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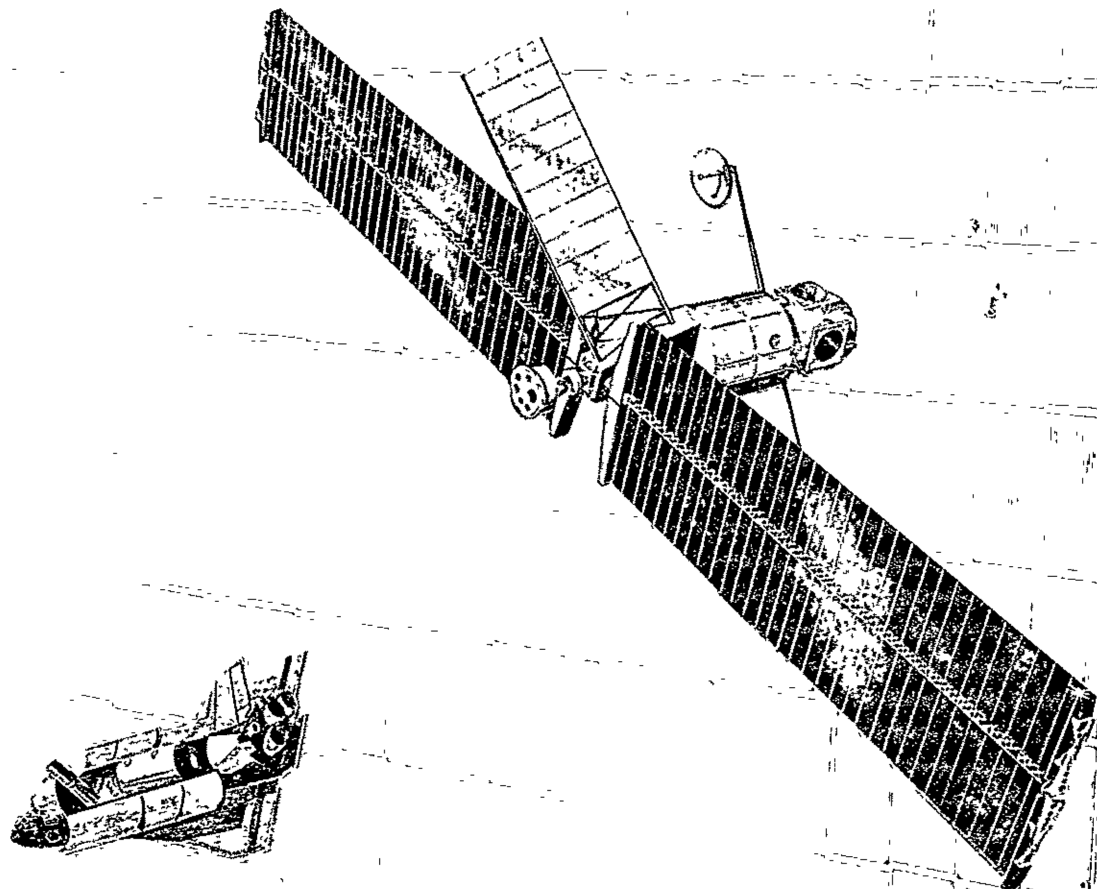

(NASA-CR-161147) THE 25 kW POWER MODULE EVOLUTION STUDY. PART 3: CONCEPTUAL DESIGNS FOR POWER MODULE EVOLUTIONS. VOLUME 3: COST ESTIMATES Final Report (Lockheed Missiles and Space Co.) 67 p HC A04/MF A01 G3/15

N79-17891

Unclas 14337

NASA George C. Marshall Space Flight Center

25 kW POWER MODULE EVOLUTION STUDY

VOLUME 3 COST ESTIMATES
PART III : CONCEPTUAL DESIGNS FOR POWER MODULE EVOLUTION
FINAL REPORT

LOCKHEED MISSILES & SPACE COMPANY, INC.

LMSC/D614944-3

FINAL REPORT

25 kW POWER MODULE EVOLUTION STUDY

PART III: CONCEPTUAL DESIGNS FOR POWER MODULE EVOLUTIONS

VOLUME 3: COST ESTIMATES

27 January 1979

SUBMITTED TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Marshall Space Flight Center
Huntsville, Alabama 35812

Contract NAS8-32928
DPD 555
MF-03A

SUBMITTED BY
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FOREWORD

This volume of the Part III Final Report for the 25 kW Power Module Evolution Study was prepared by Lockheed Missiles and Space Company, Inc. for the George C. Marshall Space Flight Center (MSFC), National Aeronautics and Space Administration (NASA), under Contract No. NAS8-32928.

The objective of the study was to define how the 25 kW Power Module can be evolved by the addition of systems elements in evolutionary steps to meet the future mission requirements. For each step, conceptual designs were prepared. The level of capability at each step was commensurate with the mission and payload requirements. Emphasis was placed on the near-term steps beyond the 25 kW Power Module.

The study activity comprised the following parts/tasks:

- Part I - Payload Requirements and Growth Scenarios

  (LMSC, TRW, and Bendix)

This analytical effort was conducted to develop payload application summaries and time-phased requirements that will drive the concepts for the 25 kW Power Module and the supporting systems definitions (for the period 1983-1990). The Part I effort was documented in Final Report LMSC-D614921A, dated 1 August 1978.

- Part II - Payload Support System Evolution

  (LMSC, IBM, and Bendix)

This effort was devoted to establishing baseline program support elements and candidate evolutionary growth capabilities for final candidate definition (element, data, cost, mods, development sequence, and precursor missions). The Part II effort was documented in Final Report LMSC-D614928A, dated 30 September 1978.

FOREWORD (Continued)

- Part III - Conceptual Designs for Power Module Evolution

  (LMSC, Bendix)

This effort was conducted to establish design approaches for the evolutionary systems, to develop associated programmatics data, and to assess the evolution scenario and capabilities of the 25 kW Power Module for representative missions.

This report constitutes Volume 3, Cost Estimates, of the Part III Final Report. It meets the requirements of Contract No. NAS8-32928 Data Procurement Document (DPD), Data Requirement MF-03A, Final Study Report.

A supplement to Volume 3, containing sensitive cost data, is being provided to limited distribution under separate cover.

The volumes comprising the Part III Final Report are:

- Volume 1 Power Module Evolution
- Volume 2 Program Plans
- Volume 3 Cost Estimates
- Volume 4 Design Analyses
- Volume 5 Mission Accommodations
- Volume 6 WBS and Dictionary

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Section 1

INTRODUCTION

1.1 PURPOSE/SCOPE

This volume fulfills the requirements of Data Requirement MF-03A of contract NAS8-32928 by reporting cost data generated for the evolutionary Power Module (PM) concepts formulated in this study. The organization of Volume 3 is as follows:

- Section 2 is a summary of PM costs
- Section 3 describes the costing methodology and assumptions; including the Work Breakdown Structure
- Sections 4 through 6 discuss the costs of the 25, 50 and 100 kw PM systems, respectively. The costs shown in these sections reflect the primary study emphasis, i.e., acquisition and per-mission costs
- Section 7 applies the estimates from Sections 4 through 6 against specific mission scenarios
- Section 8 briefly summarizes cost trades performed in support of the study
- Section 9 is a combined set of references for Volume 3
- Appendix A presents backup data to support sections 4 through 7. It contains NASA cost data forms A, C and B. Form A reports costs by WBS entry to subsystem level, arranged by program phase. Form C reports the time-phasing of these costs. For reference, the costs reported in both Forms A and C reflect a single mission scenario (Scenario I: nominal program, no Skylab). Form B shows the driving technical characteristics of the various PM concepts.

1.2 OBJECTIVES

The objective of this study was to define how the 25 kW PM can evolve in evolutionary steps to match mission growth scenarios. These scenarios, also derived in the study, match predicted mission user needs against evolutionary PM services. The evolutionary growth steps consist of PM spacecraft or kits needed to obtain building-block growth in satisfying a range of potential mission scenarios.

The objectives of the cost analysis were to:

- o Provide valid cost estimates for each building block configuration in the selected PM evolution.
- o Provide cost data to help evaluate trade studies conducted in support of concept selection.
- o Provide budgetary cost projections for selected evolutionary scenarios using the PM building blocks.

1.3 BACKGROUND

As a result of a rigorous payload user analysis of the time phasing of potential PM services (e.g. electrical power, heat rejection, pointing, data relay) in Task I of this study, three growth scenarios were identified. Based on the requirements of these scenarios, a preferred PM evolutionary concept was selected. This evolution features a building-block 25 kW PM and two additional growth steps:

1) A 50 kW PM
2) A 100 kW PM, comprising a modular version of the 50 kW PM and a growth kit to provide an additional 50 kW of power

Primary emphasis in the cost analysis was on defining the PM acquisition costs, i.e., the costs for DDT&E and production/test of a protoflight unit. These were emphasized because it was assumed that the acquisition costs would be absorbed by the Government as a sunk cost, and that hence these costs could not be recovered from the PM users. The other element receiving emphasis in this analysis was activity-level-dependent costs such as transportation and operations. These were calculated on a per-flight or per-year basis as appropriate, because the mission scenarios are subject to substantial change as user needs become more clear. Costing of specific scenarios was limited in scope and was done at high levels to get comparative costs and funding profiles.

