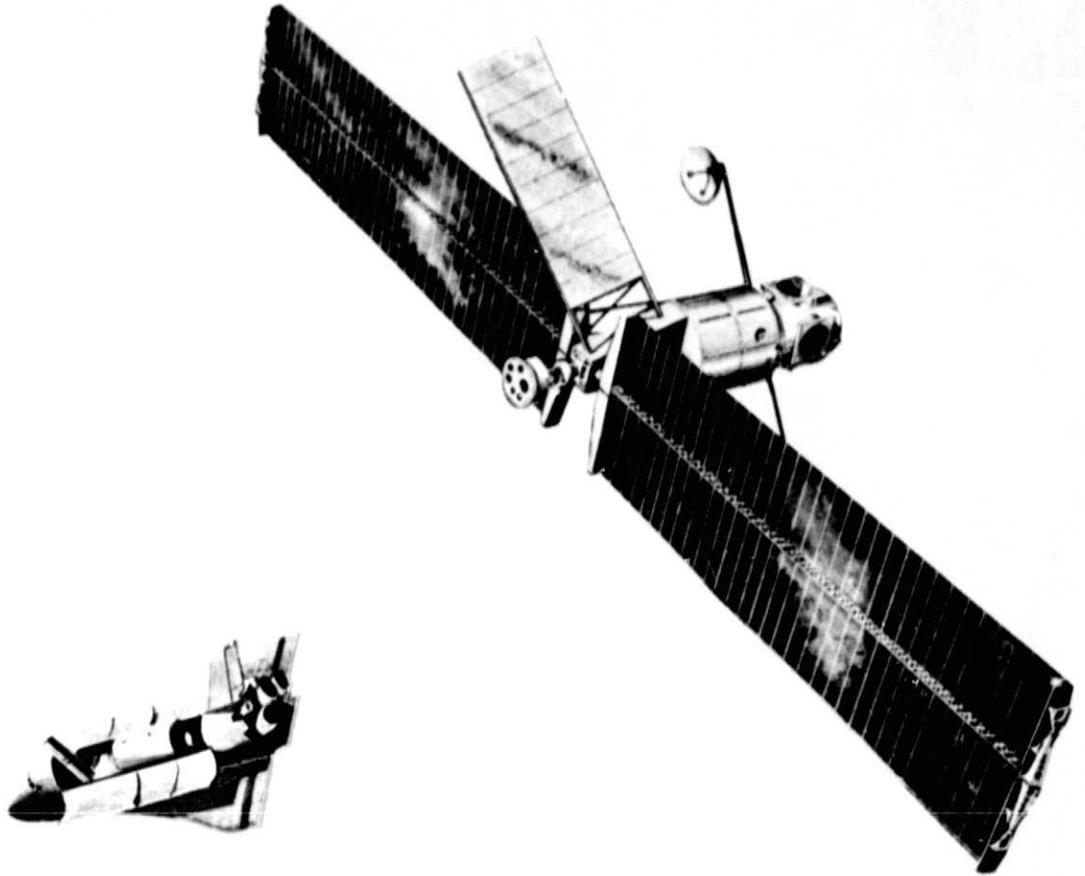


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25 kW POWER MODULE EVOLUTION STUDY

EXECUTIVE SUMMARY

LOCKHEED MISSILES & SPACE COMPANY, INC.

25 kW POWER MODULE EVOLUTION STUDY

EXECUTIVE SUMMARY

27 February 1979

Submitted to the

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FOREWORD

This document is the Executive Summary Study Report for the 25 kW Power Module Evolution Study, and is submitted to George C. Marshall Space Flight Center, Huntsville, Alabama, in compliance with NASA/MSFC contract No. NAS8-32928, DPD 555, Data Requirement No. MA-04. This document presents highlights of the more detailed documentation prepared in accordance with Contract Data Requirements (CDR) for each part of the study contract.

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EXECUTIVE SUMMARY

BACKGROUND

In February 1978, the George C. Marshall Space Flight Center (MSFC) awarded Lockheed Missiles & Space Company, Space System Division (LMSC-SSD), a contract to study evolutionary growth of the 25 kW Power Module (PM) concept to augment Space Transportation System (STS) mission support capabilities in the 1980's and 1990's.

The MSFC 25 kW Power Module concept defines an orbital-based vehicle that provides electrical power, attitude control and heat rejection for the STS Orbiter in the sortie mode. This functionally alleviates Orbiter/Spacelab limitations and enables support of long duration missions beyond present STS capabilities. Between sortie missions, the Power Module provides a free-flying capability for automated payloads.

Using the MSFC 25 kW PM reference design as a point of departure, the study defined evolutionary growth paths to 100 kW and above. A recommended development approach and initial configurations were described. Specific hard-

ware changes from the reference design are recommended for the initial PM configuration to ensure evolutionary growth, improved replicability, and reduced cost. Certain functional changes are also recommended to enhance system capabilities. Figure 1 is an artist's conception of LMSC's recommended 25 kW PM configuration for initial operations. Figure 2 shows the MSFC 25 kW PM reference design.

REFERENCE DESIGN

The MSFC-provided reference design achieved low risk and cost by emphasizing maximum use of existing hardware, designs, and technology. The design concept comprises five basic subsystems: structures, electrical power, attitude control, thermal control, and communications and data handling.

The reference structural subsystem utilizes existing Apollo Telescope Mount (ATM) structures for the equipment rack and primary structure. A new design tubular forward truss provides the structure for mounting a single axis gimballed solar array. The tubular

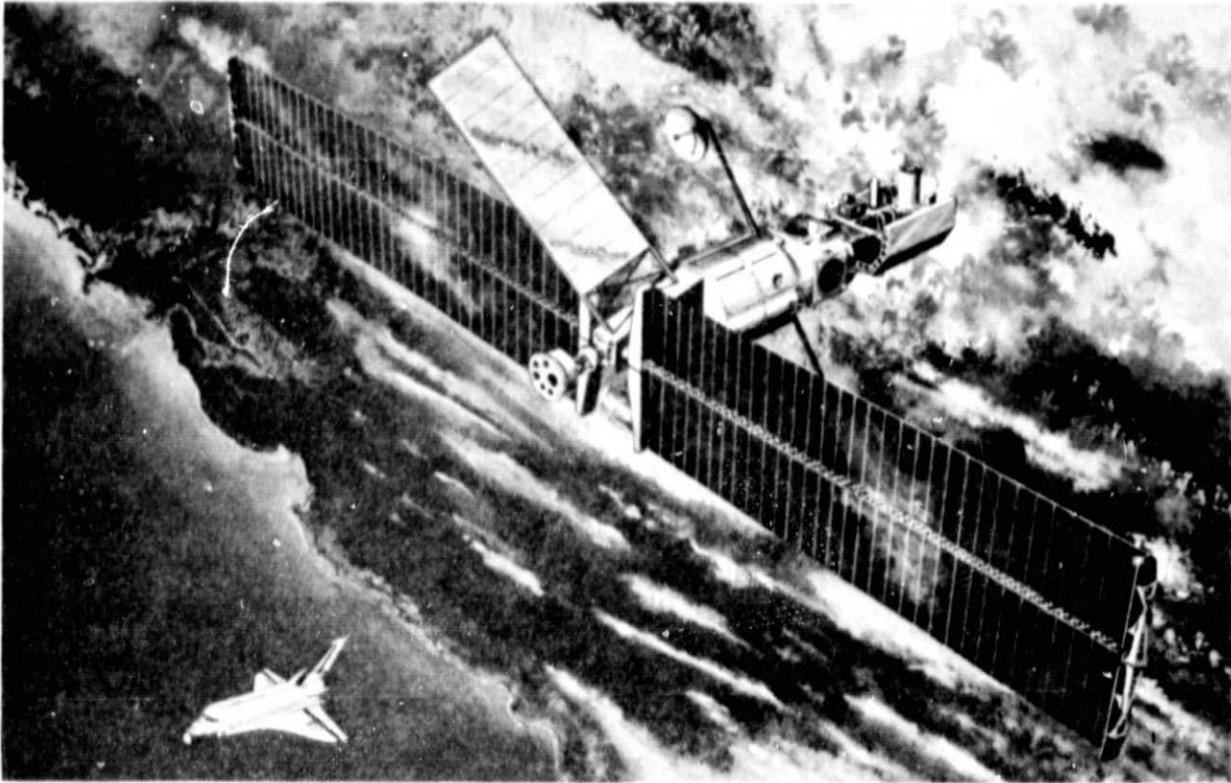


Figure 1 Recommended 25 kW Power Module Configuration

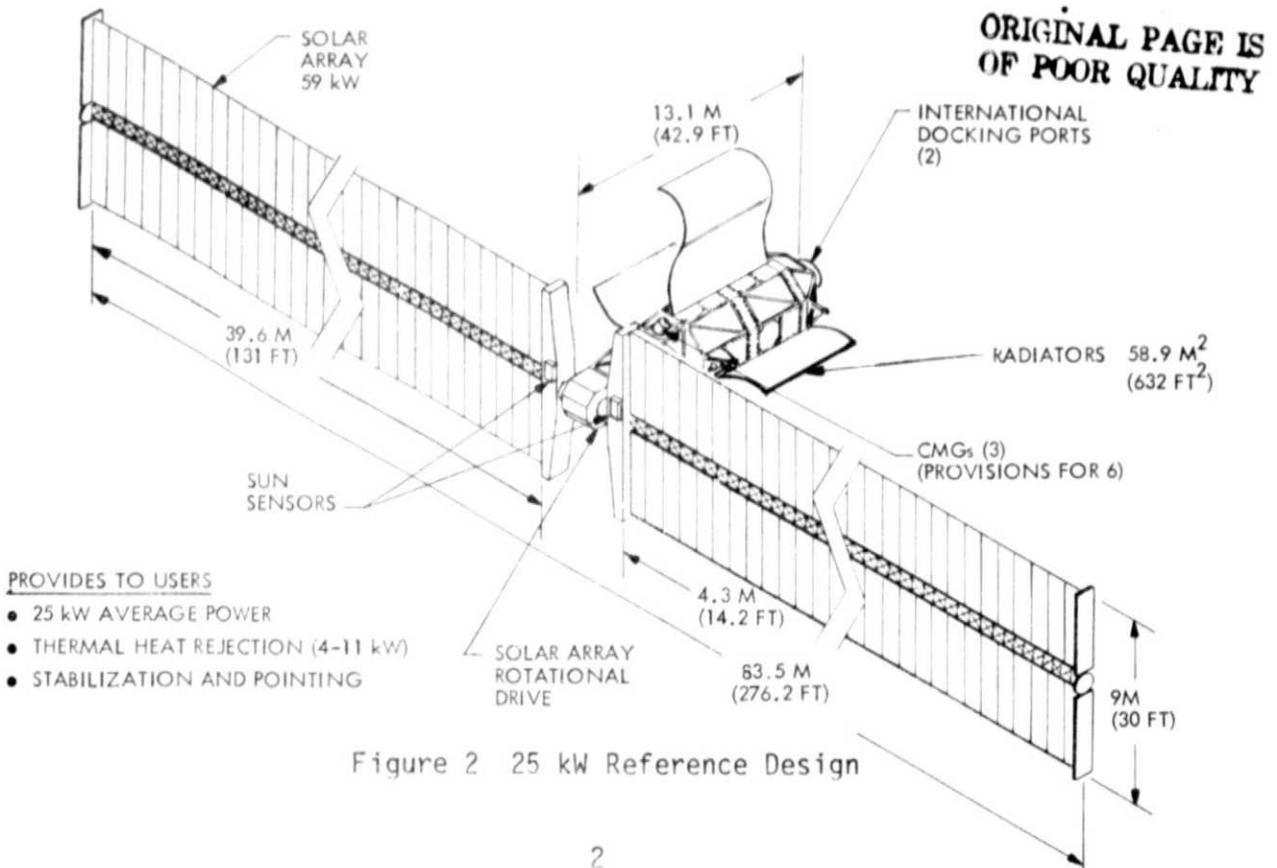


Figure 2 25 kW Reference Design

truss aft structure provides for two docking ports to permit simultaneous coupling with the Orbiter for sortie operations, and a payload for free-flyer operations. Umbilicals are provided at each port for transfer of electrical power, coolant, commands, and data.

The Orbiter Remote Manipulator System (RMS) is used for deployment and docking. A grappling fixture is provided for use by the RMS in removing the PM from the payload bay, and performing docking and berthing.

