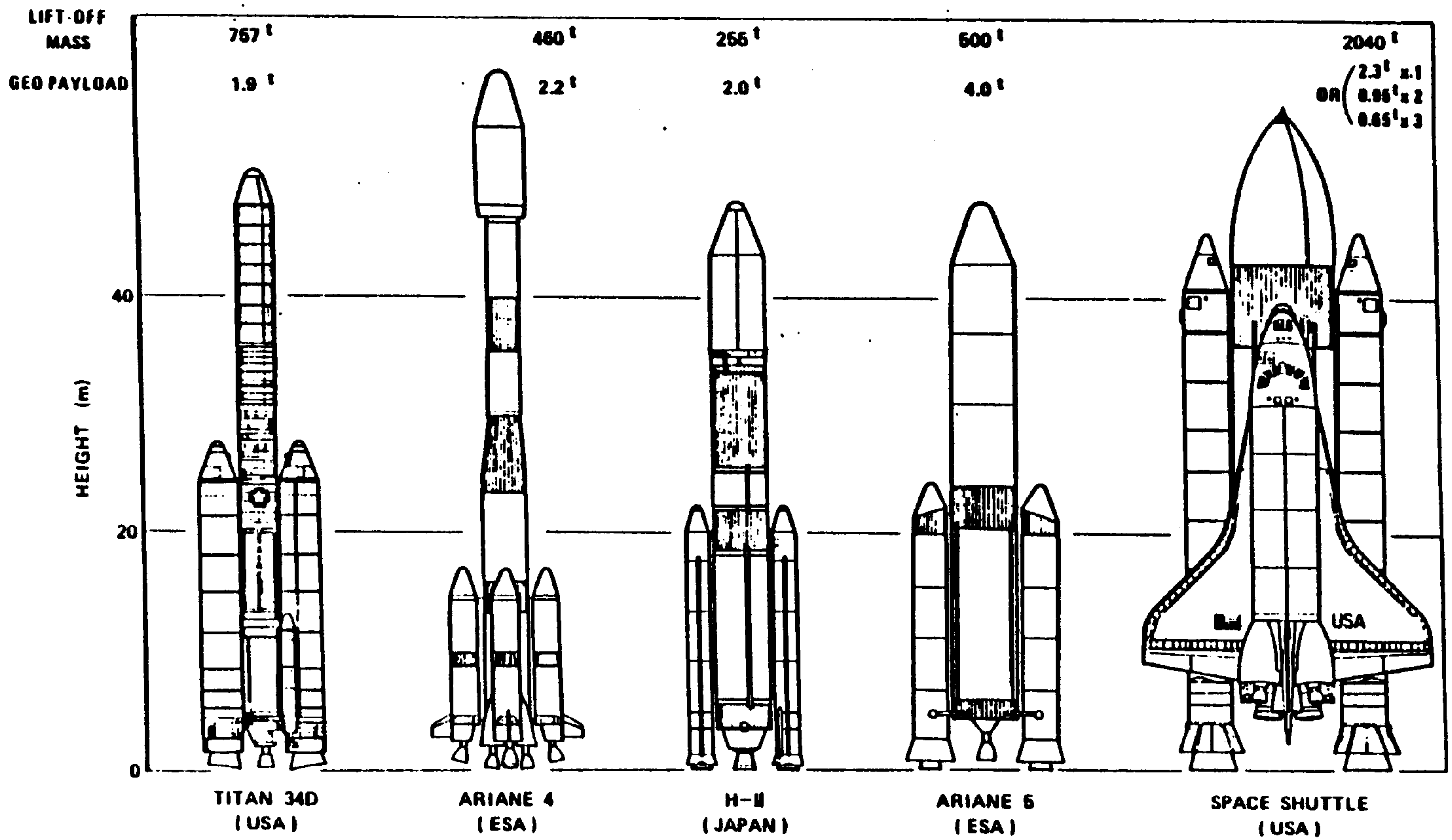


ORIGIN	USA	USA	EUROPE	JAPAN	PRC (CHINA)	INDIA	USSR	USSR
DESIGNATOR	SHUTTLE/IUS	TITAN 34D7/CENTAUR	ARIANE 5	H-II	CZ-3	PSLV	–	(PROTON)
LAUNCH WT – t	2,090	880	560	255	202	276	2,000	670
PERFORMANCE								
LEO – kg	29,480	18,000	15,000	10,000	3,800	3,000	30,000	19,500
GTO – kg	–	–	6,200/8,000	3,800	1,400	–	–	–
GEO – kg	2,270	4,535	3,800	2,000	–	–	–	–
SUNSYNCH	–	–	10,000	4,500	–	1,000*	–	
IOC	CURRENT	1988	1995	1991	CURRENT	1990	1990?	1990?

*HIGH PERIGEE

Near-term "top of line" launch vehicles.

Figure 5-7



Launch Vehicles in the 1990's

Figure 5-8

of a large Ariane 5 rocket that is an integral component of the shuttle package.

The small shuttle, dubbed Hermes, is being developed in France with the backing of the eleven-nation European Space Agency. The orbiter will be launched by the expendable Ariane 5 rocket, currently in its development stage. Hermes will carry four or more astronauts and a 10,000 pound payload into orbit, then return for a runway landing on Earth. Current plans call for two spaceplanes to be built, and for the first flight to take place in 1995 on only the third Ariane 5 launch.

Hermes will be used for independent flights of various types and servicing missions to satellites and free-flying platforms. But its most important role will be to ferry people and equipment to and from space stations.

The goals for the development of the Ariane 5 launch vehicle includes a substantial increase over Ariane 4 in payload lift capability, along with an increase in payload diameter to match that of the Space Shuttle. The new launch vehicle is designed with a reliability goal compatible with manned flights for the Hermes manned spacecraft. The first Ariane 5 test flight is scheduled for late 1994, from a new launch site at Kourou. The first operational flight is scheduled for 1995.

The Hermes concept is based on the principle that automatic payloads are launched more economically and more safely by automatic vehicles than by manned launchers, and that manned transportation vehicles should be used only when man's presence is definitely required by the mission. It leads to the Ariane 5/Hermes concept, in which the same basic core launcher can be topped with different upper stages and fairings for automatic missions, or with Hermes for manned missions.

The delta wing Hermes spacecraft, shown in Figure 5-9, is about half the size of the Space Shuttle with the size of the cargo bay considerably smaller than that of the Space Shuttle, due to the fact that it is not designed to carry satellites. Hermes, being a spacecraft and not a launcher, does not carry the launch propulsion system, but only a low thrust propulsion unit for orbit maneuvers and deorbiting.

In its initial design, Hermes is 58.7 feet long, and it stands 16 feet high. Four people would be comfortable in its crew compartment; six would be cramped. The stubby vehicle has sharply upswept rudders at the tips of its delta wings. Upper and lower elevons extend from the wings trailing edges and a single body flap will be mounted beneath the rear fuselage. Table 5-1 summarizes the main features of the Hermes spacecraft.

The Ariane 5 is being developed as a three-spage expendable launch vehicle with lower composite comprising of two solid-rocket boosters and cryogenic liquid-propellant main stage. The upper composite comprising either a low-energy storable liquid-propellant L4 stage, a high-energy cryogenic liquid-propellant H10 stage, or the Hermes spacecraft.

The Ariane 5 will use two boosters for lift-off and initial ascent each consisting of 170 tons of HTPB solid propellant each producing 450 tons of thrust. The main stage will burn 120 tons of cryogenic propellant (LOX/LH_2) with one Vulcain cryogenic engine producing 102 tons of thrust. The payload

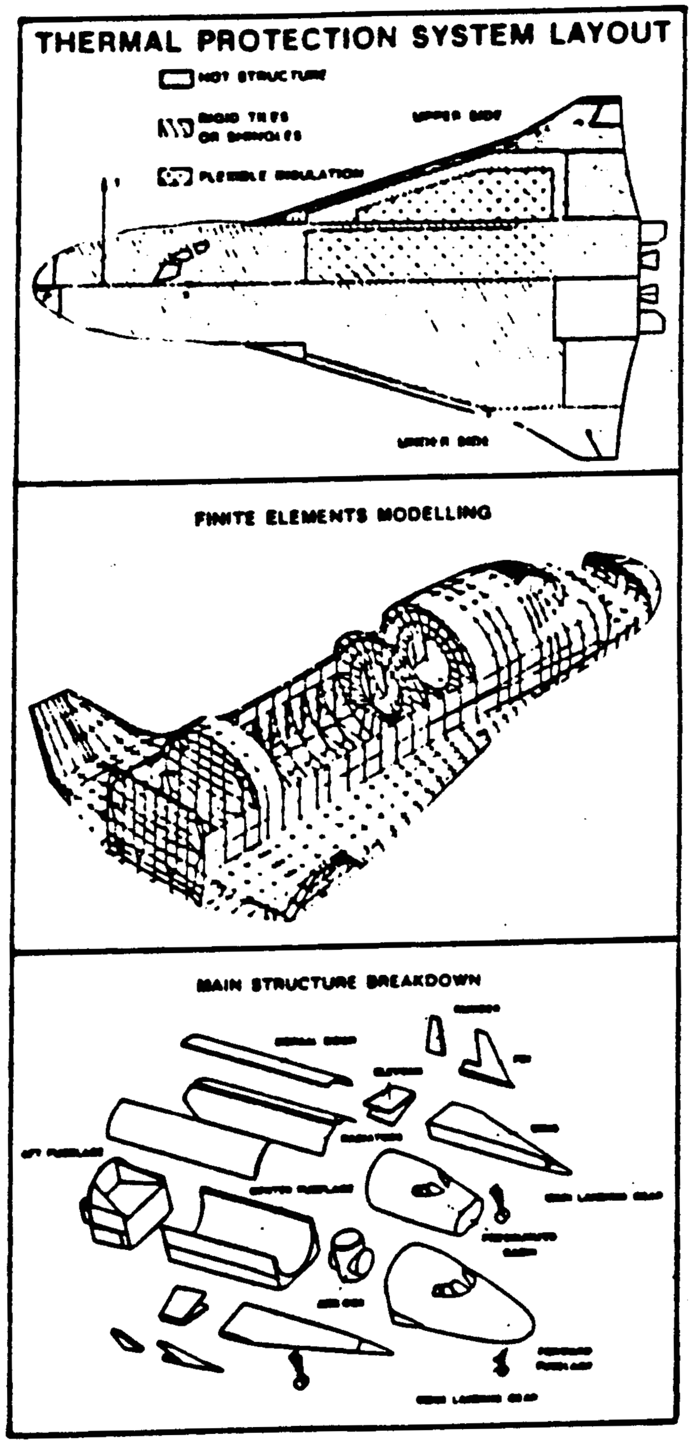


Figure 5-9. Hermes Vehicle

Hermes specifications

Length	16 m
Height	6 m
Wingspan	10 m
Cargo bay	3 m (diameter) 5 m (length) 35 cu m (volume)
Cargo capacity	4500 kg (in equatorial orbit)
Crew	4-6
Weight	9 tons (empty)
Launcher	Ariane 5
Power	Fuel cells or lithium batteries. Propellant driven turbines. Solar arrays (long duration only)
Propulsion	Three engine subsystems using 2500 kg of propellant (MMH, N204) ● Attitude control system ● Orbital manoeuvring and rendezvous system ● Orbital insertion deorbit and abort system
Orbital parameters	400 km (circular low-altitude orbit with a 0°-60° inclination) 500-800 km (sunsynchronous orbits with reduced payload capacity (1500-2500 kg) and reduced crew (2-4))
Mission duration	7-28 days (depending on number of crew) 90 days (long duration missions possible when docked with space station)
Atmospheric manoeuvring	10000 km (longitudinal range) 2500 km (lateral crossrange)
Launch site	Kourou (French Guiana)
Landing site	Kourou (French Guiana) Istres (France)
First flight	1995
Cost	2000 MAU (million accounting units in 1985 terms)

Table 5-1

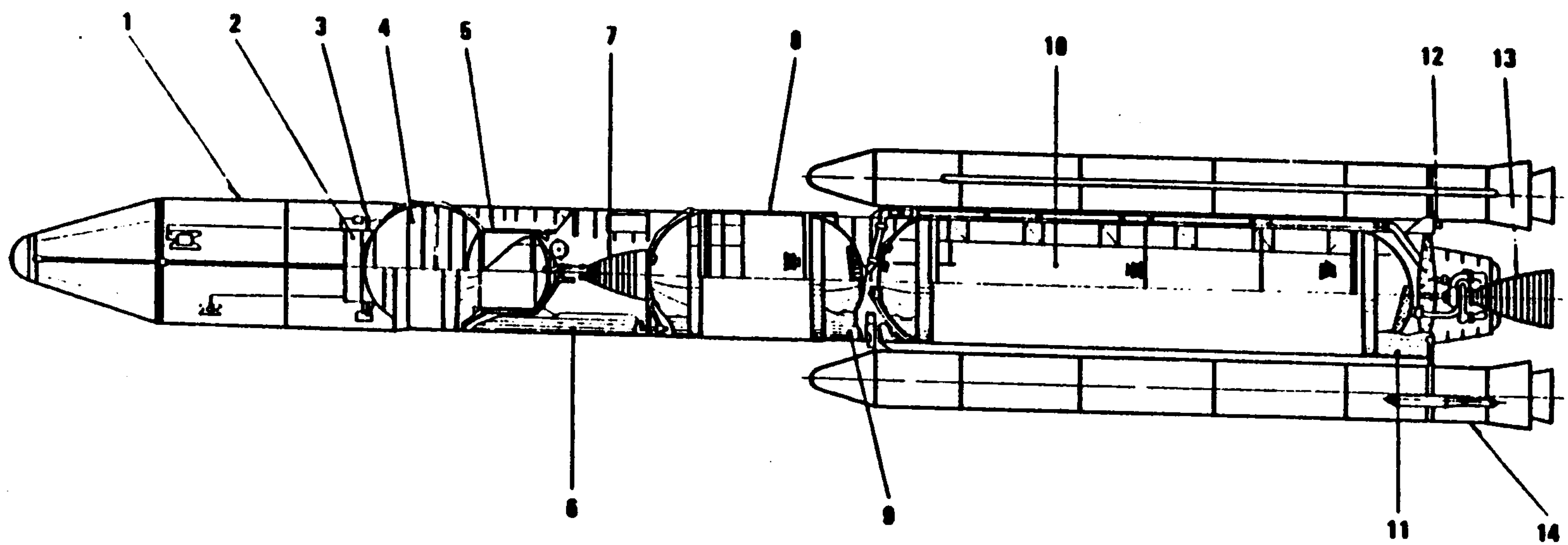
fairing will be 4.55 meters in diameter with the Spelda-type multiple launch structure developed for the Ariane program.

The Ariane 5 will have a one or two stage cryogenically fueled core and two solid-fuel strap-on boosters. With two core stages, Ariane 5 will be able to put two satellites, together weighing more than 17,000 pounds, into geostationary orbit. With a single core stage, it could carry 33,000 pounds to low Earth orbit. The single stage version would loft Hermes into space.

All launches will come from the French facility near the equator at Kourou, French Guiana. Hermes will also land at Kourou, touching down on a standard 11,500 foot runway. Like the U. S. shuttle, Hermes will return to Earth as an unpowered glider.

<u>Japanese Space Vehicles</u>

The National Space Development Agency of Japan (NASDA) has made a major effort to obtain a heavy-lift launch vehicle with the initiation in 1985 of the H-II development program. The H-II is a new expendable launch vehicle to meet the demand for Japanese space activities in the 1990's. With the successful development of the N rocket family, Japan has established the technology for launching satellites into Geostationary Earth Orbit (GEO). The H-II rocket is being designed to launch a 2 ton satellite into GEO with a projected lift capability to the Space Station orbit of 8500 pounds. First launch of the H-II rocket is proposed for early 1992. As shown in Figure 5-10 the H-II vehicle is compact in size and light in weight compared with similar launch vehicles throughout the world.



1. PAYLOAD FAIRING
2. PAYLOAD ATTACH FITTING
3. GUIDANCE SECTION
4. SECOND-STAGE LH_2 TANK
5. SECOND-STAGE LOX TANK
6. INTER-STAGE
7. SECOND-STAGE ENGINE (LE–5)
8. FIRST–STAGE LOX TANK
9. CENTER BODY SECTION
10. FIRST-STAGE LH_2 TANK
11. FIRST-STAGE ENGINE SECTION
12. AUXILIARY ENGINE
13. FIRST-STAGE MAIN ENGINE (LE–7)
14. SOLID ROCKET BOOSTER (SRB)

H–II Launch Vehicle

Figure 5-10

C-5

NASDA's goals for the H-II program include minimizing cost for payload delivery and maximizing reliability, even in the early phase of the new launch vehicle. An independent, reliable, economical, and user friendly launch vehicle, the H-II rocket, will become available in 1992 and it may result in competitive capability in the field of commercial launch services.

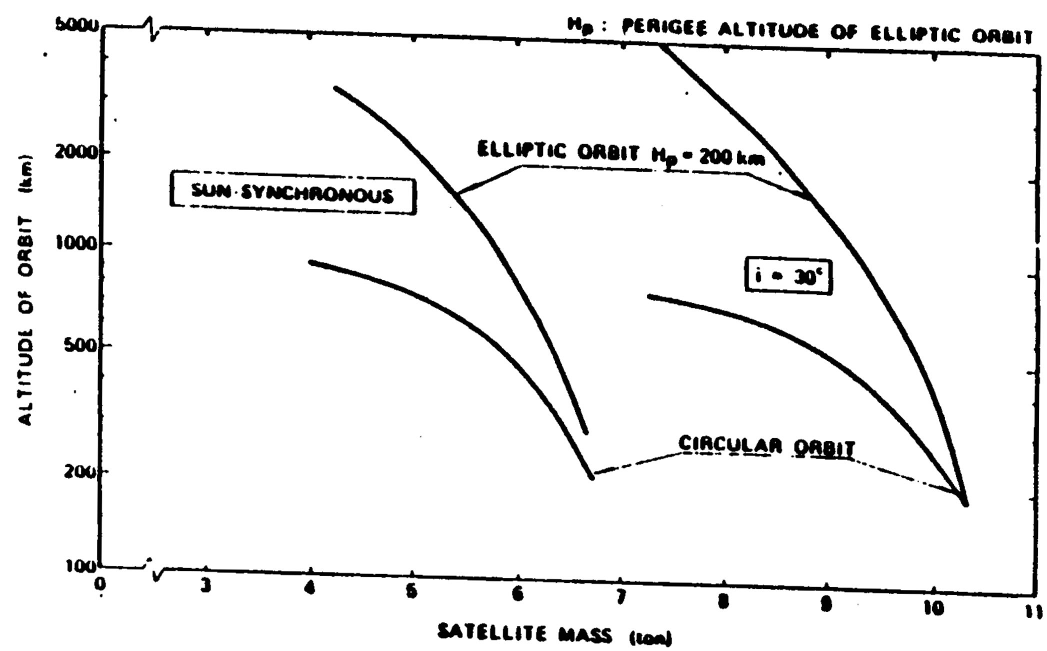
The H-II rocket consists of cryogenic first and second stages at 4 meters in diameter and a pair of strap-on solid rocket boosters. It is 255 tons in lift-off mass and 48 meters in height. The first stage loads 85 tons of LOX/LH propellants and is powered by a single LE7 engine delivering 120 tons thrust in vacuum at a specific impulse of 449 seconds. Figure 5-11 and show a general view and principal specifications of the H-II rocket, respectively. These figures are based on Phase B results. The H-II rocket employs conservative design for high reliability and low cost.

The standard payload fairing is 4 meters in diameter, matching the main body diameter, and 12 meters long. However, it is possible to increase the diameter of the payload fairing to 5 meters which is compatible with the Space Shuttle cargo bay and the Ariane 5 payload fairing.

The flight sequence of a standard GEO mission is shown schematically in Figure 5-12. The LE-7 engine is ignited, upon thrust build up of the engine, two SRB's are ignited and the H-II is released from the pad. The SRB's and main engine provide the thrust for the first portion of the flight. The SRB's burn out at 95 seconds after lift-off and seconds later they are separated from the core vehicle. The main engine continues to burn for a total duration of 315 seconds. The maximum acceleration of 3.6 g's at the first stage burnout is low enough to protect

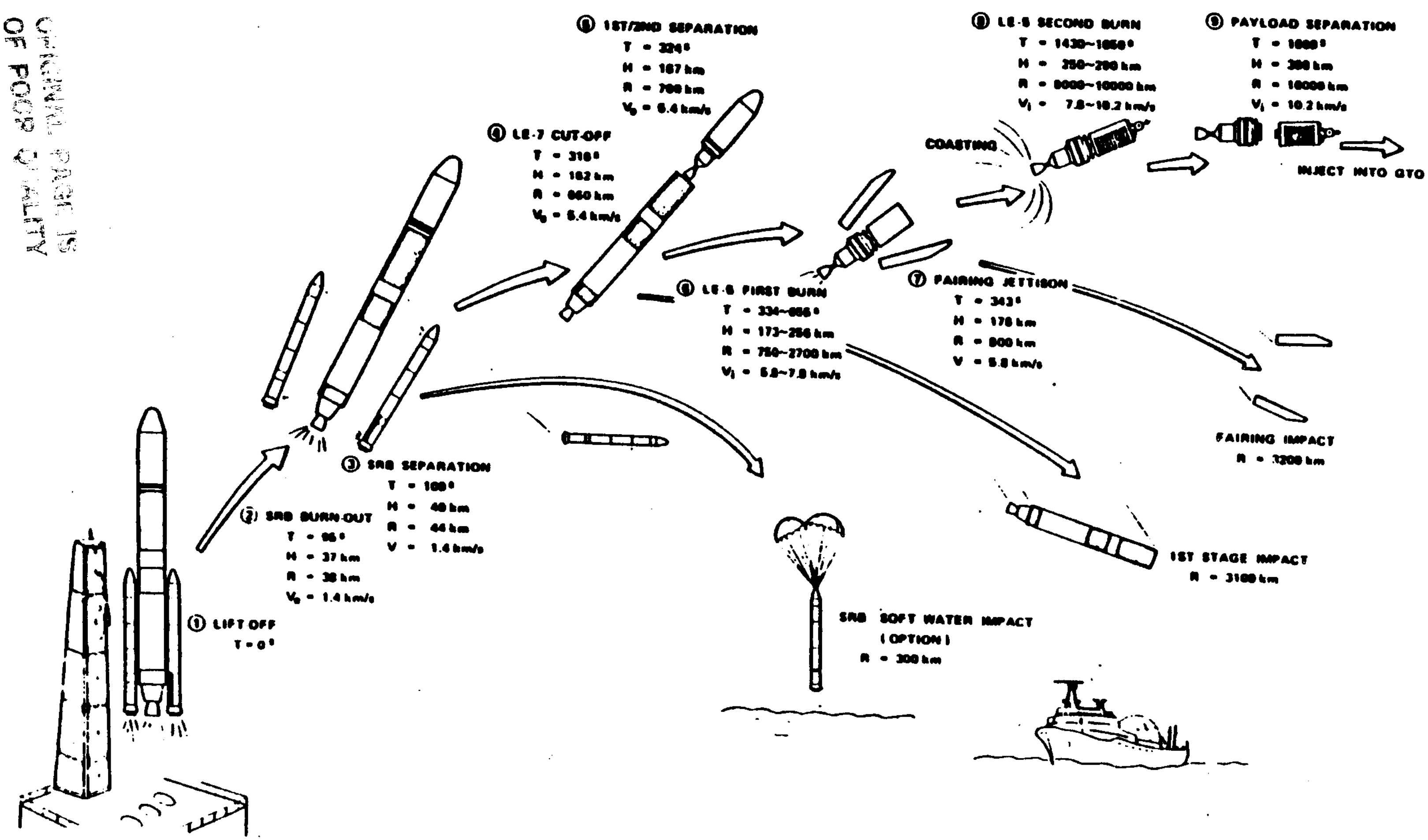
Table 1 Main Characteristics of H–II Rocket

	ITEM	DIMENSION	
	LENGTH	48 m	
	DIAMETER	4 m	
	LIFT-OFF MASS	256 t	
	PAYLOAD MASS (GEO)	2 t	
1ST STAGE	PROPELLANT	LOX/LH	
	PROPELLANT MASS	85 t	
	THRUST	93 t (910 KN)	AT SEA LEVEL
	BURNING DURATION	315 s	
	SPECIFIC IMPULSE	449 s	IN VACUUM
	TOTAL MASS	93 t	
SRB'S	PROPELLANT	COMPOSITE	
	PROPELLANT MASS	118 t	
	THRUST	320 t (3140 KN)	AT SEA LEVEL
	BURNING DURATION	95 s	
	SPECIFIC IMPULSE	271 s	IN VACUUM
	TOTAL MASS	138 t	
2ND STAGE	PROPELLANT	LOX/LH	
	PROPELLANT MASS	13 t	
	THRUST	10.5 t (103KN)	
	BURNING DURATION	554 s	RE-STARTABLE
	SPECIFIC IMPULSE	448 s	
	TOTAL MASS	15.6 t	
FAIRING	DIAMETER	4 m	PAYLOAD ENVELOPE
	LENGTH	12 m	3.65 mφ x 10 mL
GUIDANCE SYSTEM		STRAP-DOWN INERTIAL GUIDANCE	



Launch Capability of H–II Rocket

Figure 5-11



Typical Flight Sequence (GTO Launch Mission)

Figure 5-12

sensitive payload structures. The H-II will place approximately 10 tons into low Earth orbit.

The launch center of NASDA, Tanegashima Space Center (TNSC), provides the necessary preparation and support for the H-II launch vehicle. TNSC is located at 30 degrees 28 minutes north latitude allowing for resupply missions to the Space Station with limited penalty. The general accessibility from major industrial regions and Japan's large cities is sufficient to support operational activities at the site. The Tanegashima island has an extremely stable political situation as a matter of course. The new launch site is expected to accommodate four launches per year.

NASDA is now studying a growth version of the H-II rocket which will be adequate for Japan's requirements and the international context in the 2005 time frame. The advanced version of the H-II rocket will be required to be compatible with the Ariane 5 and the Space Shuttle, with a payload diameter of 4.6 meters and two-fold increase in payload launch capability. NASDA requires an accessibility to the Space Station which will include a reusable spaceplane of 15 to 20 tons. Several improvements to the basic H-II rocket are being analyzed. The most simple improvement can be performed by only increasing the number of SRB's from two to six, resulting in approximately a two fold increase in launch capability. Another concept of improvement is to remove the second stage from the basic configuration and add the SRB's. This single stage version may be a more promising candidate than the two stage one for launching the spaceplane, because of the higher reliability and lower launching cost.

Soviet Space Vehicles

In the 25 year history of spaceflight the Soviet Union has revealed few details of its launch vehicles. It is therefore surprising to find how much detailed information has been painstakingly assembled by Western observers. Their task has been simplified by the fact that there have been few completely new Soviet launchers, especially in recent years. Developments have consisted of additions and improvements to the original military missiles. This compares with the much faster development of rocketry techniques resulting from the more varied launchers produced by the competing aerospace companies within the United States. Since launching Sputnik 1 in October 1957, the Soviet Union has relied on five families of launch vehicles to orbit more satellites and space probes than any other nation. To the West, these launcher families are known as the A, B, C, D, and F classes.

Currently, the Soviet Union's largest launch vehicle, the D class is used to place satellites in geostationary orbit or space stations in low Earth orbit. The D launch vehicle (SL9) was first used in 1965 to launch the first of three scientific satellites which gave their name to this launcher family, the Proton. The Proton versions are still in use. The D1-h, first flown in 1970, has been used to launch Salyut space stations, where the D-1-e is used to launch GEO satellites.

The Soviet Union has three new vehicles in the final stages of development. The first, a medium-lift launch able to place a 15-ton payload in low Earth orbit, weighing 400 tons at lift-off and producing 600 tons of initial thrust. It is reported to be able to carry a small reusable spaceplane now under development. The second, a heavy-lift launch vehicle capable of lifting a 150-ton payload to LEO. Existence of the Saturn V-class heavy-lift vehicle has fueled speculation that the G-class launch vehicle which failed spectacularly in tests between 1969 and 1972 might finally have been perfected. The heavy-lift launcher will feature six or more liquid-propellant strap-on boosters. Lift-off thrust is estimated at 4,000 tons, more than that of the Saturn V. The third new development consists of a Shuttle-type launch vehicle comprised of a core stage augmented by two strap-on G-class boosters and carrying a reusable Orbiter-type vehicle. The major difference between this and the U. S. Space Shuttle is that the Soviet orbiter does not have main engines, instead these are located on the core stage. Estimates have the Soviet shuttle at a 1,500-ton gross lift-off weight, generating 4,000-6,000 tons of thrust, and can carry a 30-ton payload into low Earth orbit (Figure 5-13).

The Soviet shuttle payload capacity is about 65,000 pounds with a cargo bay about the same size as the U. S. Space Shuttle. Drawings released by the Pentagon show the Soviet vehicle lacks the three large main engines. In their place, the Soviet designers put a pair of jet engines and a limited fuel supply that gives their vehicle a "once-around" capability for landing. Without on-board rocket engines, the Russian shuttle will get its launch power from the SL-16, class G, medium-lift boosters. Also, the orbiter's wing tips are more sharply angled than the rounded tips on the U. S. Shuttle allowing better stability during atmospheric flight.

5.2 ORBITAL MANEUVERING VEHICLE (OMV) (IOC1991)

The OMV is a reusable, remotely controlled, free-flying vehicle capable of performing a wide range of on-orbit services in

SOVIET LAUNCH VEHICLES FOR 1990s

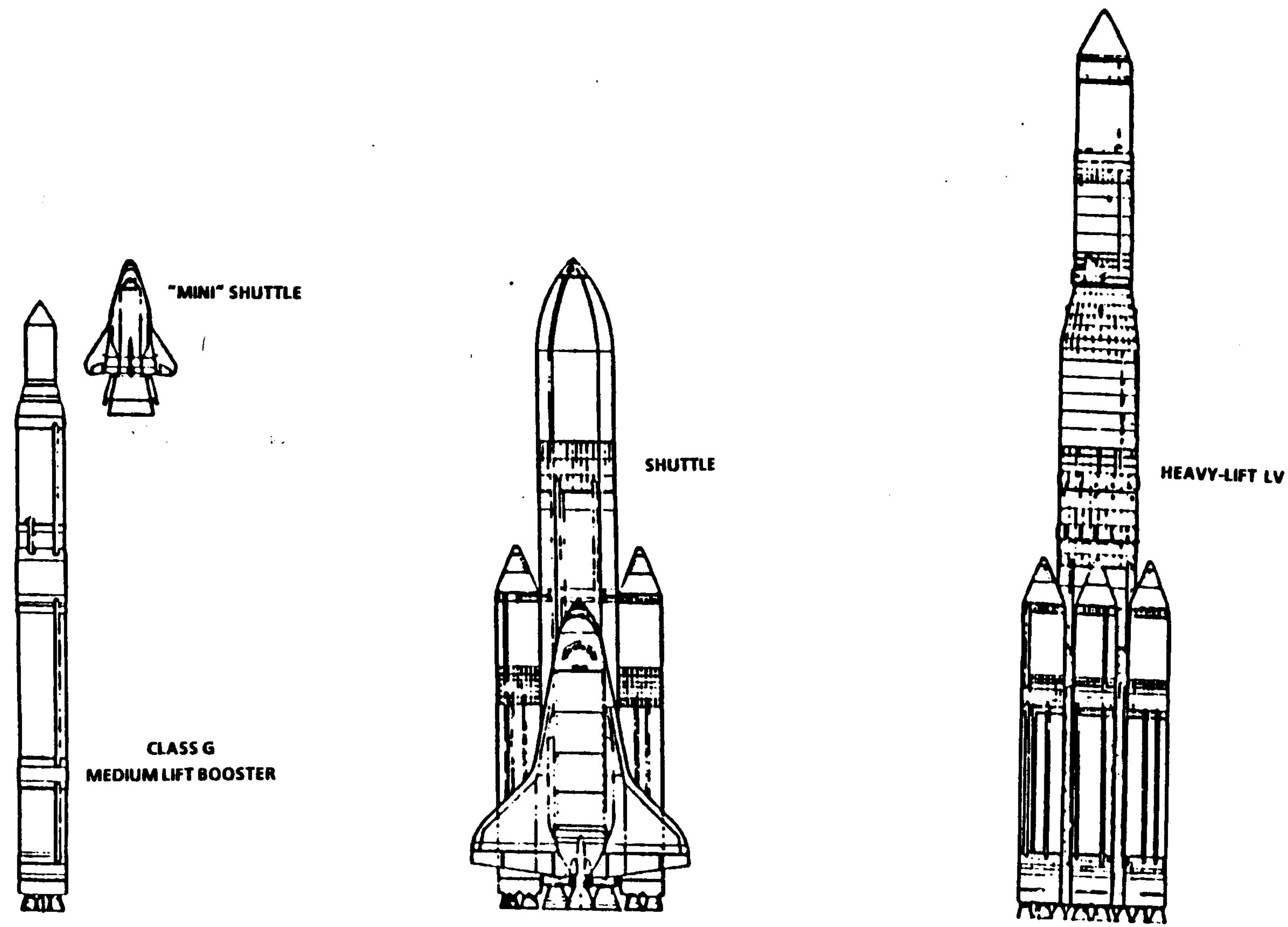


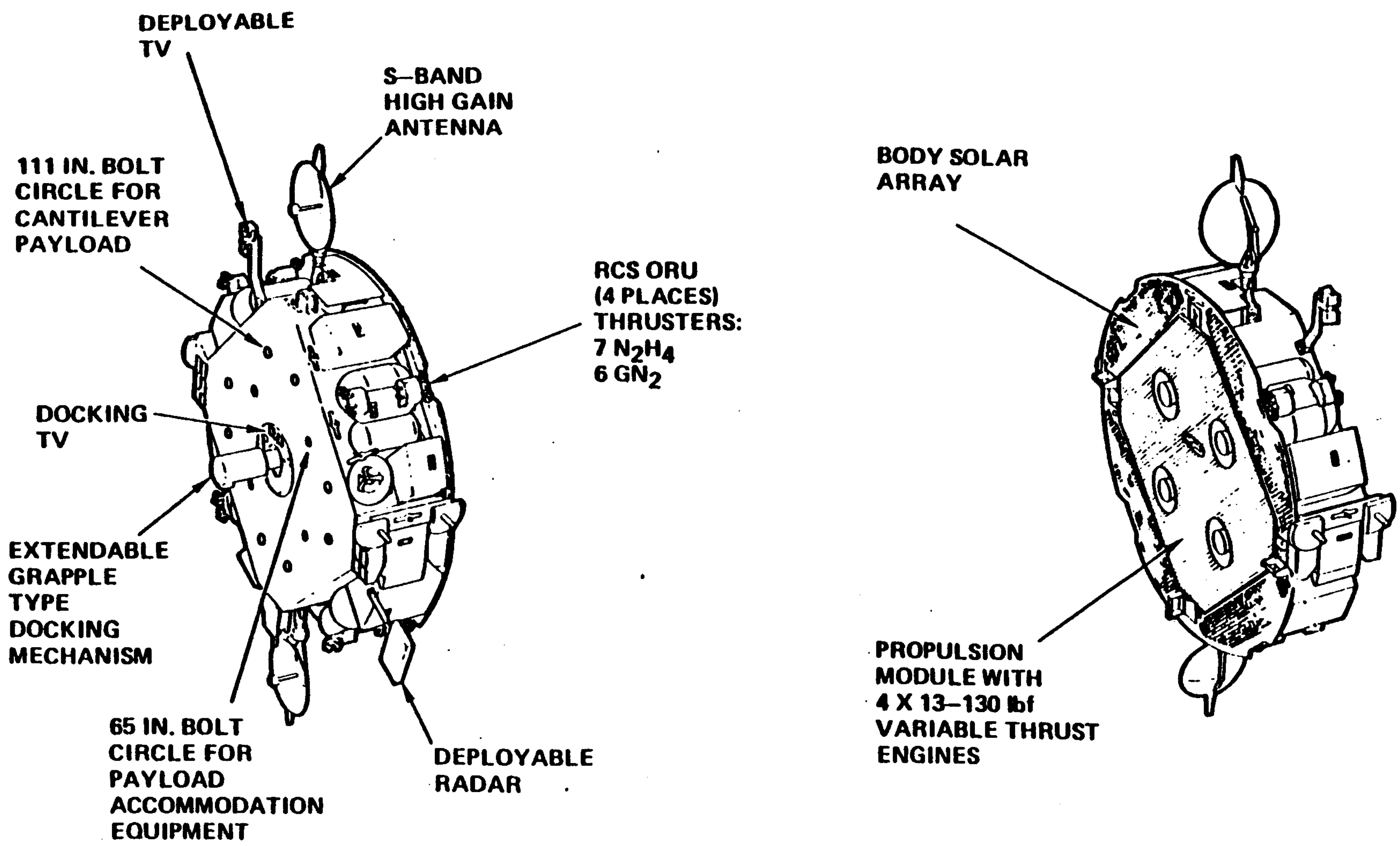
Figure 5-13

support of orbiting spacecraft and the Space Station (SS). The OMV can be based at a Shuttle, at the SS, or space based.