Section 2

COST SUMMARY

2.1 COMPARATIVE COSTS

Comparative costs for the three evolutionary PM concepts that make up the LMSC recommended evolution are as follows:

	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

The evolutionary nature of the PM program focuses most design and development costs on the first step, the 25 kW PM, whereas the production and test costs of the first flight article (a protoflight unit in each concept) increase with

PM size. The driver in the comparative cost of protoflight units is the solar array size. Other subsystems such as structures and avionics are far less size sensitive and these costs do not double with doubled power output. Other cost drivers in the PM evolution are:

- Launch Operations: To achieve a 100 kW PM capability, a 50 kW kit must be readied for launch in addition to the basic 50 kW PM.
- Mission Operations: Ground-controller crews must control the on-orbit assembly of the 100 kW PM.
- Space Transportation System (STS) Delivery to Orbit: One complete Shuttle flight delivers the 25 and 50 kW PMs, whereas the 100 kW PM requires one flight plus a partial Shuttle for delivery of the kit.
- STS Deployment: The 25 and 50 kW PMs require use of the second-RMS service. The 100 kW PM requires this, plus Extra Vehicular Activity in the orbital assembly process.
- STS Retrieval: Assuming that retrieval flights are not dedicated Shuttle missions (but rather "opportunity" missions), the 25 and 50 kW PMs can be retrieved for the cost of launching their SSE. The 100 kW PM requires an additional flight to carry the cradle for the 50 kW kit.
- On-orbit Servicing: These costs scale with the size and complexity of the PM concepts.

Section 3

COSTING APPROACH, METHODOLOGY AND RATIONALE

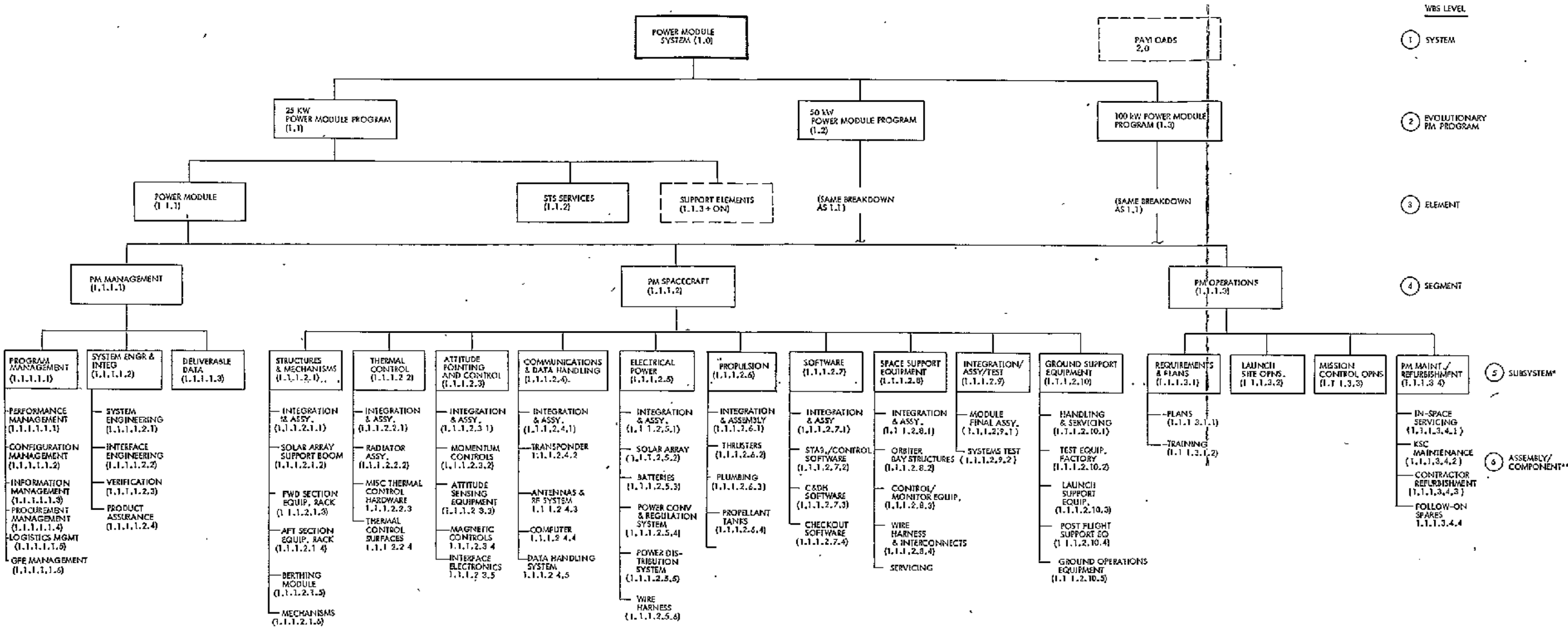
3.1 APPROACH

The approach used in estimating PM costs was to concentrate on defining and modeling the initial acquisition costs (design and development plus production and test of a protoflight unit) for the baseline 25 kW PM configuration. By building a parametric model of this initial building block, it was possible to derive the cost of the 50 kW PM and the 100 kW PM by defining only their configuration and programmatic differences from the 25 kW baseline. Variations in PM cost for the quantities needed to fulfill potential mission scenarios were derived by applying appropriate learning curves.

3.2 WORK BREAKDOWN STRUCTURE

All cost estimates in this study were generated and reported in accordance with the Work Breakdown structure (WBS) displayed in Figure 1. This WBS (which is fully defined in Reference 1) is end-item oriented. It was developed under the following philosophy:

- Costs identifiable against specific end items are reported separately from service or function-oriented costs (e.g. management, operations).
- Hardware and software end items are reported separately.
- The same WBS format is used for the 25, 50 and 100 kW PM concepts.
- The same WBS is applicable for all phases of development, deployment and operations.
- PM costs are separated from STS user charges.



* LEVEL 5 IS KEY COST-REPORTING LEVEL; VISIBILITY INTO ENGINEERING, TEST-HARDWARE, PRODUCTION (AND FIRST-UNIT), AND SPARES COSTS

** LEVEL 6 BACKUP DATA INCLUDE ENGINEERING, PRODUCTION AND TOOLING COSTS DOWN TO COMPONENT LEVEL

FOLDOUT FRAME

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Figure 11 Work Breakdown Structure

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3.3 METHODOLOGY

A mixed costing methodology was used in this study. The approach shown in Figure 2 is primarily parametric in nature, but incorporates throughput values for items for which cost has been established by other sources. The principal tool for parametric analysis was the RCA PRICE family of models, consisting of interrelated hardware, software and life-cycle cost prediction programs. PRICE was selected for space system hardware costing because of its following features:

- o Ability to model at component level.
- o Ability to calculate Integration and Test (I&T) costs at all levels of hardware assembly.
- o Ability to accept throughput costs and to incorporate them into integration and test costs.
- o Direct link to historical data base, including a "two-way" cross-check capability.
- o Ability to accommodate sensitivity analyses and trade studies by means of file manipulation.

The PRICE software model (PRICE 'S') and the PRICE life-cycle cost model (PRICE 'L') were selected for specialized cost calculations because each is unique in its ability to predict costs given a very limited set of inputs. PRICE 'S' costs the design, coding and verification of ground and flight software. PRICE 'L' calculates the cost of operation and maintenance of flight hardware.

The following system of checks and balances was used to ensure credibility of costs:

- o Where end-item costs were estimated parametrically, the costs were compared against known costs for similar items
- o Where point costs were the primary estimating method, the PRICE program complexity factors were derived by running the model backwards and comparing the derived factors with historical and book values