Electrical power is obtained from a single axis tracking array that is based on MSFC-sponsored SEPS solar array technology developments. Sun sensors are used to search and point the array to the sun. Reference secondary batteries are derived from the SEASAT design. The battery charge control and the power regulation functions are provided by programmable power processors (P³) under development at MSFC.

The attitude control subsystem is based on the use of existing ATM hardware. The Control Moment Gyros (CMGs) (designed and built by Bendix) would be refurbished and updated to improve

life. In the free-flyer mode, CMG desaturation can be accomplished by maneuvering or by gravity gradient operations. In the sortie mode the Orbiter Vernier Reaction Control System (VRCS) may be used, as well as these methods.

The MSFC reference design uses an ATM computer for both attitude control and command and Communications and Data Handling (C&DH) functions. The C&DH functions are handled through the umbilical to the Orbiter; links to the ground are provided by the Orbiter. A 4 KB Data link is provided through an omnidirectional antenna to the Tracking and Data Relay Satellite (TDRS) for free-flyer operations, or to the Orbiter for approach and docking. This would provide for PM commands, basic payload commands and status data. The PM C&DH subsystem used Multi-mission Modular Spacecraft (MMS) components, where applicable.

The Thermal Control Subsystem (TCS) is based on use of Orbiter developed components. The curved thermal radiators, designed to contours of the Orbiter bay, are folded around the equipment section for ascent in the Orbiter bay. On orbit, the radiators are deployed for dissipation of heat to space. A

freon 21 coolant loop in the TCS provides approximately 11 to 14 kW cooling capacity to payload and PM equipment in the sortie or free-flyer modes. In the sortie mode, the PM provides payload heat rejection. Orbiter heat rejection is provided by the Orbiter TCS. If additional cooling is required in the free-flyer mode, the capability would be provided by the payload.

This MSFC reference design was used as the point of departure for the 25 kW evolution study. Revisions to the reference design have been made by MSFC which were not completed in time for this study.

STUDY APPROACH

The 25 kW PM Evolution Study was initially a three-part, interrelated effort to: (1) establish user-payload requirements; (2) define evolution paths and trade-offs for system Initial Operational Capability (IOC) and growth development; and (3) establish a recommended program and conceptual designs.

A mission accommodation analysis task was added shortly after program go-ahead to evaluate the effectiveness of variations in conceptual approaches for satisfying user-payload mission requirements. Figure 3 illustrates the study approach and task flow utilized to accomplish the evolution study objectives.

Guidelines specified by MSFC were that the PM must:

- o Achieve PM IOC in October, 1983
- o Be STS compatible, serve multi-user needs, and substantially extend user on-orbit time.
- o Minimize development costs and peak funding, and facilitate PM vehicle replication.
- o Extend mission operations and capabilities substantially beyond those possible from the current STS and its available support systems.
- o Provide evolutionary growth to meet multi-orbit requirements of payload user community applications through 1990.

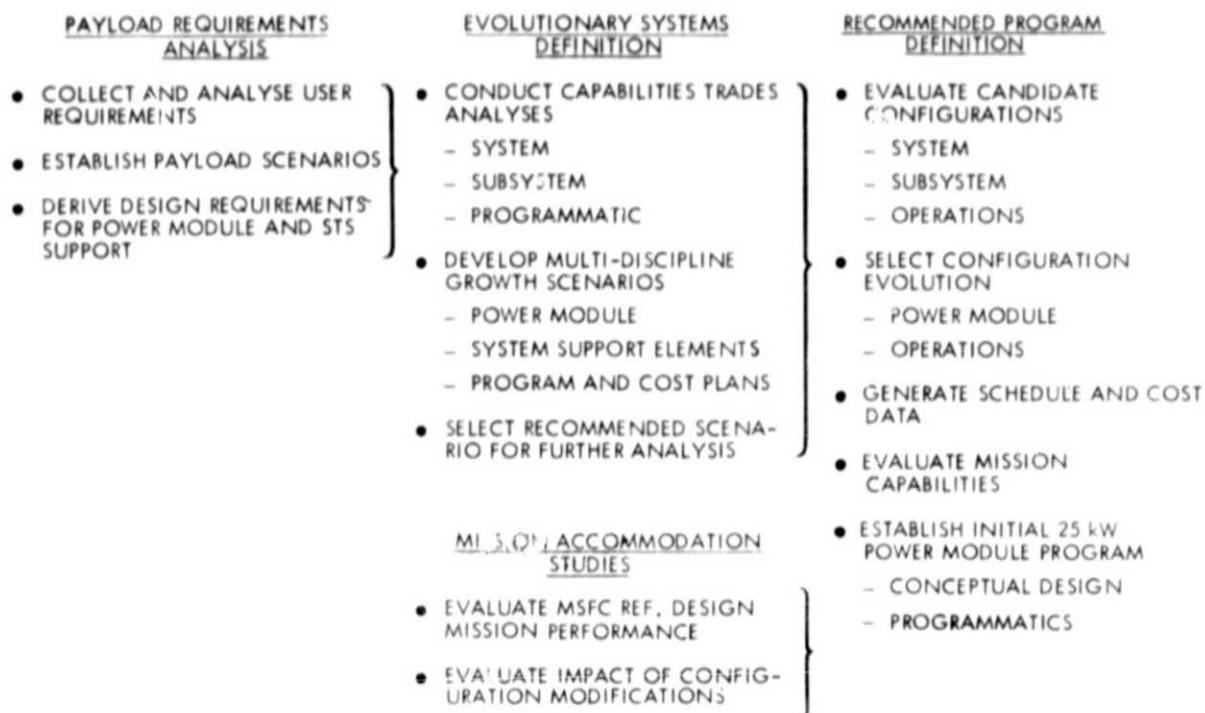


Figure 3 25 kW Power Module Study Task Flow

PART I PAYLOAD REQUIREMENTS ANALYSIS

The Part I study was a three-month effort conducted by LMSC, Thompson-Ramo Wooldridge (TRW), and Bendix, and provided a basis for definition and development of candidate PM concepts in the Part II and III studies. This task collated future NASA payload user requirements, and established preliminary time-phasing for a broad spectrum of desired NASA missions that impact PM design selection. NASA payload discipline specialists were interviewed and their requirements analyzed and identified with applications concepts and principle PM support requirements. NASA selected payload groups, program planning, and payload support requirements were used to drive program scenarios to identify missions, payloads, system configurations, system operations, and schedules for deployment and operations. Trade studies were performed to identify recommended program scenario approaches.

Dynamic User Requirements Analysis

An analysis was made of selected future space payloads and their potential impact on the initial 25 kW PM and growth

versions. Data provided by experimenters, user agencies, and numerous NASA and LMSC sources were reviewed and consolidated. Payload requirements were time-phased into mission scenarios for the period of 1983 through 1990. These payload requirements were strongly impacted by the advent of the PM. This resulted in extensive user revision of payload and program concepts for exploitation of PM capabilities to support longer-duration sortie and free-flyer missions than current STS capabilities would permit.

Emphasis and Secondary Missions

Payload requirements study emphasis was focused on those disciplines having the most firm requirements; i.e., Materials Processing in Space (MPS), Public Services (PS), and Solar Terrestrial Observatories (STO). Other less defined payload disciplines were evaluated on the basis of projected expansion in community-wide PM usage for five manned and unmanned space payload systems. These included Space Science (SS), Earth Observation (EO), Life Sciences (LS) disciplines, large space struc-

tures, and construction platforms.

Payload Requirements Summary

Figure 4 is a summary of derived payload electrical power requirements impacting selection of a design approach for the initial 25 kW PM and subsequent growth of its derivative configurations into the 1990's. Electrical power output is the prime PM design driver.

In parallel with the growth in payload power will be additional power for support elements. In 1986 at the 28.5° orbit a workshop will be required, followed by a manned habitat in 1988, to support the Construction Base and Life Sciences Missions. The MPS mission will require an additional manned habitat/workshop in 1989. Spacecraft Maintenance (including lighting) will require significant power beginning in 1987. A depot will be required to support maintenance by 1990.

In the 57° orbit the manned habitat and a workshop will be required for the STO mission in 1986. This mission will require another set of these elements in the 90° orbit by 1988, and yet another set at GEO in 1990. Manned operations at GEO will expand by 1990 to

require a depot.

A 25 kW PM is needed in 1983 to implement early experimental MPS and STO dedicated flights. Multidiscipline payload grouping can be employed to cost-effectively utilize a single PM on a time-shared basis, particularly for free-flyer modes. This approach, however, is limited to payloads having common orbit requirements and which are compatible on the same platform, i.e., with respect to pointing, targets, g-level, heat rejection, etc.

Growth PM versions in the range of 36 to 64 kW are required in the 1986 to 1988 time frame. Further growth to 100 and 200 kW appears necessary by 1990. Eventually power levels up to 400 kW may be required to support very large manned clustered platforms deployed in the early 1990's. NASA working groups have provided or substantiated power level requirement estimates for the 1980 to 1990 time period.

Heat rejection capability for the payload has not been identified as a strong driver for the PM because separate thermal radiators can be supplied on the payload platforms.

| DISCIPLINE | 28.5° ORBIT | | | | | | | | 50° TO 57° ORBIT | | | | | | | |
|-------------------------------|-------------|----|----|-----|-----|-----|-----|------------|------------------|-----------|------------|-----|-----|-----|-----|-----|
| | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
| MATERIAL PROCESSING | 25 | 25 | 25 | 25 | 25 | 33 | 33 | 33 93 | | | | | | | | |
| SOLAR TERRESTRIAL OBSERVATORY | | | | | | | | | 10 10P | 15 15P | *20 15P | *20 | *23 | *28 | *28 | *28 |
| PUBLIC SERVICE | | | | *15 | | *20 | | | | | | | | | | |
| SPACE SCIENCE | 2P | 2P | 5P | *10 | *10 | *10 | *10 | *10 | 2 2P | 2 2P | *2 2P | *15 | *15 | *15 | *15 | *15 |
| LIFE SCIENCE | 5P | 5P | 5P | 7 | 7 | 7 | 7 | 25- *40 | | | | | | | | |
| EARTH OBSERVATION | | | | | | | | | 5 | 5 | *10 | *10 | *10 | *10 | *10 | *10 |
| SPACE CONSTRUCTION DEMO | 5P | 5P | 5P | | | | | | | | | | | | | |
| CONSTRUCTION BASE | | | | *15 | *15 | *15 | *15 | *15 | | | | | | | | |
| HABITAT | | | | 10 | 10 | 10 | 10 | 10 | | | | 10 | 10 | 10 | 10 | 10 |
| DEPOT | | | | | | | | 20 *50 | | | | | | | | |
| SPACECRAFT MAINTENANCE | | | | *10 | *10 | *10 | *10 | *10 | | | | | | | | |
| WORKSHOP | | | | 7 | 7 | 7 | 7 | 7 | | | | | | | | |
| ORBITER** | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |

| DISCIPLINE | 90° ORBIT | | | | | | | | GEO | | | | | | | |
|-------------------------------|-----------|-----|-----------|----|----|----|----|----|-----|----|----|----|----------|----------|-----------------|-----------------|
| | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
| MATERIAL PROCESSING | | | | | | | | | | | | | | | | |
| SOLAR TERRESTRIAL OBSERVATORY | | | | | | 47 | 47 | 47 | | | | | | | | *50 |
| PUBLIC SERVICE | | | | | | | | | | | | 40 | 40 50 | 40 50 | 40 50 210 | 40 50 210 |
| SPACE SCIENCE | 2P | 2P | 2P | 2 | 3 | 3 | 3 | 5 | | | | | | 10 | 10 | 10 |
| LIFE SCIENCE | | | | | | | | | | | | | | | | |
| EARTH OBSERVATION | 10P | 10P | 20 10P | 20 | 20 | 20 | 20 | 20 | | | | 10 | 10 | 10 | 10 | 10 |
| SPACE CONSTRUCTION | | | | | | | | | | | | | | | | |
| CONSTRUCTION BASE | | | | | | | | | | | | | | | | |
| HABITAT | | | | | | 10 | 10 | 10 | | | | | | | | 10 |
| DEPOT | | | | | | | | | | | | | | | | *50 |
| SPACECRAFT MAINTENANCE | | | | | | | | | | | | | | | | |
| WORKSHOP | | | | | | 7 | 7 | 7 | | | | | | | | 7 |
| ORBITER** | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | | | | | | | | |

- P - TIME SHARED PEP/SORTIE
- ** - SORTIE MODE; SHARES PAYLOAD POWER
- * - TIME SHARED TO CORRESPOND TO PM OUTPUT

Figure 4 Summary Payload Power Requirements

In precision pointing of payloads, separate gimballed mounts can be used, since these require only moderate PM-based pointing control, i.e., to within ± 0.5 degrees. Use of PM CMGs can provide the necessary low-gravity acceleration levels required by MPS and Life Sciences payloads (ranging from 10^{-3} to 10^{-5} g). CMGs also provide a contaminant-free attitude control capability to reduce fouling of contaminant-critical payload sensors.