The OMV is approximately 15 feet in diameter and 4 feet in length, excluding protuberances such as trunnion scuff plated, retrieval trunnions, and deployed sensors and antennas. The fully loaded vehicle weights approximately 13,000 pounds; standard Payload Accommodation Equipment, used singly or in combination, may add approximately 125 pounds for the grapple docking mechanism and 150 pounds for the three point docking mechanism. ASI weighs approximately 125 pounds. The vehicle weight includes 6600 pounds for usable bipropellants (N_2O_4/MMH) for variable thrust orbit adjust engines, 1000 pounds of hydrazine (N_2H_4) for the monopropellant RCS system, and 165 pounds of nitrogen for the cold gas RCS system. The cold gas RCS system can be used for close proximity operations to reduce spacecraft contamination.

The design of the OMV is illustrated in Figures 5-14 and 5-15. Figure 5-14 depicts the extendable RMS Grapple Docking Mechanism for securing payloads on orbit and the 111 inch diameter bolt circle for accommodating cantilevered payloads. Not shown, but also available, is a mating ring with latches, that correspond to the Multi-Mission Module Spacecraft (MMS) Flight Support System (FSS) interface hardware. Also shown are the docking TV and the deployable viewing TV, radar, and communications antennas used to support payload acquisition and berthing.

As illustrated in Figure 5-15, the OMV is composed of two separable modules: the Short Range Vehicle (SRV) incorporating the OMV RCS and avionics equipment, and the bipropellant Propulsion Module (PM). Shown on the SRV are the body mounted



Front Face

Back Face

Figure 5-14

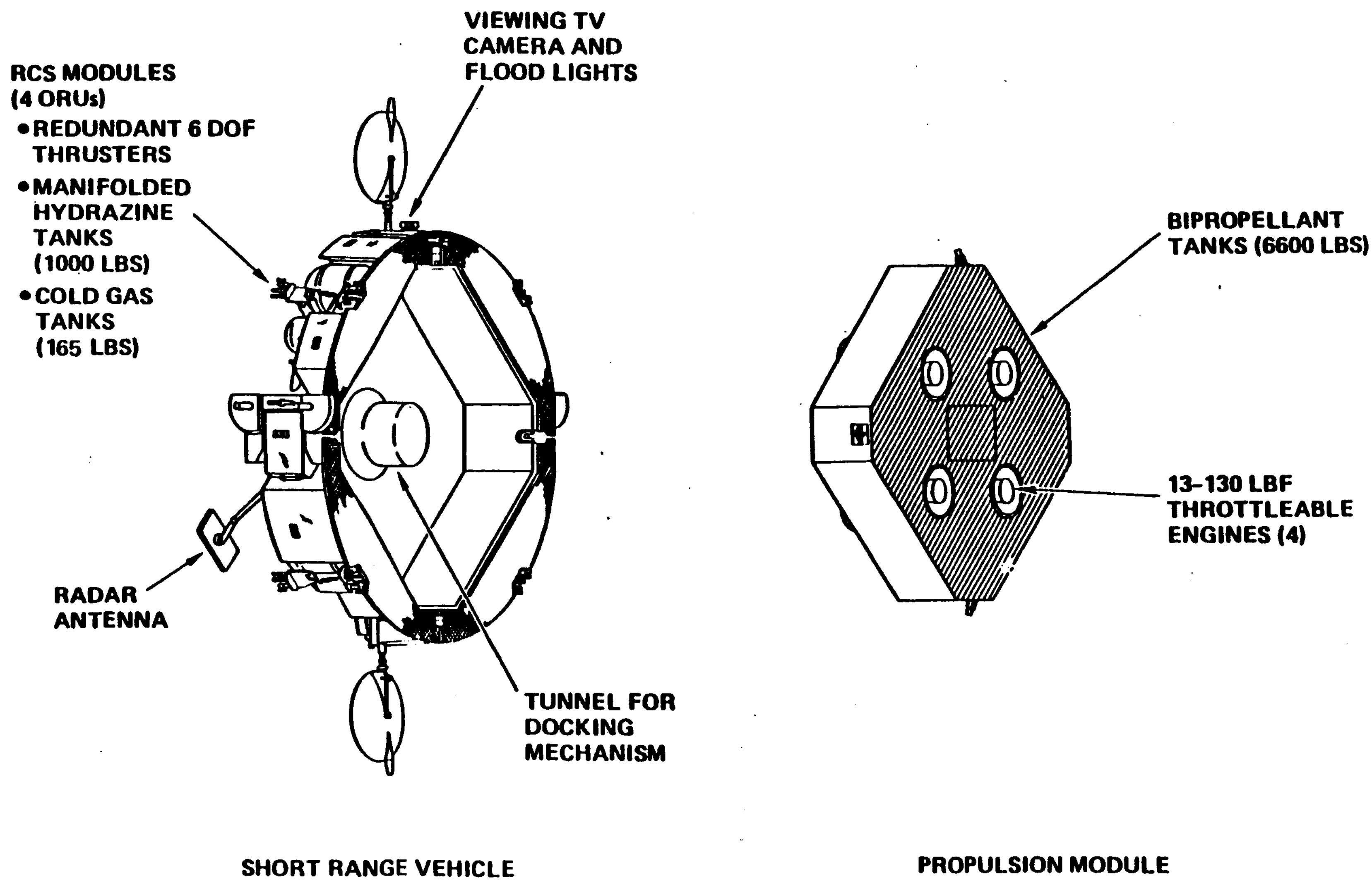

VIEWING TV CAMERA AND FLOOD LIGHTS
RCS MODULES (4 ORUs)
•REDUNDANT 6 DOF THRUSTERS
•MANIFOLDED HYDRAZINE TANKS (1000 LBS)
•COLD GAS TANKS (165 LBS)
RADAR ANTENNA
TUNNEL FOR DOCKING MECHANISM
BIPROPELLANT TANKS (6600 LBS)
13-130 LBF THROTTLEABLE ENGINES (4)
SHORT RANGE VEHICLE
PROPULSION MODULE

Figure 5-15

solar array available for augmenting OMV battery power under favorable mission conditions. The SRV is very modular, containing 10 avionic ORU's and 4 RCS ORU's. The entire PM is an ORU which permits on-orbit propellant resupply capability. The PM contains four continuously variable (13 to 130 pound) thrust engines and the 6600 pounds of bipropellant. While the PM provides approximately 91 percent of the total impulse capability of the OMV, SRV on-board monopropellant and cold gas RCS systems provide the SRV with a complete functional capability to place, rendezvous, retrieve, and berth payloads. At approximately 4700 pounds, fully fueled, the SRV can therefore be used without the PM for smaller mass payloads and missions with lower orbital maneuvering requirements. The OMV is capable of flying on the Shuttle either fully or partially loaded with fuel.

The OMV offers the following standard services to payloads: a) Five KWH (1KW Peak) of energy. Additional energy may be available on an "as available" basis or by the negotiated addition of battery kit, b) Limited data services that will be implemented via hardware interfaces to the OMV data bus and the high rate data/video data channels, and c) Attitude orientation except during orbit transfer burns.

Primary control of the OMV will be from a ground station via a two-way link through TDRSS. When based at the Space Station, control for close proximity operations will be from the station. Other than for the final rendezvous and docking operations which require TV-assisted man-in-the-loop control, the OMV is capable of automatic flight. Communication formats and data processing are compatible with TDRSS, STDN, and ground processing systems.

Orbital Maneuvering Vehicle Performance

A number of payloads have operational altitude requirements in excess of the Shuttle injection capability or require deployment from the SS. Figure 5-14 (OMV) and Figure 5-15 (SRV) show parametrically payload capability as a function of altitude above the base (Shuttle/SS) for various mission scenarios. The curve labeled "Delivery" is the capability to deliver a payload to a higher orbit, while the "Retrieval" curve represents the capability of the OMV to depart the base and retrieve a payload.

The curve labeled "Round-trip" shows the capability to deliver a payload or servicing kit to altitude, then return it to the base. The lower curve, "Retrieval and Redeploy," indicates the capability to retrieve a spacecraft to the Shuttle or SS or servicing followed by redeployment to its operational orbit. In all cases, the OMV returns to the base, and there is no plane change.

5.3 SPACE STATION TRANSPORTATION SUPPORT OPTIONS

Shuttle

The report of the NASA mixed fleet study team states throughout the document that the shuttle vehicle does not have sufficient capability to support the up-mass and down-mass requirements for the Space Station from

With the current Orbiter fleet of three vehicles (possible four) the expected flight rate will only be about 14-16 flights per year. Use of other vehicles, such as SDVs, expendables; etc., for Station missions that do not require man would relieve the scheduling load on the Shuttle. The Shuttle and/or its replacement Shuttle II should still be used for crew rotation.

Shuttle and OMV

Orbital Maneuvering Vehicle (OMV) Requirements

The OMV is necessary to support typical Space Station operations, and will provide on-orbit mobility to the Space Station in the operational era. It will be used to deploy unmanned platforms to operational altitudes, retrieve for maintenance, redeploy spacecraft and large observatories, and support a wide variety of proximity operations. Typical missions to be performed include module/element transfer from low orbit to the Space Station orbit (Shuttle or Cargo Vehicle) and deorbiting of cargo return vehicles.

Cargo Return

The ability to return cargo in some manner other than the Shuttle is necessary. One of the most attractive is to use a Cargo Return Vehicle derived from the Crew Emergency Return Vehicle. Use of the same configuration would lower development effort of a specialized cargo vehicle, and at the same time help to prove the CERV concept and provide "practice" in the event of an emergency situation. Use of a precision land recovery system could be used in cases of delicate and expensive cargo return, such as critical experiment results or pharmaceuticals.

Another option to be considered for cargo return is use of non-station Shuttle flights of opportunity that go to the same orbital inclination as the Station. This method requires considerable effort in orbit matching, but may occasionally may be beneficial.

Rescue Options

The ability to rapidly rescue the entire crew from a disabled Space Station is a major requirement. The safe haven capability that is to be provided on the Space Station cannot provide complete coverage of all failure modes, an alternate means for rescue must be provided. Rapid return to Earth of a seriously ill crewman is also desired so proper medical attention can be obtained.

Several options have been considered for crew rescue, including the Space Shuttle, a specifically tailored Station based rescue capability, and the possibility of foreign support.

Shuttle Only

The current baseline method of crew rescue is to use the Space Shuttle as it exists today with a turn-around time frame of 28 days. In the event of an emergency, the priority of the manifested payload could be overridden by the need to perform the rescue mission.

There are several avenues to this problem:

1. Payload in Cargo bay

   a. Leave the payload in the cargo bay and immediately begin to make necessary changes to flight software; etc., to perform the rescue mission. Although this is probably the fastest of any of the Shuttle options, the one problem that could arise is that the payload may exceed the lift capability of the Space Shuttle to the

Space Station orbit. Another problem could be the time involved in changing the flight software for the new mission. This option is also highly dependent upon the point in the ground processing flow when the call for rescue comes in. The flight crew would need to be reduced to provide space for the Station crew to be rescued. Even here, the entire station crew cannot be rescued and multiple Shuttle crew rescue missions would be required to complete the mission.

b Deintegrate the cargo that is on the Shuttle. This option would only be viable in the event of non-catastrophic failure at the Space Station because of the time required to accomplish the complex ground flow. If the Shuttle is on the pad, the payload would be deintegrated using RSS/PCR, possibly some type of rescue module put in the cargo bay, and then launched.

2. Orbiter on Standby

This option would be the most effective from a rapid response standpoint, but is not feasible from a cost and schedule position.

3. Orbiter on Orbit

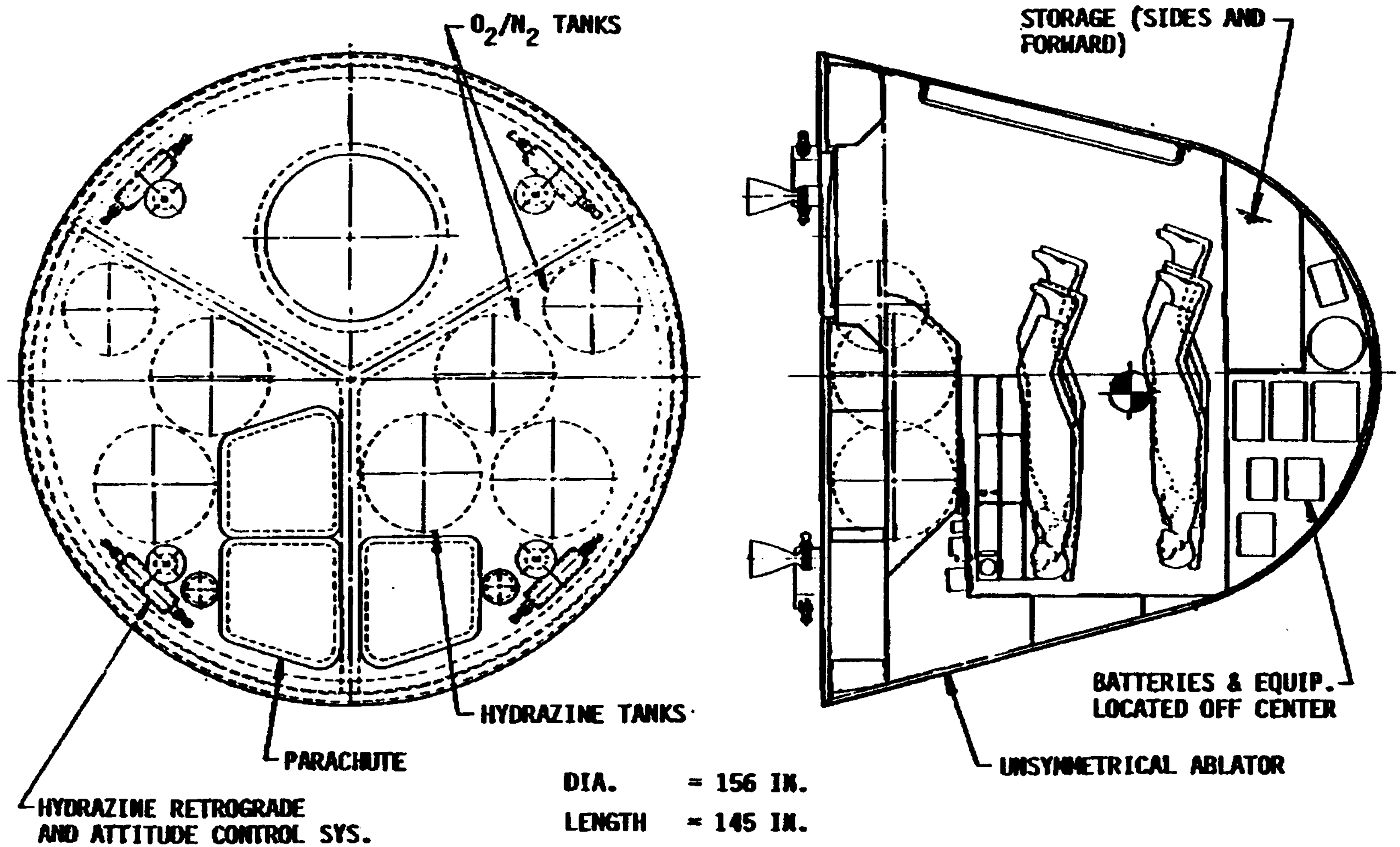
An Orbiter on orbit for another mission is probably the most attractive responsively, but is also the most unlikely. With only one mission per month predicted with a seven day nominal duration, an Orbiter is on orbit only about 25% of the time. Also, the possibility of orbits matching at the time of rescue is extremely remote.

Crew Emergency Return Vehicle

The Crew Emergency Return Vehicle (CERV) would be station based with the ability to berth at any port on the Space Station. The CERV would be moved about the Station using the MMRS or the OMV. The CERV would require Space Station power, heat rejection, data management, telemetry, state vector updates, status monitoring, and maintenance item stowage. The CERV would be automated with a recovery in the ocean within 24 hours by ship of opportunity. The CERV would have a shirtsleeve environment and medical provisions, as shown in Figure 5-16.

6-PERSON CERV WITH CARGO CAPACITY

(13 FT DIA, OFF-SET CG, LIFTING REENTRY)



DIA. = 156 IN.
LENGTH = 145 IN.
CARGO WT = 3,000 LBS
TOTAL WT = 12,000 LBS

MCDONNELL DOUGLAS

Figure 5-16

The goals of the CERV dictate that it minimize impact to the Station design and minimize required training to the crew for utilization. The on-orbit storage lifetime must be very long, and the on-orbit test, checkout, monitoring, and maintenance must be simplified. The goal for crew recovery after splash-down is 90 minutes, with delivery to a definitive medical facility within two hours.

Rescue Recommendation Options

A recognized need for a Crew Emergency Return Vehicle exists due to threats to crew health and safety and possibilities of extended Shuttle turnaround time. An assessment by a NASA Johnson Space Center has recognized 12 of 20 threats leading to crew escape potential. The safe haven concept does not accommodate all failure and rescue scenarios. The safe haven approach is still required but can be improved by the addition of a CERV. The CERV could also be used in a secondary role as an orbital ambulance in the case where an immediate return is required for severe medical care.

The concept of an escape vehicle for emergency evacuation of Space Station crew members is strongly recommended as a life saving measure in case of a catastrophic event which would compromise the ability of the Space Station to support vital crew needs. It is also recommended that medical requirements be integrated into the design of the CERV such that it would complement the capability in the Health Maintenance Facility and would allow appropriate medical treatment for a subgroup of injuries and illnesses whose prognosis would be poor without an immediate return capability.

A review of Shuttle ground processing cannot always support a 28 day rescue option. The worst case scenario requires 45 days for rescue. It is recommended that the safe haven capability be increased from 28 to 45 days minimum.

The foreign shuttle vehicles are recommended only as a backup to the rescue vehicle. The dependance on foreign shuttle systems to be prepared in a reasonable time frame for rescue would unlikely be realized. If the foreign shuttles have demonstrated an operation capability with a short turn-around vehicle, the vehicles may be involved more in the emergency rescue scenario.

Escape methods have been an essential part of almost every hazardous manned program to date when technically feasible. The CERV would provide a critical capability that can meet the requirements of evacuation of station crew, medical evacuation of crewmembers, and Shuttle grounded scenarios. The effect on the crew of not having a CERV, even if not needed, may be an increase in stress and lower performance over time. If the CERV is not provided but needed, the effect would be devastating to the space program, and could require costly rescue efforts that may not be successful.

5.4 SUMMARY

The capability of the United States and the International Partners is considerable and versatile; however, there are several basic premises that need to be established in order to insure that the most effective and flexible options will be available in the year 2010.

Since the National Space Transportation System (NSTS) will always be in great demand for NSTS unique missions and manned missions, the basic concept of resupply to the Space Station by unmanned expandable vehicles must be incorporated into the basic philosophy of the SSP. Manned resupply should only be undertaken for those missions that specifically require "man-presence". The inherent cost factor of a manned resupply would tilt the scales toward unmanned, but the real factor comes from the risk of manned vs. unmanned launch. Also, the International Partners will be able to be more fully involved with the SSP if the resupply missions utilize International unmanned launch vehicles. International launch vehicles could also be utilized as a method of "barter-exchange" for like services of the NSTS and other United States launch vehicles. The International politics of such SSP operations would be no small factor in such a premise.

One of the most important findings during the study was that a Crew Rescue Vehicle will be required at the Space Station at all times unless a Space Shuttle is available as an alternative. A variation of the CERV which could be used for an alternate Logistics Module showed some merit. The combination vehicle would undoubtedly save resources while allowing a more flexible type of operations.

The study of the Transportation Services/Rescue area of operations for the SSP during the next century showed that the supply/resupply transportation costs and the associated ground operations costs could rival the cost of the on-station activities; therefore, it is mandatory to establish the proper planning early and to explore new and innovative transportation concepts during the design phase of the SSP.

6.0 INFORMATION SYSTEMS AND COMMUNICATION

The complexity of the operation of the Space Station, its physical remoteness (i.e., in orbit), the continuing change of mission as new experiments are taken up to the station, and the importance of safety and reliability all place heavy burdens on the requirements for, and importance of, ground information and communications systems. User needs for access to their experiments either in ground test facilities or in the station or orbit and the associated data will also rely on these systems to some extent. The proper implementation and operation of these systems will contribute significantly to the overall effectiveness of Space Station operations both in the short term and the long term.

6.1 EXECUTIVE SUMMARY

The Information and Communications Systems during the Operational phase of the SSP must be highly integrated with the many computer systems networked for the sharing of data on a large scale. There must be interfaces between all organizational aspects of the program - flight operations, ground processing, logistics, sustaining engineering, etc. To do this, planning must be initiated now to eliminate pockets of "uniqueness" whether generated because of desire to stay with old systems or because of political boundaries. To do this a high level of control must be in place to manage database and network architecture and design which includes management commitment to see that it is implemented. Artificially created political boundaries can only be broken with high level of management commitment.

Evolution must be planned for all operational information systems. Budget projections seen at this time exclude capital costs. If these capital costs are not planned for, we will have archaic, unmanageable data systems which do not support the operational program.

6.1.1 Program Requirements

In order to sustain a stable long term operation which has a capability to evolve and grow, a number of requirements must be adhered to by all computer and communications system elements supporting the program.

Hardware/Software Commonality and Standards. Organizations are spending up to 80 percent of their software budget on maintenance costs alone. Also, up to 85 percent of the acquisition cost of a system is the cost of the software alone--not the hardware. In order to control costs in the information systems for the operations of Space Station, software commonality and standards must be stressed. This will allow different software systems to communicate more easily by eliminating interface problems, it will provide a simplified method of transporting software from one application to another, eliminate costs associated with generation of duplicate code to perform the same function, and minimize duplicate entry of the same data into separate systems. By decreasing the amount of unique software generated, the costs for maintenance goes down. By adhering to a set of software development standards, maintenance costs are also decreased because fewer software specialists are required - there is more sharing of software personnel between systems.

There is an initial acquisition cost increase with standardization as well as some performance penalty. The acquisition (or development) cost increase is associated with having to meet the standards. This cost is quickly recovered thru utilization of common software elements in multiple sites within the SSP. The performance penalty is associated with not being able to "tune" a software system for its specific application. With the rapidly increasing capability in computer hardware, this performance penalty generally is not a problem. Specific exceptions should be dealt with on a case-by-case basis with approval being required at as high a level as possible because of future cost implications. A manager who is trying to meet performance, schedule and cost criteria during development will generally not adequately address maintainability of a system.

While hardware commonality is not required, communication and interface standards are. Selection of hardware which does not support the program's interface and communication standards should not be permitted within the system. With the drive toward industry standards, this should not be a problem during the operations era.

The SSP is addressing software commonality and standards thru the development of the Software Support Environment discussed previously. There are many systems which are considered "institutional" systems and not within the management control of the SSP. It is important that these systems also have commonality and standardization extended to them to the greatest extent possible. They should be encouraged to evolve into the use of SSP standards and SSE. Wherever possible, the SSP should encourage agency-wide standardization. The SSP should unify its own position on standards and commonality and should have a centralized group to design the overall system architecture to assure that a cohesive system is designed without the isolated pockets of individuality created by organizations creating empires or asserting their independence.

Communications Standards. Within the last two decades telecommunication services have cascaded dramatically. Much of this growth has developed to support remote information processing and has grown in response to its physical transmission standards. In most cases the transmission method was telephone pair and early communications standards developed around AT&T products (in the U.S.) and the CCITT standards (in Europe).

The other driver in the development of communication standards has been the hardware vendors themselves. IBM and DEC as the two largest equipment manufacturers in the United States have driven the communications standards with proprietary products. With the IBM market place the IBM 3270 protocol and now SNA have become defacto standards for communications - not because of their ability to communicate efficiently but because of their proprietary nature. This has forced large networking endeavors to become proprietary (IBM or IBM compatible). In view of the Federal Acquisition Requirements (FAR) and GSA's non-sole-source requirements this is not an acceptable solution.

In 1977, the International Standards Organization began to address the problem of networking diverse computer systems and developed the Open Systems Interface (OSI) Model. The OSI Model is a seven layer model where the lowest three layers are classical communications functions. In the OSI, each layer communicates to only the layers immediately above and below itself. In all cases, the interactions between layers are controlled, not the layer's internal functions. In this fashion, manufacturers can supply equipment and software to provide an OSI's layer functionally. Therefore, data can flow through a network, independent of topology, manufacturer or technological level of the communications equipment involved.

Currently, the CCITT's X.25 (employed in the NASA Packet Switched System) meets the OSI model layer three and represents the type of protocol that Space Station Ground Operations must employ. Unless a standard like X.25 is used, the program will be locked into a specific communication technology and solution that will be difficult (if not impossible) to maintain and operate.

The selection of proper standards will allow orderly connection of international users, commercial firms and experimenters. Adherence to international standards will also allow the program to evolve over its lifetime and support infusion of new technologies into the ground supporting network.

It should be noted that adherence to a specific standard will not insure trouble free connections to all users. For example, the Federal Information Processing Standard (FIPS) 86 allows vendor specific bit utilization and the EIA's RS-232-C allows pin specific vendor applications. However, if widely accepted protocols are utilized, conversion from vendor specific applications is usually readily available.

Another difficulty in Standard Selection is the required commitment to maintain the latest revision of that standard. Standards evolve over the course of a thirty year program and management planning must include costing to maintain software and hardware at the current industry revision. This problem is one that faces the agency's institutional roles, but usually not programmatic management.

Security and Data Integrity. The capability of "hackers" and "HBO Bandits" to penetrate information and communications systems (ICS) has been demonstrated. Even without the presence of classified data, there is a need to recognize the requirement for security within the ICS. This requirement should be recognized and designed for early in the program.

Since most security systems which have been designed can be broken, the amount of risk that is acceptable for each element of the ICS should be determined early to allow for the security to be implemented in the design and development phase. Failure to do so will result in exorbitant costs for retrofitting/designs to accommodate security.

Risk Analysis and Vulnerability Assessments must be planned, scheduled and implemented throughout the design, development and operational phases of the program. The impact of a "hacker" altering data in the system, even in an "off-line" system can be extremely expensive if, for instance, some required supplies are not available on the right schedule to support a launch. With increasing levels of automation, detection of system penetration becomes more important.

Physical security must also be addressed from day one. Physical access control to data centers, disaster recovery libraries, backup libraries, communications centers and terminal areas are necessary as a minimum step.

Physical access to Data Centers may be controlled by several methods. Each site should select the appropriate method based on its own requirements, all within the guidelines of a minimum NASA-wide policy. An ever present security guard may be desired for a high risk area. Where non-classified, non-sensitive, and non-proprietary data is housed, an electronic badging system or a combination lock system may be chosen as a cost effective feature. Whatever the accepted risk is, no unauthorized personnel should ever be in the Data Center.

Security in the communications environment is a difficult task. The International Standards Organizations' (ISO) Open Systems Interface Model does not address security in the communications Levels (although a revision is addressing the problem), thereby leveling security requirements on the computer systems. However, military and increasingly industrial users have security requirements for classified, proprietary, and/or sensitive data. This security includes requirements for encryption (simple to complex) and, in the military applications, line protection and shielding to avoid radio frequency transmission of classified data. Although the ISO Model does not include security in the communications phase, it does not preclude the user from encrypting and decrypting his data.

No requirements have been forthcoming to identify the need for a high level data protection mechanism. It is the opinion of the panel that requirements will emerge to at least protect vendor proprietary software and serious consideration of this must be taken into account now.

The SSP decision to not provide security was cost-driven. Consideration of the operational cost impact of system penetrations should be done to counterbalance this decision.

Growth and Evolution. Recent history has shown that the use of computers and the associated communication systems is growing at a rapid rate. At the same time, technology in this area is changing swiftly, both hardware and software. In order to maximize the effectiveness of the Space Station while controlling costs, the information systems must be structured to grow and evolve to meet the increasing user needs on the systems.

Of primary importance in this area is planning. Data bases and systems must be planned during the development phase to allow for expansion without having to regenerate all of the application software. The data bases should be designed with future requirements for more automation in mind and more complex integration of tasks, increasing the interrelationship among the data. Much of today's planning for TMIS is based on the station development era, with little or no mention of operations. Today's planners are only looking at today's problems and not trying to plan for the long haul. It is of utmost importance that an operations concept be folded into the TMIS design philosophy for future system evolution. Without this planning, adequate scarring will not be provided for ease of future evolution.

Hardware evolution is also important. Although industry has realized the criticality in being able (and planning to) replace their computer hardware, NASA as a whole has not acknowledged this. Some of the reasons for planning system upgrades to incorporate new technology are:

- Avoid maintenance problems associated with the availability of parts for obsolete hardware

- Gain access to new software development tools

- Avoid having systems software which is no longer being maintained/supported

- Avoid increased maintenance costs

- Avoid degradation of system reliability

These reasons are all acknowledged as being drivers for replacement of obsolete hardware in the Federal Information Resources Management Regulation (FIRMR). The FIRMR also requires periodic review of equipment for obsolescence.

System design and implementation should plan on future hardware replacement. Some techniques to accomplish this are:

- Avoid uniquely designed interfaces

- Use transportable languages whenever possible

- Avoid using unique capabilities

- Avoid "homegrown" operating system changes which would have to be recoded for new hardware

Budget planning is a key element in allowing for system upgrades--both for hardware and for software. Since computer system upgrades should be a planned activity, the program should include a steady level of budget authority specifically devoted to system <u>replacement</u> not just adding to existing systems. An accountability system should also be implemented which tracks that the money is being spent on replacement to avoid the problems of obsolescence.

This budget planning will work for systems which are under the total control of the SSP. Problems will arise for institutional or shared systems. Systems which are funded jointly by other "operational" programs can be influenced by having a common philosophy across the Agency operations organization.

It is strongly recommended that the Agency institute a policy which would require all programs and all institutions be required to budget for capital replacement as well as for operations and maintenance of their information systems.

6.1.2 Data Bases, Processing and Interface Requirements

Each element of ground operations requires computer support to do specific functions which require access to a variety of data bases. Of primary importance among the many program data bases is integration across the program. This integration must be started now in the early stages of the station development rather than after a majority of the data bases are built and populated when we get into the operations era. The complexity and large numbers of interfaces between functional areas and various data bases are illustrated on a high level in the Supplemental Data. To accomplish the level of integration required, strong program management must be exercised at Level A and the Program Office to assure all elements of the SSIS are developed with a consistent set of standards, common or compatible data base management systems and a common data dictionary. A review of planned information systems should be accomplished as soon as possible to eliminate duplication of common functions. An example of this is the plan for TMIS, GDMS and SSSC to provide configuration management and documentation production capabilities. Having independent documentation production capabilities will result in added overhead when intercenter review is required. It will also drive additional software acquisition and software maintenance costs. If duplicate capabilities are required because of operational considerations, common software should be utilized for these capabilities to the greatest extent possible. This will improve the capability to share data in the future and to consolidate operations. Where use of common software is not possible, specific common formats for data should be specified for the transferal of the data, otherwise the data may prove difficult, if not impossible to use.

When the Work Package contracts are awarded, steps should be taken to assure that the work package contractors utilize the common TMIS capabilities or other program provided capabilities to the maximum extent possible rather than company (often proprietary) systems. This will improve the capability to transfer this data to a sustaining contractor. It will also improve integration of the contractors' products.

There appears to be a continuing proliferation across the agency of each Center and each organization needing to "do his own thing". They feel a need to have their own computer system that processes their way and to have total control of their data. This must be stopped in order to have a system which will be effective during the operational time frame and to assure maximum integration/sharing of data is facilitated.

In addition to requirements for integration of the many data bases, specific requirements for processing and data bases are associated with each of the major areas of ground operations.

The major requirements are specified here with the required facilities to do this processing and data base maintenance.

Logistics and Resupply. The Logistics and Resupply functions including Return are the drivers for the entire Space Station Project. If, in fact, Logistics requirements are not taken into account as a "First" step, the project will be less than adequate. Frequency of flights, number and mix of crew, supply, resupply, return, upweight, downweight, etc. will be determined by logistics requirements. The possibility for an ELV option rather than a pure STS environment will add even more credence to logistics being the drivers.

Just as Logistics dictate other factors it most certainly is the critical requirement for an ICS integrated database interface utilizing communication standards through common software.

Logistics is an unforgiving circle. Database requirements will be generated by user requirements, system design, SS configuration, maintenance, crew procedures and NSTS capability to mention a few factors. The Logistics Information System (LIS) Database must at least consist of item (ID, Category, State, Quantity, Usage, Rate), physical characteristics, environmental requirements, resource requirements, orbital support equipment/flight support equipment, requirement source and pertinent remarks based on the requirements. In addition information is required on maintenance resources such as maintenance documentation and production, life cycle costs, repair costs, failure history/trend analysis and repair costs/time vs. new buy/time analysis. Influence is then exerted on the Database by logistics element design concepts, storage requirements, crew operations, customer accommodations, internal module configuration, design, ground processing, flight manifesting and frequency which in turn establishes the original Database requirements. These interfaces illustrate a need for the LIS to be tightly coupled with the configuration management system, sustaining engineering drawing system, manifesting/scheduling systems for flight/ground processing, and safety/reliability/quality assurance systems. This type of scenario completes a very fragile and demanding circle that can only be satisfied by an integrated database. Extensive long range planning and scheduling must be exercised at all levels to maintain the delicate balance necessary to process the heavy and intricate logistics requirements.

Logistics itself is addressed daily by NASA, DoD and large commercial ventures. The Space Station, however, will induce an additional Logistics scenario previously unnecessary. Regard less of the eventual buzz word used (Downmass, Downweight, Return, etc.) careful and diligent preparation must be addressed to meet unique Logistics database requirements. Use of a common Integrated Database by all contributing organizations is a mandatory requirement. The LIS should be at a minimum a menu driven, user friendly, integrated system which provides a means of collection, analysis and summation of requirements. Failure to plan for the massive user access paths to various types of information and transaction capabilities via an integrated database will produce the normal bottleneck common to logistics.

All phases (Execution, Tactical, Strategic) of the Space Station must budget for the extremely heavy logistics requirements. Present logistics capacities and capabilities were not designed to accommodate this additional logistics magnitude. It is imperative that all logistics be a common effort utilizing common interfaces. If any organization fails to coordinate their efforts with all concerned the reinvention of the "logistic wheel" will commence again. The Space Station budget and schedule cannot be met with this independent attitude. A precise and integrated coordination of all logistics requirements must be managed at the Program Office level to assure fulfilment of Space Station needs versus piece meal, duplicating, costly logistics empire.

Since a large amount of the data required to populate an integrated LIS database is produced during the design phase (i.e., the logistics spares analysis records), planning for this system must commence immediately and not be deferred until LMRT. Deferral of this system will result in fragmented data produced in a multitude of formats from the different work packages that will, at best, be difficult and costly to integrate.

Although inventory management is a key element in the LIS, the existence of KIMS (Kennedy Inventory Management System) should not be allowed to drive the design of the LIS. The LIS should be designed to support a dynamic, highly integrated long range program. Only if the resulting design can accommodate the existing system without compromising the overall effectiveness of the system should the SSP consider the use of KIMS.

<u>Sustaining Engineering and Configuration Management</u>. The primary computer system support required for sustaining engineering can be categorized into five major functional areas:

a. Drawing and design analysis support (CAD/CAE/CAM)

b. Engineering analysis, including performance analysis, trend analysis, and failure analysis

c. Software development support

d. Simulation

e. Configuration Management

In addition, in order to perform these functions, access to a number of data bases is required

- Anomaly data
- Station and ground operation history data
- Design data including drawings, parts data, performance data, commonality data
- LRU/ORU history including failure/performance history, time and cycle data, repair history
- Configuration data including as built and as designed configurations
- Schedules

Assuming a centralized sustaining engineering organization, this organization will require a TMIS CAD/CAM/CAE capability for (a) above, an engineering analysis facility for (b) above, a soft ware development facility (SDF) for (c) and a simulation facility which may be co-resident with the SDF. An engineering data archival facility will be also required for retaining history data for the ground and station operational data as well as design history data. This archival facility could be co-resident with the engineering analysis facility.

All of the computing facilities would need to have interfaces with SSIS and TMIS to provide access to the appropriate data. As the SSP goes thru the development phase, each of the work package centers and prime contractors will have TMIS capabilities as well as the other capabilities indicated above. As the program evolves to a centralized sustaining engineering mode, a transition should be planned to migrate these capabilities to the same location. It would appear most cost effective to do this in conjunction with a planned system upgrade to eliminate obsolete equipment. This would allow functional overlap which would minimize support impacts and be cost effective. The elimination of duplicate computing facilities will save substantial amounts of money - not only in the annual operations and maintenance costs, but also in the replacement/upgrade costs. Maintenance costs for computer systems are approximately 12 percent of the acquisition costs annual. With an industry standard upgrade cycle of 5-7 years, annualized replacement costs are 14 to 20 percent. Elimination of unnecessary capabilities would thus result in an annual savings of 25-30 percent of the original acquisition cost, disregarding the operation cost which is not insignificant.