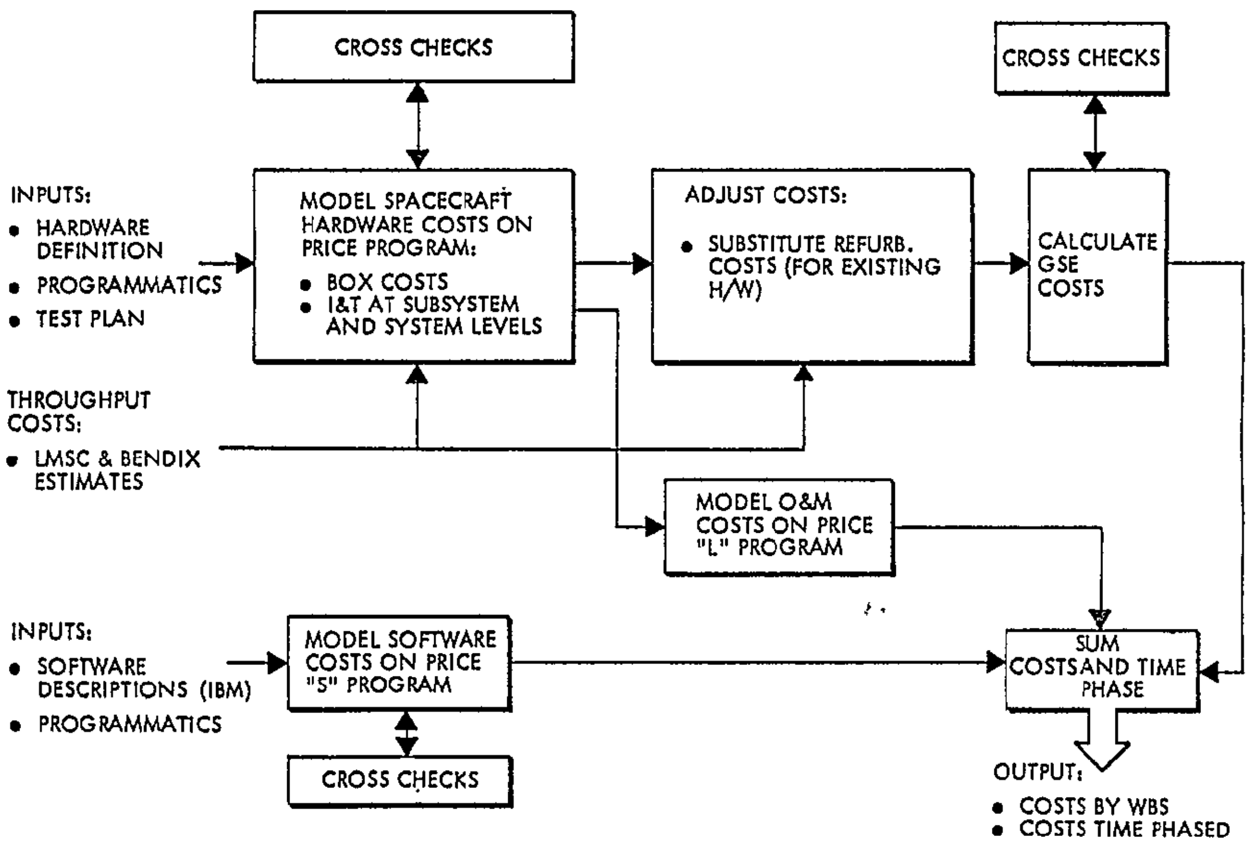


Figure 2. Cost Methodology

Estimates not consistent with the cross-check values were re-evaluated and rerun. Some of the specific sources of data used in these cross checks are shown in Figure 3.

ITEM	PRIMARY COST SOURCE	CROSS CHECK
SOLAR ARRAY	LMSC LABOR/MATERIAL ESTIMATE	PRICE COMPLEXITY FACTORS FOR SIMILAR ARRAYS
NASA STANDARD HARDWARE	PRICE HARDWARE MODEL ESTIMATE	VENDOR QUOTES/CATALOG PRICES
SOFTWARE	PRICE S MODEL ESTIMATE BASED ON IBM INPUTS	SPACE TELESCOPE (ST) PROGRAM
SSE	PRICE HARDWARE MODEL ESTIMATE	ST PROGRAM
GSE	LMSC HISTORICAL CER	ST PROGRAM

Figure 3. Typical Cross Checks

3.4 GROUNDRULES AND ASSUMPTIONS

Key assumptions made in the cost analysis were as follows:

- o Costs were expressed in constant 1978 dollars
- o Prime contractor fee and Government program management costs were excluded.
- o Existing ATM hardware (control moment gyros, rate gyros, etc.) was assumed to be available to the PM program at refurbishment cost.
- o The solar array was costed as a stand-alone effort in support of the PM, rather than as a common development serving the PM, PEP and SEP programs.
- o Solar cell costs were assumed to benefit from automation of the assembly process. The costs of plant and equipment for such processes was excluded.
- o Mission- and payload-peculiar costs were omitted.
- o An allowance for initial spares was included in the acquisition costs but is not separately identified.

Section 4

25 kW POWER MODULE COST ESTIMATE

4.1 INTRODUCTION

This section of Volume 3 contains a narrative discussion of the cost and major cost drivers for the 25 kW PM Program. The 25 kW PM (Figure 4) is the building block for all subsequent evolutionary development. It is designed for (1) simple transition to larger PM sizes and (2) satisfaction of key user requirements.

As noted earlier, the costs presented in this section are in building-block form and hence are not tied to fulfillment of any particular mission scenario. Scenario costs are summarized in Section 7 for all three selected mission evolutions, and more detailed costs for Scenario I are given in Appendix A.

Costs for the 25 kW PM may be summarized as follows:

		Costs ($ 1978 in millions)			
		Acquisition			Second Pro-
WBS Element		Design/Dev.	Protoflight	Total	duction Unit
1.1.1.	25 kW Power Module	(65.8)	(49.1)	(114.9)	(49.5)
1.1.1.1	System/Project Mgt.	18.1	0.6	18.7	0.6
1.1.1.2	PM Spacecraft	46.5	48.5	95.0	48.9
1.1.1.3	Operations (Devel.)	1.2	--	1.2	--

4.2 PROJECT COSTS

WBS element 1.1, 25 kW PM Program, sums costs for the 25 kW PM system (1.1.1) and STS user charges (1.1.2); additional WBS entries for support elements (1.1.3 and on) are not applicable since no such elements need be modified to

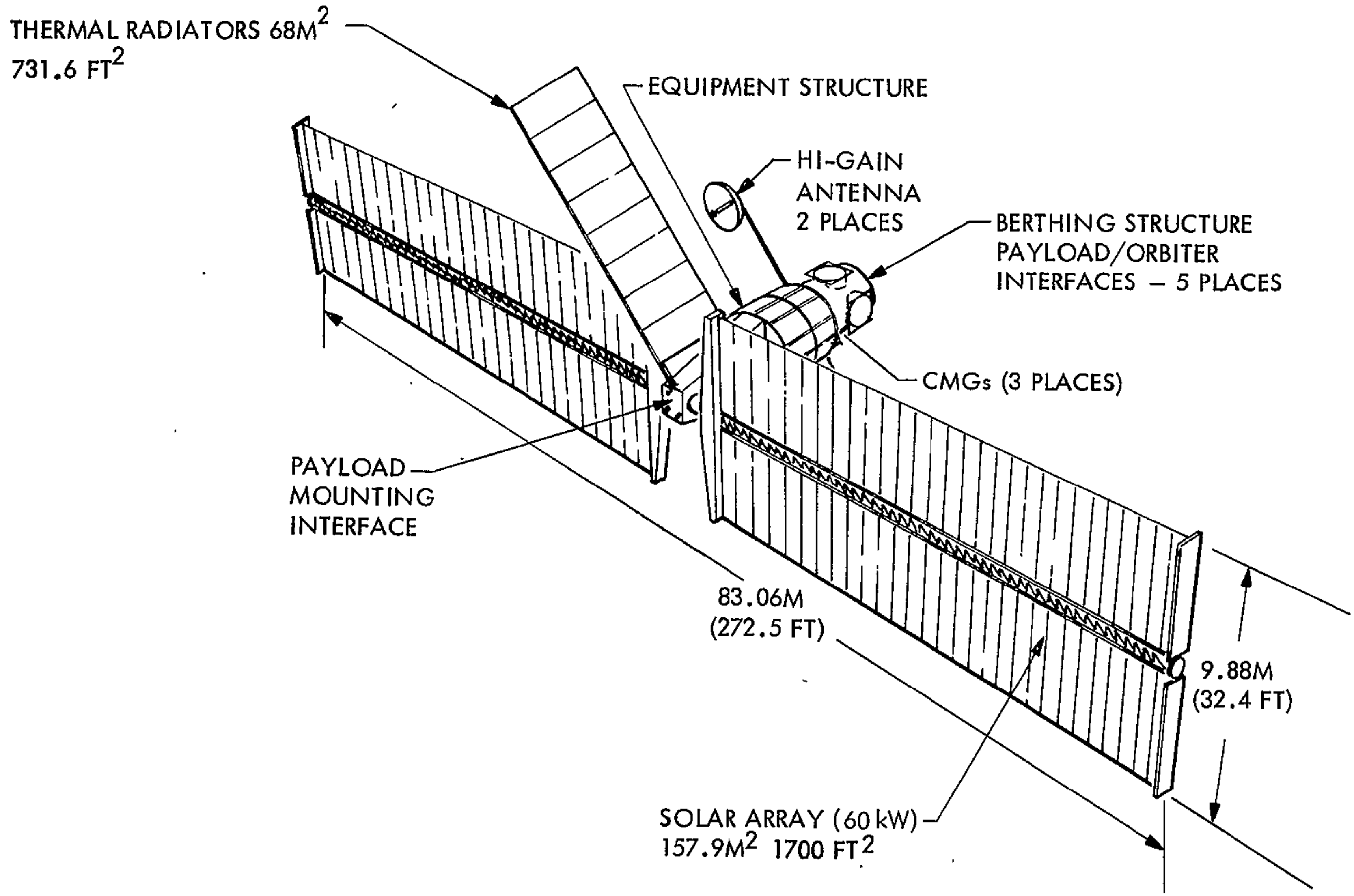


Figure 4. Recommended 25 kW Power Module Configuration - Deployed

support the 25 kW PM. The breakdown of 25 kW PM cost is given in sections 4.3 and 4.4. The STS services cost estimate is based on user charge data from Reference 2, escalated from the base year of 1975 to the PM study reference year of 1978. The resulting user charges applicable to the 25 kW PM are as follows:

	\$1975	\$1978
o Shuttle Launch, Each Flight*	18.0	24.3
o Second RMS Manipulator, Each Flight	0.09	0.12
o Retrieval (non-dedicated Shuttle flight), Each Flight	1.3	1.7

The total cost for the 25 kW PM program (WBS 1.1) is estimated to be \$140.6 million through IOC (deployment of the protoflight unit). This comprises \$114.9 M in acquisition costs and \$25.7 in deployment costs.