PM Support Requirements

NASA-planned payloads for the 1980's require extended on-orbit duration and power levels of 25 kW and higher. The PM will be useful to supply additional power to the early sortie missions.

Larger economic and operational benefits will accrue from use of PM supported free-flyer payloads. It is also apparent that PM support will be required for both dedicated discipline missions (i.e., to support MPS) and multi-discipline payload platforms.

The initial 25 kW PM will be required to accommodate MPS and STO payloads immediately in 1983. Hence, the design should satisfy these needs, and at the same time incorporate sufficient growth provisions to accommodate larger power levels required for support of future larger payload platforms. Derivatives of the Low Earth Orbit (LEO) PM can be adapted for Geosynchronous Earth Orbit (GEO) operations to support the PS and STO disciplines.

PART II CANDIDATE SYSTEM EVOLUTIONS

The Part II study was conducted by LMSC, Bendix, and IBM. Part I mission and payload requirements were used to formulate system concepts to satisfy various user system growth requirements through 1990. Evolutionary systems concepts were evaluated to derive candidate system support element requirements. Guidelines and criteria were jointly developed, and concept reviews and configuration selections accomplished with NASA to ensure validity and compatibility with future planning.

The Part II study developed STS and PM support element capabilities, and evolutionary growth requirements needed to support the scenarios of Part I. Alternate PM system and subsystem approaches were identified. Trade studies incorporated present and known near-future technology improvements. The trade studies established promising candidate conceptual approaches and modular concepts for consideration in more detailed analysis during Part III. These concepts were tested for impact on the program in the mission accommodation studies.

Mission Scenarios

Multidiscipline mission scenarios were developed to accommodate evolutionary payload requirements at various rates of accomplishment. The sensitivities of designs and requirements vs mission utility were determined. System level and programmatic trades and analyses were performed. System capabilities for each evolutionary step were compared, and resulting data summarized for recommended evolutionary paths.

Derived PM Design Requirements

Design requirements synthesized for mission/payload requirements were analyzed against the MSFC derived criteria and constraints of the 25 kW PM study report of September, 1977. Figure 5 is a summary of initial design requirements.

Recommended Program Scenarios

Programmatic, technical, and operational considerations were used to develop a feasible, funding-practical

| ITEM | REQUIREMENT |
|---|--|
| POWER (25 kW) | SORTIE ORBITER BUS, 14 kW; PAYLOAD BUS, 11 kW; FREE-FLYER PAYLOAD BUS, 25 kW |
| SOLAR ARRAY | 1-DEG GIMBAL FREEDOM; FULL/PARTIAL EXTENSION/RETRACTION |
| ATTITUDE CONTROL | STABILIZATION IN SORTIE AND FREE-FLYER MODE |
| THERMAL CONTROL | ALL POWER MODULE HEAT AND UP TO 40 PERCENT OF PAYLOAD HEAT MUST BE REJECTED BY PM |
| ON-ORBIT REPAIR/ MAINTENANCE | EVA IN BERTHED MODE, MODULAR DESIGNS |
| COMMAND AND DATA HANDLING | (1) TO ORBITER FOR RENDEZVOUS, (2) TO ORBITER WHEN DOCKED IN SORTIE MODE, AND (3) TO GROUND IN FREE-FLYER MODE VIA TDRSS |
| ORBIT ALTITUDE ADJUST | REBOOST CAPABILITY FOR DRAG MAKEUP OR ORBIT ADJUST |
| DEPLOYMENT, BERTHING, AND RECOVERY OPERATIONS | ORBITER REMOTE MANIPULATOR SYSTEM; STABILIZE POWER MODULE; RETRACT SOLAR ARRAYS, RADIATORS, AND ANTENNAS |
| SAFETY | FAIL-SAFE DESIGN FOR MANNED SPACE OPERATIONS |
| TRANSPORTATION | GOVERNMENT, CONTRACTOR, AND COMMERCIAL CARRIERS |
| STORAGE | CONTROLLED ENVIRONMENT, EXTENDED PERIODS |

Figure 5 Summary of Initial PM Design Requirements

program scenario appearing to provide the greatest utility of benefits to the user payload community. This nominal scenario was also constructed and planned to facilitate appropriate modifications to accommodate payload availabilities and changing emphasis.

Analysis of alternate scenarios has indicated the impact of increased program

funding availability and, conversely, of reductions to available funding on the PM evolution program. These additional scenarios were identified as "ambitious" and "minimum" variations from the nominal scenario. The significant differences between the nominal and ambitious scenarios is that PM growth capabilities are provided approximately one to two years earlier,

thus enabling the system to simultaneously accommodate more operational mixed discipline payloads and significantly increase user community mission benefits. Minimum scenarios defer evolutionary PM growth steps by the same one to two years and result in a proportional delay in potential payload accommodation capabilities.

Guidelines and groundrules for the nominal program scenario (Figure 6) were:

- o First PM IOC in October, 1983
- o PEP availability for all orbits
- o STO/MPS/PS discipline emphasis
- o Integration of Space Science, Earth Observations, Life Sciences, Space Construction Demonstration and Space Construction Base requirements as they emerge
- o Separate operations for Space Construction and MPS because of "g" levels
- o Nominal program scenarios derived by means of stretched-out mission programs, deferred starts, and shared PM resources
- o No multiple PM additions in a given year
- o On-orbit PM refurbishment, replacement, and growth where advantageous
- o SPS missions considered as additive

to present study results

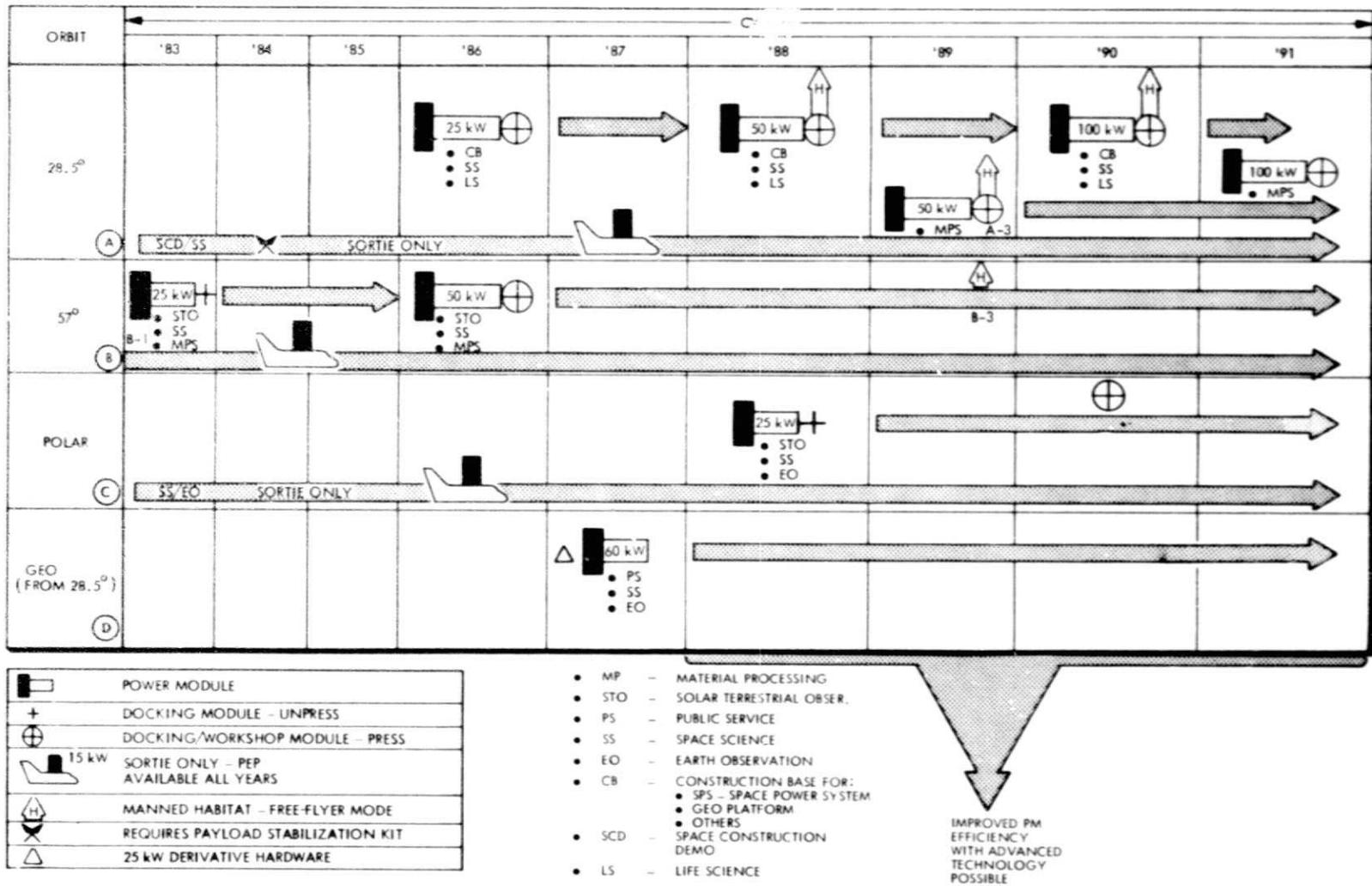
- o Second PM IOC must follow the first by at least two years

The ability of the nominal scenario to satisfy user requirements for electric power was developed under the Mission Accommodation Task.

System Configurations and Trade Analyses

On-orbit growth concepts considered (Figure 7) included both multiple power modules and kit addition/replacement. The latter appears to be the most viable approach. Evolutionary configuration development will depend on realistic technology forecasting; risk assessment of design; and providing the capacity to cost-efficiently maintain, replace, and grow system capabilities. Planned on-orbit growth will permit changing system capabilities to meet new needs at minimum cost and schedule delay. System configurations were derived to support each discipline group in the nominal scenario; these concepts proved to be relatively insensitive to funding and schedule variations.

The most complex system configuration is deployed in the 28.5° orbit. It is assumed that early 1980 space-



14

Figure 6 Nominal Program Scenario

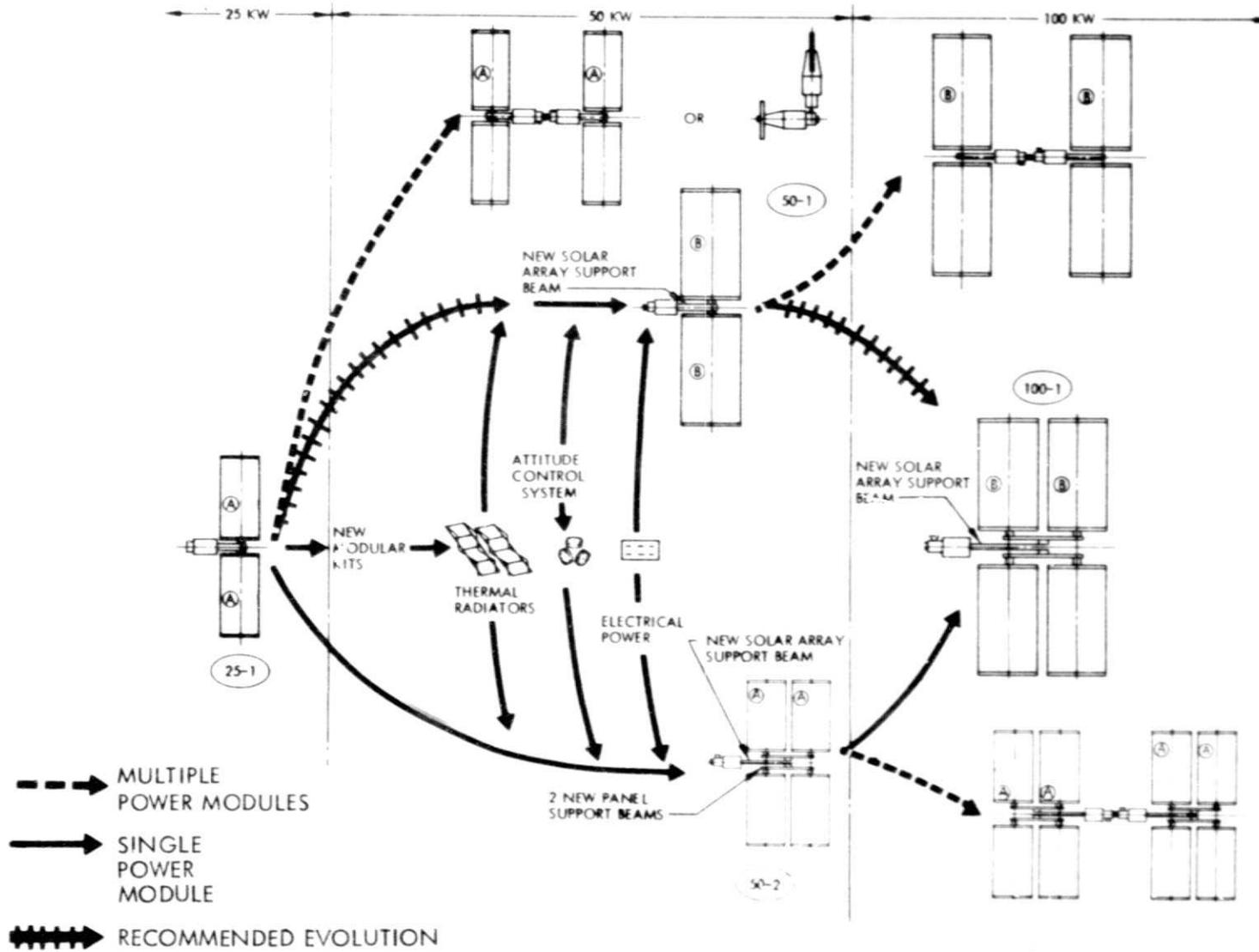


Figure 7 PM On-Orbit Growth Concepts

construction technology will be available to construct a free-flyer LEO platform. Space payloads and a Power Module would be added. A pressurized module will be included for sortie supported LS missions.