Payload Processing. The prelaunch integration and post landing deintegration information systems support will be provided by a mix of TMIS and GDMS. The GDMS utilizes the SSE for development in software design and implementation, production, training, networking and various management tools. GDMS unique software will be generated in ADA and will have some limited Artificial Intelligence (AI) applications.

The GDMS will support procedure development, simulations, real time test monitor and control, post test retrieval and will include a record and playback station for raw data retrieval. The GDMS will provide for real time control and monitoring during rack to Space Station interface testing with GDMS providing a SS interface simulation. Current program planning calls for GDMS to interface with TMIS at KSC through the KSC Office Automation System. Data that will be required to pass the interface include:

- o Problem Reporting/Repair Paper
- o Planning Data/Performance Reporting
- o Change Paper
- o Modification Data
- o Configuration Data and Reports
- o Manifesting & Scheduling Data
- o Test Requirements
- o Engineering Data

With a GDMS & TMIS interface, the information systems support is relatively insensitive to the location of initial rack integration/deintegration (see prelaunch options) but some impact may be experienced at the interface and the resultant intercenter communications. It is imperative that the program reevaluate the GDMS/KSC OAS/TMIS interface for sizing and throughput. There also is a requirement for a GDMS and STDN interface to support prelaunch verification, and GDMS and Logistics System interface to support prelaunch activities.

6.1.3 Support Systems

Operations. The information systems supporting the SSP will have hardware and system software distributed at remote sites which should be operated and maintained by the local institution. The application software on these systems should, in many cases, be common. This common software should be centrally maintained and configuration managed to assure continuous system compatibility.

Operations philosophy will vary between field installations, but support activity parameters should be established by SSP policies and standards. With an operational system that will be heavily dependent upon the computer systems, data bases and the communication networks, it is highly recommended that operational philosophy and system design (including facilities) should be oriented toward a high percentage of system availability rather than the current attitude of a management information system being non-mandatory, therefore, reliability is not an issue. In order to support the Space Station on a reliable basis, all systems must be user supportive.

Disaster plans should be developed which include utilization of other program resources to transfer critical functions to another similar facility in order to maintain the support required to meet scheduled launches or provide real-time support to the Space Station. An overall analysis of SSIS elements should be done while the systems are being designed and developed to identify critical functions and where they could be transported to. An operations plan cannot correct for lack of design planning. This level of planning must come from the Program Office since it must, by nature, cross program elements and centers.

Capability to share resources should also be provided in system design. If a function can be moved in case of a disaster, it should be able to move if a particular facility is over-utilized while another is underutilized. Rather than buying more capability, the functions could be redistributed to effect a more even workload, This type of decision could only be effective if there is centralized management and funding control for ICS.

Another aspect of operations to be considered is the provision for a centralized care center/control center to be established.

This center would be responsible for being a single point for user's to contact for problems on the network and a centralized decision-making point for resource utilization of ICS systems which would be for the support of the SSP and not based on institutional preferences.

Facilities. Some Space Station Program support shall be provided through institutional capabilities at various NASA centers. In other cases, facilities will be retrofitted to house information systems or new facilities will be constructed. Where facilities are generated for Information Systems support the following items are recommended as a minimum set of generic requirements:

a. Equipment Accommodations:

- o Maintenance Laboratories
- o Engineering Laboratories
- o Raised Floor Space
- o Printer Area (Separate from computer operations)
- o Control Center (Separate from computer operations)
- o Spare Parts Storage & Supplies Area
- o Minimum Security Access Control
- o Halon Fire Suppression
- o Emergency Power Shutdown Switch
- o Conditioned Power & Emergency Switch-over
- o Individual Air Conditioning Units
- o Water Detection System & Controls
- o Computerized Monitor Interface
- o Library Space

- o Lighting (Controlled and Emergency)
- o Communications Areas (Including Common Carrier Interface Areas)
- o Cooling Water Supply
- o Disaster Control Equipment

b. Personnel Accommodations:

- o Office Areas
- o Comfort Air
- o Conditioned Power
- o Break Area
- o Personal Computer Communications
- o Fire Protection
- o Emergency & Controlled Lighting
- o Building Access Control
- o Phones
- o Paging & Area Warning
- o Conference Areas
- o Video Distribution Equipment

c. Required Equipment:

- o Main Frame(s) and Peripherals
- o Back Up Main Frame(s)
- o Back Up Power Equipment
- o Personal Computers
- o Halon & Halon Control Equipment
- o Communication Transmission & Receiving Equipment
- o Break Out Racks & Trouble Shooting Equipment

- Acoustical Control Apparatus
- Trouble Shooting Communications
- Fire Proof & Static Resistant Floor Covering
- Master Consoles - Computer Control and Communications
- Spare Parts & Racks
- Disaster Recovery Library (Separate from Computer Facility)

It is recommended that a uniform set of criteria be developed which all key information system facilities supporting the SSP would have to meet. This would preclude the problem of a key system not supporting because of the routine and mundane facility issues. A reliable computer system coupled with inadequate facility support will result in poor computer support.

6.1.4 Management Structure

The management structure of information and communications systems is divided basically into the strategic, tactical and execution levels as depicted in Figure 6-1.

Strategic Management. The strategic management of communication and information systems consists of the long range planning--primarily in the five to thirty year range. Strategic planning of this range is important to assure that long range goals and policy are set far enough ahead to assure that budgetary planning can be done to promote smooth transitions required by evolutionary upgrades in both hardware and software.

Historically the mission support systems have been implemented early to support a program and become obsolete during the support of the program. This could be tolerated in short range programs such as Apollo. As we enter the Space Station Program which is planned for a minimum of thirty years, the life cycle of computer systems must be considered as discussed in the Growth and Evolution Section. Budgetary planning for the associated upgrades is of utmost importance and should be done on an agency-wide basis.

Another area which involves strategic planning for communication and information systems is the establishment of policy regarding standards--not what the specific standards should be, but what general class of standards should exist and the scope of activity to which they should apply. This is important in assuring all systems can participate in evolution plans for future hardware changes and development of future interfaces.

The final area of strategic planning for communications and information systems is the area of operations policy. The strategic management level should set policy guidelines for information/communication security, data integrity and overall commonality of systems.

Because of the scope of the activities of strategic management of communication and information systems, this management would best be placed at as high a level as possible. Since many systems which support Space Station also support other programs, this management could best be effected on an Agency-wide basis rather than a program-wide basis. Realizing the current structure of the agency places funding control at the program level, the only effective place for this to be during the development phase is at the Level A program level. As the transition to operations occurs and associated funding shifts, this function should shift with the funding to the operations organization, which then places it in a position to assure all operational programs are subject to the same policies.

Tactical Management. The tactical management of communications and information systems consists of the intermediate range planning--primarily in the one to seven year range. This management level will be responding to the foundation of long range planning provided from the strategic level to assure that plans for evolution and growth become more definitized and that budget requirements become more specific. This level of management is also responsible for the specification of the specific standards to be applied across multiple systems as well as assuring the standards are implemented at the execution level. Implementation planning for the operations policies established by the strategic level would also be performed at the tactical level.

An important function of Tactical Management is the provision for data base planning across the program. This would be done by a Data Strategist. The Data Strategist is a top-level data-base planner who should create a program-wide plan for what data resources are needed. This plan should also address what data bases should exist at different sites and to what extent they share the same data structures. The Data Strategist would assure that a common Data Dictionary would be maintained across the program to assure any future integration of data bases could be effected with minimum impacts. Because the future evolution of data bases is heavily dependent on activities during the development program, the Data Strategist function must be put in place now with strong top program management support to assure his affectiveness across the work packages.

The tactical management would also be responsible for determining the functional distribution of responsibilities among the institutional and center program support facilities when new capabilities are required. This will assure duplicate non-common capabilities will not be generated.

Another function which would co-reside with the tactical function but is more execution by nature is the management of combined acquisitions. In order to assure compatibility between systems and to get better leverage in the procurement process, combined acquisitions should be done whenever possible to implement the evolutionary upgrades of the hardware and soft ware. Because these acquisitions would involve multiple centers, it is recommended that these acquisitions be managed from the program level.

<u>Execution Management</u>. The execution management of communications and information systems consists of near term planning (0-3 years) and operations implementation. It will include the implementation of the evolution plans thru actual hardware acquisition and installation. They are also responsible for the operations and maintenance of the systems once installed as specified in the Operations section.

Execution level management is decentralized and resides with the hardware systems whether they are institutional or program unique resources. An oversight function performed by a contractor such as the Program Support Contractor will assure policies and standards established at the tactical level are being adhered to. This is required because of the diverse locations involved and the reporting hierarchy for the many organizations involved.

APPENDICES

Appendix A	Guideline and Definitions
Appendix B	Briefings/Documents
Appendix C	Scoring Criteria Definitions
Appendix D	White Papers, Meeting Minutes
Appendix E	Sustaining Engineering Functional Description Outline
Appendix F	Configuration Management Functional Description Outline
Appendix G	White Paper/Sustaining Engineering and Configuration Control
Appendix H	White Paper/Ocean Systems Engineering
Appendix I	References
Appendix J	Industrial Briefings
Appendix K	Government Briefings
Appendix L	Personnel Contact
Appendix M	Information Systems and Communications Information Flow Model, Space Station Ground Operations Revision Record
Appendix N	Space Station Facilities, White Paper

APPENDIX A

GUIDELINES AND DEFINITIONS

1. Single authority source for all safety for both NSTS and SS.

2. SS and NSTS will only document and verify user requirements associated with interfaces (physical and operational) and safety for flight and ground operations.

3. Telescience concept to be implemented by NASA such that user support to NASA directed test operations can be provided, where appropriate, using Telescience network.

4. All NSTS involved operations to be controlled by NASA NSTS.

5. All NASA SS facility simulators to user hardware/software interface testing to be controlled by NASA.

6. SS logistics function treated as another user for preflight/postflight operations.

7. Fluid carrier, and propellant carrier processed only at launch site (KSC).

8. ELV processing, relative to payloads, is part of total ground processing operations.

9. Space Station system racks for supply, replacement, spares, modification kits, etc., will be processed in accordance with logistics processing including prepacked lockers and/or racks, etc., as may be required to maintain flow and verification activities.

10. Racks processing hardware, procedures, documentation, handling gear, and installation kits will have reached a mature point by time of start of IOC phase, thereby providing for generic procedures and minimum changes to both payload and system users.

11. A processing flow providing for minimum time for hardware and personnel at locations away from the principal investigator/developer is required by users and highly desirable to NASA to encourage and facilitate Space Station user developments.

12. A flexible flow enabling changeout of experiment elements, additions, deletions, change in manifest, early and late access is essential for operations flexibility, management, and user friendly considerations.

DEFINITIONS:

Payload Integration Organization (PIO)

The PIO will perform the functions required to integrate, verify, and certify to Space Station (SS) and NSTS a Space Station Incremental Mission. Among these functions are:

- o Provide interface to users for requirements, verification operations, etc.
- o Provide interface to SS and NSTS to satisfy their requirements for the mission.
- o Responsible for development of required documentation for the mission.
- o Conducts and supports reviews, meetings, etc. required to support planning and implementation of the mission.

Space Station Incremental Mission is defined as the flight of an NSTS carrier to support the Space Station (SS). Mission hardware includes all items going up to the Space Station to support next configuration of the SS and that hardware or other items returned from the SS.

Science and Technology Center (S&T Center)

The Science and Technology Center (S&T) is defined as that location having the unique expertise to support a particular payload discipline. For example for Life Sciences, this would include Johnson Space Center for the human elements and Ames Research Center for nonhuman (plants, animals, cells) elements. For Materials Processing this would be referenced to Marshall Space Flight Center for metals and inert substances and one of the life science organizations if at a cellular level; i.e., antibiotics.

Option Evaluation Categories:

- o Flexibility
- o Feasibility
- o User Friendly
- o Management Efficiency
- o Cost Effectiveness
- o Performance
- o Safety

APPENDIX B

BRIEFINGS/DOCUMENTS

ARC	* "OSSA Space Station Waste Inventory" (Draft 11/28/86), J. Bosley, G. Curan - Bionetics Corp., R. Maines, Nina Saint, R. Hoffman - Maines Assoc.	14
ARC	* "Presentation on Space Station Science Management Center" (S3MC), 10/2/86	14
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Center for Space Policy/M. Voucher	* "Considerations for Space Station Policy", 11/13/86	15
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GE/ASD/S.Williams	* "Expert Systems Applications for Space Station Operations", 1/14/87	1
GE/ASD/A.Alvarado	* "Gathering Early Operational Data for SSP Planning", 1/15/87	1
GSFC/T.A. LaVigna P. Rainey	* "Space Station Servicing Scenarios", 10/16/86	3
IBM/J. Hundley	* "Data Management System Hardware", 1/15/87	2
IBM/FSD Houston/ A. Macina	* "Shuttle Software Development", 1/15/87	2
IOWG	* "Resource Allocation"	7
Japan	* "Some Comments on Operational Principles Japan/NASA Meeting", 12/4-5/86	7
Japan	* "Japan's Concept of Operating Cost Categorization #6 IOC-WG Ottawa", 10/22-24/86	7
Japan	* "Japan's Simulation and Training Concept IOCWG #6", 10/22-24/86	7
Japan	* "JEM Operation Facilities Development Plan and JEM Operations WBS", 12/4-5/86	12
Japan	* "Japan's Operations Concept - Tacitical and Execution Level", 12/4-5/86	12

JPL/J. L. Smith	* "Pricing Policy Options", 10/15/86	1
JSC/D. Webb	* "Status of the Operations Management System", 10/16/86	3
JSC/M. C. McEwen	* "User Operations Support Concept", 10/86	6
JSC	* "Space Station Program Definition and Requirements, Section 4: Space Station Operations Requirements, 7/15/86	2
JSC	* "JSC-30201, Pages 1-1, 1-2"	2
JSC/J.F. Whiteley	* "Operations Programming", 3/21/86	2
JSC/J. Aaron	* "Space Station Work Package and Systems Integration, Rev. B", 9/17/86	8
JSC	* "Space Station Program Definition and Requirements, Section 4: Space Station Operations Requirements, JSC-30000, Section 4, Part 1", 7/15/86	8
JSC	* "Space Station Operations Process Requirements, JSC-30286"	14
JSC	* "Space Station Verification and Installation, Assembly, and Checkout Concept, JSC-30457", 10/86	15
JSC	* "Space Station Prelaunch/Postlanding Operations Plan, JSC-30202", 11/18/86	22
JSC/S. Blackmer	* "Space Transportation System Payload Integration", 11/6/86	2
JSC/ASD	* "Concept Proposal for Space Station Flight Systems Integration, Verification, and Checkout (Taverns)"	14
KSC/R. Tilley	* "Space Station Experiment Integration", 10/30/86	6
KSC/C. Giesler	* "User Ground Processing Analysis", 8/19/86	6
KSC/R. Tilley	* "User Ground Processing Analysis", 8/15/86	6
KSC/DL-DED-2	* "Engineering Management Information Systems (TMIS)"	6

KSC/R. Tilley	* "Master Integration Facility Study", 12/15/86	2
KSC	* "KSC Integrated Control Schedule", 1/28/87	1
KSC/D. Bohlmann	* "Science and Applications Payloads Spacelab Processing", 10/9/85	7
KSC/J. G. Oertel	* "Space Station Launch Site Facilities and GSE/Briefing, Lt.Gen. McCartney", 10/27/87	7
KSC/J. M. Johnson	* "Space Station Operations to Lt.Gen. McCartney", 10/27/87	7
KSC/D. Hahn	* "Space Station Ground Data Management System Facility and Equipment Requirements", 10/20/86	9
KSC	* "Space Station Ground Data Management System (GDMS) Facilities and Equipment Requirements Document, KSC-STA-60.07", 10/6/86	9
KSC/G. Powers	* "Space Station Processing Facility (SSPF) Facility and Equipment Requirements Document (FERD)", 10/3/86	10
KSC/F. Bryan	* "Space Station Hazardous Fluids Processing", 10/7/86	10
KSC/H. Rushing	* "User-Friendly/KSC Operation", 10/31/86	14
KSC/M.C.Williams	* "Study on the Feasibility of NASA Establishing Qualifying Standards for Contractor and NASA Para-professionals"	14
KSC	* "STS Payload Integration Documentation"	15
KSC	* "Mission Integration Documentation"	15
KSC	* "Data Requirements (miscl)"	15
KSC/PT-SSO/F.Bryan	* "SSS Operational Philosophies and Requirements Synopsis for Book 1", 1/6/84	1
LaRC/L. Clark	* "Technology Missions for Space Station", 12/9/86	12
Lockheed/S.Floyd	* "What is (SPDMS) Today? (Shuttle Processing Data Management System)", 11/3/86	6

Lockheed	*	"Briefing to Space Station Operations Task Force", 1/13/87	2
Martin Marietta	*	"Overview of DOD Spacecraft (S/C) Processing"	15
McDonnell	*	"Prelaunch Operations Planning; Keeping Pace with Change"	15
McDonnell/A. Rose	*	"Space Station Logistics Concepts for Life Science Systems (EOS Model)", 12/8/86	15
McDonnell/ C. Walker	*	"Customer Integration and Development Briefing Electrophoresis Operations", 11/19/86	24
McDonnell Douglas/ KSC	*	"Space Station Proprietary Operations Study Summary for Space Station Operations Task Force", 1/87	2
McDonnell Douglas/ KSC/E. J. Scully, M. D. Edwards	*	"Verification of Post Permanently Manned Configuration Space Station Elements"	1
McDonnell Douglas/ KSC	*	"Ground Operations Logistics Resupply", 10/86	13
McDonnell Douglas/ KSC/P. Johnson	*	"KSC Operations Analysis Space Station Processing", 10/86	13
McDonnell Douglas/ KSC	*	"KSC Operations Analysis KSC Level C Prelaunch/Postlanding Operations Plan Microgravity	13
Microgravity Research Associates, Inc./B. Pace	*	"Panel 3 - Customer Integration and Development" 11/19/86	25
MSFC	*	"Space Station Engineering and Operation Safety Panel (Phase I Final Report)", 8/19/86	2
MSFC/J. Weiler	*	"Mission Timelining", 12/9/86	12
MSFC/P. Craven	*	"Spacelab Science Operations", 12/9/86	12
MSFC/Goldsby	*	"Shuttle Payload Capabilities", 8/73	19

MSFC/Simrall	* "Spacelab Flight Hardware Requirements", 5/75	19
MSFC	* "Integrated Mission Planning First Two Years of Shuttle Missions 1979-1980", 7/23/73	19
MSFC/Goldsby	* "First 20 Suttle Missions", 4/74	19
MSFC/M. Goldsby	* "STS/Spacelab Utilization Planning", 10/74	19
MSFC	* "The October 1983 NASA Mission Model Cost and Economic Analysis, NASA TM X-64802", 1/74	20
MSFC	* "The October 1983 Space Shuttle Traffic Model, NASA TM X-64751", 1/74	20
MSFC	* "Mission Requirments on Facilities/ Instruments/Experiments for Space Transportation System (STS) Attached Payloads JA-447, Revision A", 9/30/86	21
NASA/Hdqs/D. Hall	* "Space Station Information System/SSIS", 10/16/86	3
NASA/Hdqs/G.Peters	* "Some Aspects of User Management and Operations", 11/20-21/86	2
NASA/Hdqs/ J. Gunderson	* "Integrated Logistics", 12/4/86	2
NASA/Hdqs/ P. Culbertson	* "Space Station, A Cooperative Endeavor", 3/26-28/85	8
NASA/Hdqs/ H. Benson	* "Verification and Integrated Assembly and Checkout", 10/3/86	8
NASA/Hdqs/ T. Finn	* "Space Station Overview Presentation to SSOTF", 9/30/86	8
NASA/Hdqs	* "Space Station Program Operations Functions"	7
NASA/Hdqs	* "U.S. Draft MOU Cost Approach", 10/16/86	7
NASA/Hdqs	* "Work Breakdown Structure Presentation to the Operations Task Force", 11/13/86	14

NASA/Hdqs J. Underwood	* "Civil Needs Data Base (CNDB) Update Version 2.0 Status Report", 11/5/86	14
NASA/Hdqs	* "Space Station Program Operations Functions", 10/8/86	15
NASA/Hdqs	* "International Partner Functional Responsibilities and Financial Accountabilities for Space Station Operations", 11/17/86	15
NASA/Hdqs W. Nelson	* "Nelson Letter to J. Fletcher, RE: Operations", 6/2/86	15
NASA/Hdqs	* "Report on Space Station Operations Cost Management", 12/85	15
NASA/Hdqs/ Culbertson	• "The 1973 NASA Payload Model", 10/73	20
NASA/Hdqs/ Teledyne Boeing	* "Microgravity and Materials Processing Facility Study Data Release, Volume 1 User Requirements, NASA 8-36122", 6/30/86	23
NASA/Hdqs/ Teledyne Boeing	* "Microgravity and Materials Processing Facility Study Data Release, Volume II Experiment/Equipment Development, 6/30/86	23
NASA/Hdqs/ Teledyne Boeing System	* "Microgravity and Materials Processing Facility Study Data Release, Volume III MMPF Requirements Development	23
NASA/Hdqs/ Teledyne Boeing	* "Microgravity and Materials Processing Facility Study Data Release, Volume II Experiment/Equipment Development Integrated Data Base, Appendix A	23
Rocketdyne/ R. Dietzler	* "Electrical Power System Launch Package Processing at KSC", 10/8/86	11
Rocketdyne	* "Operations Task Force Automation and Robotics(A/R)", 11/14/86	11
Rockwell/ R. Caldwell	* "Prelaunch and Postlanding Operations Planning", 12/10/86	15
Sapce Industries, Inc./J. Allen	* "Customer Integration and Development", 11/19/86	24

Stanford Univ.	*	"Background Information for the AdHoc Committee on Telescience of the Stanford University School of Engineering Advisory Council", 12/2/85	12
SSOTF/C.B.Shelly	*	"OTF Presentation to the Space Station Program Coordination Committees", 9/11-15/86	8
SSOTF/C.B.Shelly	*	"OTF Presentation to the Space Station Program Coordinating Committees Annotated - Results of Level A Reviews", 9/12/86	8
SSOTF/C. B. Shelly P. Lyman	*	"Briefing to the International Operations Concepts Working Group (IOCWG)", 10/23/86	7
SSOTF/C. B. Shelly	*	"Objectives and Status of the Space Station Operations Task Force", 11/14/86	14
SSOTF P1/ R. B. Williams	*	"Strawman White Paper on Transaction Management", 11/28/86	2
Teledyne/ Bionetics Corp.	*	"Survey and Assessment of Ground-Based to Support Experiment Development for the Space Station Microgravity and Materials Processing Facility", 5/86	6
TRW/E. Gibson	•	"Skylab Real-Time Mission Planning", 1/16/87	2
TRW/E. Gibson	*	"Space Station Operations", 1/13/87	2
Univ of Colorado/ R. Davis	*	"Science and Applications Information System Teleoperations Panel Report", 11/5/86	11
	*	"Flight Operations Support Architecture", 7/9/86	2
	*	"SSOTF Dictionary of Abbreviations and Acronyms", 12/86	5
	*	"Flight Operations Support Architecture", 10/2/86	8
Unknown/M. Sander	*	"SSIS Issues/Options", 10/14/86	11

APPENDIX C

SCORING CRITERIA DEFINITION

1. FEASIBILITY - "Doable," capable of being carried out completion.

2. FLEXIBILITY - Capable of responding to new situations, i.e. Space Station growth and evolution to a new configuration, does not (necessarily) have to be scrapped or junked.

3. USER FRIENDLY - Provides easy training and use to a journey level person with average IQ, intellect and motor sensory skill/perception.

4. EFFECTIVENESS:

   a. Transition - How easy is it to go from phase C/D to Phase E (Operational)?

   b. Management - Does this option lend itself to "effective" management skills, tools?

   c. Cost - What is relative life cycle cost of one option compared to other options for the function or subfunction?

   d. Performance - Is it capable of doing the function in a timely and sufficient (all that is required) manner?

5. SAFETY - What is the relative risk of bodily harm or hardware/software damage?

6. TERMINATION - Can this option be terminated/eliminated/phased out without terminating the total station/having cataclysmic affects:

APPENDIX D

WHITE PAPERS/MEETING MINUTES

Blackmer, Stan	o An approach to Space Station Documentation
Dalton, Bonnie P.	o Spacelab Experiences and SS Decentralization
Dalton, Bonnie P.	o User Friendly Meanings
Moore, James W.	o Minutes MSFC Presentation to the SSOTF
Nelson, Eugene (Panel 2)	o Minutes of Ken Frost Briefing 1/21/87
Nelson, Eugene	o Minutes Of Japanese Briefing Concept for Space Station Organization
Oyler, William	o Flight Rack Process Analysis
Suddeth, David	o Verification Consideration A. Rack Mechanical Interface B. "Telescience" Remote Operations of Experiments
Suddeth, David	o Space Station Platforms
Suddeth, David	o Quick User Access to Space Station
Wiskerchen, Michael	o A Users Path to Space Station

AN APPROACH TO SPACE STATION DOCUMENTATION

S. Blackmer

DOCUMENTATION

A major function of the PIO will be to negotiate and document agreements with a wide range of Space Station users. A document/data base system should be established to meet the following requirements:

- o User friendly to Space Station users, the Space Station operator, and the STS operator.
- o Flexible.
- o Complete (all necessary data).
- o Minimum superfluous data.
- o Eliminate need for multiple entry of same data.

A system structured in a manner similar to that currently used with the STS but streamlined by incorporating modern data base techniques could meet the above requirements.

The basic planning document in the STS payload integration process is the PIP (Payload Integration Plan). It is a joint payload/STS agreement and is normally initiated after NASA Headquarters has accepted the payload by signing an STS form 100. Several PIP outlines (blank books) have been developed as guides for the various types of payloads. This allows minimum P/L interaction with the STS for simple payloads while providing the technical depth required for the integration of complex payloads. Short paragraphs and tables in a structured form in the PIP address all areas of mutual STS/Payload concern. Other subsidiary documents, where appropriate, called "annexes" are controlled and signed by managers at the implementation level. This provides a mechanization for detailed agreements with working level personnel but these detailed agreements must always be within the boundaries prescribed in the PIP. In addition there is an ICD defining in detail the interfaces specified in the PIP.

A negotiated document/information system conceptually similar to the PIP could be developed for Space Station users. Management of the system would be a function of the PIO. In this scenario a Space Station "User" would be virtually any identifiable (by AA) entity or group of entities; (i.e. experiment, rack or Space Station element). Several top level "blank book" documents would be structured to simplify the documentation task for the various classes of "users". "Annexes", as necessary, would be developed between the user and implementation level Space Station personnel. Use of a single properly structured data base for the top level document and "annexes" should preclude the problem of multiple entry of the same data. This data base is then a basic information tool in the manifesting process and is used by the PIO and implementing organizations as input data for integrated engineering analysis. It is also used for ground processing and integrated flight documentation. Having gathered the "user" information, even in preliminary form, the PIO can serve as the agent for all Space Station users and becomes the "Payload" in the STS/Payload PIP process. This concept serves a dual purpose in that the Space Station user has a single contact in the Space Station PIP and the Space Station appears as a single payload to the STS.

Table 1 provides an example of the types of documents/information that the PIO may need from a user. The level of complexity may be such that only a brief paragraph or set of tables in the top level document is required or one or more detailed lower level documents may also be required. For convenience the requirements are separated into four categories; Design, Verification and Test, Space Transportation, and Space Station Flight Planning and Implementation. A brief description of each listed document follows:

ICD

A unique ICD for each user based on a single Space Station ICD specifying all standard Space Station services.

Data Package

Specifies user mass properties, provides configuration drawings, and provides user physical function data.

Software/Data System

Provides all necessary user information for User/Space Station command and data interaction.

Equipment Buildup

Defines user equipment build-up requirements for on-orbit configuration.

Joint Space Station/user Test Req.

Defines interface tests for that testing that can be accomplished on the ground and for that testing that must be deferred until on-orbit.

Equipment Assembly Requirements (ascent)

Specifies any unique requirements while in the ascent configuration.

Equipment Assembly Requirements (return)

Specifies any unique requirements while in the return configuration.

Equipment Dispersal (postlanding)

Defines requirements for return of equipment to user and any special handling requirements.

Flight Planning

Defines flight activity requirements such as crew operations, sequence of events, etc.

Flight Operation Support

Defines support operations such as major operations decisions, user support plans, malfunction operations, etc.

Training

Defines training requirements and responsibilities for ground and flight personnel.

POCC Interface

Defines POCC/Space Station control center interfaces and operations.

TABLE 1

DESIGN	VERIFICATION AND PHYSICAL INTEGRATION	SPACE TRANSPORTATION	SPACE STATION FLIGHT PLANNING AND IMPLEMENTATION
O ICD	O ANALYTICAL (SS AND TRANS) STRUCTURAL THERMAL	O EQUIP ASSEM REQ (ASCENT)	O FLIGHT PLANNING
O DATA PACKAGE		O EQUIP ASSEM REQ (RETURN)	O FLIGHT OPS SUPPORT REQ
O SOFTWARE DATA SYSTEM	O EQUIPMENT BUILDUP (SS CONFIG)	O EQUIP DISPERSAL (POSTLANDING)	O TRAINING
	O JOINT SS/USER TEST PREFLIGHT ON ORBIT		O POCC INTERFACE
O SAFETY*	O SAFETY*	O SAFETY*	SAFETY*

* Safety is an ongoing consideration from design through postlanding requiring periodic reviews and approval.

A USER'S PATH TO SPACE STATION

Dr. Michael Wiskerchen, Jan. 21, 1987

The following discussion will follow through a scenario for a typical solar-terrestrial investigator wanting to utilize the Space Station. It will be assumed that the investigator will be funded through an organization like the Office of Space Station and Application (OSSA-Code E) for the investigation and that all elements of the Space Station (modules, platforms, etc. both U.S. and international) will be accessible.

The investigator is from Standfud University (USA) and had never flown a space-borne experiment before. The investigator is a member of the International Solar-Terrestrial Science Society and had heard about the Space Station through that organization. The investigator's first action is to contact the Space Station office in Washington (this would be assumed because of the Federal funding) and ask for the Space Station science office (single point contact office for Space Station utilization). This utilization office should be staffed with personnel, one of which is assigned to the potential Space Station user, who are knowledgeable about possible funding sources (NASA, NSF, other federal agencies, private sector, international) for this area of science investigation. This utilization office will also provide detailed descriptive documentation on all Space Station capabilities and historical documentation on present and past usage of Space Station. All of this material should be made available electronically (on-line) so that the potential user may browse through the documentation. The investigator then decides to participate through the NASA OSSA route. The investigator may get all of the OSSA documentation from the on-line library or request that the Space Station Utilization Office (SSUO) assist in making the necessary contacts in OSSA. The investigator finds out that at OSSA, Solar-Terrestrial Division has issued an announcement of opportunity (AO) which provides funding for this area of science research.

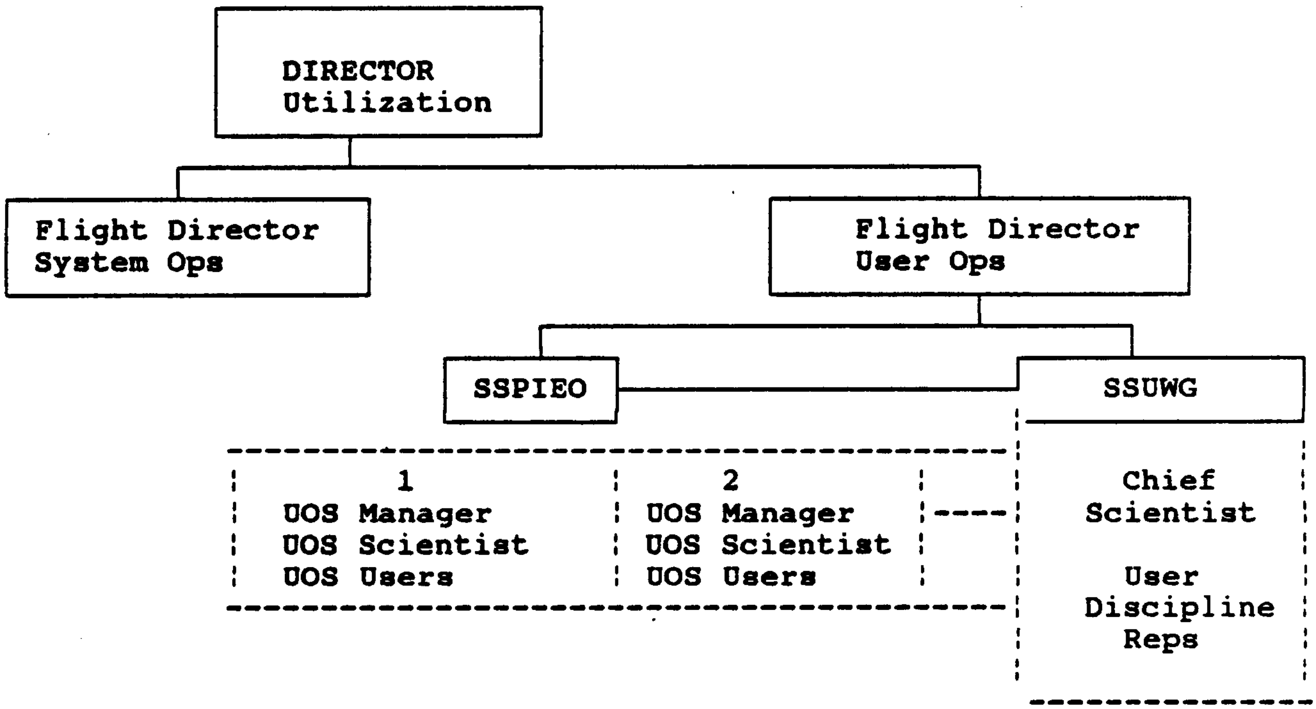
The investigator responds to the AO by submitting a proposal for an investigation involving the building of an instrument set (one to be flown in polar orbit and the other at 28 degrees) and doing coordinated research with instrumentation provided by investigators from Japan and Europe. OSSA receives the proposal and has it peer-reviewed. The peer review (based solely on science objectives) is positive. Before the proposal can be accepted, OSSA must determine the technical, scheduling, and logistics aspects of the proposed investigation and whether they can be accommodated. OSSA contacts the SS Payload Integration and Engineering Office (SSPIEO) for this accommodation information. The SSPIEO evaluates resource, logistics, schedules requirements and informs OSSA that it is possible to accommodate the investigator with certain constraints. OSSA then notifies the investigator that the proposed investigation is selected with certain specified constraints. OSSA, by accepting the proposal, commits to funding the construction of the instrumentation, checkout and integration of instrumentation, experiment operations (investigator team), subsequent analysis of scientific data, archiving of scientific data as a national resource, and finally publication of science results. To carry out the above functions, OSSA will designate a science program staff consisting of a program manager and scientist to provide an interface point to the investigator in each of the above OSSA budgeted areas.

Although during this phase the SSUO has transferred single point contact responsibility to OSSA, it remains fully aware of the disposition and activities of this SS user. The SSUO should maintain an on-line data base of all this information for future reference and marketing analysis.

At this phase of the program the investigator begins construction of the instruments and also begins detailed science planning discussions with other investigators (from Japan, and Europe) who will be directly involved in the investigation. Also, at this time, the investigator will become a member of the Space Station User Working Group (SSUWG). Although OSSA will retain management responsibility for those areas covered by the OSSA budget, the investigator will be referred to the SSUO to be guided on all contact interfaces, procedures, and responsibilities associated with the Space Station.

The SSUO will define for and inform the investigator about the interfaces to the Space Station for engineering, operations planning and scheduling, and management procedures and details. The investigator will be directed to the SSPIEO where the investigation will be assigned to a particular Utilization Operations Segment (UOS). The figure below is an organizational diagram of the utilization organization.

UTILIZATION ORGANIZATION CHART



The investigator will be assigned to a specific Utilization Operations Segment (UOS), therefore, being assigned a UOS manager and scientist and becoming a member of the UOS user working group with input into the SSUWG. The rights and responsibilities the investigator has with the SSUWG are fully documented and defined. The investigator will now be reporting to two separate offices with specific responsibilities to each but on a single schedule agreed to by OSSA and the SSUO. The following list indicates some of those responsibilities.

Time Progression		OSSA	SSUO
	1.	Announcement of Opportunity	Resource envelop assign
	2.	Proposal science evaluation	Technical assessment
	3.	Investigation selection	
	4.	Assign program manager & scientist	Assign SSPIEO contacts
	5.	Manage instrument devel. & science planning	UOS engineering, science planning, timelining
	6.	Deliver instrument to SSUO	Integration into UOS
	7.	Discipline science goals presented to SSUWG	Evaluate resource alloc. against resource envelopes
	8.	Provide funding for user participation to ops	Provide SS ops services
	9.	Support Data acquisition	Support data acquisition
	10.	Support analysis	Provide SS system analysis information
	11.	Support publication of scientific results	
	12.	Support archiving of data	Support archiving of system information
	13.	Provide information about user activities to SSUO	Update utilization data base

SPACELAB EXPERIENCES & SPACE STATION DECENTRALIZATION

B. P. Dalton

Use of the primary aspects of processing an experiment into a configuration for flight in O-G, is the physical integration of hardware. This applies to all Space Station support elements rack, payload interface adaptors, platforms. Integration associated activities must reflect a processing flow providing minimum time for hardware and personnel at locations away from the principle investigator/hardware developer sites in order to encourage and facilitate Space Station use. As with any other marketable item or service, Space Station must accommodate, not intimidate the user.