4.3 SYSTEM COSTS

System level costs for the 25 kW PM (WBS 1.1.1) comprise hardware, management, and operations costs. The one-time costs incurred through delivery of the protoflight unit to the launch base make up the 25 kW PM acquisition cost. It is this acquisition cost which will probably be considered NASA's "sunk" investment in the program and, hence, not subject to amortization in the user fee. The acquisition costs of the LMSC recommended baseline 25 kW configuration are \$114.9 million; of this, \$65.8 million is for design and development, and \$49.1 million for production and test of the protoflight unit.

The WBS breakdown of the LMSC 25 kW PM acquisition cost comprises \$18.7 million in System/Project Management (WBS 1.1.1.1) and \$95.0 million in

*Although the 25 kW PM is charged for a complete Shuttle flight, sufficient volume and weight are available to accommodate a payload on this flight.

end-item PM Spacecraft costs (WBS 1.1.1.2) and $1.2 million in one-time operations development (WBS 1.1.1.3). The System/Project Management costs further break down as follows:

o Program Management (1.1.1.1.1)	$ 3.6 M
o Systems Engineering and Integration (1.1.1.1.2)	14.3 M
o Deliverable Data (1.1.1.1.3)	0.8 M

The breakdown of PM spacecraft costs by subsystem is given in Section 4.4.

Note that the production cost for a second unit beyond the protoflight would be $49.5 million assuming continuous production. This is slightly higher than the protoflight unit because it is assumed that refurbished ATM hardware used on the protoflight would be unavailable at the time a second 25 kW PM would be produced, and that the loss of this existing hardware would not offset learning-effect savings for the second unit.

Operations costs for the 25 kW PM are as follows:

o Requirements and Plans (1.1.1.3.1)	$1.2 M, one time
o Launch Site Operations (1.1.1.3.2)	$1.3 M, per launch
o Mission Control Operations (1.1.1.3.3)	$0.7 M, per year
o PM Maintenance/Refurb. (1.1.1.3.4)	
On-orbit Servicing	$2.4 M, per year
Ground-based Refurbishment	$12.4 M, per occurrence

The launch and mission operations costs were based on crew manloadings derived in Reference 3. The launch crew was assumed to have a peak manloading of 35 persons and the mission control crew a constant manloading of 15 persons. The on-orbit servicing costs, which were derived from PRICE L simulations, comprise costs for spares, logistics management, and actual on-orbit maintenance operations by crew members performing Extra Vehicular Activities from the Orbiter. It was assumed that this maintenance would occur on payload revisits paid for by the users and, hence, no STS transportation costs were assessed for this activity. The cost for ground-based refurbishment of the 25 kW PM covers costs of replacement spares and all labor for teardown, maintenance, re-assembly and checkout of the retrieved PM.

4.4 SUBSYSTEM COSTS

The acquisition cost breakdown, at subsystem level, for the 25 kW PM spacecraft is as follows:

WBS ITEM		COST ($1978, MILLIONS) DESIGN AND DEVELOPMENT	PROTOFLIGHT UNIT	TOTAL
1.1.1.2.1	STRUCTURES	6.3	3.6	9.9
1.1.1.2.2	THERMAL	3.9	2.7	6.6
1.1.1.2.3	ATTITUDE CONTROL	5.6	3.5	9.1
1.1.1.2.4	COMMUNICATION AND DATA HANDLING	1.9	6.7	8.6
1.1.1.2.5	ELECTRICAL POWER	21.4	28.7	50.1
1.1.1.2.6	PROPULSION	0	0	0
1.1.1.2.7	SOFTWARE	2.4	-	2.4
1.1.1.2.8	SPACE SUPPORT EQUIPMENT	1.6	1.3	2.9
1.1.1.2.9	INTEGRATION/ASSEMBLY/TEST	-	2.1	2.1
1.1.1.2.10	GROUND SUPPORT EQUIPMENT	3.3	-	3.3
	TOTAL WBS 1.1.1.2	46.4	48.6	95.0

Key features and cost drivers for the individual subsystems are summarized below. Cost breakdowns below this level have been transmitted to NASA in Reference 4.

4.4.1 Structures - The structures subsystem features a mixture of existing and new design. The existing Space Telescope (ST) equipment section design is incorporated with only minor modifications to serve as the principal body structure for the 25 kW PM; two such units are used on the PM versus one on the ST. New structures incorporated into the PM are the solar array support and the berthing module. The solar array support structure is a modular design planned to accommodate growth to larger array sizes with minimum reconfiguration. The berthing module provides all necessary docking services needed for support of unmanned payloads (in earlier PM configurations a GFE docking module was required).

The structures subsystem costs also cover the cost of all mechanisms except the high-gain antenna drive.

4.4.2 Thermal - The thermal control subsystem comprises a radiator system (panels, pumps, accumulators, plumbing, controls) and various passive thermal control devices. The radiator system drives thermal control costs. It makes use of technology and hardware from various LMSC space systems, particularly the STP80-2 (SIRE) program, but must be reconfigured into the larger PM design.

4.4.3 Attitude Pointing and Control - This subsystem is built around existing ATM control moment gyros. These existing units can be made available to the PM program for their refurbishment cost. The 25 kW PM program, as first user of these CMGs, pays for startup (one-time) charges and the cost of three refurbished units. All of these costs were estimated directly by Bendix, the original CMG vendor. Existing ATM rate gyros and sun sensors are also incorporated into the PM attitude control subsystem; the refurbishment costs for these units were estimated by LMSC.

The AP&C subsystem features additional stabilization and control equipment to support user requirements and system improvements. These include additional attitude sensing equipment (horizon sensors, wide-angle sun sensors) to give a pointing accuracy of 0.5 deg., and a magnetic torquing system for attitude recovery.

Note that the computer, which serves several subsystems, is included under the Communications and Data Handling subsystem rather than the AP&C subsystem.

4.4.4 Communications and Data Handling (C&DH) - The C&DH subsystem is sized for growth and is compatible with the Tracking and Data Relay Satellite (TDRS). It consists of transponders (TDRS compatible), two steerable antennas and RF connections; NSSC-II computers with 32K memory; and a 256 kilobit data processing system.

4.4.5 Electrical Power - The cost of the electrical power subsystem is driven by the large solar array. As noted in the groundrules and assumptions the costs presented here assume that this solar array is developed independently of contemporary programs that would benefit from a large solar array. The fact that NASA has planned a common solar array program serving the PM, the Solar Electric Propulsion (SEP) system, and the Payload Extension Program indicates that an appreciable fraction of the PM array development costs can be shared among these programs, resulting in lower solar array DDT&E costs being charged against the PM program.

The solar array costs assume that near-term improvements are realized in the fabrication and procurement of individual cells and in the assembly of arrays. The fabrication and procurement improvements, which include vendor screening and matching, are expected to result in costs of just over $20 per cell.

4.4.6 Propulsion - No requirement for a propulsion subsystem was identified in the recommended 25 kW PM program.

4.4.7 Software - Costs for the development, coding and verification of 25 kW PM software are driven by the spacecraft on-board attitude stabilization and data management functions. The magnitude of these functions was estimated by IBM as just over 13,000 new machine-level executable instructions. The software costs are highly sensitive to the fraction of computer memory and speed used by the program; hence software cost increases can be limited by selecting a modular computer with simple modular growth in its memory. The IBM NSSC II computer is sized for 32K word memory capacity in the PM application, which gives 50% utilization of the core--well below the threshold of rapid software cost growth.

4.4.8 Space Support Equipment (SSE) - The 25 kW Power Module Program requires the development and production of one set of SSE. This equipment includes a PM display panel, berthing supports, interconnect cabling, and various on-orbit maintenance aids. The panel is carried in the crew compartment of the Orbiter and the remainder of the SSE is carried in its cargo bay. PM SSE is reusable; hence, a single set can serve the 25-, 50- and 100- kW PM programs.

The development status of the individual SSE items is that, although they are new designs for the PM program, their technology is second generation because of similarity to the ST SSE.