Early requirements defined for STO are best satisfied in a 50-57⁰ orbit, and utilize a multiple docking interface with the PM.

The system level considerations and trade analyses performed during this study specifically addressed configuration, orientation versatility, maintenance and return to earth, berthing, minimizing costs, growth capabilities, and refurbished system reboost.

The selected PM configuration was relatively insensitive to LEO altitude, inclination, time of launch and any one payload mission. The PM design provided for growth to meet all combinations of user payloads and orientations, and provided a basis for conceptualizing a recommended PM configuration and identifying its interfaces with supporting elements in Part III.

MISSION ACCOMMODATION STUDY

This study was conducted by LMSC and Bendix to evaluate capabilities and limitations of various power module options to support contemplated sortie and free-flyer missions. The functional equivalent of MSFC's reference design was the basic point of departure. Three representative PM missions were employed: Solar Terrestrial Observation, Material Processing and Stellar Observation. Multi-mission capabilities were also evaluated. The mission accommodation study provided support to both Part II and III studies by enabling an independent evaluation of various PM designs for sortie and free-flyer payload user support. System performance was characterized for varied orbital attitude modes and Beta angles; and associated power, heat rejection, observation duration, and low G-level capabilities were determined. This analysis was accomplished iteratively with subsystem design/analysis to assess the impact of variations in PM design on system effectiveness. Accordingly, recommendations were crystallized for functional additions to the PM design

that enhance performance, pointing, and accuracy.

Coverage Analysis

In both the sortie and free-flyer modes, total viewing coverage available to payloads is a key PM design driver. Figure 8 illustrates results of an analysis of blockages affecting payload fields-of view in both the sortie and free-flyer mission operating modes. The vehicle was assumed to be in a stable attitude. The solar pointing package and sensors mounted on a pallet utilize the Annular Suspension and Pointing System, (ASPS). The available coverage or viewing window, was determined considering both gimbal limits ($\pm 100^\circ \times \pm 60^\circ$) and vehicle blockage. This coverage capability and the available stable vehicle attitudes were used to evaluate the ability of each configuration to meet mission viewing requirements.

In the sortie mode, the payload is installed in the Orbiter cargo bay. Viewing blockage is imposed by the Orbiter tail, the Spacelab, and the PM solar arrays and thermal radiators. However, the viewing coverage when combined with alternate Orbiter attitudes, will accommodate mission requirements.

In the free-flyer mode, Orbiter related blockage is no longer present and coverage is significantly improved, particularly with provisions for multidirection instrument mountings enabling simultaneous viewing both up and down. Therefore, the combination of orbit attitude modes attainable and improved coverage available to the free-flyer, enhances the ability to carry out dual-pointing or two target mission observations (e.g., sun-nadir).

STO Mission

STO missions employ integrated sets of instruments to investigate individual or combined solar, terrestrial, and geomagnetic phenomena. Some instruments require integral gimbaling. The study of STO applications indicated PM performance requirements as follows:

- o Power: 10 to 20 kW
- o Pointing Accuracies/Stability:
Seconds of arc
- o Payload Viewing: Sun, Earth, Nadir, Zenith & Magnetic Field alignment
- o Pointing Durations: Seconds to days
- o Simultaneous viewing:
 - Sun-Nadir
 - Sun-Zenith
 - Sun-Earth Limb

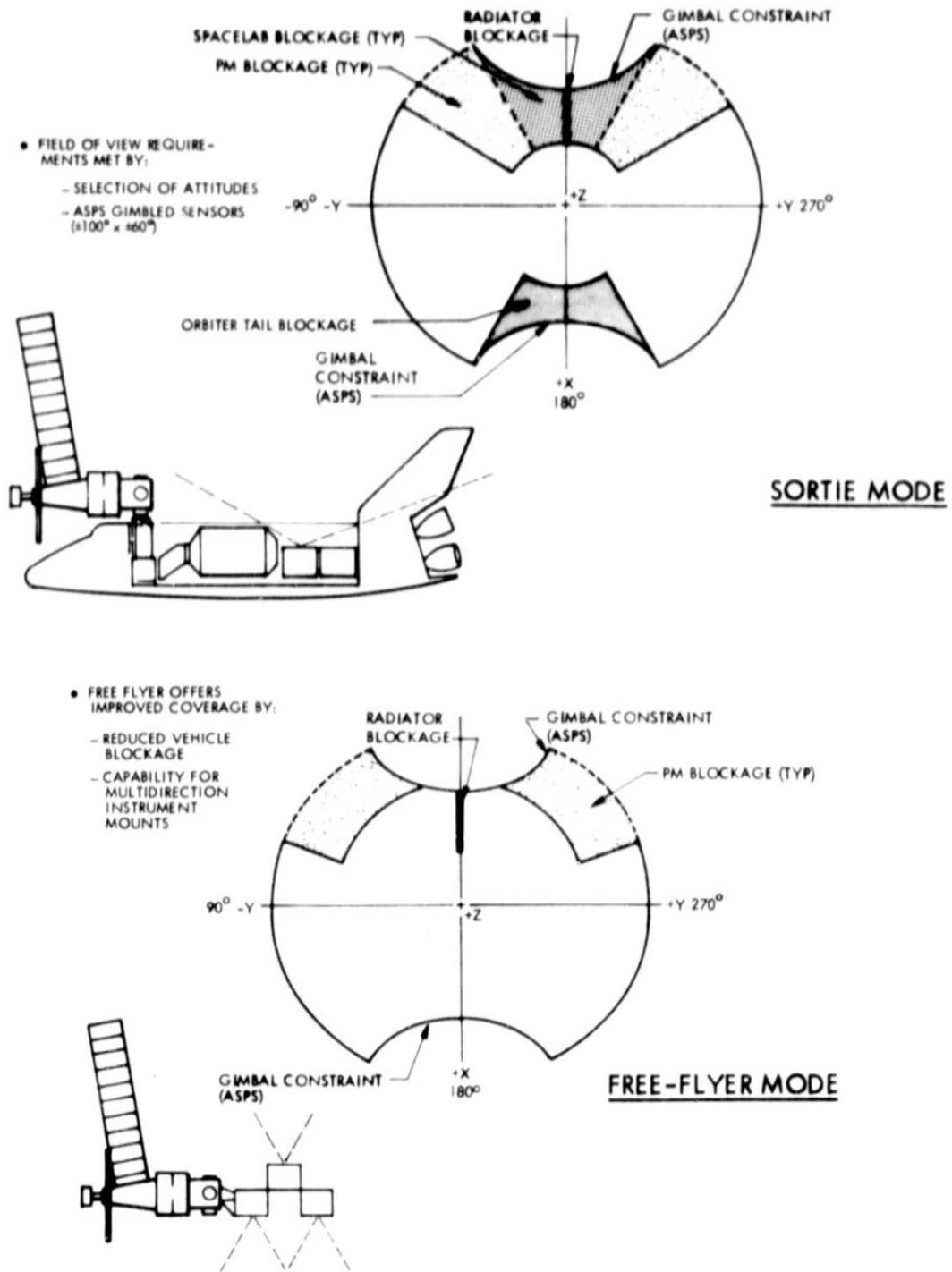


Figure 8 Viewing Availability of 25 KW PM in Sortie and Free-Flyer Operations

Implementation of the STO Mission may be carried out with sensors mounted on a pallet in the Orbiter bay for the sortie mode. Pallets may also be used with the PM in the free-flyer mode. A solar pointing instrument package may also be mounted on the PM solar array support structure for either mode, and for use in simultaneous viewing.

Evaluations affirmed the adequacy of the reference PM electrical power concept in both sortie and the free-flyer modes. Thermal rejection is adequate for sortie operations. An experiment timeline analysis will be required to verify thermal rejection subsystem adequacy for various payload-optimum free-flyer operational modes.

The minimum Attitude Control Subsystem (ACS) can accommodate sortie stabilization requirements in attitudes suitable for required observations. By the addition of an attitude sensor, free-flyer ACS stabilization and pointing accuracies can be maintained within discipline tolerances. Substantial viewing capabilities are available for STO viewing. In the sortie mode sun-nadir coverage deficiencies exist as a result of payload operations from within the

Orbiter bay. The use of a sensor package on the PM solar array support structure would minimize this problem.

MPS/LS Mission

A driving requirement for MPS/LS missions is achievement and maintenance of a low acceleration environment ($10^{-5}g$) for extended periods of from hours to days. The MPS/LS missions were combined in analysis because of their common requirements and general lack of attitude reference requirements (except for stability). Three candidate attitudes were defined to provide long-term stability and minimum "g's" (rotational and translational). The selected PM ACS is adequate for both sortie and free-flyer modes.

Stellar Mission

In the Stellar missions considered, no viewing blockages were imposed for either free-flyer or sortie modes. Stellar mission instruments require relatively low levels of power, but are demanding in terms of pointing accuracies and positional stability over long observation durations. Pointing accura-

cies are enhanced by use of payload mounted sensors and fine pointing subsystem packages. Two orbits and three pointing modes (vehicle/instrument) were defined; and four astronomical targets were designated. Yearly viewing opportunities, power generation, and solar exclusion were considered and assessed.

It was concluded that in the sortie mode, the reference PM performance with three CMGs can manage 28.5° or 57° orbit missions. Four CMGs will permit continuous viewing opportunities. Five CMGs, with desaturation, will provide an alternative to experiment aiming packages.

In the free-flyer mode, the PM reference design, with attitude reference, satisfies 28.5° and 57° missions. A CMG desaturation capability will offer contamination-free alternatives to experiment aiming package utilization.

User Electric Power Requirements Satisfaction

The mission discipline requirements in 28.5°, 57°, and polar orbits from 1983 through 1990 are shown in Fig. 9. These are individual requirements shown

in the figure; i.e., not stacked. Also shown are the capabilities available in these orbits provided by the PEP and PM evolution of the nominal scenario.

No attempt was made to plan the flight missions in detail. However, it is clear that time and power sharing of the PM facilities will permit satisfaction of user requirements. In this mode, the user needs are met in the 57° orbit.

The early power requirements in the 28.5° orbit can be partially satisfied by the sortie mode and by shifting MPS activities to the 57° orbit. Likewise, early polar orbit requirements could be satisfied by the sortie mode and a shift of some needs to the 57° orbit.