During the Spacelab era, accommodation was not foremost. One of the primary issues contributing to U.S. users' cost was denial of use of flight racks at the hardware development sites (Science and Technology, S&T Centers) for integration of flight hardware. In Spacelab, this is formally defined as a Level IV activity. This meant several things to the user:

- o No Spacelab flight rack was allowed to leave Kennedy Space Center (KSC) to be sent to a U.S. S&T Center.
- o All physical handling of user experiment hardware to install that hardware into a flight rack was done by KSC personnel at KSC.
- o All handling/testing of hardware, after it was within the rack was limited to KSC personnel.
- o All procedures for handling hardware within the rack were KSC procedures.
- o All problem reporting (PR) on hardware was within the KSC system.

At the outset of STS/Spacelab activities, flight racks were to have been distributed to the NASA S&T Centers. An eleventh hour mandate rescinded this program policy. The reverse decision went into effect 12 months prior to delivery of Spacelab 1 hardware to KSC.

Theoretically, this mode of operation was a cost savings to NASA for the following reasons:

- o Logistics of distribution of racks would require additional sets.

- o Distribution of racks would add shipping costs to NASA KSC operations.

- o Development Center personnel lacked qualified, trained, personel to handle flight hardware.

Terms of rack and shipping costs, the above were potentially true. NASA incurred added costs at the development centers because of this highly centralized mode of operation. The development centers were:

- o Forced to procure and integrate hardware into very high fidelity ground racks ($45K/U.S. constructed unit, $90K/ESA constructed unit); the units also had to withstand the rigors of functioning as shipping containment for hardware to the launch site.

- o Required to maintain a cadre of personnel at the launch site for extended periods often in accordance with KSC schedules and according to the work pace of KSC technicians; i.e., 12 man-weeks/rack for developer post shipment testing and deintegration of highly complex hardware from a GSE rack, 48 man-weeks support during KSC integration/test in the flight rack configuration, 8 man-weeks support during stowage integration.

The S&T Centers have provided for Spacelab and will provide for Space Station, flight hardware at a level of complexity far exceeding that of a rack structure. These Centers operate hardware and experiment development under rigid configuration control, perform all integration/test activities only to approved procedures and require certification of all "off the shelf procured items," and in fact will not procure fabrication services unless there is verification of an "in place" OA program or DCAS on site surveillance. The developers maintain the expertise pool which designed the hardware for O-G qualification and operation.

In addition to the TDY personnel support costs incurred during Spacelab ground operations, the inability to readily gain access to PRs proved very nonproductive in terms of time required for corrective action and final closure of paper work prior to flight.

During the operational phase of Space Station, the launch site will be exceedingly busy maintaining schedules of 90 and eventually 45 days resupply with the logistics modules (LM and ELMs). The launch site could readily become a "bottle neck" if hardware is not delivered in as near launch readiness as possible. Users and their representative hardware development centers can only deliver to that level if racks are provided to them for integration. Because of their Spacelab activities, the S&T Development Centers currently maintain ground support equipment (GSE) such as ground cooling carts, power carts, and air flow carts. A simplied Data Management System (DMS) simulator or its specifications should also be provided to the Centers. This would allow them to perform a limited interface verification.

This is not to say that no capability should exist for last minute interface verification capability (as required) at the launch site. This capability must be present for contingency situations; i.e., shipping damage for both U.S. and International Users, and to accommodate that user not associated with a Development Center.

Centralized integration is not user friendly, allows no flexibility, and while potentially cheaper to SS operations, results in long term costs to NASA S&T Centers representing the world of users.

USER FRIENDLY MEANINGS
B. P. Dalton

The term "user friendly" has been oft repeated since the inception of the Space Station Operations Task Force. One of the initial activities of the Pre/Post Flight Operations sub-panel was to define this term on the basis of our individual experiences from pre/post flight operations during STS missions and to poll members of the STS user community for their definitions.

It was felt that the Space Station Operations organization, in its approach to providing "user Friendliness" must accommodate the existing user organization relationships, not break them. Users were defined to include:

- An experimenter, whether science, technology, or commercial oriented, i.e., the customers of Space Station.
- An entity (crew person or robotic) that works on or from the Space Station to function an experiment, to implement the manufacturing process or to service the elements on board.
- The developer, builder, or assembler of all elements incorporated into Space Station ranging from large support structures through rack level entities.
- To the Space Station Program, this is anyone using the Space Station elements as a test facility whether launched via the NSTS or any other mode.
- To the Kennedy Space Center Launch Site support operation, the user is any element passing through KSC/Dryden and requiring pre/post launch support.

The "user friendly" scope of activities includes operations leading up to and including pre/post flight integration, test, and distribution along with the associated user personnel services. This includes the provided:

Hardware, i.e., GSE simulators and flight interfaces
Facilities, both on and off line
Ground systems
Procedures and documentation.

The requirements specified by users in functioning of the above included:

- o Easy to use which equates to:
  - Predictable operation for the user; when you do the same thing again, you get the same result.
  - No lies or misleading; what you are asked to do will achieve the use desired and expected result.
  - No hiding of significant requirements or neglect to tell
  - Assistance easily available and applicable to the situation
  - Assistance is given at the level needed.
- o Easy to adapt to an interface with hardware, software, and people. The means of accomplishment are through:
  - One person/organization identified to support the user from the point of manifest acceptance through final post flight product delivery whether that product is in the form of transmitted data, specimen/sample, or hardware.
  - One time information input is used to serve multiple documentation sources.
  - Minimization of documentation and resources required in terms of meetings/review support, time, and funding.
  - Flexibility in terms of schedules for hardware/software changes. This also implies an output of timely decisions.
  - Self training available to show user how to use the system (whatever it may be).
  - Quick look availability of data/results.
  - Transparent operating system.

The last three above items are particularly applicable to data handling systems incorporated for pre/post flight test, inflight and post flight data and analysis.

The second category, personnel accommodations, are applications of "user likes" which may assure a feeling of belonging and identification with the Space Station program. These were identified as:

- o Providing offline areas for user work under user control.

- o Eliminating/easing badging procedures. Considerations included:

  - No badge to get to buildings

  - Badges/authorization good for all NASA STS Centers

  - If badging at gate cannot be eliminated, provide a system that gets badge to user at his home location before traveling (potentially telemail authorization)

  - Provide Shuttle Bus pickup/delivery of user personnel to/from motels on fixed schedule and schedule contingencies.

  - Provide beepers as an intercom from work area to office area so user may be easily located/warned.

Input Sources:

H. Rushing (MSFC KSC Resident) representing:

ESA Herman Kuaschoid D-1, D-2
PI Scientist Marsha Torr (Memo Attachment)
Payload Specialist Sam Durrane, ASTRO, John Hopkins U.
Payload Specialist David Bartoz, NRL
Japanese SL participants, N. Kawashima (Memo Attachment)

D. Suddeth (GSFC)

October 31, 1986

From: MTORR
To: HRUSHING
CC: MTORR
Subj: KSC-ACTIVITIES

HALLEY,

We spent some time yesterday considering the "user-friendly" aspects of the KSC processing. When trying to define "user-friendly" we found that we automatically tried to think of problem areas that we had encountered and what would need to be done to improve or remove these. We could not come up with very many, which must mean that KSC is fairly user-friendly already. Here are our thoughts so far:

1. Terminology

After some thought, we could not come up with an improvement on the term "user-friendly", so suggest that you stick with it.

2. General KSC Activities

What would be very useful would be a booklet in simple layman terms (NOT NASA JARGON!!!) which tells each user group what will be expected of them and walks them through each stage of the processing at KSC. This should be brief and simple. . . at the grade 10 level . . . and should not read like NHB 5300! It should refer to the formal documents but be clear and readable.

One of my engineers suggests that it would be useful to have a KSC coordinator assigned to each user group. . . one coordinator could handle a few groups, and would act as the general interface/tour guide. This needs to be someone who knows the system well, where to find things, what needs to be done next, who should be contacted for what . . . not an engineer who is involved with other tasks.

3. Shipping/Receiving

The booklet described above should include illustrations on how to mark and label equipment, who to talk to regarding shipping, etc.

The only major problem that we encountered in the shipping/receiving area was the following: The KSC areas where a user may be busy at any one time cover a very large space. We were most anxious to be present at the off-loading of our equipment at the time of our last shipment to KSC. My engineers made efforts to be available and were waiting to be notified. They were in one of the KSC engineer's offices at the time that the truck arrived. However, the buildings are large enough that no one had the time to find them. As a result our computer was damaged and is still sick.

SUGGESTION: Check out a beeper to the lead engineer of each user group so that they can always be reached.

4. Off-line Checkout

Problems here seem to be pile-up in the off-line user space. Since space will always be limited the only solution seems to be that each group needs to be clearly notified, in advance, of how long and when they can occupy the area.

"User-friendly" seems to boil down to knowing clearly what is to be done.

5. Level 4/3 etc.

Basically the system as it stands works well. The only problem that we have encountered turned out to have a major impact on us. During one of the integration tests, we found a problem in our data stream. The individual with whom we had to interface in this area insisted the problem was ours and would not investigate it further. As the problem had only occurred in the one test and not in the others it was eventually abandoned. It turned out that this was the HRM channel 7 problem and as a very significant portion of the flight data was taken in this mode, our flight data was seriously marred by sync losses. A simple review should have brought to light that this was the only time that a test was run in this mode, and the HRM problem would have been flagged in advance.

SUGGESTION: The default mode should not be to make a user engineer feel that every problem is his until he can prove otherwise. He just does not have enough insight into the overall system to prove otherwise. A higher individual(s) should review all such problems and no individual should be able to resist/discourage further investigation of a problem.

6. Maintenance/Handling

The only relatively high time consuming activities here tend to be in areas of safety and I don't see a way to avoid them. Clear details of what the user will have to do to, for example, run a GN2 purge to his instrument would be useful . . . rather than the "tell us what you want to do and we will tell you if you can do it" series of iterations, through multiple Centers.

7. Procedure Development

All we can think of here is electronic exchange of documents.

Let me know if any of this is useful, or if we can expand it in any way.

Regards,

Marsha Torr

(User friendly comments from Japanese who have participated flown on S/L and are working on other missions)

December 1, 1986

Dear Haley,

I am not sure whether we have fully understood "USER FRIENDLY" but if it is ok to write the impression of KSC support for our activity, it is as follows:

> We started our activity from the beginning of 1982. We had had no experience of activity at KSC before. We felt a little uneasiness at the beginning and were a little frightened by the strictness of the entrance to the high bay area and the quality control.
>
> The uneasiness soon melted away when we found that everything went smoothly if we went to your office and asked you and Dave Jex what we needed. Since then we have not had any trouble nor felt inconvenience during numerous activities of SEPAC in KSC.
>
> Moreover, we must express kind cooperation of experiment support group people. They solved all. Moreover, we must express our gratitude to kind cooperation of difficult interface problems rather smoothly. We felt that each of those people had very friendly personality and only such people might have been selected for the job.
>
> One example is that about a week before the start of activity, we sent a fax or telemail to you a list of GSEs to be used for the coming activity. We were very much impressed when we found those GSEs in the room assigned for our activity.
>
> Another is that we had long depended to our transportation agency too much and since they are not used to KSC system we had much trouble in the transportation. In the last transportation of a part of our GSE to Japan, I asked you to send it to Japan relying much on you and KSC transportation system and we have found that it is much simpler and goes smoothly.
>
> In parallel to SL-1 activity, we had a rocket campaign as a joint experiment with Stanford Univ and USU using NASA sounding rocket. There we experienced inconvenience which cannot be compared with activity in KSC. The system at

KSC are well organized and we can find rather easily the right person for a problem.

In our future activity of ATLAS, we hope that we can find you or the equivalent person at KSC.

I hope that the above is the one what you requested us.

Regards,

Nobuki

February 21, 1987

SS-OTF

TO: SS-OTF/Chairman, Ground Operations, Panel 2

FROM: SS-OTF/Pre/Post Launch, Panel 2

SUBJECT: Minutes of MSFC Presentation to the SSOTF

On February 9, 1987, the MSFC presented a ground verification and processing briefing to the SSOTF at KSC. Present from the MSFC Space Station Program Office were Messers Axel Roth, Tom Dellinger and Bill Bowen.

A few opening remarks were made by Axel mainly to the effect that the presentation would be keyed to the MSFC approach for the phase C/D initial station assembly flights. He commented that MSFC has not as yet done much work in regards to the mature ops period, but that they would be willing to share their thoughts on it with the panel.

Following Axel's remarks, Tom Dellinger presented the MSFC Space Station approach for prelaunch verification and processing. Mr. Dellinger's presentation is attached. The approach as presented and discussed is not a pure "ship and shoot" but one that recognizes that some testing may or will be required at the launch site, but that the goal will be to reduce it to the minimum consistent with the program requirements. The presentation was concluded with a general discussion of various ways processing could be accomplished during the mature ops period.

James Moore

cc:
MSFC/KA61/A. Roth
MSFC/KA51/T. Dellinger
MSFC/DA31/B. Bowen
SS-OTF/C. Mars
SS-OTF/L. Wells
SS-OTF/J. Mizell
SS-OTF/G. Parker
SS-OTF/K. Kersey
SS-OTF/E. Nelson
SS-OTF/J. Anderson
SS-OTF/J. Kelley
SS-OTF/D. Bohlmann
SS-OTF/J. McBrearty

CONCEPT FOR SPACE STATION OPERATIONS

Eugene Nelson

INTRODUCTION/BACKGROUND

The Space Station will be the first long term sustaining operations managed by NASA. Since its inception, NASA has functioned as an R&D organization. This R&D management implementation is evident in the decentralized multi-center management structure and by the very nature of its personnel complement and their work environment. Personnel are hired by NASA for their specific expertise. Understandably, engineering and scientific degrees are the predominant salary winners even though those salaries may not be comparable to industry. Regardless of salary, personnel maintain an intrinsic identity with NASA's leadership in technology and are attracted and retained because of the academic atmosphere, the intellectual freedom, and the ability to work at a pace commensurate with goals of excellence and creativity. As a result, NASA has functioned well as an R&D organization and has contributed extensively in placing the U.S. in a role of leadership in science and technology. Indeed, these characteristics observed in the NASA structure, parallel those identified by J. L. Hunsucker, Ph.D., University of Houston, in his presentation to the Space Station Operations Task Force (see attachment).

Initially, the Space Transportation System (STS) was also perceived to evolve into a routine operation, similar to that of an airline firm. Because of inherent problems and the complexity of the vehicle, that goal was never reached.

Historically when the manned Centers are assigned a new program, the Centers form Program Offices which respond and are under the direction of the main Program Office at NASA Headquarters. During the STS/Spacelab era, this approach was utilized. Each mission had a designated payload manager, whether payloads consisted of experiments in the orbiter middeck lockers, pallets, spacelabs, or any combination of the preceding. With the exception of the dedicated life sciences missions (Spacelab Life Sciences 1/2) managed by Johnson Space Center Projects Mission Office, payloads have been managed by the Marshall Space Flight Center Payloads Project Office. The Spacelab Mission Manager was the single point of control for payload integration including analytical and physical integration, for flight operations, and for interfacing to the STS.

Within NASA centers, whether in the role of mission management or in response to mission management requirements, documentation and supporting analyses for missions have been performed by matrixed engineering or contractor support to a Project Office. This type of operation provided a technique whereby an R&D structure was maintained to support Project Offices. Final responsibility whether in the role of support engineering, Mission Manager, or Project Office has been to the respective Center Directors.

The Mission Manager was the single point of control for payload integration including analytical and physical integration and for flight operations, as germane to the payload. In his role, the STS/Spacelab Mission Manager represented a Payload Integrating Organization (PIO) responsive to the guidelines, specifications, and requirements for STS and Panel 2, in assessing the pre/post flight ground operations perceived analytical and physical integration as the major function occurring under these operations. Analytical integration was perceived to apply to all those activities, following manifesting, aside from actual hardware design, fabrication, test, and installation into flight structures, which implement an experiment into a flight acceptable configuration, operation, and execution. These are the functions required to integrate, verify, and certify to Space Station and the NSTS, an incremental mission.[1]

Among these functions are:

- o Provide single point interface for S&T and/or users for definition of their requirements, verification, operations, etc.
- o Provide single point interface to SS and NSTS to satisfy their requirements for the mission
- o Obtain/coordinate Space Station resource requirements and ground processing requirements for payload elements from S&T Centers and/or users

[1] Because of the continuous nature of Space Station operations, an incremental mission is defined as culminating with the flight of an NSTS carrier to support the SS and its return with cargo from the SS. The incremental mission begins with the start of assembly of the manifest of mission cargo on ground and on SS that is to be carried on that NSTS flight . Mission cargo includes all items going up the SS to support next configuration of the SS and that hardware or items returned from the SS.

- Perform analytical integration of integration mission to confirm compatibility of payload mission requirements to Space Station logistics carriers, and STS launch vehicles

- Develop required documentation for the mission

- Conduct and support reviews, meetings, etc., required to support planning and implementation of the mission

- Provide SS Program with MANAGEMENT CONTROL and INTEGRATION for various products, i.e., engineering analysis (power, thermal, structures, safety) needed from experimenters for use by the program

- Development test requirements and specifications for the test integration Centers(s) and monitor test activities.

The concept of a PIO was a natural evolution during Subpanel 2 option analyses as a result of optimizing "user friendliness" by minimizing interfaces. Additionally, it was felt that interfaces that are utilized must embody the expertise and knowledge to effectively translate user requirements to functional application in flight. A single Payload Integrating Organization, embodying corporate knowledge, was perceived as the most appropriate entity to fulfill such a function. Simultaneously, such an organization must answer only to the Space Station Program (or as interface applicable-to NSTS) and not be "performance diluted" by the parochial interests of multi-Centers or in competition with other programs within those centers. Over the life of the Space Station, it is anticipated there will be R&D efforts related to the Aerospace plane, manned lunar base, the manned Mars mission and others. All of these divert from a truly operational activity.

CONCEPTS

Establishment of a PIO for tactical and execution levels, should be apart from the Institutional parameters of existing Centers and should maintain a direct interface to the Associate Administrator for Space Station. Logistics and sustaining engineering would be active supporting subelements of the PIO. Their payload requirements would be like that of any other user. Sustaining engineering would provide configuration control and be capable of providing to PIO the particular incremental mission resource boundaries: logistics would interact very closely with PIO to evaluate resupply/download requirements relative to proposed experiments. Support to users for experiment development would be retained within the Science and Technology Centers as an R&D effort or would be funneled directly into the PIO from the self-represented user.

Implementation of the above concept would be through the physical headquarters of the PIO in its own building at some site or Center. Other assemble, test, and control elements, while potentially located on the same center property would be managed and budgeted by the Space Station management. The PIO should be composed of two fundamental units. The first unit would be responsible for the operation and care of Space Station systems in flight and on the ground; the second unit would be responsible for integration and operation of payloads that utilize the Station as their base.

A further factor in implementing such an organization is staffing by both engineering support personnel and purely operations personnel. Currently, operations personnel of the type envisioned necessary for long term Space Station activities are not in the forefront of hiring queues. If a long term organization is planned within the current NASA structure and culture, the issue of recruitment and development of operational personnel will have to be addressed to assure that Space Station is a truly routine operation and not a research and development activity.

To compare the objective pre-requisites for effective management approaches between R&D and Operational organizations, the only organization that is relevant for the "Sustaining Operational Era" of the Space Station is an operational organization set up outside of the present NASA R&D structure that more closely reflects the characteristics and capabilities of an operational organization.

R&D VS. OPERATIONAL MANAGEMENT

Characteristics	R&D	Operational
Organization Structure	Functional	Hierarchical
System Hierarchies	Expertise	Position
Leadership Behavior	Delegation	Participation
System Management	Decentralized	Focused Power
Performance Criteria	Long Term	Result Oriented
Reward System	Intrinsic	Extrinsic
Communication System	Informal	Formal
Information System	Open/Shared	Structured
Flexibility	Long Term Commitment	Structure Job Description
Work Environment	Intell. Freedom	Target Oriented
Cultural Climate	Participative	Competitive
Political Climate	Contest for Expertise	Contest for Control of Power

TO: Charles B. Mars/Chairman, Panel 2

FROM: Pre/Post Flight Subpanel, Panel 2

SUBJECT: Minutes of January 21, 1987 Briefing by Mr. Ken Frost, Goddard Space Flight Center, Assoc. Director of Space Flight Center, Assoc. Director of Space and Earth Sciences, for Space Station Integration/Verification Issues for Users

Copies of briefing charts used by Dr. Frost in his presentation are attached.

The briefing began with a description of a modern instrument (experiment) design which includes computer processors in the flight package. These processors operate the experiment, process and compact the data, allow its reconfiguration, and now allow increased application of expert systems and artificial intelligence to control the data-gathering elements. The experiment computer interfaces by data link with a sophisticated ground-based computer. The ground computer develops uplink commands, and processes data. It can also serve as a simulator for the experiment data interface with the Space Station (SS) Data Management System (DMS). The point was made that while the pre/post doctoral experimenters of today are conversant with computer technology, by the start of operations of the Space Station, such experimenters would be computer virtuosos.

An extension of the modern instrument would be two or more such instruments working together on Space Station through the extremely flexible DMS communication link (See multi-payload chart). Since the DMS uses addressed packets of data and commands circulating through its network, instead of the old preplanned rigid frames of data, reconfiguration of user data and instrument relationships is easy.

Based on this view of modern instrument a description of the user's view of the Space Station DMS concept was provided. The DMS communications network would be transparent to the user, which would allow the user to interact with the experiment from the ground in a straight-forward manner, using his own selected computer language. The Space Station DMS would allow a flow of the constantly available ancillary data on Space Station status to be selected by the experimenter's flight computer for insertion into its telemetry stream to ground. This identifies the environment in which the payload is operating. The DMS would also include an enabling capability for those few types of commands which have system level impact on the SS or other users, such as:

payload power envelope; movement of large masses; and venting of gasses. This would prevent damage to other users. Of all user commands, only about one percent would have such impact, the other commands could flow the experiment directly. The briefing concluded with a vigorous discussion of the role of simulators (test beds) in the experiment design, development and verification. Frost proposed that from the start of development of the experiment, simulations in the user computer should interface with Space Station simulations in a host computer. These experiment data-to-DMS interface (data traffic and networking). These emulations would go through an evolution process from low fidelty, to high fidelty, to use of the actual DMS hardware. The other mechanical, thermal and safety verifications would take place before launch in a one-time full-up test. This approach would allow the user to operate/verify his experiment remotely, from his own facility and gain competence in use of the DMS system. The implication for the Space Station program is a need for simulation capability of the user's complete communication link, before launch, through simulated DMS networks. This method would support both "Telescience" and conventional control of experiments.

A suggestion was made and accepted as feasible by Frost indicated a new possibility that the final compatibility verification of the Space Station data management system with an instrument that has not yet been launched could employ a special ground-to-space link to the DMS on Space Station (or platforms). This would allow directly checking the operation of that instrument with the flight DMS, while the instrument is still on the Ground. This method would remove the need to provide any high fidelity ground simulator of the Space Station DMS for checkout of payloads before launch. Frost commented that on the "Solar Maximum Mission" spacecraft, the only successful prelaunch checkout of the interactions of the multiple instruments and the spacecraft data system was through the spacecraft data system itself. A substitute simulator was impractical.

Eugene Nelson
cc:
SS-OTF/P. Lyman
SS-OTF/C. Shelley
600.0/GSFC/K. Frost
SS-OTF:GNelson:crb:853-9917:2-2-87
SS-OTF/Official
SS-OTF/Reading
SS-OTF/G. Nelson
Library

FLIGHT RACK PROCESS ANALYSIS

W. H. OYLER

The analysis of flight rack processing was performed to determine the sensitivity of rack fleet quantities to the length of the overall supply and return cycle of Space Station experiments. The cycle of rack processing consists of (1) preparing the rack for experiment integration, (2) physical integration of experiments into the flight rack and verifying ready for launch processing, (3) installation of experiment rack into the Pressurized Logistics Module, (4) launch to Space Station, (5) on-orbit operation, (6) return to Logistics Module and de-boost to Earth, (7) de-integration and return of flight rack to fleet inventory.

The overall cyclical process with representative timelines is presented in attached figure (Rack Stuffing Off-Site). Also considered is the accumulative effects of multiple Logistics Modules being launched on 90 day intervals. The duration of each portion of the processing cycle will vary as design and operations planning matures, but the times are representative of present planning and current flight experience with similar hardware.

The conclusion is that a minimum quantity of racks can be accommodated when physical integration of experiments into the flight rack begins within approximately 7 months prior to launch. Based on return from Station intervals, if a rack is required for experiment integration between 7 and 10 months prior to launch, then an additional rack is required in the overall fleet sizing, assuming each concurrent Logistics Module flight continues to have a full complement of User experiment racks. Each additional 3 month increment required for experiment integration into the flight rack would require an additional rack to be added to the overall fleet.

NASA-C
PAYLOAD
OPERATIONS

SPACE S ON
LOGISTICS MODU RESUPPLY
RACK STUFFING OFF-SITE

CH 10, 1987
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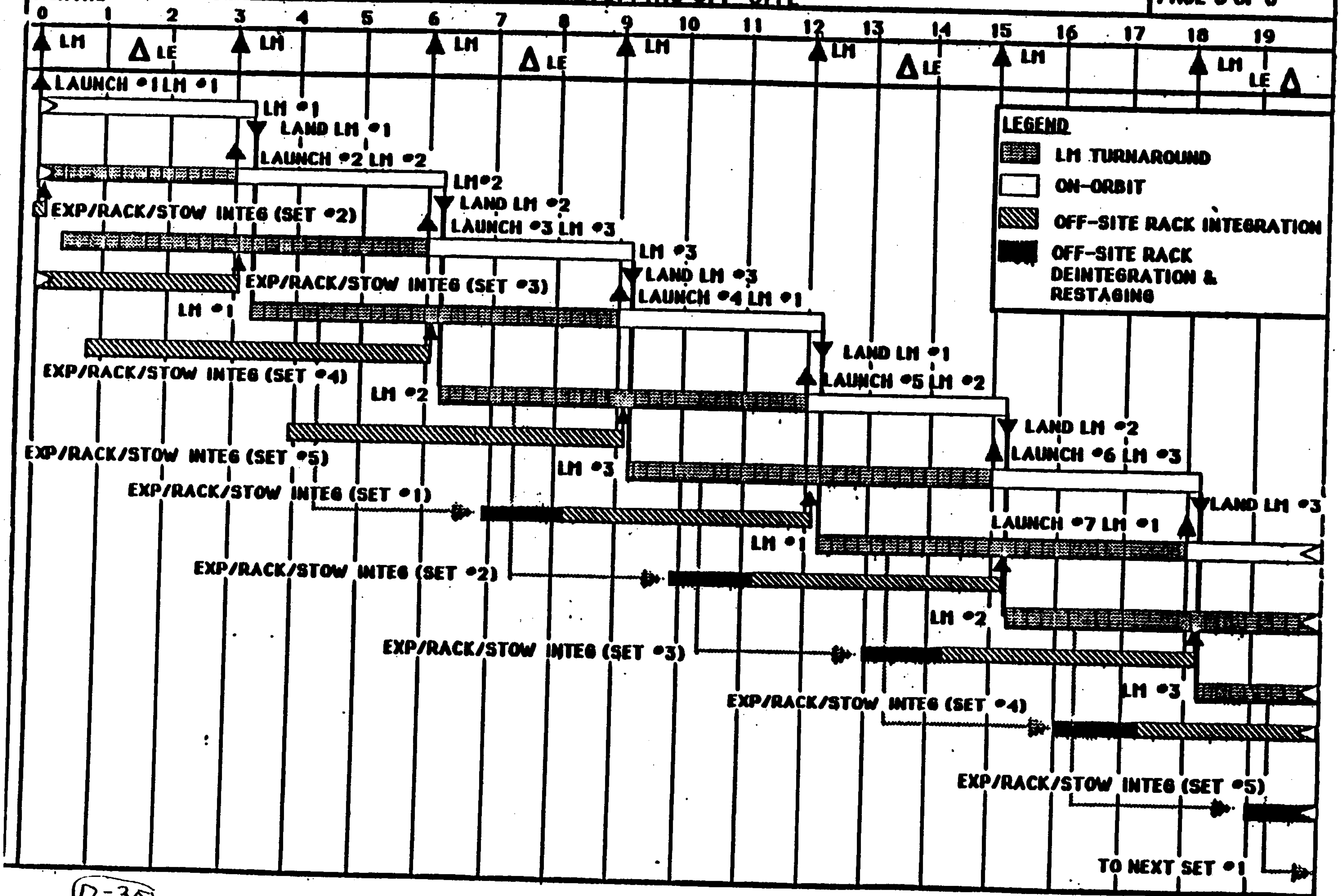

D-30

VERIFICATION CONSIDERATIONS

A. Rack Mechanical Interface

A suitable method for verifying the mechanical interface of the physical latch and hinge attachments of rack-mounted Space Station payloads is to use the container in which they are to be shipped to the launch point as a master three-dimensional structural interface gauge. All such shipping containers are required to be strong and rigid. The rack attachment points of both the container and rack normally must withstand all shipping loads without shifting. The shipping container attachment points could be designed to be set in the exact configuration that duplicates the attachment points on Space Station. All electrical plugs and fluid connections would be duplicated also. If the users rack-mounted payload fit such a shipping container, for shipment to the launch site, it would fit the Space Station attachment points also. The rack attachment points in the logistics module would also be required to be in the same configuration as the attachment points on space station.

B. "Telescience" Remote Operation of Experiments

A special aspect of prelaunch ground checkout of the user's experiment equipment and data systems is that a large proportion of user equipment on Space Station will be remotely operated by users from their own ground laboratories. From there, they will use Earth links to send uniquely addressed packets of commands to the Tracking and Data Relay Satellite System (TDRSS), which will link those data packets to the Space Station Data Management System (DMS), which will in turn link the data packets to their various Space Station-mounted equipments. Those few user commands that would have an effect on other parts of Space Station would first be routed to a Verification and enable system" that is transparent to the user. This system would hold execution of those commands until it is verified that their interactions are not harmful to Space Station or other users.

Data of all sorts from the user equipment on Space Station is returned back through these same electronic links to the various users laboratories on the ground, where users can immediately observe the data and act on it. The users subsequent commands, sent directly to their equipment through these links, will change and refine the data taking modes, change pointing direction, etc.

All of the relation of users to their experiment described above is meant by the term, "Telescience", which is defined as: "the direct, iterative, and distributed interaction of remote users with their instruments, data bases, specimens, and data handling facilities, especially when remote operations are essential."

Those Space Station users who control their experiments with such "Telescience" data links will desire to check that data link operation during the final interface verification test. A good verification of the data link requires that a good emulation of the real Space Station DMS be available on the ground. This will demonstrate that Space Station will carry through the user data and commands intact and verify that user operation in "Telescience" mode will work. It might be possible to use the actual flight DMS itself for such operational interface verification.

QUICK USER ACCESS TO SPACE STATION

David H. Suddeth

There are classes of short term Space Station users whose interface verification needs are different from those of the major program and facility users, who intend to make a long-term time and money investment in operations on Space Station. The short-term users are characterized by a positive need for quick access to Space Station and only a few months residence on it. Their physical and data interface verification needs may be much simpler, and can be met by standard in-process tests. These users might wish to test new theoretical concepts or processes with some special equipment; test the operation of a piece of new equipment; or make new kinds of measurements on a subject. The scientific community is especially desirous of quick access to Space Station. They have stated that desire in the phrase:

"QUICK IS BEAUTIFUL"

"Quick access" users would include: university graduate students trying to get thesis material; corporations and research institutions testing new concept ideas, and others. This user objective may best be met by user design of very simple interfaces and ones that are more under user control.

Many Space Station users may not need a direct verification by Space Station program at its verification facility of their interface to the Space Station, because they would not attach directly to a standard Space Station interface. Instead, they would attach at a "subinterface" to a larger element that is already on such a standard interface. However, the verification testing of user operation at these subinterfaces would be appropriately controlled by PIO for purposes of Space Station safety.

Examples of larger elements that might have such "subinterfaces" available include:

(a) Double racks "owned" by a university or corporation that are intended to stay on Space Station for a long continuing research program, but has drawers or slots available for other users from their justification;

(b) "Multiple payload adapters" (MPA) attached at one external "Station Interface Assembly (SIA)" port on the Space Station truss. These MPA's are intended to carry five or more separate payloads that will be attached at the one SIA port. These payloads may be interchanged individually;

(c) A Space Station-based SPARTAN, small free-flyer system like those flown from STS. The SPARTAN system base would permanently reside at an SIA as an attached payload.

The SPARTAN free-flying vehicles carrying small experiments would leave the base system, fly separately from Space Station, be returned to their base system, and be interchanged on the base system for other SPARTAN vehicles carrying new experiments. All the "subinterfaces" in the above examples would be verified during the buildup process and finally verified for that user by the organization controlling the larger element attached to Space Station. Responsibility for physical verification of those users for the health and safety of Space Station would rest with the larger element, with review by the Space Station PIO. The data those users take may be largely self-recorded for quick return.. Their data link through Space Station may be small.

SPACE STATION PLATFORMS

David H. Suddeth

The Space Station Program will design and build two large unmanned spacecraft called "Platforms" that will carry experiment instrument payloads in orbit separately from the manned Space Station. The platforms may do their work separately from the Space Station. The instruments and Platform operating systems will be in modules that have standardized interfaces to the Platform structure. These modules can be removed in orbit from the platform structure and be replaced with new modules at the same interface.

The platforms are expected to remain operating in orbit continuously for 30 years. They will be maintained by periodic servicing visits for instrument module exchange or change of platform operating sub-system modules for repair. Servicing visits would be by NSTS to a platform, or by returning a platform to the Space Station. A servicing facility on Space Station will be provided, where servicing work on platforms and other spacecraft will be performed. Servicing visits of platforms would occur at intervals of 1 year or longer.

Although platforms will orbit separately from the Space Station, they are elements of the Space Station Program. Therefore, the ground operations system to support/process them will be integral with the ground operations system to maintain the Space Station itself.

Initially, platform modules would be verified for proper function and operation through their platform interface during the platform buildup process, in the same manner as other Space Station payloads. After platforms are in orbit, final ground verification of new experiment and sub-system module interfaces to the orbiting platforms will be done with mechanical and electrical simulators of the standard platform interfaces that are as high quality as is feasible. The location of the final interface test of platform modules is expected to be at GSFC, under direction of PIO. Final checkout of the platform modules would be on the platform in orbit.

The Space Station Program will not have the responsibility to maintain other free-flying spacecraft owned by other groups, but will service them as their owners request. Equipment to support the other spacecraft that passes through the Space

Station logistics system will be handled essentially the same way as user resupply items used to maintain user experiment equipment onboard Space Station. The PIO will assure that tests show those items are safe for Space Station, but the users must make their own assurance of fit and function.

Appendix E

SUSTAINING ENGINEERING

FUNCTIONAL DESCRIPTION OUTLINE

This section is an outline definition of the Sustaining Engineering functions necessary to support operations of the Space Station Program. These functions are replicable to any area of Sustaining Engineering organizations. The scope of this effort is flight hardware and software, ground systems hardware and software, ground support equipment and ground processing software, and support to customer integration. The sustaining engineering functional area includes:

- Performing the analysis and engineering necessary to maintain and enhance the Space Station Program orbital and ground support program elements.
- Designing, building, and supporting the installation and integration of approved modifications to the program elements.
- Developing and maintaining integration and verification requirements for flight systems, ground systems, and the interfaces to customer systems, transportation systems, and institutional tracking, data relay, and ground data communications systems.
- Performing the day-to-day management of approved program configurations and supporting the overall configuration management and control program.