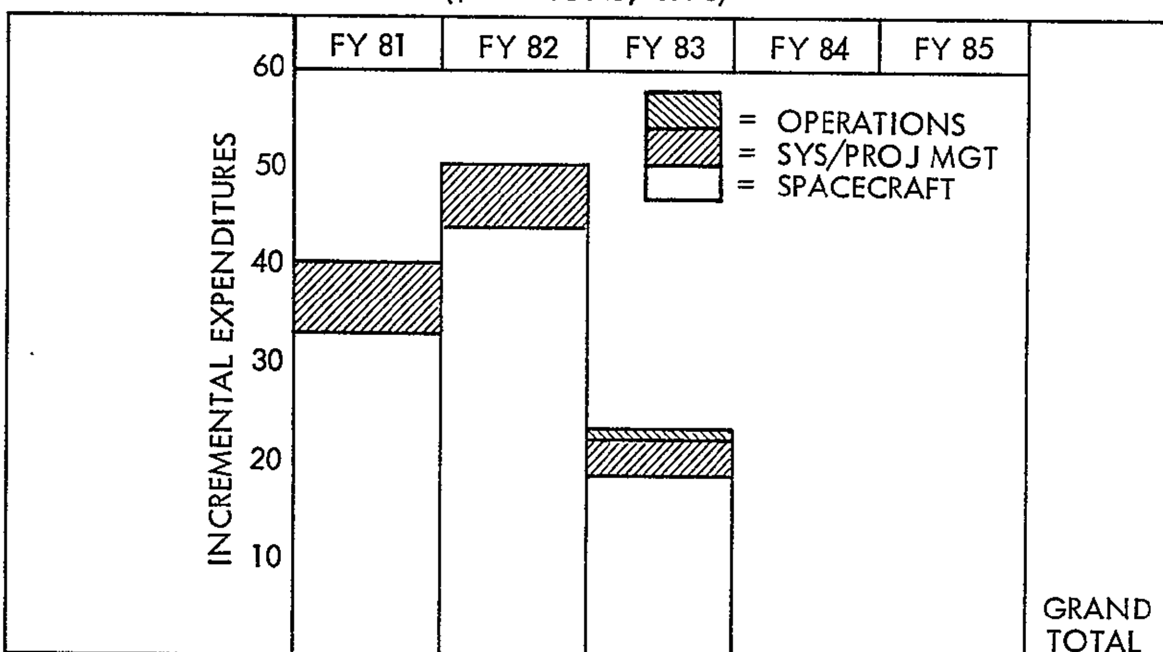
4.4.9 Integration, Assembly and Test - The protoflight 25 kW PM is assembled and undergoes a rigorous system-level test before being delivered to Kennedy Space Center (KSC). The test sequence, which demonstrates both qualification and acceptance levels, includes ambient functional testing and acoustic environmental simulation with the assembled PM. After the acoustic test, minor refurbishment is accomplished and the spacecraft is retested to verify its flight readiness.

4.4.10 Ground Support Equipment (GSE) - The GSE for the 25 kW PM includes transportation and handling equipment and checkout sets. The transport/handling equipment is PM peculiar but its design inheritance is from the ST program. Factory checkout equipment is primarily composed of existing hardware with software modifications for PM peculiar checkout sequences. Launch site checkout equipment will be based on similar ST program hardware.

4.5 PROJECT FUNDING DISTRIBUTION

A funding distribution by fiscal year for the acquisition costs of the 25 kW PM is presented in Figure 5. This funding pattern, which reflects prior completion of a Phase B study, incurs a peak of $51 million in fiscal year 1982.

($ MILLIONS, 1978)



	FY 81	FY 82	FY 83	FY 84	FY 85	GRAND TOTAL
OPERATIONS (DEV)		0.3	0.9			1.2
SYS/PROJ MGT	7.2	7.5	4.0			18.7
SPACECRAFT	32.9	43.6	18.5			95.0
TOTAL	40.1	51.4	23.4			114.9

Figure 5. 25 kW Power Module Acquisition Funding Distribution

4.6 MINIMUM CAPABILITY SYSTEM

The costs shown in this section are for the LMSC recommended 25 kW PM configuration. This configuration is augmented with key user-oriented features. It is feasible to develop a lower cost 25 kW PM that will provide minimum required system capabilities; however, for an increase in acquisition cost of 10 percent above this minimum concept, the LMSC configuration provides a marked enhancement in capability. Features available in the LMSC configuration at a delta cost of about $10 million include:

- Attitude sensors for 0.5 degree pointing accuracy
- CMG desaturation (magnetic)
- Provisions for accommodating an STO payload with PM in a single launch
- S-band steerable hi-gain antenna (TDRS compatible)
- 256 kB data system
- 5 berthing ports with internal connection

Section 5

50 kW POWER MODULE COST ESTIMATE

This section of Volume 3 contains a narrative discussion of the costs and major cost drivers for the 50 kW PM Program. The 50 kW PM (Figure 6) is the second step in the LMSC recommended PM evolution. It benefits in design and technology from the predecessor 25 kW PM. The costs presented in this section are in building-block form and hence are not tied to fulfillment of any particular mission scenario. Scenario costs are summarized in Section 7 for all three selected mission evolutions, and more detailed costs for Scenario I are given in Appendix A.

Costs for the 50 kW PM may be summarized as follows:

		Costs ($ 1978 in millions)			
		Acquisition			Second Production Unit
WBS Element		Design/Dev.	Protoflight	Total	
1.2.1.	50 kW Power Module	(18.6)	(77.5)	(96.1)	(76.4)
1.2.1.1	System/Project Mgt.	0.8	0.7	1.5	0.7
1.2.1.2	PM Spacecraft	17.5	76.8	94.3	75.7
1.2.1.3	Operations (Devel.)	0.3	--	0.3	--

5.1 PROJECT COSTS

WBS element 1.2, 50 kW PM Program, sums costs for the 50 kW PM system (1.2.1) and STS user charges (1.2.2); additional WBS entries for support elements (1.2.3 and on) are not applicable since no such elements need be modified to support the 50 kW PM. The breakdown of 50 kW PM costs is given in sections 5.2 and 5.3. The STS Services cost estimate is based on user charge data from Reference 2, escalated from the base year of 1975 to the PM study reference year of 1978; the resulting user charges are the same as for the 25 kW PM (section 4.2).

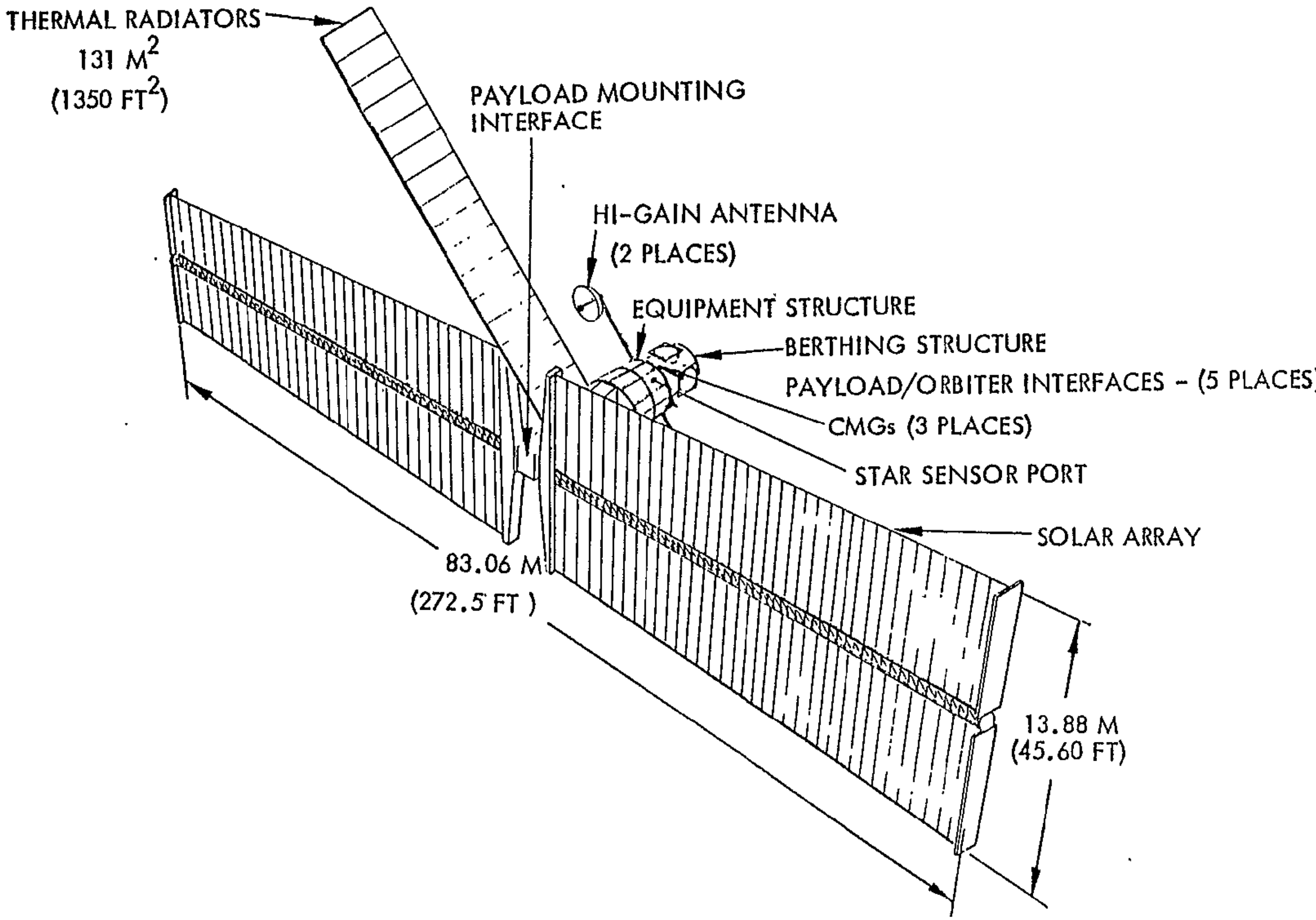


Figure 6. Candidate 50 kW Power Module Configuration - Deployed

The total cost for the 50 kW PM program (WBS 1.2) is estimated to be $121.8 million through IOC.