Mission Accommodation Capabilities

Analysis indicated that the MSFC reference design power module free-flyer mode capabilities can be improved in terms of cost-effective mission accommodation by: (1) addition of attitude sensors and magnetic torquers, and (2) provisions for installation of additional CMGs to accommodate some mission applications. Incorporation of these

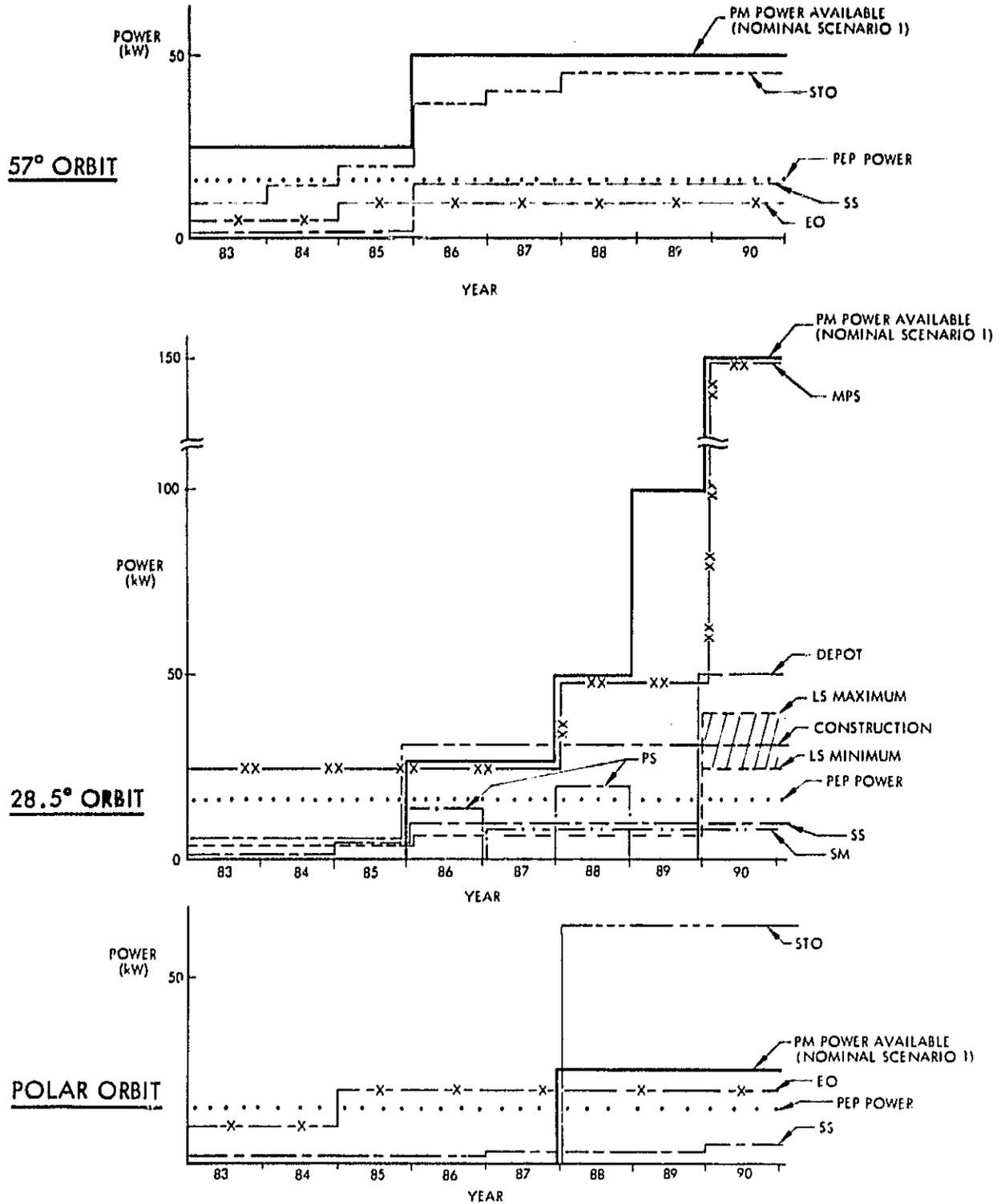


Figure 9 User Electric Power Requirements

PM enhancements:

- (1) Provides for increased sortie mission durations by a factor of 5 to 10 over the Orbiter alone; and by a factor of 2 to 3 over PEP supported sortie.
- (2) Provides payloads with about 3 times the power available from Orbiter alone and about 2 times the power available from the PEP supported sortie.
- (3) Provides increased payload heat rejection capabilities that are roughly proportional to the increased electrical power available.
- (4) Provides Orbiter-equivalent stabilization and attitude control for long duration observations without ACS and flash evaporator contaminants.

PART III SELECTED PM EVOLUTION CONCEPT DESIGN

The selected (nominal) scenario provided a basic framework for these studies. The mission accommodation study, performed iteratively with Part II, provided input to the Part III study for identification of the impact of specific system/subsystem variations on mission performance, cost, and schedule factors over the selected time frame. Particular attention was given to near-term requirements driving concept selection for the initial PM configuration and other supporting elements.

The following paragraphs are a summary of major study program highlights and results.

Part III Study Accomplishments

The Part III study provided design/analysis of the selected configuration and growth evolution, including:

- o A mission time-line analysis
- o An up-dated evolutionary system requirements and configuration definition
- o Subsystem trades and analysis of interrelated system configuration impacts

- o A recommended conceptual design for the 25 kW PM and growth versions for 1983 through 1990 operations.
- o A detailed equipment list for the initial PM flight system to the component level
- o Support development and test planning
- o Operational ground and flight sequence analysis
- o A complete Work Breakdown Structure (WBS) for program planning and cost estimating.

Recommended 25 kW Power Module System

Figure 10 shows the recommended sortie and free-flyer configurations. The recommended PM system approach has the flexibility to accommodate a range of changing mission needs and resulting program implementation requirements.

Figure 11 is a comparison between the recommended 25 kW PM initial flight vehicle configuration and the MSFC reference design. The concept permits open-ended modular growth to meet advanced mission requirements, and cost-effective incorporation of new technology as it becomes available.

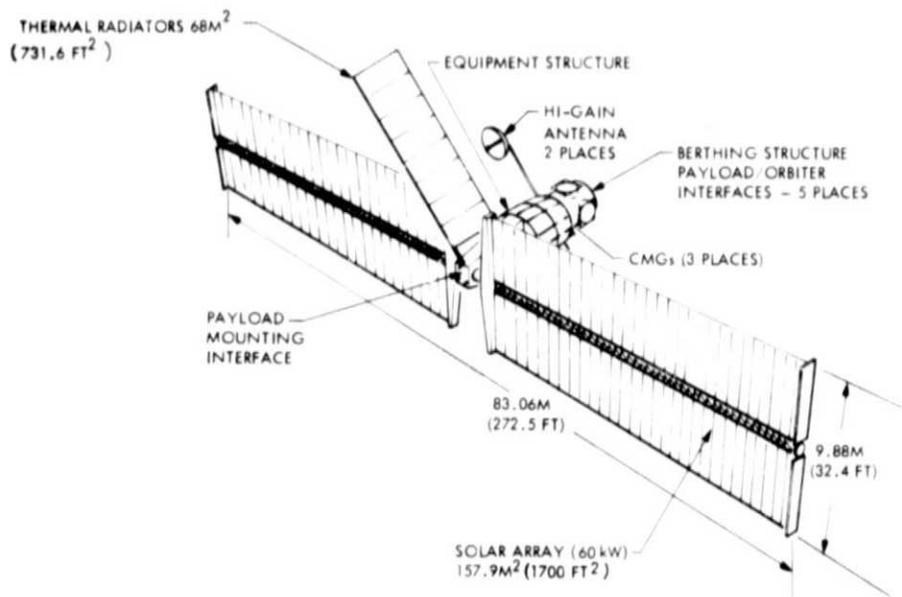
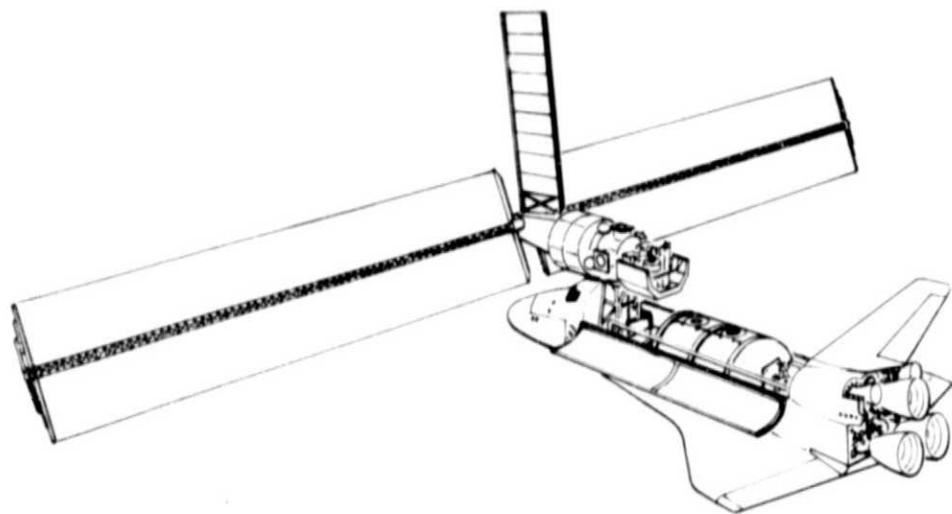
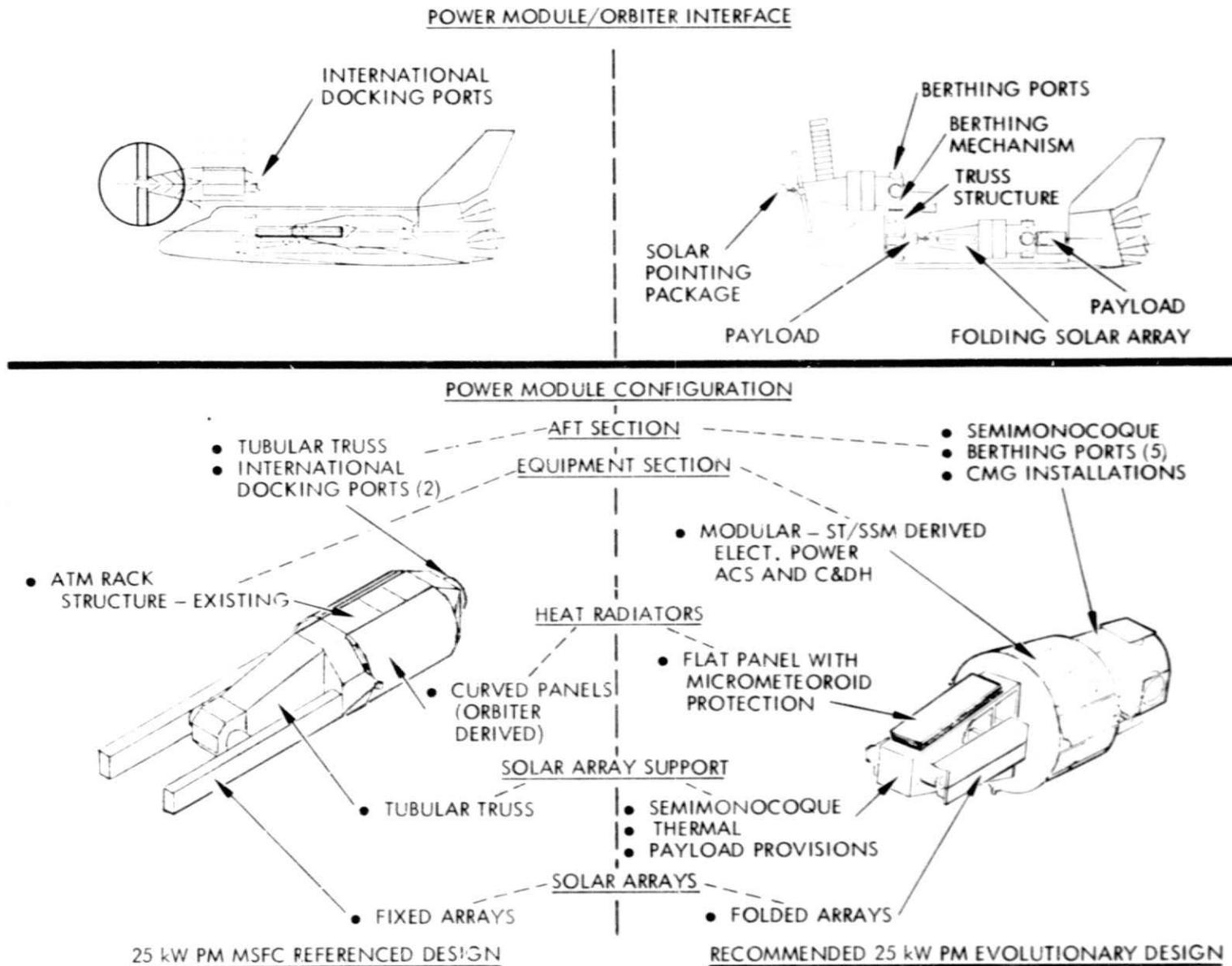


Figure 10 Sortie and Free-Flyer Configurations



25

Figure 11 Comparison of MSFC Reference Design and Recommended 25 kW PM Configuration

Growth to 100 kW Power Module

Growth to 50 and 100 kW PMs can be achieved on subsequent vehicles on the ground in original manufacture or on-orbit by replacement kits. Figure 12 shows the common modular design concept for growth. Figure 13 shows the candidate 100 kW configuration.