FUNCTION OUTLINE:

1. Planning and Management
2. Systems Analysis
3. Design Engineering
4. Engineering Integration and Verification
5. Documentation

SUB FUNCTIONS:

1. Planning and Management

   A. Planning and Scheduling

   B. Budget Management

   C. Contract Management

   D. Resource Management

   E. Manage Station System Advanced Technology Programs - As Assigned

   F. Evolution and Growth Management - (Space Station Impacts)

2. Systems Analysis

   A. Flight Certification Engineering Analysis (from customer recommendations and station/platform system modifications and enhancements)

   B. Systems Performance Analyses - Conduct Trend Analyses and Evaluate Test Data

   C. Provide Analyses of System Performance Degradations

   D. Identify Requirements for Operational Performance Enhancements

   E. Failure Analyses

   F. Mass Properties Analyses and Configuration Analysis

   G. Support the Feasibility and Supportability Analyses of Proposed Enhancements and Modifications

   H. Technical Risk Assessments - for flight and ground support hardware and software systems

      1. Criticality Assessments
      2. Failure Mode and Effects Analyses
      3. Single Point Failure Analysis
      4. Safety and Hazard Analyses and Assessments
      5. End-to-End Analysis
      6. Sneak Circuit Analysis
      7. Control Logic Reviews

8. Feasibility
9. Availability
10. Commonality
11. Maintainability
12. Operability
13. Cost
14. Schedule

I. Environmental Analysis and Control

1. Vibration Analysis
2. Acoustical Analysis
3. Thermal Loads Analysis
4. RFI Analysis
5. Load Stress Analysis

3. Design Engineering

A. Design and Engineering of Flight Systems and Ground Support Systems Enhancements/Modifications

1. Conceptual, Preliminary, and Detailed Design Products (includes documentation, analyses, and reviews)
2. Integrated Design Reviews
3. Specifications, Drawings, Requirements
4. Design Criteria
5. Design Verification Requirements
6. O&M Documentation
7. Installation/Modification Requirements
8. Preparation and Maintenance of "As-Built" Drawings, Specifications and S/W Source Code Listings
9. Systems Reconfiguration and Installation Requirements. Also Includes Payload Installation/Removal Requirements. Includes Schematics, Installation/Removal Instructions and Software Products.
10. Transportation Configuration Design

B. Design of Test Article Hardware, Software, and Ground Support Equipment

4. Engineering Integration and Verification

A. Modification Enhancement Hardware and Software Integration and Implementation

1. Flight Systems
2. Ground Systems
3. Customer Systems to Flight/Ground Systems
4. Flight/Ground Systems to Transportation Systems
5. Flight/Ground Systems to Institutional Tracking, Data Relay, and Ground Data Communications Systems

B. Customer to System/Subsystem Integration, Verification, and Compatibility Assessments

C. Verification Testing Planning

1. Test Objectives and Requirements
2. Evaluation Criteria
3. Test Procedures and Plan
4. Training
5. Scheduling

D. Support to Verification Testing (testing performed by operations)

E. Customer-System Interface Engineering. Includes Customer-System Interface Designs as Required

F. "Build" Process
1. Make or Buy Decisions
2. Procurement Support
   a. Hardware
   b. Software
   c. Materials
   d. Services

G. Real-Time Engineering Support to Operations
1. Engineering for Anomaly Resolution
2. Systems Performance Monitoring
3. Engineering for Critical Operations

H. Integrate and Coordinate Evaluations, Assessments, Analysis, and Anomaly Resolution

5. Documentation

A. Maintain and Update Flight Hardware ICD's

B. Maintain and Update Flight S/W Source Code Listings

C. Maintain and Update Ground-Flight Systems ICD's

D. Maintain and Update Ground System S/W Source Code Listings

E. Maintain and Update Architecture Control Documents (ACDs)

F. Design Documentation

G. Configuration Status and Updates (Data Base Products)

H. Mass Property Documentation

I. Performance Trend and Prediction Reports

J. Design Review Packages

K. Analysis Reports

L. Flight Certification Status

M. Commonality Identification and Status

N. Access Requirements to Customers, Space Station Elements, and Support Systems

O. Updates to Controlled Documentation is Approved by Configuration Management

APPENDIX F

CONFIGURATION MANAGEMENT

FUNCTIONAL DESCRIPTION OUTLINE

This section is an outline description of the configuration management Functions required to support the Space Station Program. These functions are replicable to any level of configuration management Systems.

Day to day activities are a mixture.

Very Top-Level function can be strategic - i.e., Bilateral Agreements to change the Fundamental Configuration of the Space Station Flight or Support Systems.

FUNCTION OUTLINE:

1. Configuration Identification

2. Configuration Control

3. Configuration Verification (Auditing)

4. Configuration Accounting

SUBFUNCTIONS:

1. Configuration Identification

    A. Selecting End Items of Hardware and Software to Come Under Configuration Control

    B. Develop and Maintain Baseline Identification of H/W and S/W Under Configuration Control

    C. Develop and Maintain Engineering Documentation
        1. Prepare and Maintain H/W & S/W Specifications, Drawings, and S/W Source Code Listings
        2. H/W & S/W Engineering Documentation and Computer Program Media Records and Releases

2. Configuration Control

    A. Controlling H/W & S/W Such That Demonstrated Physical Status and Performance Satisfy Mission, Safety, and Security Requirements

B. Managing Changes to the Baseline System Through a Formal Review and Approval Process Prior to Directing H/W & S/W Changes

C. Closing Out Configuration Change Directives Upon Completion of the Configuration Verification and Configuration Accounting Processes

3. Configuration Verification (Auditing)

A. Conduct Reviews to Assure that the Design of the Changes to the Baseline Configuration Satisfies Approved Requirements (Mission, Safety, & Security)

B. Conduct Reviews, Tests, Inspections, etc., to Assure that H/W or S/W End Items Conform to the Released Design Documentation

C. Conduct Reviews, Tests, Inspections, etc., to Assure that the Modifications Have Been Incorporated in Accordance with the Configuration Change Directive (i.e., Verify "As-Built" is the Same as "As-Designed")

D. Conduct Periodic Reviews and Audits to Verify that the Change Control Process is Effective

4. Configuration Accounting

A. Establish and Maintain a Data Collection and Storage System Which Provides for Tracking and Auditing the Change Control Documentation. These Include Change Requests, Disposition Actions for Change Requests, and Verification Reports

B. Provide Approved Inputs to the System(s) Containing the Identification of the Baseline Systems

C. Manage Program Configuration Data Base(s)

APPENDIX G
Sustaining Engineering and Configuration Control Scenarios/Schemes for the Space Station Program Operational Era

Glenn R. Parker

INTRODUCTION

After the Space Station Program (SSP) becomes fully operational, the methods by which the engineering changes associated with SSP maintenance, modifications, upgrades, and overall evolution are handled and managed will be similar to those methods that are implemented during the SSP Design, Development, Test, and Evaluation (DDT&E) phase, but the management scheme for these methods/functions should be different than that employed for the early DDT&E phase of the program. Required management and operational response time, efficiency, and cost effectiveness will dictate that an evolution in sustaining engineering and change management schemes take place that will allow such systems to be operationally oriented and streamlined in order for the program to cope efficiently with the multifaceted scenarios that will exist during the SSP operational era. These scenarios will probably be different than those faced early in the program due to the increased complexity in SSP subsystems/ systems, operations, and interrelationships/ interdependence with other program/agency elements. This treatise will describe typical engineering change scenarios that might occur during the SSP operational era, and will also describe operational change management and sustaining engineering schemes that could be utilized to handle these scenarios.

ENGINEERING CHANGE SCENARIO DESCRIPTION

For the purposes of this paper, two typical engineering change scenarios that might occur during the SSP operational era are considered. It is realized that other scenarios may exist which will be different than those described herein, or that a combination of scenarios may exist that embodies some elements of those described herein. However, these two scenarios are felt to be representative of the boundary conditions that will exist for such changes that may occur during this era. The two chosen scenarios are:

(1) An engineering change that affects multi program/agency elements such as the Space Station Program elements, International elements that are a part of the SSP, National Space

Transportation System (NSTS) elements (e.g., Orbiter), and other program/agency elements such as users (customers), the Tracking Date Relay Satellite System (TDRSS), and/or the Global Positioning System (GPS). Examples of such changes are: a.) A change to the basic station electrical power scheme involving wiring size changes, electrical frequency changes, load carrying capabilities, etc., b.) changes in data rate/channel requirements, high resolution video requirements, or uplink/downlink data requirements, and c.) a requirement for Orbiter control of the Station Remote Manipulator System. Such changes would not only affect U. S. Space Station Element subsystems/systems, but could affect international element, customer, Orbiter, TDRSS, and/or GPS subsystems/systems, dependent upon the example considered.

(2) An engineering change that affects only the U.S. supplied elements of the SSP and does not involve any other supplied elements of the SSP or any other elements of various programs/agencies. An example of such a change might be a change involving the addition/upgrade of a work/maintenance bench in the U.S. Laboratory or Habitation Module.

For each of these scenarios, a proposed operational era engineering change management and sustaining engineering scheme will be presented and described.

OPERATIONAL CHANGE MANAGEMENT AND SUSTAINING ENGINEERING SCHEME

Typically, early phases of any program utilize a change management and sustaining engineering scheme that involves the program manager, the program's project managers, a configuration management team, a systems engineering and integration (SE&I) team, project systems engineering experts, and a distributed change evaluation process to evaluate, disposition, and implement program/project change requests (CR's). The program/ project managers usually have all of the approval/disapproval authority for the purposes of dispositioning such CR's, and operations personnel are usually only a part of the submittal and/or the change evaluation/ implementation process. As such, operations personnel have very little control over their own destiny, and operational considerations, including cost, often are not properly considered during the change control/management process. During the operational era of the SSP, and other programs, a change management and sustaining engineering scheme should evolve to one that is primarily controlled by operations personnel via a single Program Operations Manager, who is in charge of both flight and ground operations for the program(s). The appeal route for such a scheme would be from the Program

Operations Managers to an Associate Administrator for Operations. A proposed top-level organizational structure for such a scheme is depicted in Figure 1. Such a structure would replace the normal structures that exist during the early phases of various programs. The operational era structure would make a change management and sustaining engineering scheme more operationally controlled and oriented, in tune with operational needs, more streamlined, and, hopefully, more cost effective. In a program`s operational era, it would be desirable if all programs could evolve their organizational structure, change management schemes, and sustaining engineering schemes along such a philosophy to facilitate inter-program compatibility.

With such a philosophy in place, an engineering change and/or sustaining engineering effort that affected the SSP only would be supported by the "generic" change management and sustaining engineering scheme shown in Figure 2. An example of such a change, as previously mentioned, might be an addition of an/or upgrade to a work/maintenance bench in the U.S.A. supplied Labratory or Habitation Modules.

If a change affected multiple programs, such as the SSP, the NSTS program, and the Canadian (International) program, the "generic" change management and sustaining engineering scheme would be expanded, as shown in Figure 3, to encompass the three programs. An example of such a change would be one that required a modification to allow for control of the Space Station Manipulator Arm (MRMS) from the Orbiter Aft Flight Deck.

Finally, if a change affected all programs that may be interrelated with the SSP, during the operational era, the "generic" change management and sustaining engineering scheme would be further expanded, as shown in Figure 4.

The only differences between the three schemes are the number of participants involved and the magnitude of the required integration effort among the various involved programs. However, the same basic eleven step process would be followed for all of the depicted schemes. In order to describe the basic eleven step process of these change management and sustaining engineering schemes, the example depicted by Figure 3 is chosen. This example was chosen because it adequately depicted the complexity associated with multi-program interrelationships, while at the same time remaining simple enough in scope to allow the reader to relate to the "generic" scheme. In describing the basic eleven step process, it should not be assumed that all changes must go through the entire process. Some changes, such as 'quick turn changes' or changes to basic customer`s hardware/software, may be able to skip some steps. These factors

TOP—LEVEL ORGANIZATIONAL STRUCTURE FOR CHANGE MANAGEMENT AND SUSTAINING ENGINEERING DURING OPERATIONAL FLOW

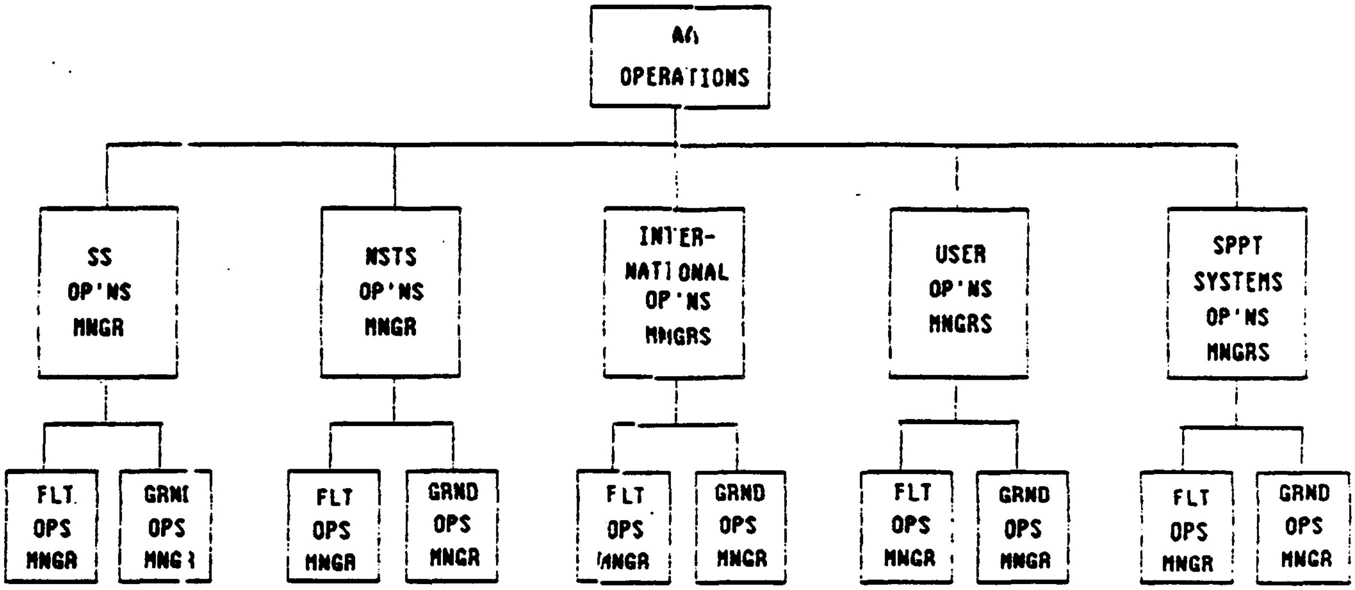

FIGURE 1

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SUSTAINING ENGINEERING GENERIC FUNCTIONAL FLOW U.S. SSP ONLY MOD CHANGE PROCESSING

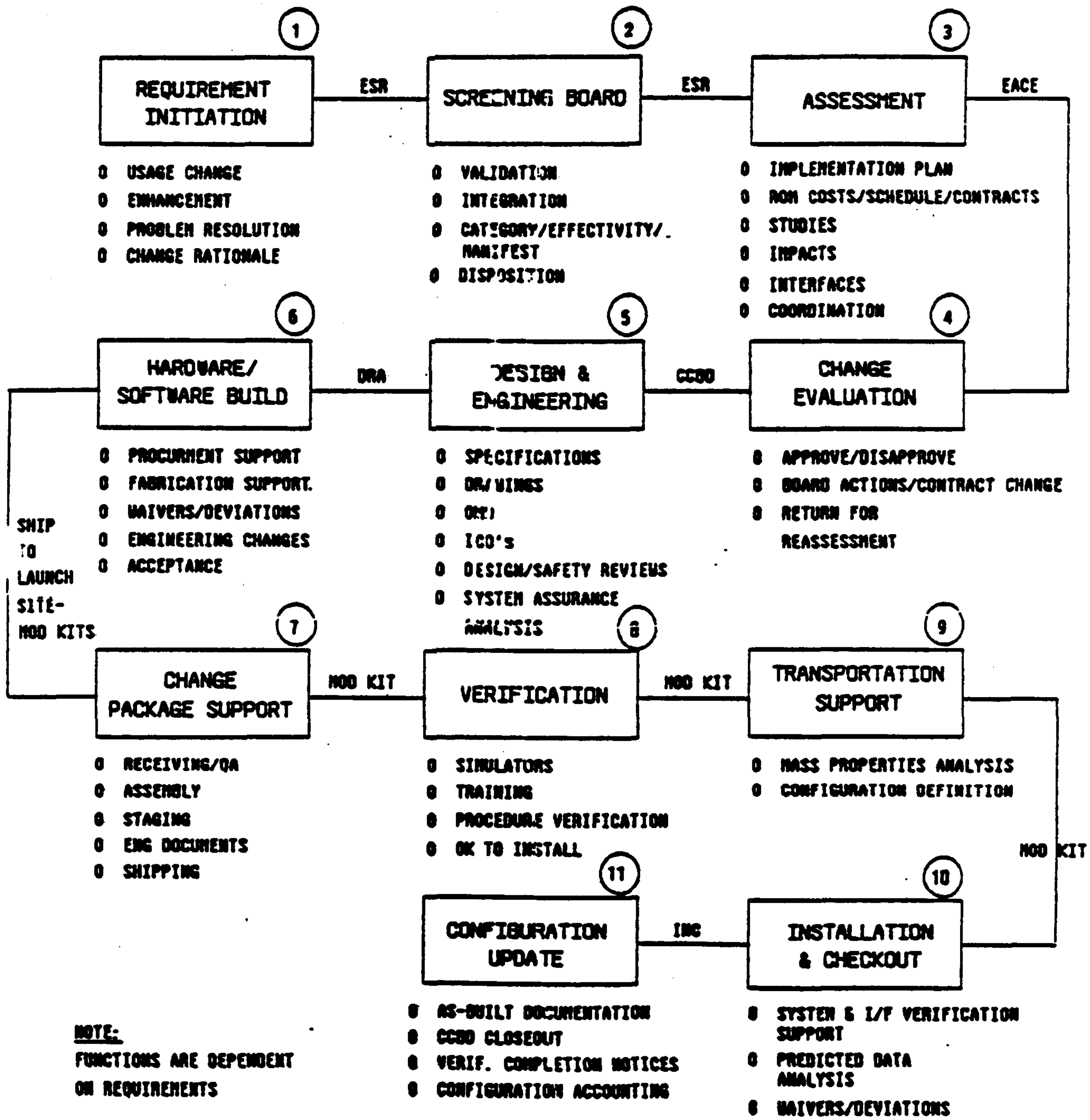

FIGURE 2

SUSTAINING ENGINEERING
MODIFICATION TO PROVIDE ORBITER CONTROL OF MRMS
MULTI-PROGRAM/AGENCY MOD
CHANGE PROCESSING

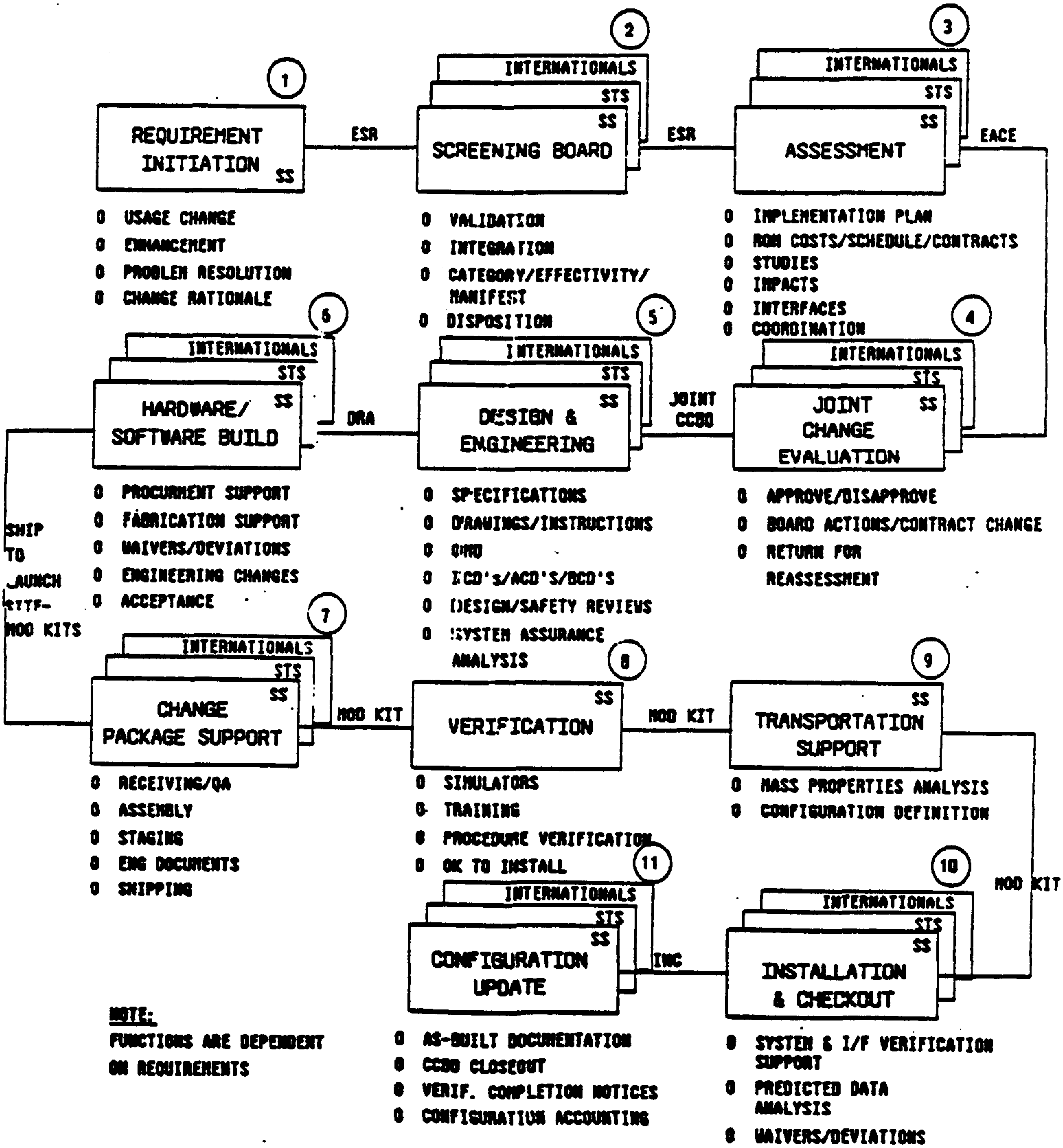

FIGURE 3

SUSTAINING ENGINEERING
MULTI PROGRAM/AGENCY MOD
CHANGE PROCESSING

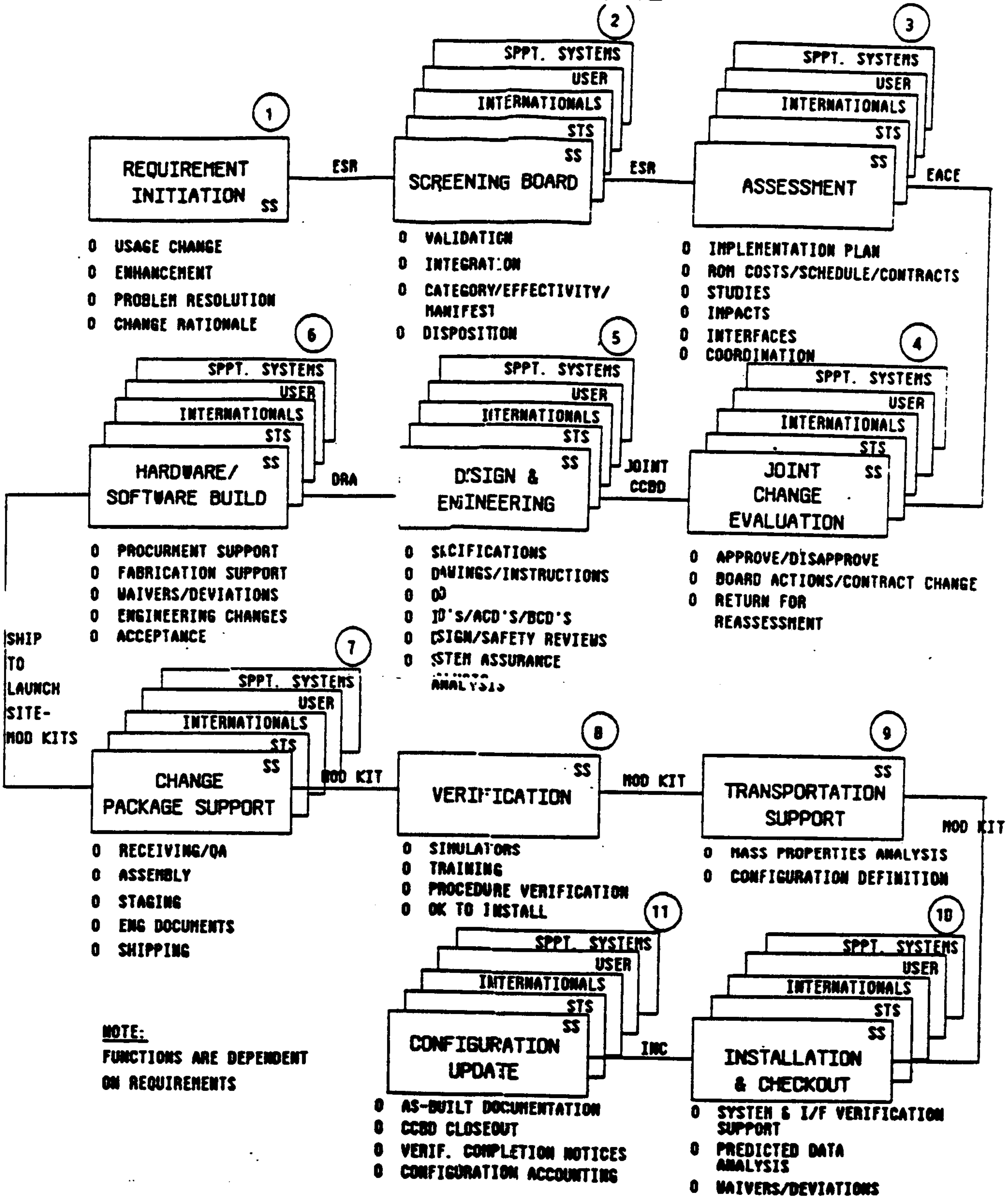

FIGURE 4

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would be considered on a case-by-case basis. However, what follows, is a basic description of the eleven step process for the change example chosen.

OPERATIONAL CHANGE MANAGEMENT
AND SUSTAINING ENGINEERING SCHEME
STEP DESCRIPTION

STEP #1 - Requirement Initiation - An engineering change could be initiated by anyone from any program/agency at any level. Such a change request could be in the from of a Program/Project Change Request (CR), an Engineering Support Request (ESR), Engineering Change Proposal (ECP), or any other program equivalent. For the purpose of this paper, a generic term, "Change Request (CR)", will be used to describe such changes.
When the CR enters the system, a requirements initiation team would receive it and perform the following functions:

A. The team would determine whether the change affected the usage of the station and/or operations, whether the change represented an enhancement to present station design, or whether the change was needed to resolve a problem on board the station. It would also determine if one or more programs/agencies were affected by the CR.

B. The team would determine the criticality of the change.

C. The team would assess the change rationale and insure that the originator had included enough information with the CR (eg. design concepts, etc.) to allow for a future impact assessment.

D. The team would prepare and forward an Engineering Support Request (ESR), or equivalent, that reflected the original CR. The ESR would be forwarded to the appropriate screening boards, where Step #2 of the process would begin.

STEP #2 - Screening Board - The screening boards would be chaired by the Program Operations Managers or designate and supported by various operations discipline and SE&I discipline personnel such as logistics personnel, customer (user) representatives, engineering personnel, operations personnel, manifest personnel, safety reliability and quality assurance (SR & QA) personnel, etc. Each program/agency affected by the change would have a similar arrangement. The purpose of the screening boards would be to initially screen the change and provide for a preliminary disposition in order to keep unwanted changes from choking the full assessment process. Upon receiving the ESR, the screening boards would perform the following functions:

A. The screening boards would perform an initial validation of the ESR to determine if the change paper contained enough information for an assessment, if the change rationale and criticality assessments were proper, and if the change`s effect on their programs design/operations were properly assessed. Each screening board, via its SE&I personnel, would perform an initial integration task to insure that the above tasks were accomplished and that an integrated assessment existed across all affected programs/agencies.

B. The screening boards would determine the changes category (ie mandatory, highly desirable, etc.), its effectivity (eg. one or more orbiters), and would perform an initial determination of how the change would be manifested for launch or by which flight it would be implemented. Again, each screening board`s SE&I support would insure that an integrated assessment existed across all affected programs/agencies. In addition,the screening boards manifesting personnel would work with any other SSP/NSTS manifesting experts (e.g., a Tactical Operations Control Board) to properly coordinate manifesting.

C. Finally, each screening board would provide their initial disposition of the change. The dispositions would take one of two forms: (1) Approval for further full assessment of the change by a change assessment team, or (2) Disapproval of the change, which would result in no further action regarding the change. Any disagreement between dispositions of any of the affected screening boards would result in a conflict resolution appeal to the Associate Administrator for Operations. Such an appeal route would also be available to the CR originator. If all of the screening boards approved the ESR for further assessment, or if the Associate Administrator for Operations, directed approval, then the ESR would be forwarded to an Assessment Team for each affected program/agency and Step #3 of the process would begin.

<u>Step #3 - Assessment</u> - An assessment team for each effected program/agency would perform the following functions:

A. The teams would develop an implementation plan and schedule for the change.

B. The teams would determine the Rough Order of Magnitude (ROM) costs for the change and assess the required contract changes for their programs.

C. The teams would initiate and complete any required studies that might result because of the change.

D. The teams would determine any other impacts resulting from the change (e.g., weight impacts, launch slip impacts, etc.).

E. The teams would assess the interfaces affected by the change and prepare appropriate ICD/IRD changes.

F. Each team, via its SE&I personnel, would coordinate with each other to insure that an integrated assessment would be achieved.

G. Upon completing an integrated assessment, the teams would forward the assessment in the form of an Engineering Analysis and Cost Assessment (EACE), or equivalent, to a Joint Change Evaluation Board, which would begin Step #4 of the process.

Step #4 - Joint Change Evaluation Board - A Joint Change Evaluation Board would receive the EACE for consideration. This board would be chaired by the SSP Program Operations Manager and supported by similar operations managers from all other affected programs/agencies, each with an equal vote. The functions of this board would be:

A. The Board would either approve or disapprove the change. If the Board disapproved the change, no further action on the change would occur, unless a subsequent appeal to the Associate Administrator for Operations reversed the decision. Upon Board approval of the change, a joint Change Control Board Directive (CCBD) would be issued to the Design and Engineering Organizations of the affected programs/agencies, and Step #5 would begin.

B. In considering the change, the Board might also issue further actions regarding the change or as a result of the change. The Board could also return the change back to the respective Assessment Teams for further reassessment.

C. The Board would also issue Contract Change Authorizations (CCA's) to the involved contractors of each affected program/agency, and would notify the affected manifesting/logistics personnel of the decision so that proper manifesting/logistics planning could begin.

Step #5 - Design and Engineering - Each program/agency Design and Engineering organization would receive their respective CCBD's, and begin the normal activities for implementing the change. These activities would include:

a. defining the detailed design requirements and specifications,

b. preparing drawings and/or implementation instructions,

c. defining detailed verification and test requirements,

d. supporting the preparation of test procedures and/or analyses,

e. updating various affected ICD's/IRD's/ACD's/BCD's

f. conducting appropriate design and safety reviews, and

g. performing appropriate assurance analyses.

Each program's/agency's SE&I staff would be responsible for integrating their own activities and coordinating with the other affected SE&I staffs in order to assure an integrated approach to the design and engineering effort. From this effort, Document Release Authorizations (DRA's), or equivalent, would be released to each program's/'agency's manufacturing personnel to begin Step #6 of the process.

Step #6 - Hardware/Software Build - Each program's/agency's manufacturing team would begin the process of actually building the hardware/software associated with the change modification. These efforts would include:

A. support for the procurement of the piece parts and/or software code from the vendors (subcontractors/contractors),

B. the support required for the actual fabrication of each program's/agency's hardware portion of the modification, and the support required for the building of software programs required by any program/agency,

C. the processing of any waivers/deviations required to the original design, including coordination between each program/agency by their respective SE&I personnel,

D. the processing of engineering changes to the original modification design, to facilitate the manufacturing process, by each affected program/agency, along with appropriate integration of these changes by the affected SE&I personnel, and

E. the factory verification support from each program/agency for their portion of the modification, including development through final acceptance verification and certification. Such verification would also include an integrated certification and acceptance verification for the end-to-end system affected by the modification using actual flight hardware/software and/or simulators as required. Such verification would be coordinated and integrated by each program's/agency's SE&I personnel.

Once this step is complete, each program/agency would ship their portion of the mod-kit to the launch site, where the final phase of this scheme would begin with Step #7.
Step #7 - Change Package Support - Each program/agency would have engineering and management support personnel located at the launch site to help perform this step, which would include the following functions: (NOTE: The actual hands-on work at the launch site would be performed in accordance with established methods of operating.)

A. the shipping, receiving and quality assurance (QA) inspection for each program's/agency's portion of the mod-kit,

B. the final assembly and staging for each portion of the mod-kit along with stand-alone power-on-testing that would be required, and

C. the preparation of any final engineering documentation associated with any portion of the mod-kit required for final installation and integrated testing.

Once this step is complete, the mod-kit portions would be turned over to the SSP launch site personnel for the beginning of Step #8.

Step #8 - Verification - SSP launch site personnel would receive each program's/agency's portion of the mod-kit and, off-line from the NSTS processing, integrate the mod-kit into a total on-orbit configuration using actual flight hardware and appropriate simulators. This would be done to accomplish both single and multiple launch package integration and verification to assure that the mod-kit will operate as designed with station/orbiter hardware/software that is already on-orbit. In addition, such verification could augment crew training and be used to verify on-orbit flight procedures. Once this step is complete, Space Station personnel could begin Step #9 of the process.

Step #9 - Transportation Support - Space Station personnel would prepare a configuration definition and mass property analysis for installing various portions of the mod-kit in the Orbiter Aft Flight Deck, Orbiter Payload Bay, and/or the SSP Logistics elements. Close coordination between the SSP and NSTS SE&I, Logistics, and Ground/Flight Operations personnel would be required to assure that orbiter mods were properly scheduled, logistics elements were properly manifested, that the Orbiter Payload Bay and/or Aft Flight Deck was properly manifested, and that on-orbit station installation and checkout operations were properly scheduled. Once these function were completed, Step #10 of the process would begin.

<u>Step #10 - Installation and Checkout</u> - Each affected program/agency would begin the task of supporting and/or installing/manifesting, as appropriate, portions of the mod-kit into their affected hardware/software subsystems/systems. Actual hands-on work would be accomplished by established methods of operating. installations would be followed by appropriate support for final verification and checkout of the affected subsystems/systems. This installation/checkout could occur on the ground and/or on-orbit, and would be followed by an analysis of predicted data and the processing of any final waivers/deviations by each affected program/agency. At the completion of this task, "installation complete (INC)" notices would be given to each affected program's/agency's configuration management and verification personnel teams to begin Step #11 of the process.

<u>Step #11 - Configuration Update</u> - Each program's/agency's configuration management and verification personnel teams would accomplish the final step of this process, which would include:

A. updating all drawings and documentation to the as-build configuration,

B. providing CCBD closeout documentation,

C. completing verification completion notices, or equivalent, (VCN's) and updating the appropriate verification data bases,

D. performing any other required configuration accounting actions required by each affected program/agency.

The completion of the step would complete the entire change management and sustaining engineering effort for such a change.

<u>SUMMARY</u>

This paper has attempted to deal with one aspect of the sustaining engineering effort required for the SSP and other interrelated programs during the SSP operational era - the "Change Management/Implementation Process". The proposed change management scheme is but one way that such a scheme could evolve, but it is felt that such an evolution, or a similar one, will be necessary if the SSP is to cope with the operational complexities that will exist during this era.

Ocean Systems Engineering, Inc.

FRF-108-87
February 27, 1987

C. Mars/SS-OTF
Nasa K.S.C.
Kennedy Space Center, FL 32899

Dear Mr. Mars,

Attached is our "White Paper" giving an overview of the development of teleoperated work systems for sustaining engineering applications. I have also included a section on the development and application of a 30 year sustaining engineering program. Finally, there are papers that address the subsea approach to work systems development and one on applying the man/machine synergy to subsea operations.

If you have any questions or need any additional information, give me a call.

Respectfully yours,

F. Richard Frisbie, P.E.
President

FRF:em

Attachment

CC: J. R. Huff

1441 Park Ten Blvd., Houston, Texas 77084 Telex: 762454 OCEAN SYS ENG (713) 492-2800

An Overall Review of the Development of Teleoperated Systems and Sustaining Engineering Programs in the Deepwater Industry

F.R. Frisbie/M.L. Gernhardt - Ocean Systems Engineering

The subsea industry has been involved in performing subsea work in support of the offshore oil and gas industry for the past twenty years. Initially, none of the subsea equipment was designed for serviceability and all the work tasks were performed by hands on divers (analogous to gloved astronauts). As oil and gas drilling and production moved into deeper water depths, a number of advanced work systems, tools and techniques evolved to service the associated subsea equipment.

These advanced work systems evolved from atmospheric diving suits with mechanical end-effectors, to manned submersibles with manipulators, on to a large variety of tele-operated manipulator work systems.

Presently we are now beginning work on developing autonomous robots with low level artificial intelligence.