5.2 SYSTEM COST

System level costs for the 50 kW PM (WBS 1.2.1) comprise hardware, management, and operations costs. The hardware and management costs incurred through delivery of the protoflight unit to the launch base make up the 50 kW PM acquisition costs. The acquisition costs for the LMSC recommended baseline 50 kW PM configuration are $96.1 million; of this, $18.6 million is for design and development, and $77.5 million for production and test of the protoflight unit. The design and development cost reflects considerable design inheritance from the 25 kW PM, whereas the protoflight costs reflect the greater spacecraft size of the 50 kW PM—especially the 59% increase in array size.

The WBS breakdown of the 50 kW PM acquisition cost comprises $1.5 million in System/Project Management (WBS 1.2.1.1), $94.3 million in end-item PM Spacecraft costs (WBS 1.2.1.2) and $0.3 million in one-time operations development (WBS 1.2.1.3). The System/Project Management costs further break down as follows:

o	Program Management (1.2.1.1.1)	$ 0.30 M
o	Systems Engineering and Integration (1.2.1.1.2)	1.20 M
o	Deliverable Data (1.2.1.1.2)	0.04 M*

The breakdown of PM spacecraft costs by subsystem is given in Section 4.4.

The production cost for one more unit beyond the protoflight would be $76.4 million assuming continuous production. This is slightly lower than the protoflight unit because, although refurbished ATM hardware would be unavailable at the time a second 50 kW PM would be produced, the loss of this

*Assumes minor modification to 25 kW PM documentation.

existing hardware would be offset by learning-effect savings. Subsequent units would follow roughly a 95 percent learning slope.

Operations costs for the 50 kW PM are as follows:

- Requirements and Plans (1.2.1.3.1) — $0.3 M, one time
- Launch Site Operations (1.2.1.3.2) — $1.3 M, per launch
- Mission Control Operations (1.2.1.3.3) — $0.7 M, per year
- PM Maintenance/Refurb. (1.2.1.3.4) — $3.9 M, per year

These costs were derived using the same approach as used to estimate the 25 kW PM operations (Section 4.3), but scaling the costs as required to account for any differences in complexity for the 50 kW PM.

5.3 SUBSYSTEM COSTS

The acquisition cost breakdown, at subsystem level, for the 50 kW PM spacecraft is as follows:

WBS ITEM		COST ($1978, MILLIONS) DESIGN AND DEVELOPMENT	PROTOFLIGHT UNIT	TOTAL
1.1.1.2.1	STRUCTURES	2.1	4.2	6.3
1.2.1.2.2	THERMAL	0.5	5.1	5.6
1.2.1.2.3	ATTITUDE CONTROL	0.7	4.0	4.7
1.2.1.2.4	COMMUNICATION AND DATA HANDLING	0.3	6.5	6.8
1.2.1.2.5	ELECTRICAL POWER	10.8	53.3	64.1
1.2.1.2.6	PROPULSION	-	-	-
1.2.1.2.7	SOFTWARE	0.2	-	0.2
1.2.1.2.8	SPACE SUPPORT EQUIPMENT	-	-	-
1.2.1.2.9	INTEGRATION/ASSEMBLY/TEST	-	3.7	3.7
1.2.1.2.10	GROUND SUPPORT EQUIPMENT	2.9	-	2.9
	TOTAL WBS 1.2.1.2	17.5	76.8	94.3

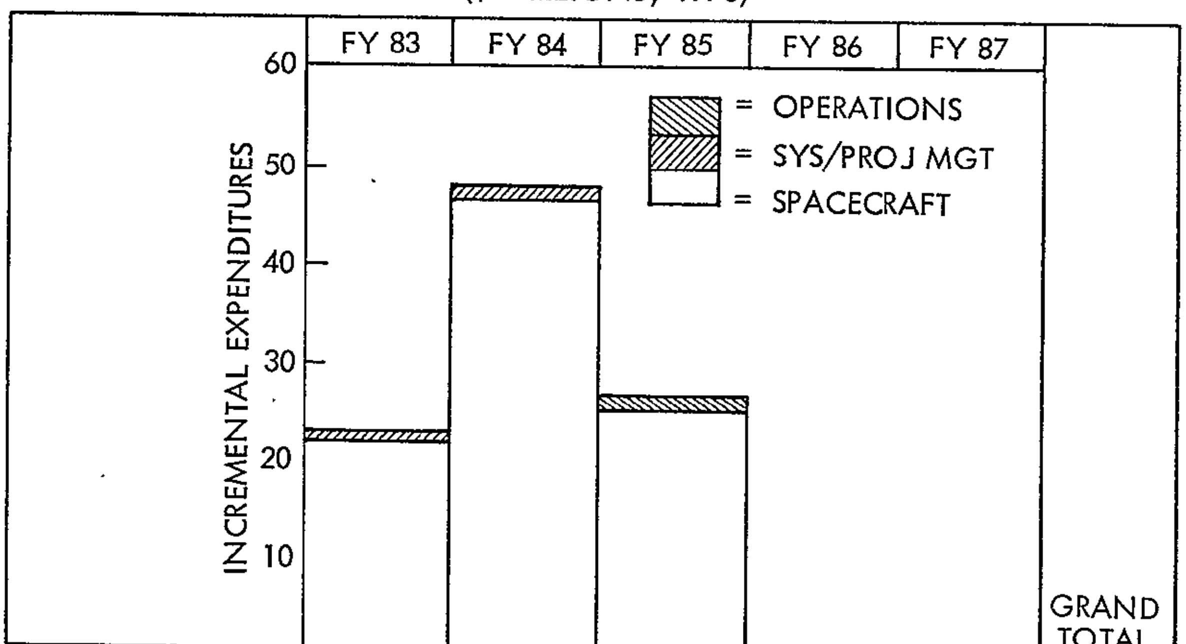
Principal cost drivers at subsystem level are as follows:

- Structures: A modular section is added to the solar array support to accommodate the larger array; additional deployment mechanisms are provided
- Thermal Control: The radiator is doubled in size by doubling the number of identical panels used on the 25 kW PM
- Attitude Control: The system is reconfigured slightly to accommodate the larger spacecraft
- C&DH: No major change
- Electrical Power: The array is increased in area by 59 percent and the efficiency of the solar cells is increased from 12.5 percent to 16 percent. $Ni\text{-}H_2$ batteries at 40 percent depth of discharge are used in place of the Ni-Cd batteries used on the 25 kW PM. The total estimated development cost of the $Ni\text{-}H_2$ batteries has been charged to the 50 kW PM; this cost can be reduced by long-lead development of battery technology.

5.4 PROJECT FUNDING DISTRIBUTION

A funding distribution by fiscal year for the acquisition costs of the 50 kW PM is presented in Figure 7. This funding pattern incurs a peak of $48 million in fiscal year 1984.

($ MILLIONS, 1978)



	FY 83	FY 84	FY 85	FY 86	FY 87	GRAND TOTAL
OPERATIONS (DEV)			0.3			0.3
SYS/PROJ MGT	0.4	0.6	0.5			1.5
SPACECRAFT	22.1	47.1	25.1			94.3
TOTAL	22.5	47.7	25.9			96.1

Figure 7. 50 kW Power Module Acquisition Funding Distribution

Section 6

100 kW POWER MODULE COST ESTIMATE

This section of Volume 3 contains a narrative discussion of the costs and major cost drivers for the 100 kW PM Program. The 100 kW PM (Figure 8) is the final step in the recommended PM evolution. It consists of a 50 kW PM and a 50 kW kit which are assembled on orbit to give 100 kW total power. The costs presented in this section are in building-block form, and hence are not tied to fulfillment of any particular mission scenario. Scenario costs are summarized in Section 7 for all three selected mission evolutions, and more detailed costs for Scenario I are given in Appendix A.