Recommended Subsystem Design Approach

The recommended first flight vehicle structural subsystem employs a Space Telescope derived equipment section, an unpressurized berthing port structure with five berthing ports for multiple payloads, and a solar array support structure with detachable folding solar arrays and thermal radiators. Use of berthing ports will postpone development of pressurized international docking ports (and associated costs) until needed for the manned workshops/habitats to be developed later in the decade. This also will simplify the PM/Orbiter interface, and result in a lighter combined Orbiter/PM/SSE, and lower cost. Five berthing ports, rather than the two ports of the reference design, provide flexibility and additional payload interface capability in either sortie or free-flyer modes.

CMGs are installed in the berthing structure to provide easy external access for EVA maintenance and installation. The aft section has provisions for growth from three to six CMGs. The ACS and C&DH equipment section also provides for projected growth requirements; e.g., improved pointing or broader bandwidth data links.

The semimonoque solar array support section contains the thermal subsystem components, as well as the capability of mounting a forward facing solar pointing package.

The folded solar array assembly, which reduces the PM launch configuration length in the Orbiter cargo bay, conserves cargo bay space for payloads (such as the solar pointing package and an aft pallet) for cost effective deployment with the initial PM.

The two recommended modular equipment sections are derived from the Space Telescope System Support Module (SSM), and provide low cost, enhanced replicability, with external EVA access for maintenance and on-orbit system growth.

The recommended 25 kW PM first flight vehicle electrical power system in-

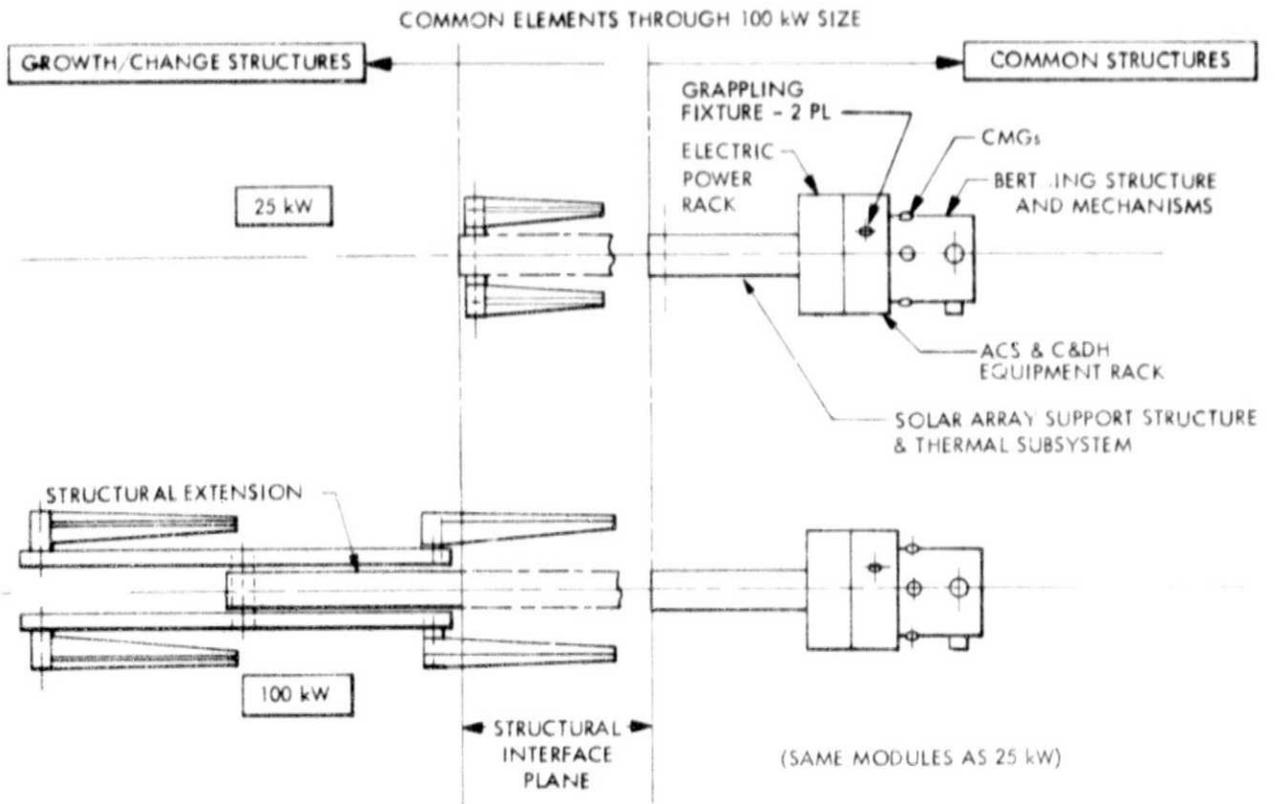


Figure 12 Modular Growth

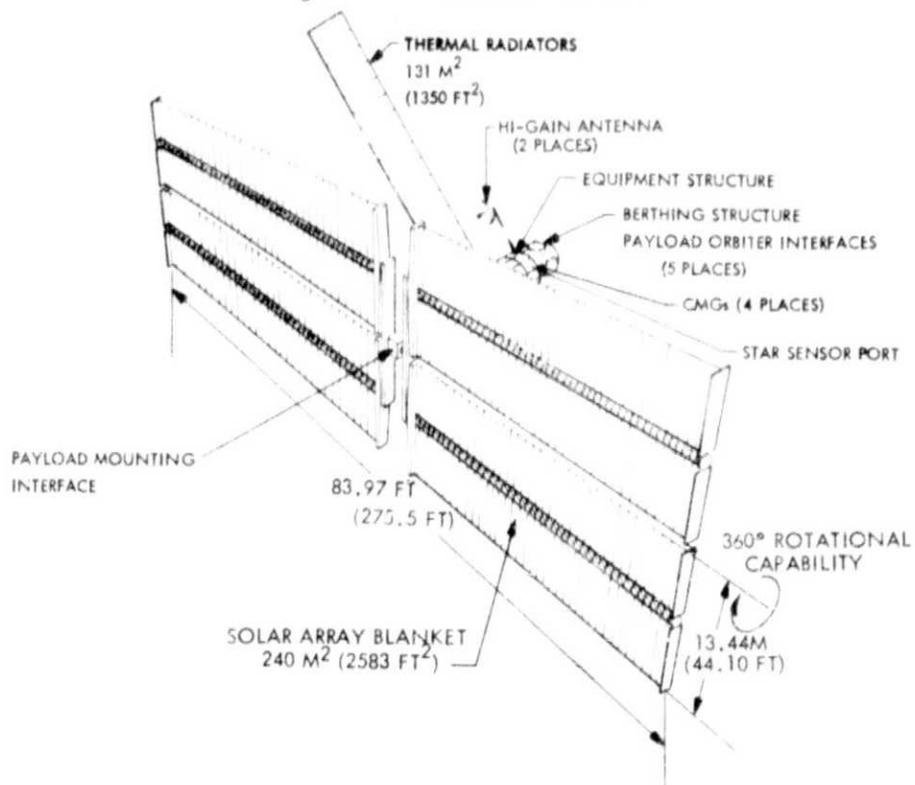


Figure 13 Candidate 100 kW PM Configuration

cludes the SEP technology solar array, a single-axis drive system, sun sensors/electronics, high power regulators, and NiCd batteries. Growth can be achieved by incorporation of NiH₂ batteries, improved solar cells, high voltage unregulated power, and improved electronics. NiH₂ battery technology is now under development, and ultimately will provide longer life and high depth of discharge (up to 80% vs 20% for NiCd). This, and the addition of more power processing equipment, can upgrade the equipment section to support up to at least 100 kW.

Additional solar array modules (with improved technology) and support structure extensions provide for growth to at least 100 kW. This modular approach enables incorporation of advanced technology as it becomes cost effective.

The growth capabilities can be incorporated in subsequent vehicles or, as an option, in existing vehicles by means of an on-orbit growth modification.

Thermal rejection, to augment both payload and STS capabilities, is provided by flat thermal radiators, equipment cold plates, payload heat exchangers, and a dual pump and accumulator package.

Optional thermal modules dedicated to user payloads are recommended as a means to provide additional heat rejection. The flat radiators are more efficient than the curved. Improved meteoroid protection and dual fluid loops provide long life and increased reliability for the recommended heat rejection subsystem configuration. The thermal subsystem may be expanded by additional radiator panels and associated thermal control components installed in the solar array support structure.

The attitude control system (ACS) employs narrow angle sun sensors, rate gyros, three control moment gyros, and signal conditioning. Magnetic torquers under development for Space Telescope are used for backup attitude control, contingency retrieval, and gyro desaturation. Horizon sensors are utilized for attitude determination; and wide-angle sun sensors for attitude control reacquisition. Growth is enabled by adding star sensors that can improve attitude determination for improved pointing in the free-flyer mode. Additional gyros are added to accommodate larger payloads and extend pointing times.

The recommended initial Communications

and Data Handling (C&DH) system capabilities are provided by a 256 KBS data rate system. A Space Telescope steerable +21 db-gain antenna (S-Band) is used in the free-flyer mode to transmit payload-user data above the reference housekeeping 4 KBS. A Ku-band kit can be substituted in future systems to provide growth to 300 MBS.

A NASA standard NSSC II computer and transponder is satisfactory for early payload system requirements. A distributed data bus system (remote telemetry and command units) is provided to minimize wires crossing payload and power module interfaces. Performance and memory improvements will provide future growth by adding remote computer capability units for payload data processing to the basic system.

Program Operations

The recommended 25 kW PM conceptual design is compatible with all concepts for STS ground and flight operations and performance capabilities. The PM factory-to-launch sequence will deliver a flight-ready vehicle to the launch site. Ground operations will center around PM and Support Equipment preparation for launch at KSC.

Space flight operations will include both sortie and free-flyer modes. Where the Orbiter is an active element, mission operations are controlled by Johnson Space Flight Center, and will be supported by a Payload Control Center that controls free-flyer mission operations.

Ground Test Program. The 25 kW PM test program comprises factory component, subsystem, and system assembly testing in an acoustic environment test of the assembled vehicle. Launch site testing is minimized and primarily oriented to systems and interface verification. To maximize flexibility, the test program will be sequenced for delivery and installation of solar arrays and flight batteries at the launch site. PM refurbishment after retrieval from orbit will be performed at the factory over a 5 month timespan. Retest of the refurbished PMs and growth kits at the factory will be similar to initial PM testing.

Ground Operations. Existing and planned facilities will be used for ground processing without modifications. The PM Space Support Equipment (SSE) will be serviced and installed in the Orbiter to support launch and orbit place-

ment, sortie payload delivery and re-visit space operations. PM and SSE processing will be achieved within Orbiter-established timelines. Figure 14 shows the typical ground/flight operations at KSC. The timeline for PM processing at KSC is 30 operational days. Of this, 20 days are "off-line" to STS operations and 11 days are "on-line" with STS operations.