Development of Remote Work Capabilities

The evolution of these work systems has been shaped by the simultaneous demands of safety, cost effectiveness, reliability, flexibility and ease of maintenance and repair. Over the past 20 years the subsea industry has gained several million hours of operating experience with these systems. Through this experience we have learned the types of tasks that various systems performed well, the tasks they don't perform well, and the special tooling and interface engineering that can be applied to greatly improve the systems' performance.

One of the most fundamental lessons that our industry learned is that the performance and efficiency of tele-operated manipulators is determined more by function of the task design, task-to-manipulator interfaces, and manipulator tools than of the manipulator itself. This lesson came from hard experience. Initially, all of our engineering efforts went into developing more sophisticated manipulators. The resulting manipulators (produced in the 1970's) were quite sophisticated and probably unmatched even today. These manipulators incorporated six degrees of freedom and seven controllable axis with a compliant, spatially correspondent, inverse kinematic control system based on a master/slave user interface. They also incorporated force feedback and dynamic compliance, allowing the operator to feel the loads imposed on the master. Stereo video cameras and hydrophones were employed to increase the tele-presence capabilities and the operator's performance.

In spite of these technological advances, the ability of the manipulators to perform cost effective work was generally poor. The primary reason for this was that we had not addressed the work tasks that the manipulator had to perform. This limitation in the ability to perform work restricted the depth of cost effective oil production to those depths where divers could intervene if necessary.

The same limitation could very easily result in space, and like the oil industry, the commercialization of space will be suppressed if cost effective work systems are not developed.

In the past five years we have seen an enormous expansion in the areas of equipment design interface engineering and tele-operated tooling.

We now work very closely with the oil companies to design their equipment for serviceability. This work typically has a minimal impact on the overall cost of the equipment but increases the performance of tele-operated manipulators by orders of magnitude. Typically this work includes:

- o defining the tasks and subtasks down to specific functions, degrees of freedom, forces and torques,
- o defining manipulator work envelopes and access requirements,
- o establishing docking ports and alignment guides,
- o establishing visual identification and reference points,
- o developing standardized manipulator-to-equipment interfaces,
- o developing a variety of modular tools with standardized manipulator-to-tool interfaces.

The resulting subsea equipment is then not only easier to service with tele-robotic systems but is proportionally easier to service with hyperbaric divers and atmospheric diving suits with end-effectors. The same analogy would apply to astronauts using gloves and mechanical end-effectors.

This design process has significantly reduced the costs of supporting deepwater drilling and production and has resulted in cost effective drilling operations in 7500 fsw and sophisticated subsea production facilities in 1500-2000 fsw. This was not thought possible in the seventies, even though the manipulator technology existed. These cost savings have been documented in numerous case studies which show between five hundred and several thousand percent cost savings over a two-year period.
Clearly, the same type of design process is applicable to space operations. This does not mean that a premium should not be placed on developing and expanding robotic technology. Quite the opposite is true. Defined spatial orientations, tasks, and interfaces provide the basis for implementing a number of robotic technologies, including machine vision systems, advanced control systems and sensors, knowledge based artificial intelligence systems and a variety of advanced robotic tools. All of which can be designed to address multiple tasks on a modular basis.

Without this type of design process, implementation of advanced robotics will be suppressed because when the relationship between the work task and work system is changing in an undefined manner it is at best difficult to coordinate and at worst almost impossible.

Sustaining Engineering Concepts

Deepwater production equipment is installed with a 30 year operating life in mind. Certain elements of the subsea equipment can be recovered, at a very high cost, whereas other elements will remain on the seabed throughout the life of the field and must be inspected, maintained, and repaired in situ. Failure is permanent unless replacement/repair was addressed at the outset of the planning process. This area is actively addressed because of the economic implications of lost production, pollution, etc. There are two phases to long term IMR (Sustaining Engineering): Preservice and Inservice.

Preservice: This phase calls for the complete, in excruiating detail, examination of the equipment, life cycles, inspection needs, maintenance requirements, and repair criteria. This falls under Development Engineering and incorporates historical data, analytical input, field service input, manufacturer's data, and experience. From this examination, long term IMR specifications can be developed that address the total range of support that the equipment will require throughout its operating life.

The IMR specifications are combined with the input from the Maintenance Engineering for the Development of the IMR System which includes a database program supporting a 30 year program broken into five-year and one-year cycles . The database is developed such that annual IMR requirements can be modified in real time by incorporating future requirements based on the results of an ongoing inspection.

The definition of work task requirements is carried out to insure that all the necessary work tasks required to form the long term IMR have been defined. This phase takes into account all of the various types of equipment and the work tasks that are associated with each individual item of equipment. This leads to the definition of the maintenance and repair procedures which is also dependent on the development of the IMR system itself. The maintenance and repair procedures are laid down as a subset of the work task requirements such that the method and equipment required to execute the work could be defined and analyzed for flexibility, cost effectiveness, and reliability.

Once the work tasks are defined it is essential to determine the work envelopes and functions required. This is critical when dealing with procedures to be performed by teleoperated systems. Work envelopes and functions must be fully analyzed to insure that accessibility of both a teleoperated system and the manipulator or automated tooling system is compatible with the items to be inspected, maintained, and/or repaired. The purpose of the work envelope and function analysis is not only to prove their appropriateness but to attempt to reduce the number of work envelopes and functions such that a reasonable teleoperated system is capable of supporting a wide range of maintenance and repair procedures. If the work envelope and function work is carried out properly the amount of additional tooling and the need for additional teleoperated systems can be reduced in number, hopefully to one.

It is also in this phase when it becomes obvious whether a special purpose teleoperated system is a more effective tool than a more generic teleoperated system which has changeable work packages. Further analysis may lead to the point where manned intervention is a more satisfactory solution than the teleoperated options in that the task may be so specialized or difficult that it is not reasonable or prudent to depend on a teleoperated system. This area leads to the selection of the best system to carry out long term IMR work on the equipment and also insures that the minimum number of systems are required to carry out the full range of IMR tasks. The selection of the proper work system is fundamental to long term, cost effective maintenance of the subsea production facilities.

Subsequent to this it is necessary to address the interface engineering on the equipment itself to insure that it is compatible with the work systems which will be carrying out the IMR work. Again, the driving force is to come up with standardized interfaces such that the teleoperated system does not require a wide range of interchangeable tooling or manipulator end effectors to perform the necessary work. Over the years it has been shown that the work can be carried out by a minimum number of end effectors and tools if interface engineering is carried out in a disciplined and analytical method. This leads to the design of the actual tooling, mocking up, and testing to verify that the end effectors and tools are compatible with the interface engineering which is being carried out on the subsea equipment. This is followed by final testing and acceptance prior to service.

Inservice: Development of the 30-year IMR program in conjunction with the definition and selection of the appropriate procedures, work system and interface engineering results in cost savings that exceed 50 times the cost of the front end work under normal circumstances. More importantly, it guarantees that the systems will continue to function and produce throughout the 30-year life of the program. As deepwater development costs are approaching one billion dollars for individual projects and the value of production is several times that, there is an overriding consideration for executing this front end work in a thorough, timely, and quantifiable manner. A great deal of design and testing makes up this front end (preservice) effort. Each project adds significantly to the existing database. At present there are six major developments in deepwater that are totally dependent on long term support by teleoperated systems.

The inservice aspect of IMR is the actual long term operational support of the subsea equipment. This is where the routine work defined by the 30 year program is carried out in accordance with the prescribed program and with changes that are generated with time. In addition it is in this phase where we deal with failures, faults, or inadequate performance. The following section will describe the general steps taken when a failure, fault, or inadequate performance is noted and methods taken to address and correct the deficiency. The first aspect is that information is immediately fed to safety to determine if there is a safety related problem and what interim requirements should be implemented during the time it takes to upgrade the performance. The safety group's decisions cannot be negated by any other group without a formal review process. This ensures that short term decisions cannot hamper the decisions of safety. At the same time the original design engineering is informed through an equipment failure notification process. Engineering in this case denotes both the inhouse and the equipment manufacturer's groups - if they are a separate organization. The steps which follow are similar in both organizations and are carried out in parallel with the informational results being exchanged at each step along the way. This insures that there is both a checks and balances and that nothing is left unaddressed due to oversight on either the two groups.

The engineering groups will carry out a detailed design analysis review to insure that the system as designed, met the specifications and the life cycles required of it. The determination of failure will be made to determine exactly what component or part has failed, what the method of failure was, and whether it would appear to be a random failure or a failure based on the life cycle and/or loading requirements imposed upon the equipment.

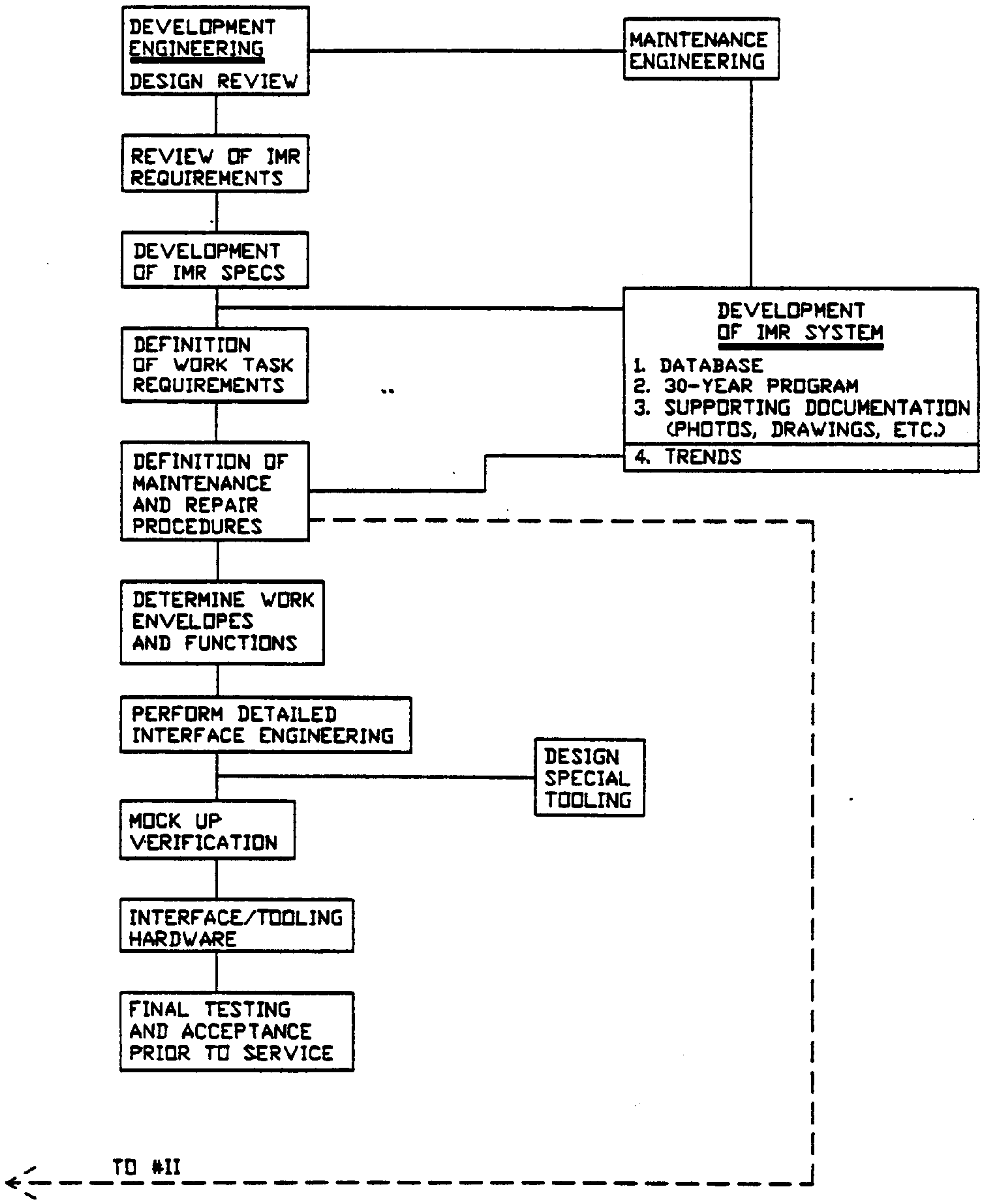
Once this phase is completed a new prototype will be defined, designed, and developed. It will then go through a series of verification phases the first of which being a materials test to insure that the new materials are appropriate and provide satisfactory results for the long term solution to the problem. The materials test verification phase leads to a functional test verification where an item is put through the full range of functional tests to verify that it satisfies the new specification generated for it and is capble of performing the work required.

After the functional test has been verified the equipment is tested to show that it can replace, exchange, and interface with existing hardware. A long term life cyclic verification is carried out to satisfy the engineering group that the new life cycle requirements are being met. This leads to final engineering acceptance testing at which time the equipment is put into the field engineering group and the installation procedures are developed in conjunction with engineering.

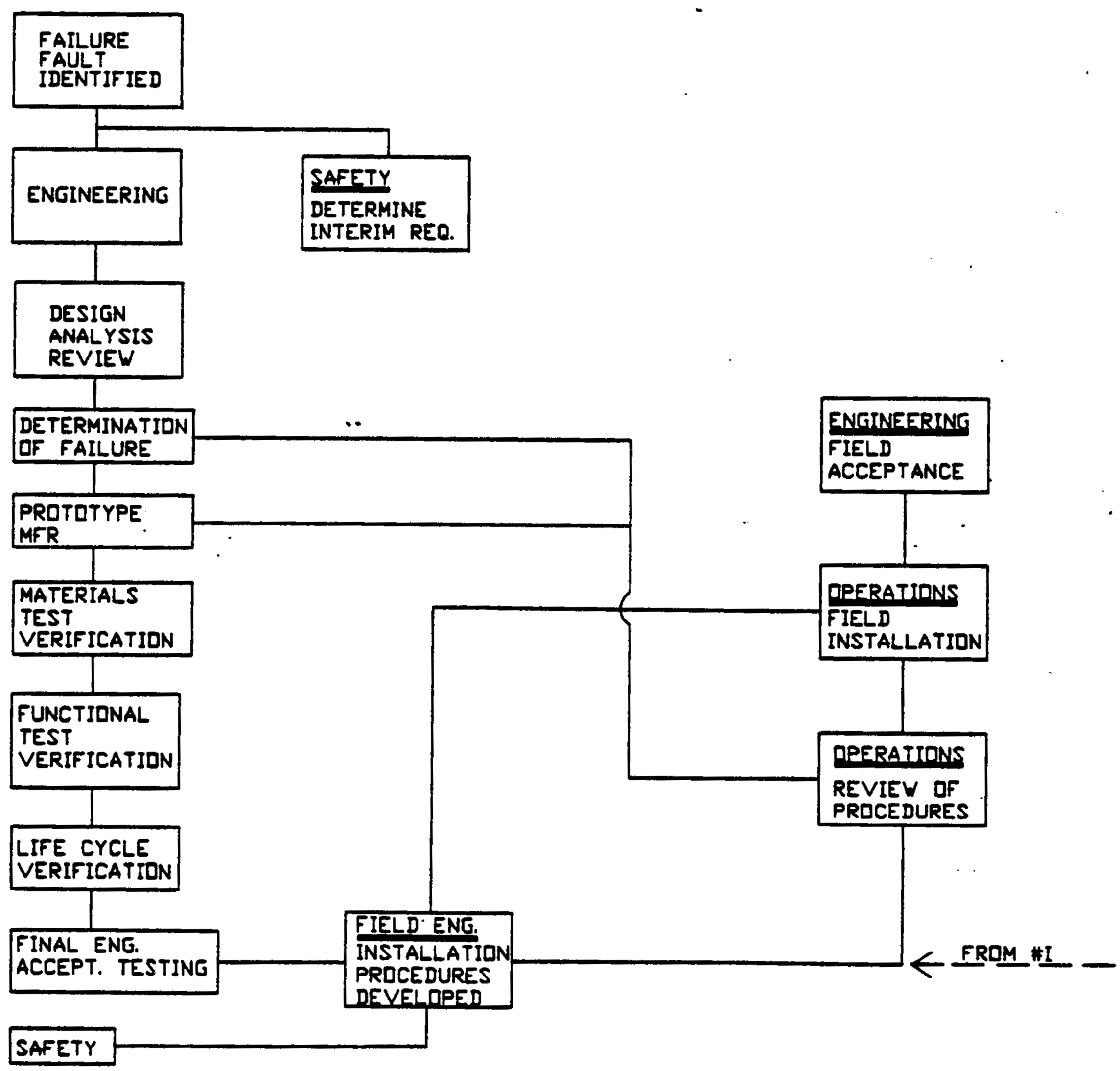
Safety is involved throughout the process to insure that the safety requirements are being addressed and satisfied at each step of the program. The procedures go through an operational review process to insure that they are compatible with both the existing system, the equipment and personnel available to carry out the work, and the long term operational support of that particular item. Field installation is carried out in conjunction with engineering and field service engineering and after the equipment is fully installed and tested there is a final field acceptance test carried out. At this time the equipment is turned over to the long term operating group.

The preservice and inservice engineering of subsea equipment has become the most important aspect of deep water development. The fact that equipment placed in deep water can neither be accessed nor recovered through conventional means throughout the 30 year life of the program means that the design, interface, and remote work support systems that will be needed to insure the 30 year operating performance of the equipment needs to be carefully addressed at the outset. History has shown that the degree of effort placed into the upfront engineering involved in this entire program is recovered many times over throughout the life of the project. Failure to address any one detail in sufficient degree to insure its compatibility with the system can lead to the total shutting in of a reservoir and the loss of production. The implications of this from an economic point of view are extremely severe. In addition failures that could effect safety have implications every bit as severe. Deep water production systems have the unforgiving element in that they can never be retrieved, repaired, and inspected by conventional methods. All this work must be done remotely through the use of predesigned, pre-engineered equipment. Many years of experience in carrying this work out in shallow water with divers has provided the basis which has allowed the production systems installed in deep water to be supported successfully to date. Each project gains considerable knowledge from the experience of prior projects and the cost effectiveness of each solution continues to grow as developments occur.

SUSTAINED ENGINEERING I
(PRESERVICE)



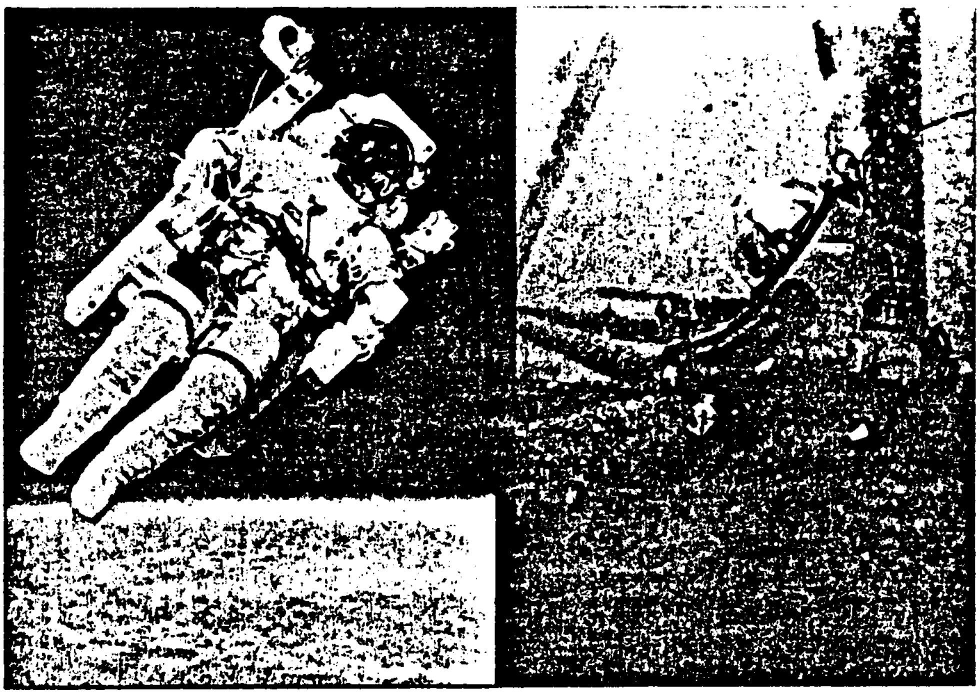
SUSTAINED ENGINEERING II
(INSERVICE)



SUBSEA APPROACH TO WORK SYSTEMS DEVELOPMENT

by

M. L. Gernhardt, F. R. Frisbie and C. E. Brown
Oceaneering International
(Ocean Systems Engineering)



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SUBSEA APPROACH TO WORK SYSTEMS DEVELOPMENT

M. L. Gernhardt, F. R. Frisbie and C. E. Brown
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INTRODUCTION

The requirement for subsea work capabilities to support offshore oil production in increasing water depths has led to the evolution and development of a variety of work systems. These work systems range from hands-on divers to manned atmospheric diving suits with end effectors and a variety of tele-operated manipulator work systems.

Selection of the optimum work system to perform an operation depends on the work task requirements, the environmental conditions, physiological limitations, logistical requirements and economic considerations. The resulting selection may be a single work system with special modifications or a combination of work systems exploiting the strong points of each.

The commercial diving industry has more than twenty-five years experience in work systems development resulting in several million hours of underwater operations.

This paper will briefly overview the working environment, physiological limitations, work task requirements and work systems in the subsea industry.

WORKING ENVIRONMENT

The commercial underwater working environment to date is characterized by the following parameters:

- pressure: 0-3350 psi (0-7500 ft)
- temperature: 32-92° F
- visibility: 0-200 ft
- waves: 0-30 ft
- currents: 0-4 kts

In many respects, the underwater environment is a more hostile environment to work in than outer space. This is particularly true with respect to visibility and current/wave forces. The underwater environment is also dynamic and capable of radical changes over short time periods, imposing greater operating ranges on the work systems.

PHYSIOLOGICAL LIMITATIONS

The main physiological limitations are summarized as follows:

<u>Decompression</u> - After working underwater at increased pressures, divers must undergo a gradual decompression to sea level to avoid the bends. This decompression time can range from minutes to days, depending on the depth and duration of the dive.

<u>Inert Gas Narcosis</u> - For air diving below approximately 150 ft, the increased partial pressure of nitrogen creates a narcotic effect on the cen-

tral nervous system. To eliminate this effect, helium/oxygen (heliox) breathing mixes are used for deeper dives.

High-Pressure Nervous System - HPNS is associated with rapid compression on heliox to deeper depths. It can cause dizziness, disorientation and mild convulsions.

Gas Toxicity - Oxygen and carbon dioxide toxicity are critical and must be carefully controlled during diving operations.

Thermal Limitations - Temperature and humidity must be maintained within narrow limits, particularly with the greater heat capacity of heliox breathing mixtures.

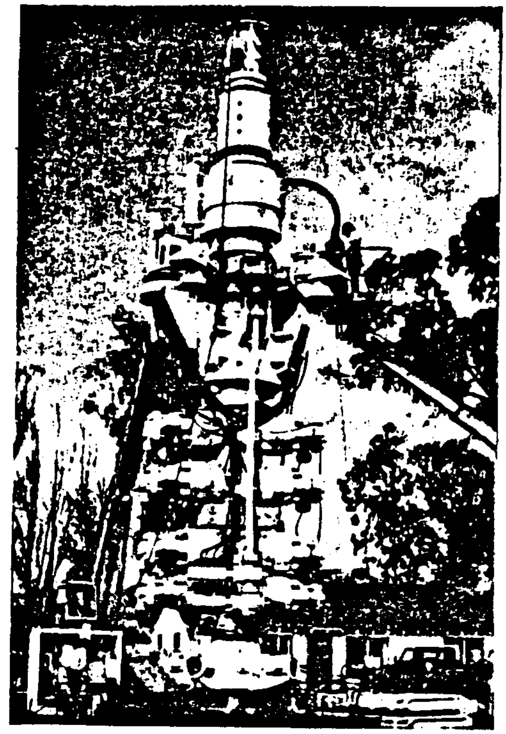
WORK TASK REQUIREMENTS

The work task requirements can be broken down into the following phases relative to the evolution of a producing oil field.

- Drilling Support
- Construction & Maintenance
- Inspection
- Repair

Drilling Suport - The work requirements for this phase are primarily related to the installation, observation, maintenance and recovery of the subsea blowout preventer and associated equipment.

The basic work tasks are simple attachments, observations, vertical alignments, valve actuation, debris removal and changeouts of hydraulic hoses, electrical cables, connectors and modules.



Typical Subsea Blowout Preventer

Construction - This phase is primarily involved in the installation and hookup of offshore platforms and pipelines. The platforms are typically fabricated onshore and then towed to the offshore location.

The work task requirements in the construction phase involve complex rigging and alignments, assembling mechanical connectors, burning, welding, water jetting, special tooling and frequently onsite fabrication and modifications.

Inspection - The work requirements for inspection are primarily involved with the cleaning and inspection of in-service platforms and pipelines.

The work tasks required are observation, water jetting, cleaning with power tools, closeup photography, detailed measurements and nondestructive testing.

Repair - The work requirements for repair are primarily involved with mechanical and hyperbaric welded structural repairs of platforms and pipelines.

The work task requirements associated with repairs are detailed measurements, complex rigging and alignments, burning, welding, special tool operation and on-site fabrication and modifications.

GENERIC WORK TASKS

DRILLING SUPPORT	INSPECTION
OBSERVATION VERTICAL ALIGNMENTS COMPLEX ALIGNMENTS HOSE CHANGEOUTS CONNECTOR CHANGEOUTS MODULE REPLACEMENTS DEBRIS REMOVAL CABLE CUTTING PLACING EXPLOSIVES	OBSERVATION SIMPLE ATTACHMENTS DEBRIS REMOVAL POWER TOOL USE SPECIAL TOOL USE NDT WATER JETTING MEASUREMENTS
CONSTRUCTION MAINTENANCE	**REPAIR**
OBSERVATION VERTICAL ALIGNMENTS COMPLEX ALIGNMENTS DEBRIS REMOVAL CABLE CUTTING METAL BURNING WELDING RIGGING POWER TOOL USE SPECIAL TOOL USE WATER JETTING ASSEMBLING ONSITE FABRICATION MEASUREMENTS	OBSERVATION VERTICAL ALIGNMENTS DEBRIS REMOVAL CABLE CUTTING METAL BURNING WELDING RIGGING POWER TOOL USE SPECIAL TOOL USE WATER JETTING ASSEMBLING ONSITE FABRICATION MEASUREMENTS

WORK SYSTEMS

This section will overview the various types of work systems. These work systems can be classified as follows:

- Hyperbaric Diving
- Atmospheric Work Systems (Manned)
- Tele-Operated Work Systems
- Hybrid Systems

Where applicable, each type of work system will be outlined in the following format:

- Work Capabilities
- Special Interface Requirements
- Limitations

HYPERBARIC DIVING

Hyperbaric diving involves divers working in an ambient pressure, "hands-on" environment. In order to work at ambient pressures, high-pressure breathing gases must be inspired to maintain a pressure equilibrium across the lungs. This leads to tissue absorption of inert gases and a decompression requirement. Diving can be classified into three types with respect to decompression:

Surface Diving - For surface diving, divers will descend to depth, perform a task within a limited amount of bottom time, and then decompress back to the surface in accordance with a predetermined decompression schedule. This type of diving applies up to depth of 300 ft.

Bell Bounce Diving - For bell bounce diving, divers will descend to depth (300-600 ft) in a diving bell at one atmosphere. After analyzing the job requirements, the bell is rapidly compressed to ambient pressure, at which point the divers lock out and

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perform the work task within a limited excursion time.

After completing the job, the diver returns to the bell and makes a pressure seal. The bell is then brought to the surface and mated to a deck decompression chamber, where the diver completes the decompression requirement. The principal limitation with this type of diving is the low working time to decompression time ratio. For 30 minutes bottom time at 500 ft, approximately 28 hours decompression is required. If a job requires long bottom times, then saturation diving will be used.

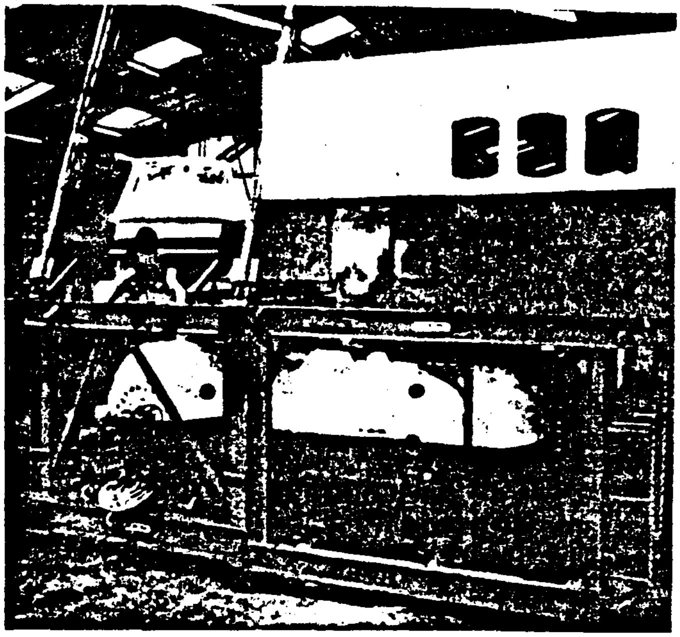
<u>Saturation Diving</u> - For saturation diving, the divers will remain at a pressure equivalent to their working depth for up to 40 days. Once the body is saturated with inert gas at a given depth (approximately 8 hours), then the decompression requirement is fixed, regardless of the time spent at that depth.

Saturation diving requires the use of a special modular diving system made up of the following components:

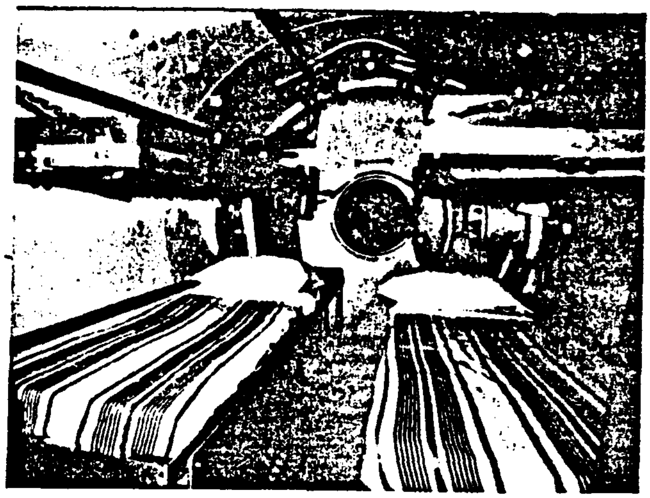
Diving Bell: The diving bell is a pressure vessel designed to be mated to a deck decompression complex, allowing diver transfer under pressure between the deck complex and the worksite.

Deck Decompression Complex: The deck decompression complex consists of two or more pressure vessels, the primary purpose of which is to provide safe living quarters for the divers while under pressure between working dives, or decompressing upon completion of the job. As the deck chambers are modular, any number can be bolted together to accommodate various crew sizes.

Control Van: Power, communications, gas control, gas monitoring and environmental control for the deck complex and the diving bell are all housed in a single control van. The life support systems are all modular so that in an emergency, any pressure vessel of the system can be isolated.



Six-Man Saturation Diving System



Inside View of Living Chamber

Control Van Showing Modular Life-Support Control Panels

Work Capabilities

Hyperbaric diving, because of human perception, judgment and dexterity, provides the most complete and versatile work system in the subsea industry. Divers were the original work system and have performed efficiently all of the underwater tasks required for offshore oil production. This baseline experience with man has provided the knowledge required to design alternate work systems, some of which can perform certain tasks more effectively than man.

Special Interface Requirements

Special man/equipment interfaces are usually not provided. Typical offshore structures are constructed from tubular trusses from 10 to 36 in. diameter. This makes it possible to attach to the structure in a variety of body positions using arms and/or legs. On larger-diameter tubulars, work restraint stations are fashioned from rope tethers and other items of opportunity.

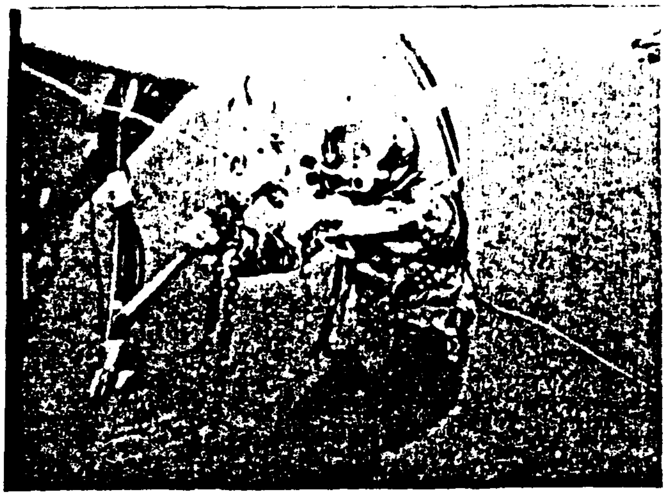
Occasionally, on special projects, diver work stations are designed into the structure at key locations. This approach has proved to be cost-effective but tends to be the exception.

Limitations

The following are some of the limitations associated with hyperbaric diving:

- Human safety
- Depth limitations
- Dive duration limitations
- Decompression penalties
- Support crew and space requirements
- Reduced accessibility to hazardous areas

Diver Using an Impact Wrench to Tighten Bolts on a Riser Clamp. Note Use of Legs as Attachment Point



Diver Attaching Come-Along to Secure Underwater Welding Habitat

ATMOSPHERIC WORK SYSTEMS (AWS)

Atmospheric work systems utilize man in a one-atmosphere shirtsleeve environment and can be subdivided into atmospheric diving suits (ADS) with end-effectors, and manned submersibles with manipulators.

Atmospheric Diving Suits (ADS)

JIM: JIM is an atmospheric diving suit with articulated arms and legs, the limbs being neutrally buoyant so that operator effort is only required to overcome the friction of the articulated pressure balanced joints. The JIM suit receives no power from the surface with its lift umbilical containing only a communications cable.

Life support up to 72 hours is provided through onboard oxygen bottles. Since the suit does not leak, the nitrogen initially in the suit serves as a dilutant inert gas throughout the dive, eliminating the requirement for a two-gas life support system. Carbon dioxide removal is provided through an oral-nasal lung-powered scrubber.

The end-effector assemblies work via a through-hull solid shaft penetration operated by the hand motions of the pilot. They can be continuously rotated in either direction and locked in position. The end-effectors have standardized grip surfaces and a rope hook used for sliding down guidewires. These end-effectors are able to interface with pre-engineered tools and work stations and have remained essentially unchanged throughout the entire commercial life of the suit.

JIM Working on Subsea Wellhead

WASP: The WASP is a free-flying atmospheric diving suit which utilizes the same articulated arms as JIM, but has no legs. The WASP receives power and communications through an umbilical to the surface. Translation and

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station-keeping are provided through four foot-controlled thrusters.

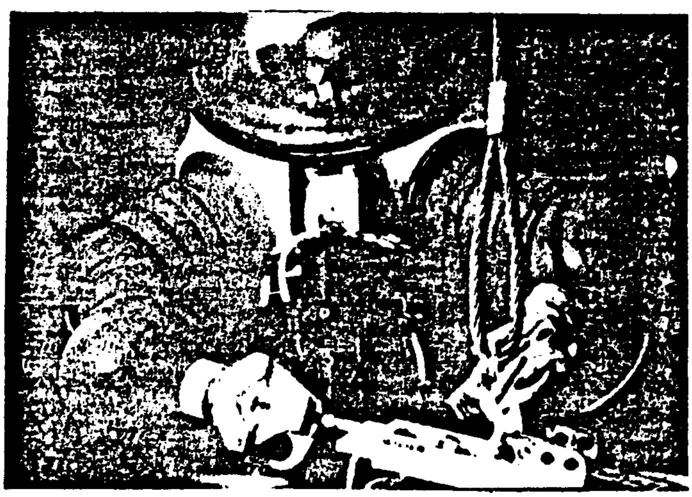
Life support is provided by an oxygen makeup system similar to JIM; however, fan-powered scrubbers are used for carbon dioxide removal.

Work Capabilities - The JIM suit is used primarily on drilling support. It has successfully performed inspections, attachments, debris removal, replaced valve assemblies and other tasks associated with drilling support.

Tasks performed with JIM require interface engineering between the end-effectors and the equipment, and typically require a longer time than a hyperbaric diver.

The WASP has similar capabilities to JIM with respect to drilling support. It can also be used for mid-water work such as general platform inspection, cathodic protection measurements, waterblasting and other simple manipulative work tasks.

The WASP has been used successfully on some specially-interfaced midwater construction and repair projects such as mechanical clamp and anode installations.



JIM Operating a Lifting Jack Using Both End-Effectors

WASP Performing Platform Inspection

Special Interface Requirements

JIM needs a pre-installed walk deck to translate around the subsea equipment. Due to the limited ability to translate the bulk of the suit, and anthropomorphic limbs length limitations, some of the subsea equipment must be extended to JIM's work envelope. The equipment must also be designed for interfacing with the jaws of the end-effector. There are a variety of hand tools used by the JIM, each having a standardized end-effector interface, allowing multiple tools to be used without changing the end-effectors.