Costs for the 100 kW PM may be summarized as follows:

		Costs ($ 1978 in millions)			
		Acquisition			Second Production Unit
	WBS Element	Design/Dev.	Protoflight	Total	
1.3.1.	100 kW Power Module	(20.8)	(114.7)	(135.4)	(108.1)
1.3.1.1	System/Project Mgt.	2.3	0.9	3.2	0.9
1.3.1.2	PM Spacecraft	17.2	113.8	131.0	107.2
1.3.1.3	Operations (Devel.)	1.2	—	1.2	—

6.1 PROJECT COSTS

WBS element 1.3, 100 kW PM Program, sums costs for the 100 kW PM system (1.3.1) and STS user charges (1.3.2); additional WBS entries for support elements (1.3.3 and on) are not applicable since no such elements need be modified to support the 100 kW PM. The breakdown of 100 kW PM costs is given in sections 6.2 and 6.3. The STS Services cost estimate is based on user charge data from Reference 2, escalated from the base year of 1975 to the PM study reference year of 1978. These costs account for separate launch of PM and kit and for assembly on orbit. The resulting user charges applicable to the 100 kW PM are as follows:

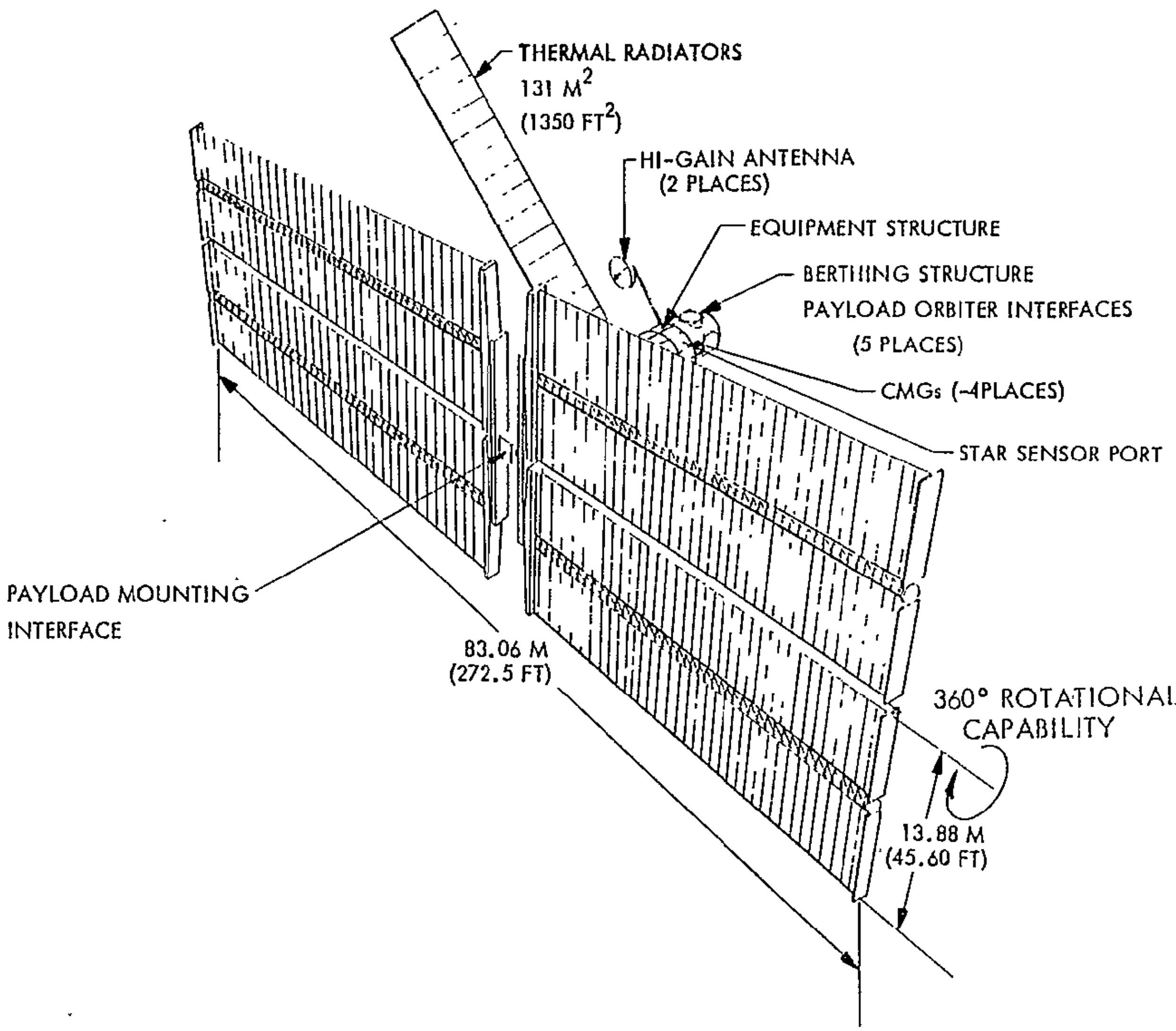


Figure 8. Candidate 100 kW Power Module Configuration - Deployed

		$1975	$1978
o	Shuttle Launch, Each Mission*	28.2	36.7
o	Extra Vehicular Activity, Each Mission	0.10	0.13
o	Second RMS Manipulator, Each Flight	0.09	0.12
o	Retrieval (non-dedicated Shuttle flight) Each Occurrence	1.9	2.5

The total cost for the 100 kW PM program (WBS 1.3) is estimated to be $174.0 million through IOC.

6.2 SYSTEM COSTS

System level costs for the 100 kW PM (WBS 1.3.1) comprise hardware, management, and operations costs. The hardware and management costs incurred through delivery of the protoflight unit to the launch base make up the 100 kW PM acquisition costs. The acquisition costs of the LMSC recommended baseline 100 kW configuration are $135.4 million; of this $20.7 million is for design and development, and $114.7 million for production and test of the protoflight unit.

The WBS breakdown of this acquisition cost comprises $3.2 million in System/Project Management (WBS 1.3.1.1), $131.0 million in end-item PM Spacecraft costs (WBS 1.3.1.2) and $1.2 million on one-time operations development (WBS 1.3.1.3). The System/Project Management costs further break down as follows:

o	Program Management (1.3.1.1.1)	$ 0.6 M
o	Systems Engineering and Integration (1.3.1.1.2)	2.5 M
o	Deliverable Data (1.3.1.1.3)	0.1 M**

The breakdown of PM spacecraft costs by subsystem is given in Section 6.3.

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*One full Orbiter payload plus a partial

**Assumes minor modification to existing 50 kW PM documentation.

Note that the production cost for one more unit past the protoflight would be $108.1 million. The cost improvement would be achieved by learning, assuming that continuous PM production occurs.

Operations costs for the 100 kW PM are as follows:

- Requirements and Plans (1.3.1.3.1) — $1.2 M, one time
- Launch Site Operations (1.3.1.3.2) — $1.7 M, per launch
- Mission Control Operations (1.3.1.3.3) — $0.8 M, per year
- PM Maintenance/Refurb. (1.3.1.3.4) — $5.2 M, per year

These costs were derived using the same approach as used to estimate the 25 kW PM operations (Section 4.3), but scaling the costs to account for differences in the size and complexity of the 100 kW PM.

6.3 SUBSYSTEM COSTS

The acquisition cost breakdown, at subsystem level, for the 100 kW PM spacecraft is as follows:

	WBS ITEM	COST ($1978, MILLIONS)		
		DESIGN AND DEVELOPMENT	PROTOFLIGHT UNIT	TOTAL
1.3.1.2.1	STRUCTURES	3.2	5.3	8.5
1.3.1.2.2	THERMAL	0.4	4.7	5.1
1.3.1.2.3	ATTITUDE CONTROL	1.6	9.7	11.3
1.3.1.2.4	COMMUNICATION AND DATA HANDLING	0.3	6.6	6.9
1.3.1.2.5	ELECTRICAL POWER	5.7	81.8	87.5
1.3.1.2.6	PROPULSION	-	-	-
1.3.1.2.7	SOFTWARE	1.2	-	1.2
1.3.1.2.8	SPACE SUPPORT EQUIPMENT	0.8	0.6	1.4
1.3.1.2.9	INTEGRATION/ASSEMBLY/TEST	-	5.1	5.1
1.3.1.2.10	GROUND SUPPORT EQUIPMENT	4.0	-	4.0
	TOTAL WBS 1.3.1.2	17.2	113.8	131.0