Flight Operations. Key flight operations are associated with Orbiter ma-

neuvering and procedures for PM rendezvous, capture, berthing and deployment. EVA will be used to accomplish on-orbit maintenance and for assisting assembly of PM subsystem growth kits. The procedure recommended for rendezvous, proximity flight, and berthing by the Orbiter is shown in Figure 15. The Orbiter approach to the PM is along the radius vector \bar{R} between the PM and earth center. This technique utilizes orbital mechanics as a braking technique and minimizes plume impingement

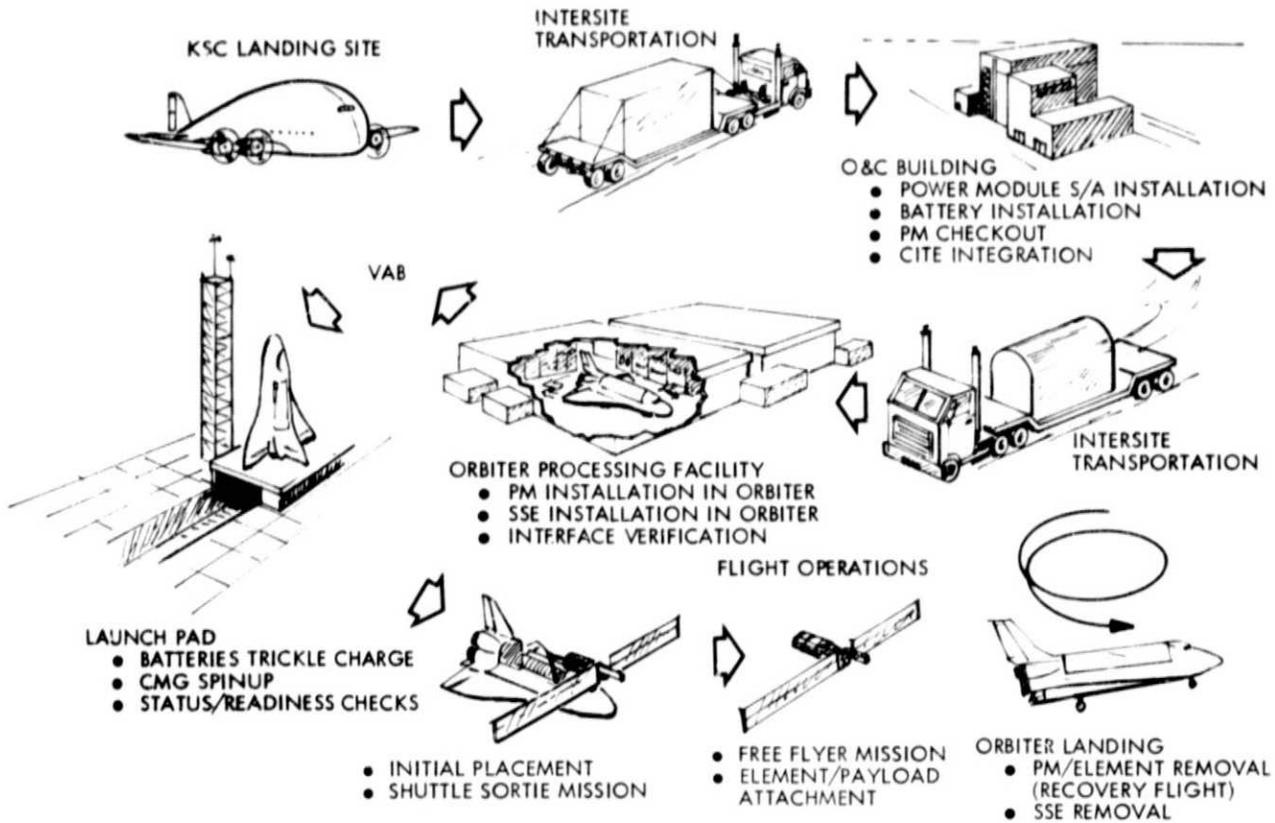
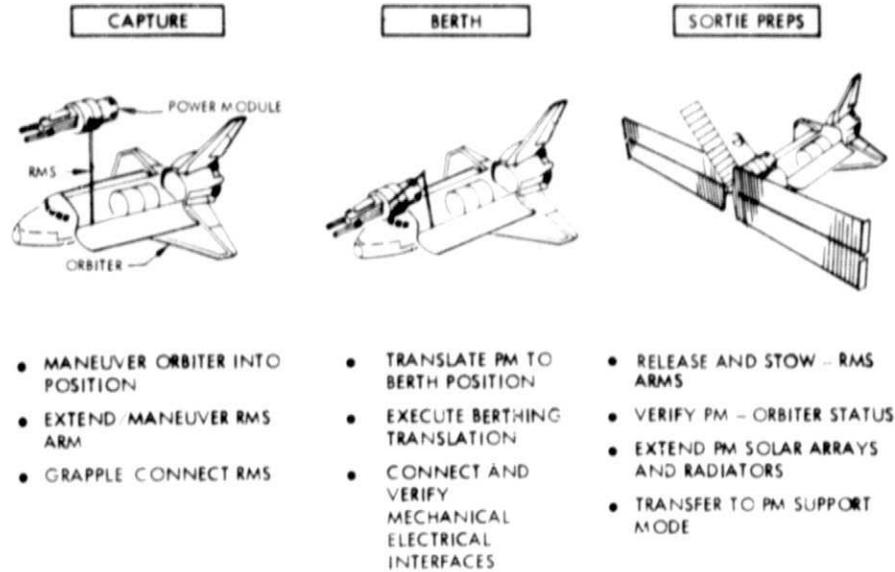


Figure 14 PM Operations Sequence



- | | | |
|---|---|--|
| <ul style="list-style-type: none"> • ORBITER AT RADIUS VECTOR • WITH RF CONTROL • VEHICLE STATUS CONFIRMED | <ul style="list-style-type: none"> • ORBITER, TRANSLATING TO REMAIN ON \bar{R}, WILL MOVE DOWNWARD • COMMAND RETRACTION ALL DEPLOYABLES • VERIFY STATUS | <ul style="list-style-type: none"> • PILOT HOLDS \bar{R} POSITION AND TRANSLATES UPWARD • PREPARE RMS ORBITER FOR CAPTURE |
|---|---|--|

Figure 15 PM On-Orbit Rendezvous and Berthing Operations

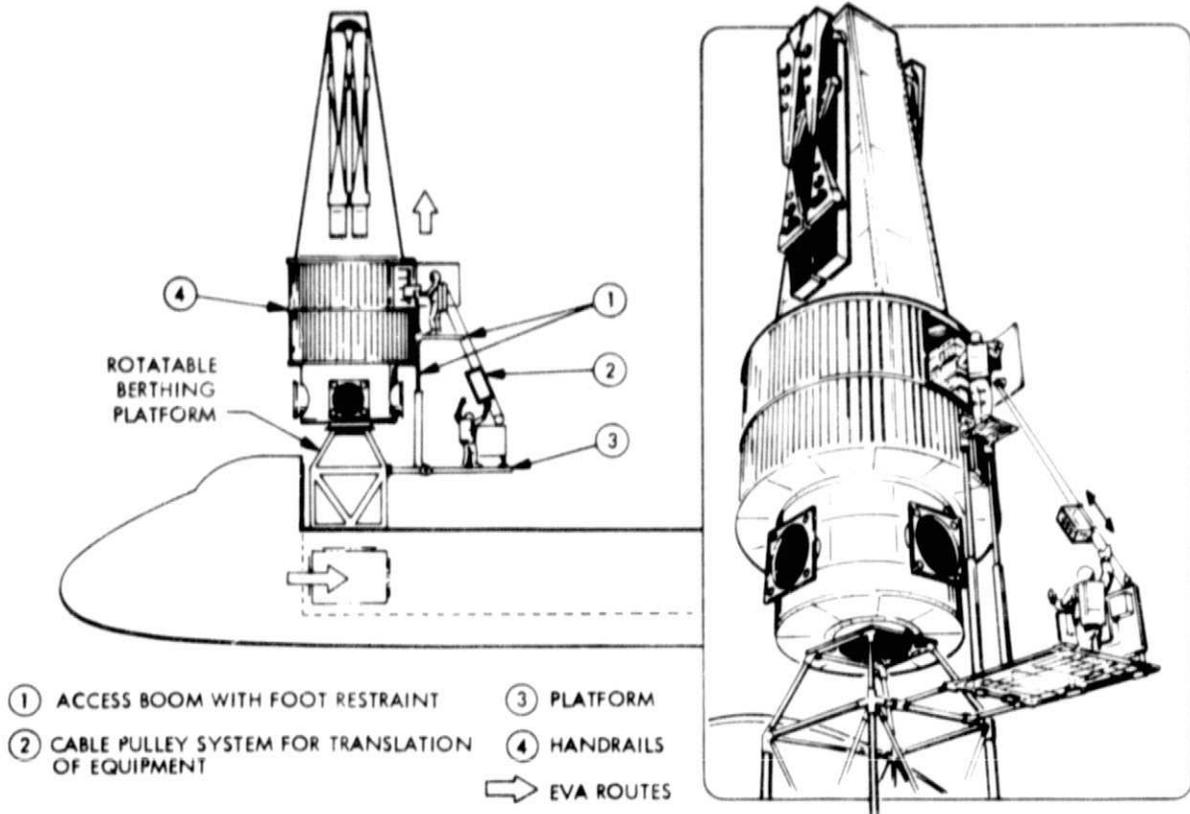


Figure 16 PM EVA Maintenance Operations

on the PM. As indicated, the PM deployables (antennas, arrays, and heat radiators) are retracted to facilitate operations.

Figure 16 illustrates EVA maintenance and growth assembly operations in the berthed position. Modular equipment units can be revised and replaced by an astronaut using a single ratchet wrench. Equipment replacement is facilitated by basic PM design features. These features include location of major sub-

system elements in the core structures for easy accessibility and the incorporation of EVA assist handrails and tethered equipment lifts at major access areas. Standard NASA support equipment, stands, lighting, and constraints are recommended.

Evolution from 50 kW to 100 kW can be accomplished on-orbit by the addition of a kit launched from the ground as a partial shuttle cargo load. Assembly requires a two-man EVA crew and an RMS

operator. Conversion takes on the order of three hours to accomplish.

PROGRAM PLANS

Program development planning, scheduling and cost estimating performed in support of the evolution study provided confidence in the ability to satisfy IOC for a 25 kW PM launch in 1983, and continued cost effective growth into 50 kW and 100 kW systems.

The basic 25 kW PM configuration development program provides an appropriate point of departure. The initial vehicle and growth versions are described in Volume 1, of the Part III Final Report. The program plan realistically provides for design, development, deployment and evolutionary growth of the recommended 25 kW concept.

The study groundrule of an October 1983 IOC requires commencement of a 36-month development and acquisition phase in October 1980. This plan is based on the following assumptions and guidelines:

- o A 12-month Definition Phase effort will precede the Acquisition Phase.
- o A prototype flight system development concept will be used to minimize test

hardware.

- o SEPS solar array technology and orbital flight test programs will be successfully concluded.
- o The CMGs from the Skylab program will be available for modification and use in the 25 kW PM.
- o The Space Telescope System Support Module (SSM) design and tooling will be available for use.

The required development, design, manufacturing, and test spans can be accommodated within the three-year span. The Solar Array assembly is the critical path.

The arrays will be mated with the PM at the launch base to provide optimum solar array development, production and test time. Prior to PM shipment to the launch base, final assembly and vehicle level test activities will utilize solar array development test or simulation hardware for fit and functional verification.

Two critical factors pace the solar array manufacturing spans: (1) cells must be produced in significantly high quantities, and (2) the welding operation is key to solar array panel fabrication.

It was determined that existing production capabilities are adequate to supply the required quantities of cells for the initial flight PM. However, to ensure availability of cell production at the beginning of the acquisition phase, procurement plans must be finalized and implemented in Phase B.

Figure 17 is the recommended development schedule for PM systems engineering, subsystem production, assembly and checkout tooling, ground support equipment, space support equipment, and system interface development over the 36 month duration.

Initial 25 kW PM system capabilities will be expanded as required to accommodate the nominal Scenario mission requirements described earlier. A 50 kW PM capability is established by 1986, evolving into a 100 kW PM capability in 1990.

In the nominal Scenario, the initial 25 kW flight vehicle will operate on-orbit for a 30-month period. It will be retrieved and refurbished. Retrieval of the initial flight vehicle will be coincident with deployment of the first 50 kW Power Module. A single orbiter flight will accomplish 50 kW PM launch

and deployment, and 25 kW PM retrieval.

The refurbished 25 kW PM will be launched on its second operational flight into a 28.5° orbit and later replaced on-orbit by another 50 kW Power Module. The initial 25 kW PM will be refurbished for the second time and then launched into a polar orbit where 25 kW capabilities are sufficient to satisfy user needs for the remainder of the decade. The first 50 kW PM at 28.5° will be grown to 100 kW on-orbit by means of STS delivery of a 50 kW augmentation kit and on-orbit RMS/EVA assembly from the Orbiter.

Launch and deployment of a 100 kW PM into a 28.5° orbit in 1990 will require more than one Orbiter flight. The configuration will require a partial (less than 50%) payload delivered by a second Orbiter; the remaining 50% of the Orbiter payload capacity is assumed to be devoted to PM user STS requirements for on-orbit delivery.