The WASP requires standardized equipment and tool interfaces similar to JIM. Also, depending on the job, special work-restraint systems and equipment extensions are utilized.

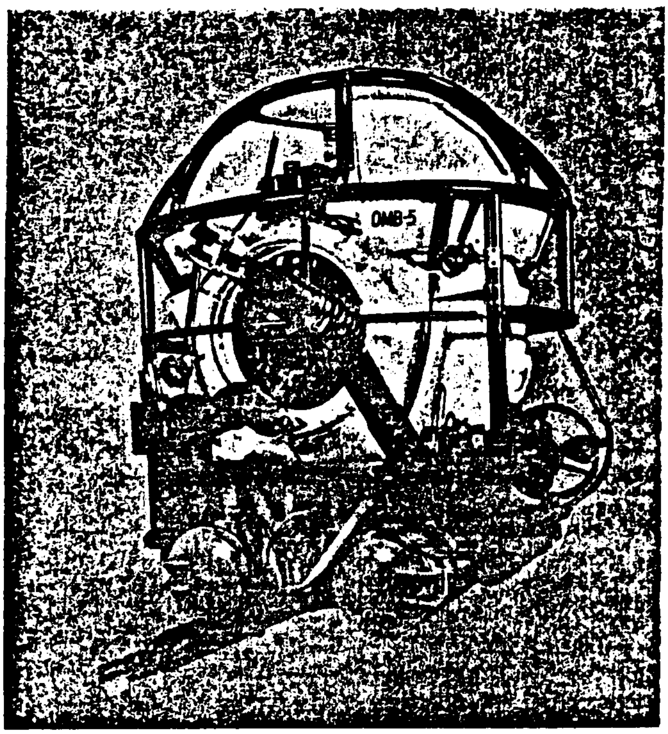
Limitations

- Human safety
- Depth
- Dive duration
- Reduced accessibility/work envelopes
- Restricted to bottom work (JIM)
- Stationkeeping when performing certain tasks in free-flying mode (WASP).

MANNED SUBMERSIBLES WITH MANIPULATORS

ARMS Bell

The ARMS bell has an interior maintained at one atmosphere, and is designed to support a two-man crew for 6 hours mission time plus 84 hours reserve. Observation of the work site is provided through a wide-angle plexiglass viewport. The bell is equipped with thrusters to provide lateral translational capabilities about the worksite.



ARMS Bell

The ARMS Bell will have up to three manipulators. The manipulator in the center of the bell has two degrees of freedom and typically is used as a work restraint system. On the left and right are either two seven-function manipulators or a seven- and five-function manipulator. The manipulators have standardized locking jaw end-effectors. Typically, the five-function manipulator is used as a grabber to initially align the work task, while the seven-function (six degrees of freedom) manipulator performs the dextrous work task. The five- and seven-function manipulators are usually spatially correspondent, utilizing a master/slave relationship. The work restraint maniuplator is typically rate feed.

On some submersibles, the seven-function manipulator is equipped with force feedback, greatly enhancing the work capabilities.

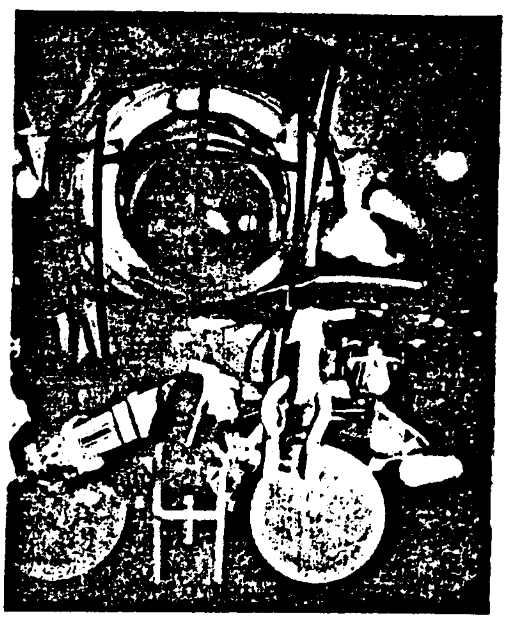
Typically, the manipulators are used only one at a time for the following reasons:

- In order to effectively use two manipulators simultaneously, both must have force feedback and dynamic compliance in order to optimize the resultant force vectors.
- Most jobs do not justify the expense of two force-feedback manipulators and can be performed using the various manipulators sequentially.
- Operator demands are greater. This is particularly true in the tele-operated systems where spatial perception is restricted by camera viewing angles and the inability of pan-and-tilt mechanisms to scan as quickly as the human eye.

In addition to the ARMS Bells, there are a variety of one-manned tethered submersibles with similar manipulator arrangements and work capabilities. These include the Mantis, Wrangler and an untethered version of the Deep Rover.

Work Capabilities

The human in a comfortable shirtsleeve environment provides high visual awareness and interpretive capability. With longer manipulators, these systems have a greater working envelope than the ADS suits, whose work envelopes are limited by anthropomorphic limbs. These capabilities have combined to produce an excellent track record in performing all the work tasks associated with drilling support. Because of size, translational capabilities and mobilization requirements, these systems are not frequently used in the other work phases.



ARMS Bell Aligning a Shackle Pin

Special Interface Requirements

- Standardized end-effector/equipment interface similar to the ADS suits
- Work restraint attachment points

Limitations

- Human safety
- Depth limitations
- Dive duration limitations
- Increased size, space, crew
- Reduced accessibility and translational capabilities

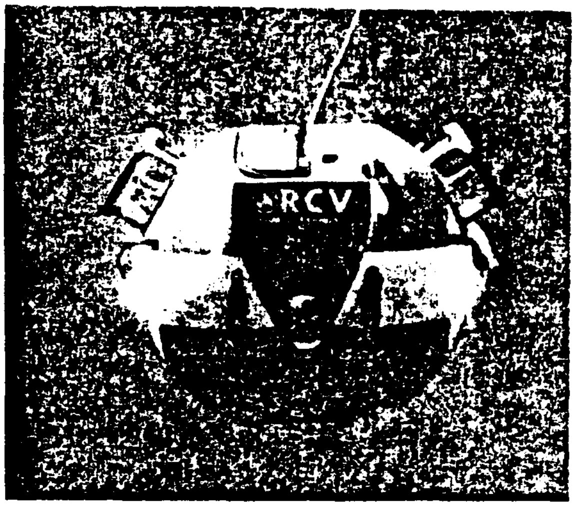
TELE-OPERATED WORK SYSTEMS

Tele-operated work systems are controlled by humans viewing television monitors remote from the worksite. The various types of systems can be classified as follows:

- Inspection Vehicles
- Light Work Vehicles
- General-Purpose Full Work Vehicles
- Modular Work Vehicles
- Special-Purpose Vehicles/Machines

INSPECTION VEHICLES

This class of tele-operated work system consists of a variety of small, tethered, remote-controlled, self-propelled observation vehicles. They have onboard video cameras typically mounted on a pan-and-tilt mechanism. This, combined with superior mobility, allows the inspection vehicle to observe underwater operations from a variety of orientations and in confined areas.



Inspection Vehicle

Work Capabilities

These vehicles are used extensively throughout all phases of oil production. In drilling support, they serve as flying eyeballs to allow surface crews to observe the underwater operation of subsea equipment and potentially identify or prevent problems.

In construction, they are used to monitor subsea operations and to locate and pre-inspect work sites, allowing the divers or other work systems to identify and plan job requirements prior to diving.

For platform inspection, they are used to perform the general visual inspection of the platform. In this role, they can be more effective than hyperbaric divers because of superior translational capabilities, depth-independent operations (within design limits), and longer dive duration capabilities. They also produce a permanent, annotated video documentation of the entire inspection.

For platform inspection, typically the divers will be performing the detailed cleaning and inspection work, while the inspection vehicle does the general "flyby" inspection. This simultaneous operation reduces the total job time requirements. These vehicles are also used to monitor diver performance and safety.

Special Interface Requirements

There are no work interface requirements, as these vehicles do not have manipulators. On some subsea equipment, location reference systems are provided to orient the pilot.

Limitations

- Limited visual awareness
- Low interpretive capability
- No manipulative capabilities
- Limited payload capabilities
- Inadequate real-time response to changing environment

LIGHT WORK VEHICLES

This class of vehicles is similar to the inspection vehicles; however, they have increased payload capabilities and are capable of utilizing small, limited manipulators.

Work Capabilities

These vehicles can perform the same role as an inspection vehicle, with some loss of mobility and accessibility. Additionally, they can carry instrument packages, tools and can perform very simple manipulative tasks, such as attachments and placements. They play a bigger role in diver support in that they are capa-

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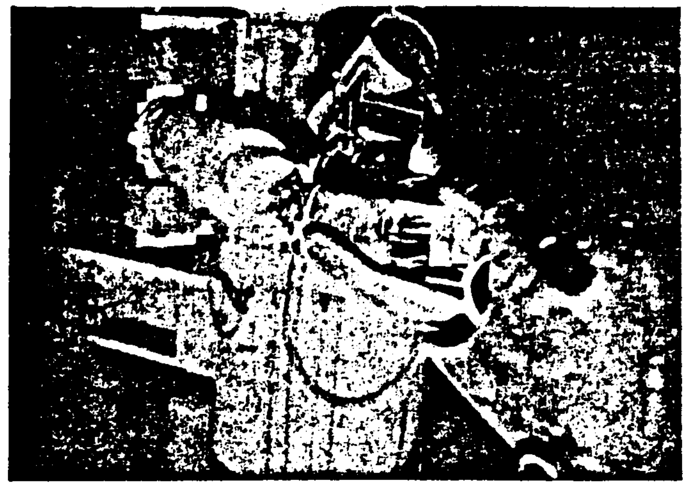
ble of transporting tools to and from the diver at the worksite. They can also be used as a temporary tool storage platform.



View from Manipulator-Mounted Camera of Work Vehicle on Subsea Blowout Preventer

Interface Requirements

- Standardized end-effector/equipment interface
- Location reference systems for pilot orientation

Limitations

- Can perform only simple manipulative tasks
- Other limitations same as inspection vehicle.

GENERAL PURPOSE WORK VEHICLES

These are larger vehicles designed to perform manipulative work. They are usually equipped with a five-function and seven-function spatially correspondent manipulators. These manipulators utilize a master/slave control with the speed of the slave proportional to the master. In some cases, the seven-function manipulator is enhanced with force feedback and dynamic compliance, which allows the operator to feel imposed loads. This capability greatly increases work performance due to increased sensitivity and awareness of the work task.

The manipulators are typically used sequentially with the five-function initially aligning the work task, which is then completed using the more dextrous seven-function manipulator.

Work Capabilities

Although vehicles of this type are used in all phases of oilfield production, their primary application is in drilling support. The main reason for this is that most of the required tasks and subtasks have been well defined and are capable of being reduced to exactly the functions performed optimally by manipulators.

General purpose work vehicles are also used in construction for observation, diver support and pre-defined work tasks.

Interface Requirements

- Standardized manipulator/equipment interfaces
- Work restraint attachment points
- Location references

Limitations

- Limited visual awareness due to restricted camera viewing angles, inadequate scanning capabilities of pan-and-tilt mechanisms, and surface viewing monitor limitations
- Low interpretive capability
- Inadequate real-time response to changing environments
- Limited manipulative capability compared to the human hand
- Requirement for standardized manipulator/equipment interfaces
- Generally inflexible to unpredicted changes

MODULAR WORK VEHICLES

Modular work vehicles consist of a basic vehicle that provides propulsion, telemetry and control. The basic vehicle is capable of carrying, controlling and operating a number of special work packages that address specific tasks. Modular work vehicles are large systems with excess power and control functions in order to accommodate a number of add-on packages, including contingencies for future expansion.

Work Capabilities

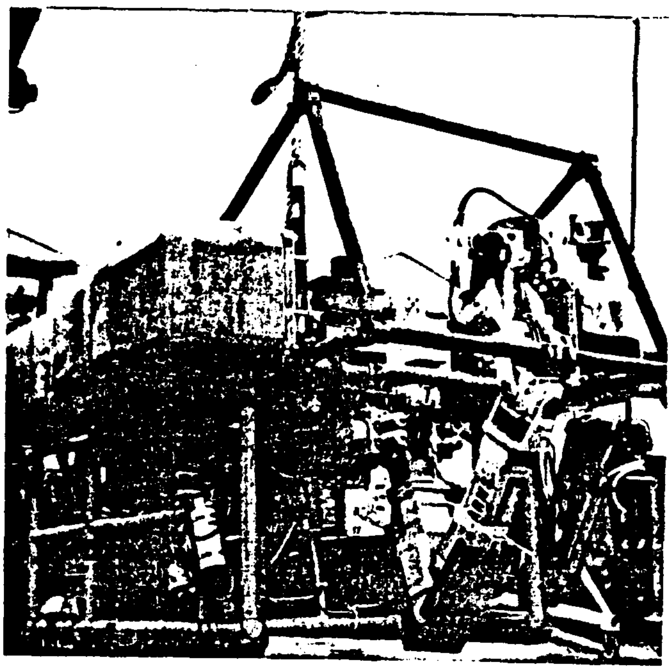
The modular work vehicle's capabilities are based on the propulsion and control characteristics available on the basic vehicle. The work packages can be tailored to drilling activities, as well as support, inspection and maintenance taks. The success of the modular work vehicle is dependent on the functional specifications and the tradeoffs of a wide range of requirements within a single basic vehicle. If necessary, opposing requirements can be eliminated from the basic unit by incorporating their characteristics within the work package itself.

Interface Requirements

- Same as General Purpose Full Work Vehicle.

Limitations

- Basic unit size and complexity increased to support range of work packages
- Accessibility limitations due to overall system size
- Other limitations same as General Purpose Full Work Vehicle



Typical Modular Work Vehicle
with Force Feedback Arm

SPECIAL-PURPOSE WORK SYSTEMS

These units are designed from the outset to carry out a specific set of tasks. The power, telemetry, configuration, manipulation, tooling, etc. are selected and/or developed to support the defined scope of work.

Special purpose systems are extremely effective in carrying out the required work, and represent a highly productive and reliable method of performing work. Two examples of special purpose vehicles are DYNACLAMP and RIG BANDIT.

Dynaclamp: The DYNACLAMP is a special purpose machine designed to carry out the cleaning, photographing and detailed inspection of the welds found at the nodal joints of tubular members. This highly complex work imposes constraints on accessibility, viewing, orientation and precise manipulator functions that cannot be addressed by standard systems. The DYNACLAMP consists of a special clamp with a rotary platform holding twin manipulators, cameras, cleaning heads and telemetry/control components supported by its own umbilical. DYNACLAMP is delivered to the worksite by diver, ADS or ROV, greatly expanding their work capabilities.

Rig Bandit: The RIG BANDIT is a passive work system designed for guidewire-supported drilling support. The RIG BANDIT consists of a frame holding manipulators, lighting and cameras that is attached to guidewire and lowered from the surface. The RIG BANDIT can be clamped to the guidewires at the working depth to provide a stable platform. This configuration restricts translational capabilities. However, the system carries out certain tasks effectively with a less complex system than would result from adaptation of a general-purpose unit.

HYBRID WORK SYSTEMS

Operational experience with the various work systems has led to sufficient understanding of their work capabilities to allow hybrid work systems to be designed. This section will briefly describe some of the hybrid work systems used in the subsea industry.

Mobile Diving Unit (MDU): The MDU is a combination of an ARMS manipulator bell and a saturation diving system. This combination provides the crew member the opportunity to complete the work task in a one-atmosphere environment without incurring any decompression penalty.

If the job cannot be completed using manipulators, then the diver can compress the bell to ambient pressure, lock out and perform the task in a hands-on environment.

Mantis Duplus: This vehicle is a combination of a manned submersible with manipulators and a tele-operated work system. It can be used in either the manned or remote-operated mode, depending on the difficulty of the task and the requirement for human perception and judgment. This type of system has the secondary advantage of allowing the submersible to be piloted remotely from the surface, while the crew member concentrates on the manipulative work task.

Dynaclamp: The DYNACLAMP is specially designed for performing detailed cleaning, inspection and maintenance tasks in restricted nodal areas. For this reason, it can perform these tasks much better than any other work system except possibly hyperbaric divers.

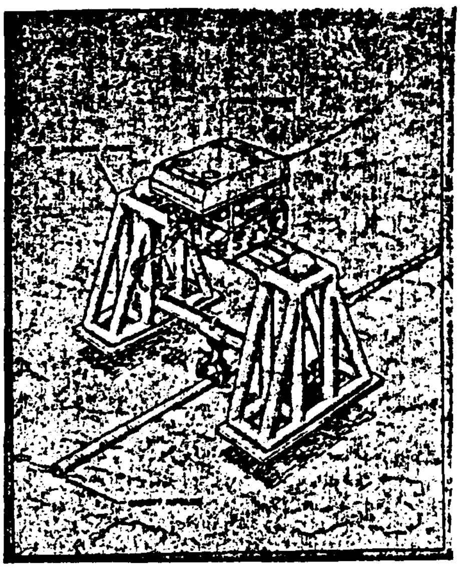
The DYNACLAMP can be delivered to the work site by a general purpose work system such as a WASP or general work vehicle. The DYNACLAMP then works through tele-operated control, while the delivery work system performs other, less complicated tasks simultaneously. This combination greatly extends the work capabilities of general-purpose systems.

DEEPWATER PIPELINE REPAIR SYSTEMS

The deepwater pipeline repair system is a combination of a modular work vehicle and a variety of special purpose work systems.

This system was designed to address one major task - the remote repair of deepwater pipelines. Within this task are multiple subtasks that are individually addressed by special purpose work packages which are interchangeable on the modular work vehicle.

The integrated system can carry out a range of specific inspection, installation and work tasks, including the precision alignment of mechanical connectors, the lifting and alignment of pipe sections, the cutting and bevelling of pipe faces and a number of measurement tasks.



Deepwater Pipeline Repair System Showing a Modular Work Vehicle Operating a Pipeline Alignment Frame

The system uses a combination of sensors, manipulators, special tools and work packages to carry out the designated work.

OPERATIONAL PHILOSOPHIES

Through operational experience, a number of very clear lessons have been learned. Some of these lessons are as follows:

- Design Equipment for Intervention - This has proven to be cost-effective. The small increase in initial cost is paid for the first time the equipment breaks down. Triple-redundant fail-proof systems cost more up front and more to repair when they do break down.

- Standardize End-Effector/Equipment Interfaces - This can make pre-planning and job execution a lot easier. It is also a more sensible approach than changing end-effectors for each task or designing complex multi-finger end-effectors.

- Design Simple Job Requirements - A job can be done in a number of ways and with a variety of methods. It is important not to over-engineer the job.

- Documentation - Poor documentation of subsea equipment can lead to inadequate planning, useless tool design and ineffective operations. When possible, equipment should be documented extensively with photographs and scale drawings.

- Select the Most Effective Work System - A number of work systems may be able to do the job, but how productive and cost-effective? In selecting the optimum work system, it is important to start at the task and work backwards as opposed to trying to fit the wrong work system where it does not apply.

A sensible approach to this process is as follows:

- Define the work tasks
- Determine work envelopes
- Determine required functions
- Incorporate operational considerations
- Select/design optimum work systems
- Perform interface engineering
- Design/manufacture special tooling
- Perform testing and optimization

For many work tasks, the answer may be hands-on divers or gloved astronauts. In other cases, hybrid work or special-purpose systems would be more effective.

CONCLUSIONS

The evolution of work systems in the subsea industry has been the result of direct operational experience in a competitive market. This experience should help to make the evolution of work systems more efficient for space operations.

THE INDUSTRY'S RECOGNIZED AUTHORITY FOR DESIGN ENGINEERING AND APPLICATION OF EQUIPMENT AND SERVICES IN THE MARINE ENVIRONMENT

Reprint

SEA TECHNOLOGY

Marine Electronics • Instrumentation • Systems Design • Marine Pollution • Ocean Research • Diving
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Integrating Divers & Remote Work Systems

Cost-Effective Operations Are the Benefit of This Evolving Breed of Working Partnership

By Mike Gernhardt
Vice President, Special Projects
Ocean Systems Engineering

Reprinted from *Sea Technology* magazine December 1986

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Integrating Divers & Remote Work Systems

Cost-Effective Operations Are the Benefit of This Evolving Breed of Working Partnership

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

By Mike Gernhardt
Vice President, Special Projects
Ocean Systems Engineering

Over the past several years divers and remotely operated vehicles (ROVs) have become increasingly more integrated, resulting in not only safer, but more cost-effective operations.

During the 1970s, ROV development was essentially pursued along a separate path from manned diving technology and experience. The resulting ROVs were frequently limited not only by the technological limitations of that time, but also by the fact that they did not incorporate the experience base gained by divers who had already performed the tasks that ROVs were attempting to accomplish.

Today, ROV developments and operations are producing more practical and sophisticated solutions that address specific work task requirements defined through diver experience. To be sure, free-swimming ROVs are well-suited to many activities—general platform visual inspection, pipeline inspections, deepwater drilling support, and work in hazardous areas where physiological limitations impose their penalties on man.

However, existing ROVs reveal many limitations when it comes to performing complex and specialized tasks.

Since a very large percentage of diver operations involve the detailed cleaning and inspection of node welds on offshore structures, Ocean Systems Engineering (OSE) wanted to investigate the performance possibilities of an ROV-based node weld cleaning and inspection system. To date, this important task has been the domain of divers because it involves accessing restrictive geometries and using a variety of tools that require a fairly high degree of perceptive and manipulative skills.

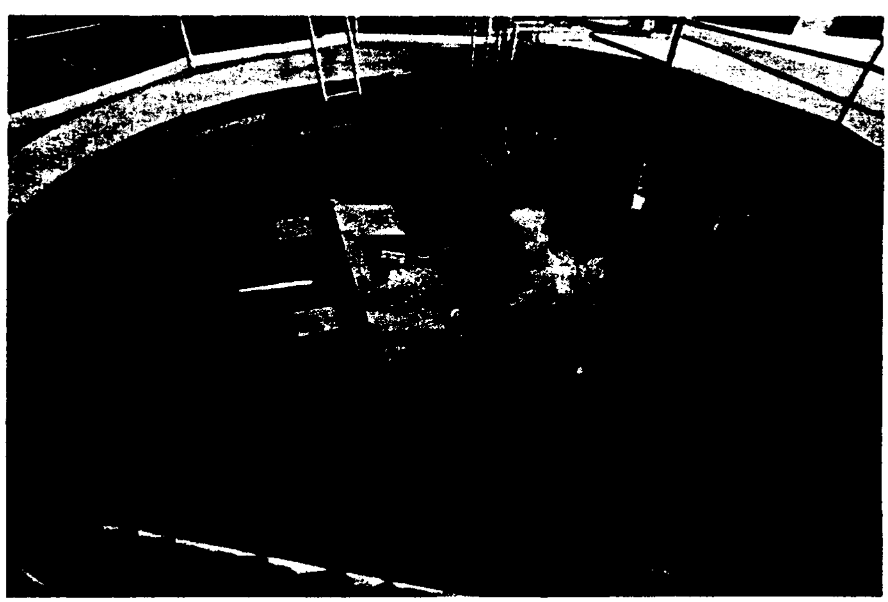
From the analysis, OSE concluded that although free-swimming ROVs could be adapted to perform these tasks, they would be limited by stability, weld accessibility, inspection accuracy, reproducibility, and overcomplexity. OSE also performed an economic analysis which set out to project the cost to clean and inspect a linear square foot of weld. The results indicated that ROV-based systems would only be cost-effective when compared to diving at ultra-deep depths or under special circumstances where safety, logistics in remote areas, labor, and other factors became the overridding consideration.

Ideal Machine Task

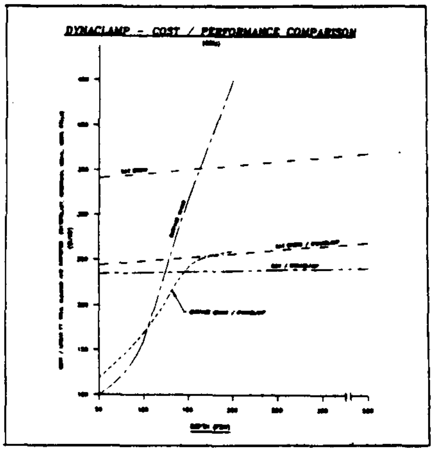
Nevertheless, the cleaning and inspection of node welds is an ideal task to perform with a machine. The task and the tools required to perform it are generally well-defined. The task has a fixed spatial orientation; the welds have a large degree of radial symmetry; it is repetitive; and it constitutes a significant portion of subsea work.

For these reasons, OSE re-examined the approach to this task using a systems development methodology that incorporated existing diver experience. An outline of this approach is shown in the chart. Based on this approach, OSE developed the DYNACLAMP® (Dynamic Cleaning and Maintenance Package).

The prototype DYNACLAMP is designed to be delivered to the nodal areas by a diver, with subsequent ver-



Cleaning and inspecting node welds on offshore structures is an ideal task for such machines as DYNACLAMP, shown here undergoing tests in the OSE wet testing pool.



sions planned for delivery by one-atmosphere diving systems (ADS) or ROVs. The device attaches to the structure using a self-centering hydraulic clamp and, once positioned, is ready to go to work; this frees the diver (or other delivery system) to simultaneously perform other tasks or return to the surface.

DYNACLAMP performs its work using two specially designed manipulators that are capable of accessing node intersections from 30° to 150°. Operated remotely through a power and control umbilical to the surface, the manipulators are designed to accommodate a variety of bolt-on cleaning and inspection tools including a high-pressure water blaster, a grit blaster, hydraulic wire brushes, and a number of photographic systems. This flexibility allows users to tailor the DYNACLAMP's cleaning and inspection methods to whatever combination best suits their requirements.

Hydraulic power and control systems are located onboard, with electrical power, control, and data communications provided through an umbilical link to the surface. Cleaning fluids are also supplied by an umbilical from the surface, leaving maintenance of the cleaning system to surface crews.

Because the DYNACLAMP does not have onboard propulsion systems and because its subsystems are distributed around the structural members, it has a much lower height envelope than traditional ROVs, which are larger and have to attach above or beside the structural members. Because of the lower height envelope, the system is able to access restrictive node geometries much the way a diver does. Also, just as a diver wraps his legs around the member and rotates around the weld as he works, the DYNACLAMP rotates a full 360° around the weld, eliminating the time-consuming task of multiple relocations that limit the effectiveness of larger ROV-based systems.

Symmetrical Rotation

The fact that it rotates symetrically about the weld reduces the demand on the topside operator to continually readjust his orientation to the weld—a limitation of ROV operations. Also, the generally fixed relationship between the weld and the work system allowed the manipulators to be designed for performing these specific tasks, which greatly reduces operator demands.

As a complementary system, DYNACLAMP can support and supplement divers in several ways. Since it is not subject to bottom time restrictions, one unit can work steadily through the time it would take a number of divers to complete the same task. For surface diving—whether bouncing to intermediate depths or working in shallow water—the diver need only spend the time it takes to reposition the system at another node; if he chooses to work at shallower depths, or even return to the surface, he spends less bottom time and decompression time. This capability should extend the depth at which surface diving is a practical option.

In conjunction with saturation diving, the system can work simultaneously with the divers and also through diving bell launch and recovery periods. This capability has the potential to significantly increase the daily production rates of an expensive saturation diving spread with only an incremental increase in costs.

Another advantage of the DYNACLAMP/diver combination is that the diver will be available to perform the more sophisticated non-destructive testing (NDT) inspections if required and also to perform the cleaning and inspection on nodes where obstructions such as debris and sacrificial anodes might impair DYNACLAMP's performance.

In preliminary onshore wet testing, the system has matched diver rates for cleaning and photographic documentation with no decrease in quality. Based on the performance data from these initial tests and using a computerized cost model, potential cost-effectiveness projections were made for use of the DYNACLAMP compared to, and in conjunction with, standard diving techniques. These projections are shown in the accompanying graph for the Gulf of Mexico. (The projections for cost savings are even more dramatic for the North Sea.)

The system is scheduled for more exhaustive onshore testing and analysis, and then offshore trials in 1987. Initially, it will be deployed by divers to establish a baseline of experience in delivery requirements before turning the task over to ROVs and ADSs.

Add Sensors, Machine Vision?

Future refinements to this type of work system will concentrate on adding advanced sensory and machine vision systems along with advanced NDT systems—all of which can be integrated with some degree of artificial intelligence that can make the unit more independent of diver intervention. All these future advancements will build on the baseline experience provided by divers performing similar tasks in conjunction with DYNACLAMP.

This cleaning and maintenance system is an excellent example of how a company can draw upon their experience to direct their next technological step. By charting the methodology of a specified task and analyzing how divers have done it in the past, engineers can pinpoint the particular skills and requirements of that task.

The next step is to determine whether a reliable work system can be developed at a reasonable cost relative to its potential to save diver hours while maintaining or increasing safety standards. /st/

Mike Gernhardt has accumulated ten years' experience in commercial diving, including six in the field as a diver and diving supervisor. At Ocean Systems Engineering, he is involved with developing advanced work capabilities for subsea and space applications—including remote and intelligent work systems and advanced inspection technqiues. Gernhardt and OSE are also looking at new decompression techniques to improve diver safety and performance. He holds a bachelor's and a master of science degree in engineering from Vanderbilt University and the University of Pennsylvania, respectively.

APPENDIX I

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APPENDIX J

INDUSTRIAL BRIEFINGS

<u>Electronic Data Systems</u>

Topics

Information Processing Center
Plant Automation
Production and Management Engineering
Business and Dealer System
Decisions Support Services
Data Management
Communications
Electronic Document Management and Distribution
Computer Graphics
Engineering Workstation
Automated Assembly Line

<u>Martin Marietta</u>

Topics

Logistics Data Base
Logistics Data Base Models
Integrated Logistics Management
Implementation, Transition, Operational for
    Logistics Integration
RFP's Strengths and Weaknesses
Logistics Resupply/Return Issues Overview
    Logistics Requirements
    Resupply/Return
    Logistics Categories
    Pressurized vs Unpressurized Carrier
    EVA vs IVA
    Mass vs Volume
    Special Requirements Environments
    Engineering/Priority/Resupply/Return

<u>IBM</u>

Topics

Future Plans
Relational Database

<u>Honeywell</u>

Topics

General Electric Logistics Systems Problems and Resolutions
Future Plans

APPENDIX K

GOVERNMENT BRIEFINGS

Kennedy Data Management System (KDMS)	NASA, KSC
Shuttle Processing Data Management System (SPDMS)	NASA, KSC
Artificial Intelligence (AI)	NASA, KSC
Ground Data Management System (GDMS)	NASA, KSC
Office Automation (O/A)	NASA, KSC
Kennedy Inventory Management System (KIMS)	NASA, KSC
Engineering Management Information Systems (EMIS)	NASA, KSC
STS Payload Safety Program and Recommendations for Space Station	NASA, JSC
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C&T Data Flow Requirements	NASA, JSC
SSIS Ground Element Overview	NASA, JSC
Users Concerns for SS Integration	NASA, JSC
STS Payload Integration Experience	NASA, JSC
MOD Operations Programming Concept	NASA, JSC
MOD Operations Integration Concept	NASA, JSC
GSFC Operations Integration Concept	NASA, GSFC
Space Industries Inc. User Integration Concept	NASA, JSC
Standardized Communications Concept	NASA, GSFC
SSIS Telecommunications and Ground Systems Overview	NASA, GSFC

APPENDIX L

PERSONNEL CONTACT

Bill Bubbers	-	TMIS	NASA, JSC
Dr. Carl Delaune	-	SS KSC Overview	NASA, KSC
Frank Debernardo	-	Communications Planning	LSOC, KSC
Ralph Jones	-	Communications Planing	NASA, KSC
Emmett Crook	-	Taverns	NASA, KSC
Tom Williams	-	GE Logistics System	Honeywell, KSC
William Grig	-	SS Requirements	NASA, MSFC
Gary Powers	-	Automated Paperless System	NASA, KSC
Wayne Stallard	-	TMIS	NASA, KSC
Tom Knight	-	ICS Technology Growth	IBM, KSC
Michael Harrington	-	SS Communications Requirements	NASA, MSFC
Robert Bradford	-	SS Communications Requirements	NASA, MSFC
Jack Loos	-	SS Communications Requirements	NASA, MSFC
Mike Sander	-	SS Information System Integration	NASA, HQ
Jack Garman	-	SS Information Systems Planning	NASA, HQ
Russell Rice	-	NASA Information System Planning	NASA, HQ
Jane Stearns	-	Shuttle Processing Data	LSOC, KSC
Peter Kent	-	Management System Logistic Information Requirements	
Mike Wiskerchen	-	Telescience	Stanford

APPENDIX M

INFORMATION SYSTEMS
& COMMUNICATIONS

INFORMATION FLOW MODEL
SPACE STATION GROUND OPERATIONS

REVISION RECORD

REV. A		INTERNAL SUBPANEL REVIEW
REV. B		INTERNAL SUBPANEL REVIEW
REV. C:	02/05/87	INITIAL PUBLICATION FOR PANEL REVIEW
REV. 1:	02/20/87	INCORPORATED LOGISTICS INITIAL INPUT (R. NORMAN)
		INCORPORATED CONFIGURATION MANAGEMENT INITIAL INPUT (SEPARATED CONFIGURATION MANAGEMENT AND SUSTAINING ENGINEERING). (D. NAIL)
REV. 2:	02/23/87	INCORPORATED PANEL 4 (BOOZ ALLEN) CONFIGURATION MANAGEMENT AND SUSTAINING ENGINEERING
		INCORPORATED INTERNAL SUBPANEL REVIEW
		INCORPORATED INTERNAL SUBPANEL REVIEW

REV. 3: 02/27/87	INCORPORATED PANEL 4 (BOOZ ALLEN) INPUTS ON SR&QA FUNCTIONS
	ADDED SR&QA FUNCTIONAL SHEETS
	INCORPORATED INTEGRATION REVIEW (J. LAROUX)
	INCORPORATED LOGISTICS SUBPANEL INPUT L. WOOLARD)
REV. 4: 03/03/87	INCORPORATED INTEGRATION REVIEW

Information Flow Model Space Station Ground Operations Assumptions

1. Support time period is the operational (post manufacturing and assembly) era.

2. Station operations are functionally composed of mission operations, ground operations, management structures (Levels A&A'), Logistics, Configuration Management, Sustaining Engineering, Information Systems & Communications, Safety, Reliability and Quality Assurance and SS Users (experimenters & Payload Owners).

3. Only informatin flow is modeled. Physical parts (failed ORU's, logistics modules, payloads) are not modeled as part of this exercise.

4. Data applies to all forms of data; ie.: Drawings, thermal models, processed engineering reports, etc are part of Eningeering data.

5. Budgetary marks and performance are assumed to flow with planning and reporting data.

6. Data owners by function:
   a. Engineering data: Sustaining Engineering
   b. Configuration data: Configuration management
   c. Strategic planning: Level A thru Level A'
   d. Commonality data: Configuration Management
   e. Repair paper: Safety, Reliability and Quality Assurance

7. Only data that crosses functional boundaries is modeled. Internal planning, for example, doen not appear in te Model.

8. Only ground operations data is modeled. Space Station uplink and downlink and mission coordination data (e.i., SSCC to Space Station User POCC) is not included.