The estimated costs to develop, deploy and operate the nominal Scenario I PM program are graphically presented in Figure 18. More detailed cost data are provided in Figure 19. Acquisition costs for the first of each size of PM

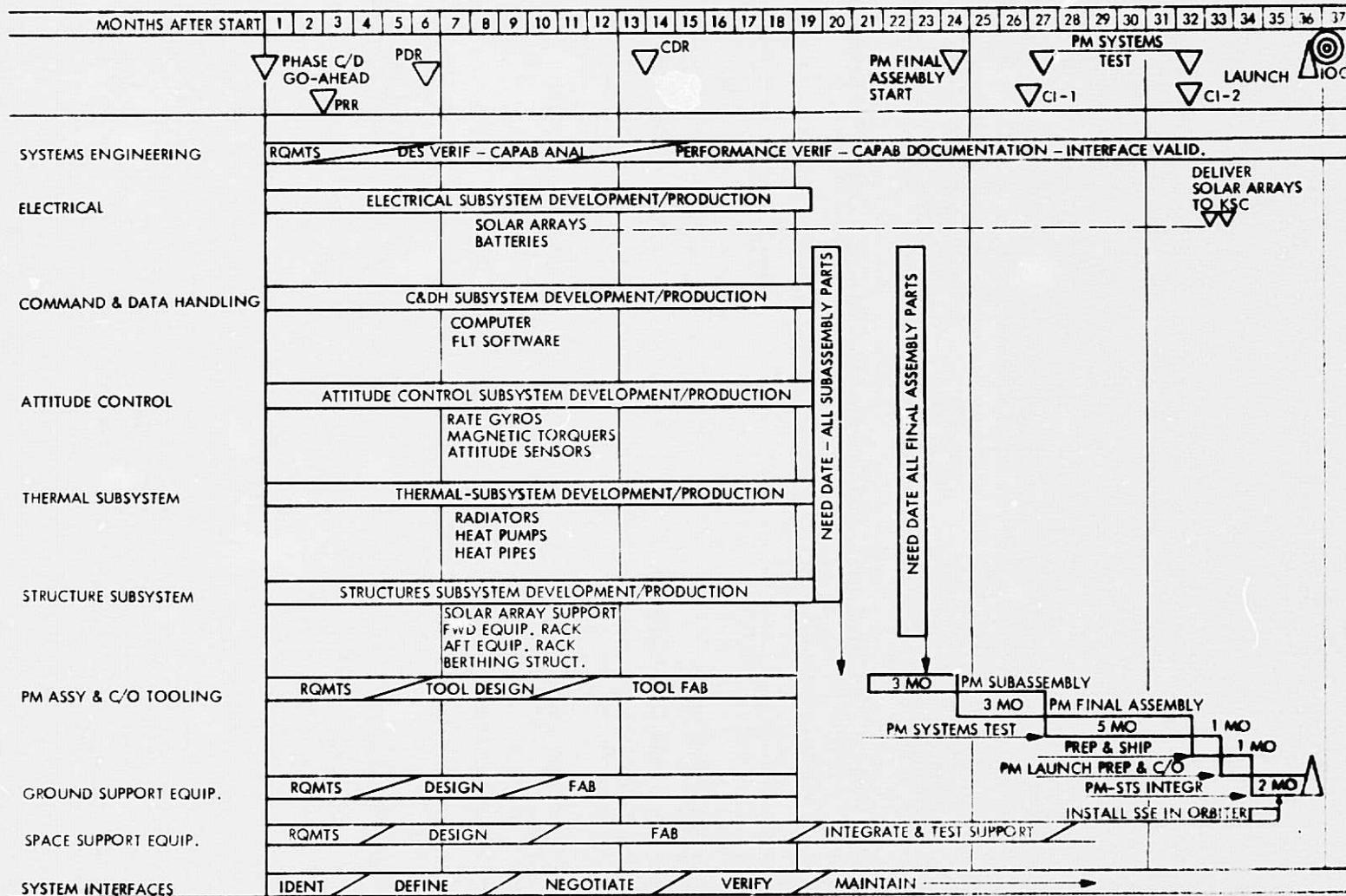


Figure 17 Master Planning Schedule - Subsystem and Support Elements

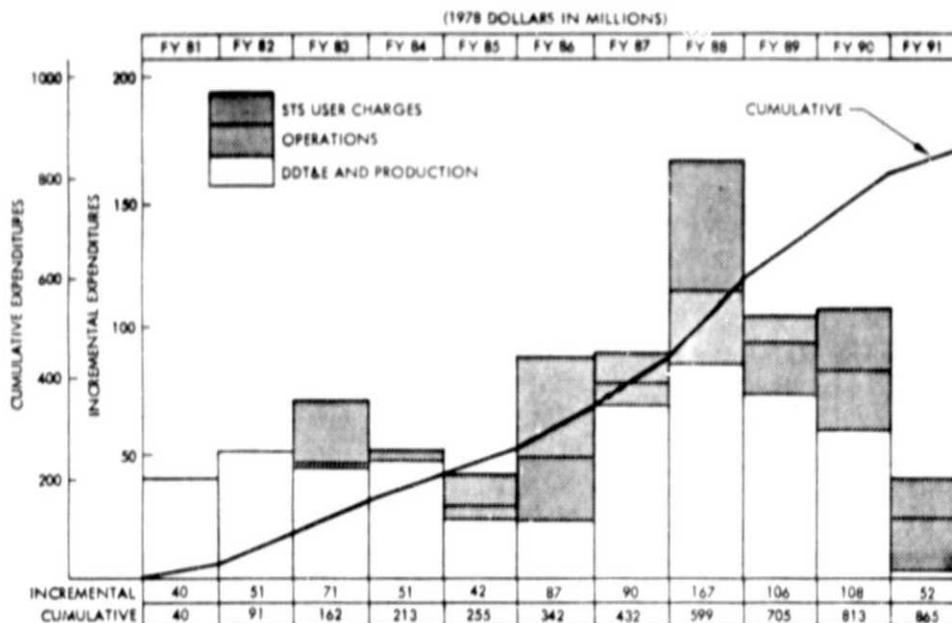


Figure 18 Funding Requirements for Nominal Scenario Program

| | Cost (\$ 1978 in Millions) | | |
|------------------------|----------------------------|----------|-----------|
| | 25 kW PM | 50 kW PM | 100 kW PM |
| ACQUISITION COSTS | (114.9) | (96.1) | (135.4) |
| - DESIGN & DEVELOPMENT | 65.8 | 18.6* | 20.7** |
| - PROTOFLIGHT UNIT | 49.1 | 77.5 | 114.7 |
| DEPLOYMENT COSTS | (25.7) | (25.7) | (38.6) |
| LAUNCH OPS | 1.3 | 1.3 | 1.7 |
| STS CHARGES | 24.4 | 24.4 | 36.9 |
| TOTAL THRU IOC | 140.6 | 121.8 | 174.0 |
| OPERATIONAL COSTS/YR | (3.1) | (4.5) | (6.2) |
| MISSION OPS/YR | .7 | .7 | .8 |
| ON-ORBIT SERVICE/YR | 2.4 | 3.8 | 5.4 |
| GROUND REFURBISHMENT | 12.4 | | |

* PRESUMES PRIOR DEVELOPMENT OF 25 kW PM

** PRESUMES PRIOR DEVELOPMENT OF 50 kW PM

Figure 19 Comparative Costs for 25 kW, 50 kW, and 100 kW PM Steps

are presented along with the development, deployment and operational cost increments. These estimates anticipate frequent revisits inherent in user missions and assume no STS user cost.

Specific results of this planning and costing effort are:

1. A plan was prepared which would achieve a 1983 IOC for the first 25 kW PM.
2. The initial 25 kW PM development/acquisition cost, including solar arrays, is estimated to be \$115 million.
3. A plan for orderly, evolutionary growth as requirements evolve has been prepared with associated funding requirements.

SUPPORTING TECHNOLOGY DEVELOPMENT RECOMMENDATIONS

The recommended PM evolution incorporates technological advances paralleling the sequential growth of the system through the 1980's to satisfy the mission scenario requirements. Most of the advances utilized are state-of-the-art (SOTA) improvements projected to occur independent of the PM program. Accordingly, the recommendations are primarily focused on the development activities to incorporate proven advanced techniques into a satellite system.

Supporting technology developments for the PM program are summarized in Figure 20. Most of the items have been identified in the design evolution discussions. Additional discussion, by subsystem, is provided in the following paragraphs.

Structures

Major structural materials advances with composites and non-metallic synthetics were achieved in the past decade. These are projected to continue

unabated into the next decade, providing improved strength-to-weight and thermal properties. Fabrication technique developments point to achievement of these property improvements in most cases utilizing more costly materials, but counterbalanced by rapidly decreasing production costs. In many areas, economies are being realized by remarkable reductions of piece-parts and associated assembly costs. These advances are anticipated to apply to, and affect design of essentially all structural components of the PM in the mid and late 1980's.

Electrical Power

Primary advances are projected for solar cells, long-life high energy-density batteries, and power processor equipment. New solar cell materials such as GaAs will improve efficiency. Solar cell assembly process advances are expected to provide significant improvements in reliability and cost reduction. Power processor equipment improvements will increase efficiency and

| Subsystem | Item | Program Benefits | |
|-------------------------|--|--|----------------|
| | | Performance | Cost Reduction |
| Structures | Advanced Concepts for Panels | Thermal Isolation | Yes |
| | Graphite/Epoxy | Reduced Wt/Greater Stiffness | No |
| | Graphite/Alum or Magnesium | Reduced Wt/Greater Stiffness | No |
| Electrical Power | Advanced Batteries | High Energy/Density | Yes |
| | Solar Cells | Higher Efficiency | Yes |
| | Mast & Mechanism Improvements | Reduced Wt/Greater Stiffness | Possible |
| | Solar Cell Assembly Processes | Reliability Improvement | Yes |
| | Power Management Equipment | Reduced Size & Weight Improve Efficiency | Yes |
| Thermal Control | Multiple Interface Concepts | Reliability Improvement | Yes |
| | Adv Radiator Panels | Reduced Wt; Long Life | Yes |
| Attitude Control | Adv Rate Gyros & CMGs | Reduced Size/Wt; Long Life | No |
| | Drag Makeup/Orbit-Adjust Equipments | Operational Flexibility | Yes |
| Command & Data Handling | Improved Processing & Handling Equipment | More Service to Payloads; Improved Reliability/Long Life | Yes |

Figure 20 Supporting Technology Development

reliability. These items as well as structural material advances discussed above, will result in significant size and weight reductions. From a system standpoint, each of these will effect cost reductions.

Thermal Control

Unique thermal control subsystem design requirements are imposed by the multiple interfaces to be provided between the PM, the Orbiter, and several payloads. Design development is required to achieve reliable, maintenance-free interface connections and flow-control subassemblies. Radiator panel, panel interconnect, and extension/retraction techniques are expected to benefit from material developments discussed previously, and these will require PM application development to incorporate the associated performance and cost economy gains projected.

Attitude Control

Since there is only a limited quantity of both rate gyro and CMG hardware in existence, new and improved components will obviously be incorporated in future PMs. These should be smaller, lighter, and designed for long-life,

incorporating the technology benefits available in the mid 1980's.

Although not provided in the recommended design evolution, potential cost-effectiveness of an integral drag-make-up propulsion subsystem dicatates that this option be considered during the Phase B study. The operational flexibility which would become available is likely to result in major programmatic cost reductions. If this is confirmed during Phase B, technology development of new high-reliability, long-life propulsion system components is likely to be required.

Command & Data Handling

Data processing including data compression and/or limit checking devices are logical candidates for PM system application in the mid-1980's. These would drastically enhance services available to the users, and at the same time provide reliability and long-life improvements. With the on-going development activities on these elements independent of the Power Module program, it is anticipated that their incorporation in PMs produced in the mid and late 1980's will not require major developmental efforts.

STUDY CONCLUSIONS

This study has provided a high level of confidence in the feasibility of LMSC's recommended configuration and program development approach. It is apparent that the 25 kW PM is a logical first step to support near-term NASA sortie and free-flyer mission requirements. The recommended 25 kW PM configuration establishes a sound basis for growth to advanced capabilities without major re-design and requalification at each step, i.e., the approach is fully open-ended.

Current technology is adequate to implement the first 25 kW PM vehicle for missions beginning in 1983 and through 1985. Moreover, 50 and 100 kW PM configurations are logical growth steps. Anticipated new developments and near

future technology advancements readily can be incorporated into PM vehicles, thereby achieving cost effective, timely system growth. System growth to increased payload support capabilities can be accomplished in-orbit.

The recommended approach has the flexibility to respond to changing technical and schedule requirements. Alternate scenarios were evaluated that had variations from the nominal in time phasing and level of support in a given orbit. The evolutionary growth path of the PM was insensitive to these changes.

There are no barriers to proceeding with full scale development.