LEVEL A

	OUTPUTS	DESTINATION
1.1.1	STRATEGIC PLANS	NASA CENTERS
1.1.2	STRATEGIC PLANS	LEVEL A'
1.2	LEVEL A SUPPORT REQ.	IS&C
	INPUTS	**SOURCE**
	NATIONAL GOALS	EXTERNAL
2.2	STRATEGIC PERFORMANCE	LEVEL A'
6.3.1	SUPPORT SERVICES	IS&C

LEVEL A'

	OUTPUTS	DESTINATION
2.1.1	TACTICAL PLANS	G.OPS
2.1.2	TACTICAL PLANS	SR&QA
2.1.3	TACTICAL PLANS	LOGISTICS
2.1.4	TACTICAL PLANS	CM
2.1.5	TACTICAL PLANS	IC&S
2.1.6	TACTICAL PLANS	F.OPS
2.1.7	TACTICAL PLANS	S E
2.2	STRATEGIC PERFORMANCE	LEVEL A
2.3	LEVEL A SUPPORT REQ.	IS&C
2.4	PLANNING/SCHED/MANIFEST	SS USERS
2.5	RESOURCE ALLOCATIONS	SS USERS

	INPUTS	SOURCE
6.3.2	SUPPORT SERVICES	IS&C
5.2	SS USER REQ.	SS USERS
8.2	CHANGE PAPER	F.OPS
7.2	CHANGE PAPER	G.OPS
4.5	CHANGE PAPER	CM
9.5	CHANGE PAPER	SE
1.1.2	STRATEGIC PLANS	LEVEL A
3.5.5	PERFORMANCE	LOGI
4.1	PERFORMANCE	CM
9.1	PERFORMANCE	SE
8.3.1	PERFORMANCE	F.OPS
7.3.1	PERFORMANCE	G.OPS
5.5.4	PERFORMANCE	SS USERS
10.1	PERFORMANCE	SR&QA
6.2	PERFORMANCE	IS&C
6.1.1	IS&C PLANS & SCHEDULES	IS&C

LOGISTICS

	OUTPUTS	DESTINATION
3.1	PURCHASE ORDERS	EXTERNAL (VENDORS)
3.2	LAUNCH REQ. G. OPS	
3.3		
3.4.1	PLANNING/SCHED/MANIFEST	CM
3.4.2	PLANNING/SCHED/MANIFEST	G.OPS
3.4.3	PLANNING/SCHED/MANIFEST	F.OPS
3.4.4	PLANNING/SCHED/MANIFEST	SE
3.4.5	PLANNING/SCHED/MANIFEST	SS USERS
3.4.6	PLANNING/SCHED/MANIFEST	ELV
3.4.7	PLANNING/SCHED/MANIFEST	EXTERNALS
3.5.1	PERFORMANCE	F.OPS
3.5.2	PERFORMANCE	G.OPS
3.5.3	PERFORMANCE	CM
3.5.4	PERFORMANCE	SE
3.5.5	PERFORMANCE	LEVEL A'
3.5.6	PERFORMANCE	EXTERNAL (VENDORS)
3.6	REPAIR PAPER	SR&QA
3.7	LOGISTICS SUPPORT REQ.	IS&C
3.8.1	MOD KIT DATA	F.OPS
3.8.2	MOD KIT DATA	G.OPS
3.9.1	COMMONALITY DATA	EXTERNAL
3.9.2	COMMONALITY DATA	SE
3.9.3	COMMONALITY DATA	CM
3.10	TREND ANALYSIS	SS USER
3.11.1	MOD STATUS	EXTERNAL (VENDORS)
3.11.2	MOD STATUS	CM
3.12.1	RESOURCE UTILIZATION	EXTERNAL (VENDORS)
3.12.2	RESOURCE UTILIZATION	LEVEL A'
3.13	CONFIGURATION DATA	CM

LOGISTICS (CONTINUED)

	INPUTS	SOURCE
4.3.4	MOD REPORT	CM
8.11	DOWNMASS REQ.	F.OPS
5.15	DOWNMASS REQ.	SS USERS
9.3.1	TREND ANALYSIS	SE
5.9.1	TREND ANALYSIS	
9.9	MANIFEST INPUTS	SE
	MANIFEST INPUTS	STS
5.10	MANIFEST INPUTS	SS USERS
	MANIFEST INPUTS	ELV
2.1.3	TACTICAL PLANS	LEVEL A'
9.2.4	ENGINEERING DATA	SE
	ENGINEERING DATA	
	ENGINEERING DATA	
8.8.2	RESOURCE UTILIZATION	F.OPS
5.12.1	RESOURCE UTILIZATION	SS USERS
8.9	RESUPPLY REQ..	F.OPS
5.13	RESUPPLY REQ.	SS USERS
9.16	RESUPPLY REQ.	SE
9.13	MOD KIT DATA	SE
5.7	MOD KIT DATA	SS USERS
	MOD KIT DATA	WP1-5
6.3.3	SUPPORT SERVICES	IS&C
9.6.5	PROCEDURE INPUTS	SE
	INTERFACE TEST REQ.	WP1-5
	INTERFACE TEST REQ.	EXTERNAL (VENDORS)
5.4.	LOGISTICS REQ.	SS USERS
9.15.1	BILL OF MATERIALS	SE
9.15.2	BILL OF MATERIALS	WP1-5

LOGISTICS (CONTINUED)

INPUTS

4.2.4	CONFIGURATION REPORT	CM
4.6.1	COMMONALITY REPORT	CM
10.6.4	REPAIR CLOSEOUT	SR&QA
	TECHNICAL DATA	EXTERNAL (VENDORS & WP)
	TECHNICAL DATA	SPACE STATION USERS
8.10	CONSUMABLE UTILIZATION	F.OPS

CONFIGURATION MANAGEMENT

	OUTPUT	DESTINATION
4.1	PERFORMANCE	LEVEL A'
4.2.1	CONFIGURATION REPORT	F.OPS
4.2.2	CONFIGURATION REPORT	G.OPS
4.2.3		SR&QA
4.2.4	CONFIGURATION REPORT	LOGI
4.2.5	CONFIGURATION REPORT	SR&QA
4.2.6	CONFIGURATION REPORT	SE
4.2.7	CONFIGURATION REPORT	SS USERS
4.3.1	MOD REPORT	F.OPS
4.3.2	MOD REPORT	G.OPS
4.3.3	MOD REPORT	SR&QA
4.3.4	MOD REPORT	LOGI
4.3.5		SS USER
4.3.6	MOD REPORT	SE
4.3.7	MOD REPORT	SS USERS
4.4	CM SUPPORT REQ.	IS&C
4.5	CHANGE PAPER	LEVEL A'
4.6.1	COMMONALITY REPORT	LOGI
4.6.2	COMMONALITY REPORT	SR&QA
4.6.3	COMMONALITY REPORT	SS USER
4.6.4	COMMONALITY REPORT	SE
4.7	REPAIR PAPER	SR&QA

CONFIGURATION MANAGEMENT (CONTINUED)

	INPUTS	SOURCE
2.1.4	TACTICAL PLANS	LEVEL A'
3.4.1	PLANNING/SCHED/MANIFEST	LOGI
10.3.5	SAFETY REPORT	SR&QA
	CONFIG. DATA	WP1-4
5.6.1	CONFIG. DATA	SS USER
8.6	CONFIG. DATA	F.OPS
7.8	CONFIG. DATA	G.OPS
3.13	CONFIG. DATA	LOGI
8.7	MOD STATUS	F.OPS
7.9	MOD STATUS	G.OPS
10.5	MOD STATUS	SR&QA
3.11.2	MOD STATUS	LOGI
3.9.3	COMMONALITY DATA	LOGI
	COMMONALITY DATA	EXTERNAL
5.14	COMMONALITY DATA	SS USER
9.7	COMMONALITY DATA	SE
10.6.5	REPAIR CLOSEOUT	SR&QA
3.5.3	PERFORMANCE	LOGI
6.3.4	SUPPORT SERVICES	IS&C

SS USERS

	OUTPUTS	DESTINATION
5.1	SS USERS SUPPORT REQ.	IS&C
5.2	SS USERS REQ.	LEVEL A'
5.3.1	TEST REQ.	SE
5.3.2	TEST REQ.	F.OPS
5.3.3	TEST REQ.	G.OPS
5.4	LOGISTICS REQ.	LOGI
5.5.1	PERFORMANCE	SE
5.5.2	PERFORMANCE	G.OPS
5.5.3	PERFORMANCE	F.OPS
5.5.4	PERFORMANCE	LEVEL A'
5.5.5	PERFORMANCE	EXTERNAL
5.5.6		
5.6.1	CONFIGURATION DATA	CM
5.6.2		
5.7	MOD KIT DATA	LOGI
5.8	PRE/POST FLIGHT REQ.	G.OPS
5.9.1	TREND ANALYSIS	LOGI
5.9.2	TREND ANALYSIS	SE
5.10	MANIFEST INPUTS	LOGI
5.11	ENGINEERING DATA	SE
5.12.1	RESOURCE UTILIZATION	LOGI
5.12.2	RESOURCE UTILIZATION	SE
5.13	RESUPPLY REQ.	LOGI
5.14	COMMONALITY DATA	CM
5.15	DOWNMASS REQ.	LOGI
5.16	REPAIR PAPER	SR&QA

SS USERS (CONT)

	INPUTS	SOURCE
9.2.5	ENGINEERING DATA	SE
3.4.5	PLANNING/SCHED/MANIFEST	LOGI
2.4	PLANNING/SCHED/MANIFEST	LEVEL A'
2.5	RESOURCE ALLOCATIONS	LEVEL A'
9.10.3	INTERFACE TEST REQ.	SE
4.2.7	CONFIGURATION REPORT	CM
6.3.8	SUPPORT SERVICES	IS&C
3.10	TREND ANALYSIS	LOGI
4.3.7	MOD REPORT	CM
4.6.3	COMMONALITY REPORT	CM
9.12.3	RESOURCE UTIL. REPORT	SE
10.6.8	REPAIR CLOSEOUT	SR&QA

INFORMATION SYSTEMS & COMMUNICATIONS

	OUTPUTS	DESTINATION
6.1.1	IS&C PLANS & SCHEDULES	LEVEL A'
6.1.2	IS&C PLANS & SCHEDULES	F.OPS
6.1.3	IS&C PLANS & SCHEDULES	G.OPS
6.2	PERFORMANCE	LEVEL A'
6.3.1	SUPPORT SERVICES	LEVEL A
6.3.2	SUPPORT SERVICES	LEVEL A'
6.3.3	SUPPORT SERVICES	LOGI
6.3.4	SUPPORT SERVICES	CM
6.3.5	SUPPORT SERVICES	F.OPS
6.3.6	SUPPORT SERVICES	SE
6.3.7	SUPPORT SERVICES	SR&QA
6.3.8	SUPPORT SERVICES	SS USERS
6.3.9	SUPPORT SERVICES	G.OPS

	INPUTS	SOURCE
8.4	F.OPS SUPPORT REQ.	F.OPS
9.11	SE SUPPORT REQ.	SE
3.7	LOGISTICS SUPPORT REQ.	LOGI
4.4	CM SUPPORT REQ.	CM
1.2	LEVEL A SUPPORT REQ.	LEVEL A
2.3	LEVEL A' SUPPORT REQ.	LEVEL A'
7.6	G.OPS SUPPORT REQ.	G.OPS
10.2	SR&QA SUPPORT REQ.	SR&QA
2.1.5	TACTICAL PLANS	LEVEL A'
5.1	SS USERS SUPPORT REQ.	SS USERS

GROUND OPERATIONS

	OUTPUTS	DESTINATION
7.1.1	TACTICAL PLANS	STS
7.1.2	TACTICAL PLANS	ELV
7.2	CHANGE PAPER	LEVEL A'
7.3.1	PERFORMANCE	LEVEL A'
7.3.2	PERFORMANCE	F.OPS
7.3.3	PERFORMANCE	SE
7.4		
7.5.1	FACILITY UTILIZATION	SE
7.5.2	FACILITY UTILIZATION	SR&QA
7.6	G.OPS SUPPORT REQ.	IS&C
7.7		
7.8	CONFIGURATION DATA	CM
7.9	MOD STATUS	CM
7.10	REPAIR PAPER	SR&QA

GROUND OPERATIONS (CONT)

	INPUTS	SOURCE
2.1	TACTICAL PLANS	LEVEL A'
3.2.	LAUNCH REQ.	LOGI
3.4.2	PLANNING/SCHED/MANIFEST	LOGI
8.14.1	PLANNING/SCHED/MANIFEST	F.OPS
5.3.3	TEST REQ.	SS USERS
9.10.2	TEST REQ.	SE
8.12.1	TEST REQ.	F.OPS
10.7.2	TEST REQ.	SR&QA
6.3.9	SUPPORT SERVICES	IS&C
	PERFORMANCE	STS
	PERFORMANCE	ELV
8.3.3	PERFORMANCE	F.OPS
5.5.2	PERFORMANCE	SS USERS
4.3.2	MOD REPORT	CM
3.8.2	MOD KIT DATA	LOGI
9.2.2	ENGINEERING DATA	SE
9.6.2	PROCEDURE INPUTS	SE
8.13.1	PROCEDURE INPUTS	F.OPS
3.5.2	PERFORMANCE	LOGI
5.8	PRE/POST FLIGHT REQ.	SS USERS
6.1.3	IS&C PLANS & SCHEDULES	IS&C
4.2.2	CONFIGURATION REPORT	CM
10.6.3	REPAIR CLOSEOUT	SR&QA
10.4.3	SAFETY STANDARDS	SR&QA
10.3.3	SAFETY REPORT	SR&QA

FLIGHT OPERATIONS

OUTPUTS		DESTINATION
8.1.1	TACTICAL PLANS	STS
8.1.2	TACTICAL PLANS	ELV
8.2	CHANGE PAPER	LEVEL A'
8.3.1	PERFORMANCE	LEVEL A'
8.3.2	PERFORMANCE	SE
8.3.3	PERFORMANCE	G.OPS
8.4	F.OPS SUPPORT REQ.	IS&C
8.5.	REPAIR PAPER	SR&QA
8.6	CONFIGURATION DATA	CM
8.7	MOD STATUS	CM
8.8.1	RESOURCE UTILIZATION	SE
8.8.2	RESOURCE UTILIZATION	LOGI
8.9	RESUPPLY REQ.	LOGI
8.10	CONSUMABLE UTILIZATION	LOGI
8.11	DOWNMASS REQ.	LOGI
8.12.1	TEST REQUIREMENTS	G.OPS
8.12.2	TEST REQUIREMENTS	SE
8.13.1	PROCEDURE/INPUTS	G.OPS
8.13.2	PROCEDURE/INPUTS	SE
8.14.1	PLANNING/SCHED/MANIFEST	G.OPS

FLIGHT OPS (CONT)

	INPUTS	SOURCE
2.1.6	TACTICAL PLANS	LEVEL A'
3.8.1	MOD KIT DATA	LOGI
3.4.3	PLANNING/SCHED/MANIFEST	LOGI
_._._	PLANNING/SCHED/MANIFEST	LEVEL A'
_._._	PLANNING/SCHED/MANIFEST	SE
9.12.2	RESOURCE UTIL. REPORT	SE
9.2.1	ENGINEERING DATA	SE
9.6.1	PROCEDURE INPUTS	SE
5.5.3	PERFORMANCE	SS USERS
3.5.1	PERFORMANCE	LOGI
7.3.2	PERFORMANCE	G.OPS
4.2.1	CONFIGURATION REPORT	CM
6.1.2	IS&C PLANS & SCHEDULES	IS&C
6.3.5	SUPPORT SERVICES	IS&C
4.3.1	MOD REPORT	CM
10.6.3	REPAIR CLOSEOUT	SR&QA
5.3.2	TEST REQUIREMENTS	SS USERS

SUSTAINING ENGINEERING

	OUTPUTS	DESTINATION
9.1	PERFORMANCE	LEVEL A'
9.2.1	ENGINEERING DATA	F.OPS
9.2.2	ENGINEERING DATA	G.OPS
9.2.3	ENGINEERING DATA	SR&QA
9.2.4	ENGINEERING DATA	LOGI
9.2.5	ENGINEERING DATA	SS USERS
9.2.6	ENGINEERING DATA	CM
9.3.1	TREND ANALYSIS	LOGI
9.3.2	TREND ANALYSIS	SR&QA
9.4.1	MISSION INPUTS	STS
9.4.2	MISSION INPUTS	ELV
9.5	CHANGE PAPER	LEVEL A'
9.6.1	PROCEDURE INPUTS	F.OPS
9.6.2	PROCEDURE INPUTS	G.OPS
9.6.3	PROCEDURE INPUTS	STS
9.6.4	PROCEDURE INPUTS	ELV
9.6.5	PROCEDURE INPUTS	LOGI
9.7	COMMONALITY DATA	CM
9.8	PARTS, INSTRUCTIONS	LOGI
9.9	MANIFEST INPUTS	LOGI
9.10.1	TEST REQUIREMENTS	F.OPS
9.10.2	TEST REQUIREMENTS	G.OPS
9.10.3	TEST REQUIREMENTS	SS USERS
9.11	SE SUPPORT REQ.	IS&C
9.12.1	RESOURCE UTILIZATION REPORT	LOGI
9.12.2	RESOURCE UTILIZATION REPORT	F.OPS
9.12.3	RESOURCE UTILIZATION REPORT	SS USERS
9.13	MOD KIT DATA	LOGI
9.14	REPAIR PAPER	SR&QA
9.15.1	BILL OF MATERIALS	LOGI
9.16	RESUPPLY REQ.	LOGI

SUSTAINING ENGINEERING (CONT)

	INPUTS	SOURCE
2.1.7	TACTICAL PLANS	LEVEL A'
8.8.1	RESOURCE UTILIZATION	F.OPS
8.3.2	PERFORMANCE	F.OPS
7.3.3	PERFORMANCE	G.OPS
5.5.1	PERFORMANCE	SS USERS
3.4.4	PLANNING/SCHED/MANIFEST	LOGI
10.3.1	SAFETY REPORTS	SR&QA
4.2.6	CONFIGURATION REPORT	CM
4.3.6	MOD REPORTS	CM
3.9.2	COMMONALITY DATA	LOGI
_._._	COMMONALITY DATA	EXTERNAL
_._._	COMMONALITY DATA	SS USERS
10.6.6	REPAIR CLOSEOUT	SR&QA
3.5.4	PERFORMANCE	LOGI
5.3.1	TEST REQ.	SS USERS
5.9.2	TREND ANALYSIS	SS USERS
5.11	ENGINEERING DATA	SS USERS
5.12.2	RESOURCE UTILIZATION	SS USERS
6.3.6	SUPPORT SERVICES	IS&C
4.6.4	COMMONALITY REPORT	CM
7.5.1	FACILITY UTILIZATION	G.OPS
10.4.1	SAFETY STANDARDS	SR&QA

SAFETY, RELIABILITY & QUALITY ASSURANCE

	OUTPUTS	DESTINATION
10.1	PERFORMANCE	LEVEL A'
10.2	SR&QA SUPPORT REG.	IS&C
10.3.1	SAFETY REPORT	SE
10.3.2	SAFETY REPORT	F. OPS
10.3.3	SAFETY REPORT	G. OPS
10.3.4	SAFETY REPORT	LEVEL A'
10.3.5	SAFETY REPORT	CM
10.3.6	SAFETY REPORT	IS&C
10.3.7	SAFETY REPORT	SPACE STATION USERS
10.3.8	SAFETY REPORT	LOGI
10.4.1	SAFETY STANDARDS	SE
10.4.2	SAFETY STANDARDS	F. OPS
10.4.3	SAFETY STANDARDS	G. OPS
10.4.4	SAFETY STANDARDS	LEVEL A'
10.4.5	SAFETY STANDARDS	CM
10.4.6	SAFETY STANDARDS	IS&C
10.4.7	SAFETY STANDARDS	SPACE STATION USERS
10.4.8	SAFETY STANDARDS	LOGI
10.5	MOD STATUS	CM
10.6.1	REPAIR CLOSEOUT	LEVEL A'
10.6.2	REPAIR CLOSEOUT	F. OPS
10.6.3	REPAIR CLOSEOUT	G. OPS
10.6.4	REPAIR CLOSEOUT	LOGI
10.6.5	REPAIR CLOSEOUT	CM
10.6.6	REPAIR CLOSEOUT	SE
10.6.7	REPAIR CLOSEOUT	IS&C
10.6.8	REPAIR CLOSEOUT	SS USERS
10.6.9	REPAIR CLOSEOUT	EXTERNAL

SR&QA (CONTINUED)

	INPUTS	DESTINATION
2.1.2	TACTICAL PLANS	LEVEL A'
9.2.3	ENGINEERING STAT	SE
4.2.5	CONFIGURATION REPORT	CM
4.3.3	MOD REPORT	CM
4.7	REPAIR PAPER	CM
9.14	REPAIR PAPER	SE
3.6	REPAIR PAPER	LOGI
8.5	REPAIR PAPER	F. OPS
7.10	REPAIR PAPER	G. OPS
5.16	REPAIR PAPER	SS USERS
	REPAIR PAPER	EXTERNAL
4.6.2	COMMONALITY REPORT	CM
6.3.7	SUPPORT SERVICES	IS&C
7.5.2	FACILITY UTILIZATION	G.OPS

APPENDIX N

SPACE STATION FACILITIES

White Paper

Objective: This paper represents the recommended Facility Maintenance Concept, and identifies the Required Operations Facilities for:

Space Operations
Ground Operations
Customer Integration

This paper also presents the Operations Task Force's recommendations for disposition of proposed Space Station Facilities.

1.0 Facility Maintenance Concept

The Base Operations Contractor will be responsible for utilities and basic building maintenance. The OPS Contractor (PGOC at KSC) will be responsible for maintenance of GSE, FSE, flight hardware and systems, and equipment that interfaces with flight hardware.

Specific responsibilities are:

Potable water	BOC
Sewage Systems	BOC
Painting	BOC
Janitorial	BOC
Roof repair	BOC
Relocating doors/floor to ceiling walls	BOC
Administrative Telephones, FTS	BOC
Power distribution to ckt breaker	BOC
Heating ventilation & air conditioning	BOC
Phenmatic system (GN_2, Shopair) up to Reg. Panel	BOC
Maintenance of cranes, elevators, and doors	BOC
Processing operations	PGOC
GSE O&M	PGOC
FSE maintenance	PGOC
Flight hardware	PGOC
Housekeeping in OPS areas	PGOC
Operation of doors & cranes	PGOC
Processing Ops in User Areas	USER
Maintenance of User GSE & Equipment	USER

2.0 Space Operations Facilities

MSIF	Multi-systems integration FAC
SSSC	Space Station Support Center
SSTF	Space Station Training FAC
POCC	Payload OPS Control Center
S/W Prod FAC	Software Production Facility
SSSI&L	Space Station Sys Integration & Lab Mock-up
POIC	Payload Operations Integration Center
ROF	Regional Ops FAC
DOC	Discipline Ops Center
UOF	User Ops Facility
ESC	Engineering Support Centers
SSIS	Space Station Information System

SSIS consists of:

- TDRS
  - Satellites
  - Ground Stations
- DIF Data Interface Fac
- PSCN

  And
- NASCOM

  connection among

SSSC	Space Station Support Center
SSTF	Space Station Training Facility
CCC	Customer Coordination Capability
SSOMF	Space Station Ops Mgmt. Function
MACC	Multiple Application Control Center
DHC	Data Handling Center
CDSF	Customer Data Services FAC
ESC	Engineering Support Center
POIC	Payload Ops Integration Center

PSC	Platform Support Center
IGE	International Ground Elements
IPF	International Partner FAC
ICN	International Comm. Network
ITVF	Integration Test & Verification FAC
SPF	Software Production FAC
EAF	Engineering Analysis FAC

3.0 Ground Operations Facilities

3.1 Information and Communication Systems

Central Computing Facility

This Facility will house the computer hardware and related systems and equipment to support the Space Station Developed Data Bases. The major data bases to be developed are the Logistics Information System, the Sustaining Engineering Data Base, and the Configuration Management System.

3.2 Prelaunch - Post landing Processing Facilities

Space Station Processing Facility (SSPF)

The SSPF is a new facility to be built at KSC to perform the prelaunch processing of Space Station Elements, systems, equipment and payloads. The integration and interface verification of "Launch Packages" will be done in this facility. The estimated $69.5M CofF and $101M R&D cost is approved, and budgeted.

Baseline Data Collection Facility

A Crew Baseline Data Collection Facility (BDCF) is required at each launch and landing site. Existing BDCF's at KSC and DFRF currently supporting the NSTS will be required to support determination of potential of the long-term humans in Space Program. This will require the maintenance of the BDCF's to he year 2010 and beyond.

Materials Processing and Life Sciences User Facility

This facility must support the following requirements:

- o Assure animal specimens conform to defined microbiological requirements preflight.
- o Assure that animals are cared for and maintained per AALAC procedures. (Both U.S. & International)

- o Provide sterilization (autoclave, ethylene oxide, and irradiation) capability, system evacuation and pressurization. and/or incubation.

- o Immediate post-flight analysis and testing of live specimens.

Space Station Hazardous Processing Facility (SSHPF)

The SSHPF was to be a new facility to be constructed at KSC to perform the hazardous loading of propellants and pressurants in Space Station OMVS, propellant carriers and payloads. This facility has been dropped from the program, due to deletion of the Space Station OMV and the change to LH_2 as the only fuel for Station Reboost.

VLS Payload Processing FAC (VSLPPF)

The VLSPPF is a new FAC to process Space Station Polar Orbiting Platforms. Estimated cost is $3M CofF and $8.7M R&D.

MODs to PAD A and B

Mods to LC 39 Launch pads are planned to provide required late access to logistics modules and carriers. Estimated cost is $8.5 R&D.

Transportation

3.3 Crew Emergency Rescue Vehicle Facility

Maintain CERV on the ground, perform postlanding refurbishment, store and maintain GSE and rescue KIT. The rescue KIT is the set of equipment required to retrieve the CERV and crew after a water landing off the Florida coast. The facility will provide access to a terminal into the SSIS for periodic health checks of on orbit CERV's. Synergism can be achieved by combination with the OMV facility planned by the STS program.

3.4 Logistics

Initial Logistics support will be provided by:

		Mods Cost	Year Budgeted
Warehouse #1	M6-794	$616K	FY90
Ship & Rec	M7-505	$199K	FY90

Space Station Logistics FAC (SSLF)

The Space Station Logistics Facility will provide the capability to consolidate and integrate Space Station Logistics Activity including:

1. Maintenance Capability Intermediate & Depot
   Clean rooms, ATE & software, tech doc, piece parts verification and recert. equ., staging areas.

2. Warehouse
   - Spares, supply support

3. Storage
   - GSE, FSE, Flt. HW
   - Customer hardware

4. Logistics Carrier/Rack Buildup

5. International Support

6. Shipping and receiving
   - Packing and unpacking

7. Training facilities
   - Classrooms
   - Computer Assisted Instructional Trainers (using AI & Interactive videodisk, etc.)

8. Office space for log. personnel
   - Gov. and contractor

9. Read/write IF with data and info systems
   See Info & Comm Sys Central Computing Fac.

4.0 Customer Integration

CDOF Customer Data & Operations Fac
Platform Support Center
PL accom. Control Center
Servicing Supp Center
Cust. Coord. Center Node
S/W Production FAC
Eng. Analysis Capability
Data Handling Center

SSDIF Space Station Dev. and Integration FAC
Servicing and Assembly Verification
Telerobotic Ser. Dev., Test and Verification
Att. PL Interface Test and Verification
Int. Log Sys. Node

5.0 Disposition of Proposed Space Station Facilities

The Facilities in the attached listing have been proposed as Space Station Program Facilities. Many of these Facilities are existing and only require minor modification or refurbishment to support the Space Station Program. These Facilities are proposed for use by Development Centers, Work Package Contractors, Payload Users, or Operations Centers/Contractors. All of these Facilities could be of some use to the Space Station Program during some Phase of Development/Operations. However, the Space Station Program is faced with a strict limitation on yearly operating costs. If the Program accepted responsibility for Operations and Maintenance of these Facilities, the increase in yearly operating cost would be unacceptable.
The SSOTF reviewed the Proposed Facilities and Dispositioned each one into one of the following categories:

1. Mandatory for Concept
   - SSOTF concept cannot work without this Facility
   - The Space Station Program should support development of these Facilities

2. Need Further Justification/Data

3. Required on as Needed Basis
   - Facilities which may be required in a specific Phase of Design, Development, or Verification
   - The Space Station Program should negotiate cost effective use of these Facilities

4. Not Required
   - The SSOTF concept does not require the use of these Facilities
   - The Space Station Program should not expend any funds for these Facilities

FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
1	MSIF *(MULTI-SYSTEMS INTEGRATION FACILILTY)*	JSC	MULTI			93.0	115.0	23.0
1	SSSC *(SPACE STATION SUPPORT CENTER)*	JSC	C&T/DMS	88	15.8	196.0	198.4	22.4
1	SSTF *(SPACE STATION TRAINING FACILITY)*	JSC		88	3.4	157.0	132.3	14.9
1	S/W PROD. FACILITLY	MSFC	ALL					
1	S/W PROD. FACILITY	JSC	ALL					
1	S/W PROD. FACILITY	GSFC	ALL					
1	S/W PROD. FACILITY	LeRC	ALL					
1	S/W PROD. FACILITY	KSC	ALL			14.0	4.5	
	TAVERNS??	JSC	DMS			8.0		
1	SSE *(SOFTWARE SUPPORT ENVIRONMENT)*	A'	DMS/ALL			228.0	103.0	18.0
1	WETF *(WATER EVALUATION TEST FAC)*	JSC	EVA					
1	SS AUTO INTEG & ASSY FAC	JSC	STRUCT/ ME	89	9.2			
1	SES-STATION ON ORBIT *(SHUTTLE ENG. SIMULATOR)*	JSC	GN&C					

1. MANDATORY FOR CONCEPT
2. NEED FURTHER JUSTIFICATION/DATA
3. REQ. ON AS NEEDED BASIS
4. NOT REQUIRED

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04/18/87

FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER (CONTINUED)

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
1	MANNED SYSTEM INTEG TB *(SYSTEM INTEG & MOCKUPS)*	JSC	MANNED BY	87	5.0	19.1	7.0	2.4
1	ONE G MOCKUP *(OPS DEV COMPLEX)*	MSFC	MULTI	87,89	1.1	6.1	1.2	0.2
1	OPS TRNG SIM *(OPS TRAINING SIMULATOR)*	MSFC	MULTI			18.2	4.0	0.5
1	NEUTRAL BUOYANCY FAC	MSFC	MECH			2.2	3.4	0.6
1	I/F VERIF/SIMULATION FAC	MSFC	MULTI	89	0.7		0.9	0.1
1	CORE MOD INTEG FAC/	MSFC	MULTI	87	0.7	2.3	0.8	0.1
	CORE MOD INTEG SIM							
1	GRND CONTROL EXP. LAB	MSFC	MULTI			0.5	1.3	0.1
1	HOSC *(HUNTSVILLE OPS SUPT CENTR)*	MSFC	MULTI			5.0	1.6	0.2
1	SS PROCESSING FACILITY	KSC	ALL	88,89, 90	64.0	100.8	17.6	2.8
1	# MODS TO SSPF: MIF	KSC						
1	MODS PAD A&B	KSC	ALL			8.6	1.3	0.3

1. MANDATORY FOR CONCEPT
2. NEED FURTHER JUSTIFICATION/DATA
3. REQ. ON AS NEEDED BASIS
4. NOT REQUIRED

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04/18/87

FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER (CONTINUED)

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
1	LOG WAREHOUSE	KSC	ALL					
4	CUSTOMER DATAF OPS FAC	GSFC	ALL	CODE T	10.0			
	CUSTOMER COORD CNTR	GSFC						
1	ENG ANALYSIS FAC	GSFC						
1	PLATFORM SUPT CNTR	GSFC						
1	ATT P/L SUPT. CNTR	GSFC						
1	SERVICING SUPT CNTR	GSFC						
1	DATA HANDLING CNTR	GSFC						
	SPACE SYS DEV. FAC	GSFC		CODE T/E				
1	SAVF (SERCICE & VERIF FAC	GSFC						
1	INTEG. LOG SYS. NODE	GSFC						
1	INTEG TEST & VERIF FAC	GSFC						
1	OPS SUPST CNTR.	LeRC	POWER			5.5		
1	#POIC	MSFC	ALL					
1	VLS P/L PROCESSING FAC *(VANDENBURG LAUNCH SITE)*	KSC	ALL			8.8	0.7	0.8
1	# CERV WAREHOUSE FACILITY	KSC						
3	SYSTEMS OPS DEV LAB	JSC	DMS					

1. MANDATORY FOR CONCEPT
2. NEED FURTHER JUSTIFICATION/DATA
3. REQ. ON AS NEEDED BASIS
4. NOT REQUIRED

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04/18/87

FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER (CONTINUED)

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
3	USER OPERATIONS FAC	JSC						
3	EVA-LSS TEST BED *(EVA-FILE SUPPORT SYSTEMS)*	JSC	EVA					
3	EVA TEST BED	JSC	EVA					
3	THERMAL VAC MAN RATED *(CHAMBER B)*	JSC	EVA					
3	THERMAL VAC NOT MAN RATED *(8' AND 11' AND CHAMBER B)*	JSC	EVA					
3	ECLS TEST BED *(ENVIRON, CONTROL LIFE SUPT)*	JSC	ECLSS					
3	THERMAL SYS TEST BED	JSC	THERMAL					
3	EMI TEST FACILITY *(ELECTRO-MAGENTIC INTERFERENCE)*	JSC	C&T					
3	RF COMMUNICATION LAB *(RADIO FREQUENCY)*	JSC	C&T					
3	TRACK SYS TEST BED	JSC	C&T					

1. MANDATORY FOR CONCEPT
2. NEED FURTHER JUSTIFICATION/DATA
3. REQ. ON AS NEEDED BASIS
4. NOT REQUIRED

OSS-8130 (4 OF 9)
04/18/87

FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER (CONTINUED)

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
3	COMM SYS SIM LAB *(CSSL)*	JSC	C&T					
3	ESTL	JSC	C&T					
3	ANECHOIC CHAMBER	JSC	C&T	87	0.7			
3	CONTROL & MONITORING TB	JSC	C&T/DMS					
3	SYSTEM TEST BED	JSC	C&T/DMS					
3	ADV. SYSTEMS DEV. LAB	JSC	DMS/ MECH					
3	KC-135	JSC	EVA					
3	E&D COMPUTATIONAL FAC	JSC	MULTI	87,88	1.4			
3	# COMPUTATIONAL FACILITY	KSC						
3	GN&C LAB	JSC	GN&C					
3	AC&S SYSTEM TB	JSC	GN&C					
3	EPDC LAB/TB	JSC	PWR					

1. MANDATORY FOR CONCEPT
2. NEED FURTHER JUSTIFICATION/DATA
3. REQ. ON AS NEEDED BASIS
4. NOT REQUIRED

OSS-8130 (5 OF 9)
04/18/87

FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER (CONTINUED)

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
3	DMS TEST BED	JSC	DMS					
3	AUTOMATION TEST BED *(EH)*	JSC	DMS					
3	PROP SYS TEST FAC?? *(LOSS OF HW/TEST EQUIP)*	JSC	PROP					
3	LG ATOMIC OXYGEN FAC *(B 77)*	LeRC	POWER					
3	TANK 5/6	LeRC	POWER					
3	SOLAR DYN CONCENTRATOR TEST FACILITY	LeRC	POWER					
3	POWER SYS FACILITY	LeRC	POWER	87	5.8	16.0		
3	MTLS COMPATIBILITY LAB	LeRC	POWER					
3	ELEC POWER SYS TEST BED	LeRC	POWER					
3	BATTERY LABS	LeRC	POWER					
3	SOLAR CELL LAB	LeRC	POWER					

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OSS-8130 (6 OF 9)
04/18/87

FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER (CONTINUED)

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
3	OPTICS FACILITY	LeRC	POWER					
3	ATOMIC OXYG BEAM TEST FAC	MSFC	STR			1.8	1.9	0.3
3	SP ENVRN EFFECTS FACILITY	MSFC	STR	87	0.7	4.5	2.0	0.3
3	ON-ORBIT REPAIR FACILITY *(MODS TO PROCESS TECH. FAC)*	MSFC	STR	88	3.0	17.3	7.9	1.0
3	SPACE DEBRIS FAC	MSFC	STR			2.1	1.8	0.3
3	ECLSS SYSTEM SIMULATOR	MSFC	ECLSS	87	0.7	21.0	8.6	1.2
3	PROPULSION TB	MSFC	PROP			2.1	2.2	0.2
3	TEST STAND 300 (H/O)	MSFC	PROP	87	2.1			
3	DYNAMIC TEST STANDS	MSFC	STR					
3	PROCESS MATLS MGS SYS TB	MSFC	STR			4.3	4.1	0.5
3	OMV/FTS I/F SIMULATOR	MSFC	MECH			3.0	4.5	0.3
3	ELEC SYS BREADBOARD	MSFC	POWER			1.7	0.8	0.1

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FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER (CONTINUED)

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
3	A/V/DMS BREADBOARD	MSFC	DMS/C&T			3.1	0.8	0.1
3	ACS TEST BED	MSFC	ACS			5.7	1.6	0.2
3	CMG VAULT	MSFC	ACS	88	0.2			
3	MECHANISMS TB/FLAT FLOOR	MSFC	MECH	88	0.7	2.2	0.8	0.2
3	ROBOTIC LAB	MSFC	FLUIDS			0.7	0.5	0.1
3	THERMAL TEST BED	GSFC	THERMAL					
3	DMS TEST BED	GSFC	DMS					
3	LIQUID HELIUM TB	GSFC	PROP					
3	FLIGHT DYNAMICS FAC	GSFC	GN&C					
3	MANUFACTURING FACILITY	MSFC	ALL					

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FACILITY CAPABILITY ALL PROGRAM PHASES WORKING PAPER (CONTINUED)

REQ. FOR FACILITY	FACILITY	WP	SYSTEMS	YR. OF FACILITY BUDGET	COF RY$M BRICK & MORTAR	FY 87 $M		
						DEV	OPS	MATURE OPS
4	THERMAL VAC THERMAL SYS *(CHAMBERS A, B, E)*	JSC	THERMAL					
4	SS HAZARDOUS PROCESSING	KSC	PROP			14.2	1.0	1.0
4	SPACE PROP FACILITY *(PLUMBROOK)*	LeRC	POWER	89	19.1	26.4		
4	POCC *(PAYLOAD OPS CONTROL CENTR)*	MSFC	MULTI			4.7	1.4	0.2
4	POCC TRNG B 4755	MSFC	MULTI					

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