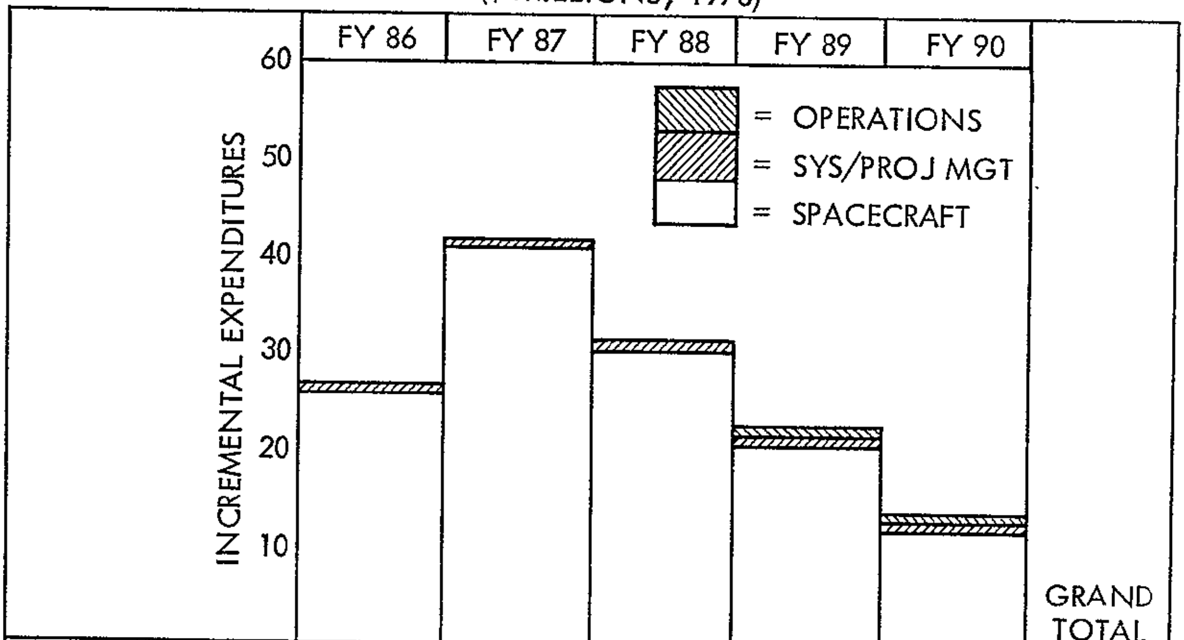
Principal cost drivers at subsystem level are as follows:

- Structures: A new solar array support extension, and associated mechanisms, is added in kit form
- Thermal Control: Radiator size is unchanged but its location is moved and a rotational capability is added
- Attitude Control: Three control moment gyros are added (total=6) to stabilize the larger 100 kW PM configuration
- C&DH: No significant change
- Electrical Power: The array size is doubled and the Ni-H_2 batteries are operated at 80 percent depth of discharge
- Software: Stabilization and control algorithms are modified for the 6-CMG configuration
- Space Support Equipment: The growth kit requires a new Orbiter cargo-bay cradle to accommodate the delivery of this hardware to orbit.

6.4 PROJECT FUNDING DISTRIBUTION

A funding distribution by fiscal year for the acquisition costs of the 100 kW Power Module is presented in Figure 9. This funding pattern incurs a peak of $42 million in fiscal year 1987.

($ MILLIONS, 1978)



	FY 86	FY 87	FY 88	FY 89	FY 90	GRAND TOTAL
OPERATIONS (DEV)				0.9	0.3	1.2
SYS/PROJ MGT	0.6	0.6	0.7	0.7	0.6	3.2
SPACECRAFT	25.4	41.1	30.3	21.1	13.2	131.1
TOTAL	26.0	41.7	31.0	22.7	14.1	135.5

Figure 9. 100 kW Power Module Acquisition Funding Distribution

Section 7

SCENARIO PROGRAM COST ESTIMATES

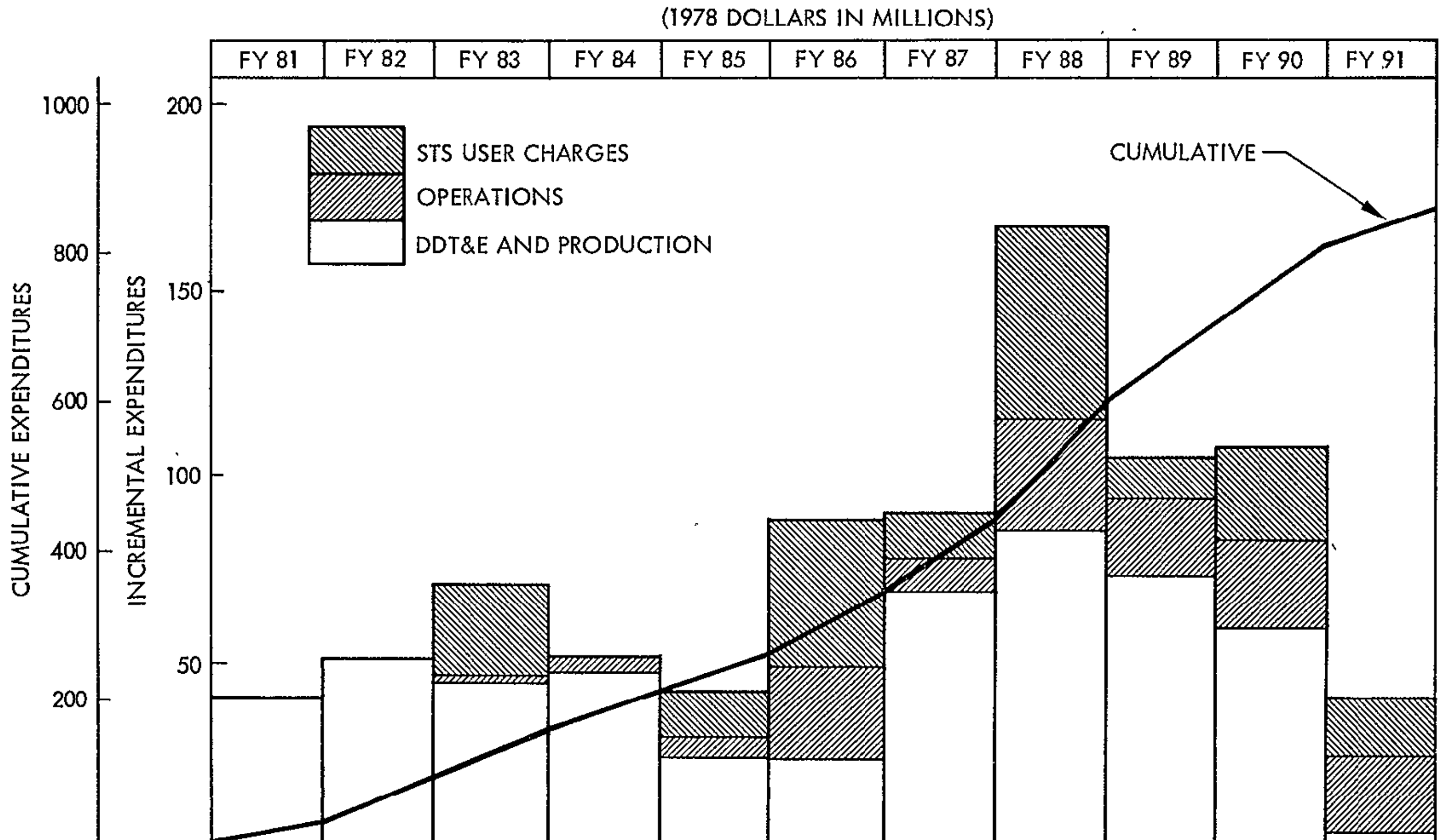
Cost estimates for Scenarios I, II and III are presented in this section, in the form of estimated funding requirements by fiscal year. The development of these projections draws upon the cost estimates presented in Sections 4, 5, and 6 for the 25 kW, 50 kW and 100 kW PMs, respectively. The scenarios and the associated program plans are more fully described in Reference 5. These scenarios call for launch of a geosynchronous PM in 1987. This configuration, a derivative of the 25 kW PM, has not been costed in this study.

The nonrecurring costs for each PM are distributed over the development span preceding each launch for the first of a kind (25, 50 or 100 kW) PM. The recurring costs are distributed over the span of manufacturing, test and launch preparations prior to each individual launch. In the case of the refurbished 25 kW PM, refurbishment costs, which are predominantly assumed to be associated with inspection, maintenance, test and re-launch preparations, are distributed within the 6 month refurbishment span.

7.1 SCENARIO I - NOMINAL PROGRAM, NO SKYLAB

Scenario I funding requirements are presented in Figure 10. This scenario requires production of five power modules, one at 25 kW and two each at 50 and 100 kW. The 25 kW PM is refurbished twice and relaunched into a different orbit after each refurbishment. One of the 100 kW PMs is deployed and operates initially at 50 kW and then is upgraded to 100 kW by a later launch of the kit.

The funding requirements separate STS user charges and PM operations costs from the basic PM development, manufacture and test efforts. The operations costs include on-orbit maintenance of the PM spacecraft. Revisit flights are assumed available from using-payload service flights at no cost to the PM program. Ground operations support for the orbiting power modules and ground



	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
INCREMENTAL	40	51	71	51	42	87	90	167	106	108	52
CUMULATIVE	40	91	162	213	255	342	432	599	705	813	865

Figure 10. Funding Requirements for Scenario I

based logistic support functions are also included in the operations cost category.

Peak funding for Scenario I is $167 million in FY 1978.

7.2 SCENARIO II - NOMINAL PROGRAM WITH SKYLAB

The projected funding requirements for Scenario II are presented in Figure 11. This scenario calls for production of three 25 kW, one 50 kW and two 100 kW PMs. In addition, one 25 kW PM is refurbished and redeployed.

Peak funding for Scenario II is $155 million in FY 1988.

7.3 SCENARIO III - MINIMUM PROGRAM, NO SKYLAB

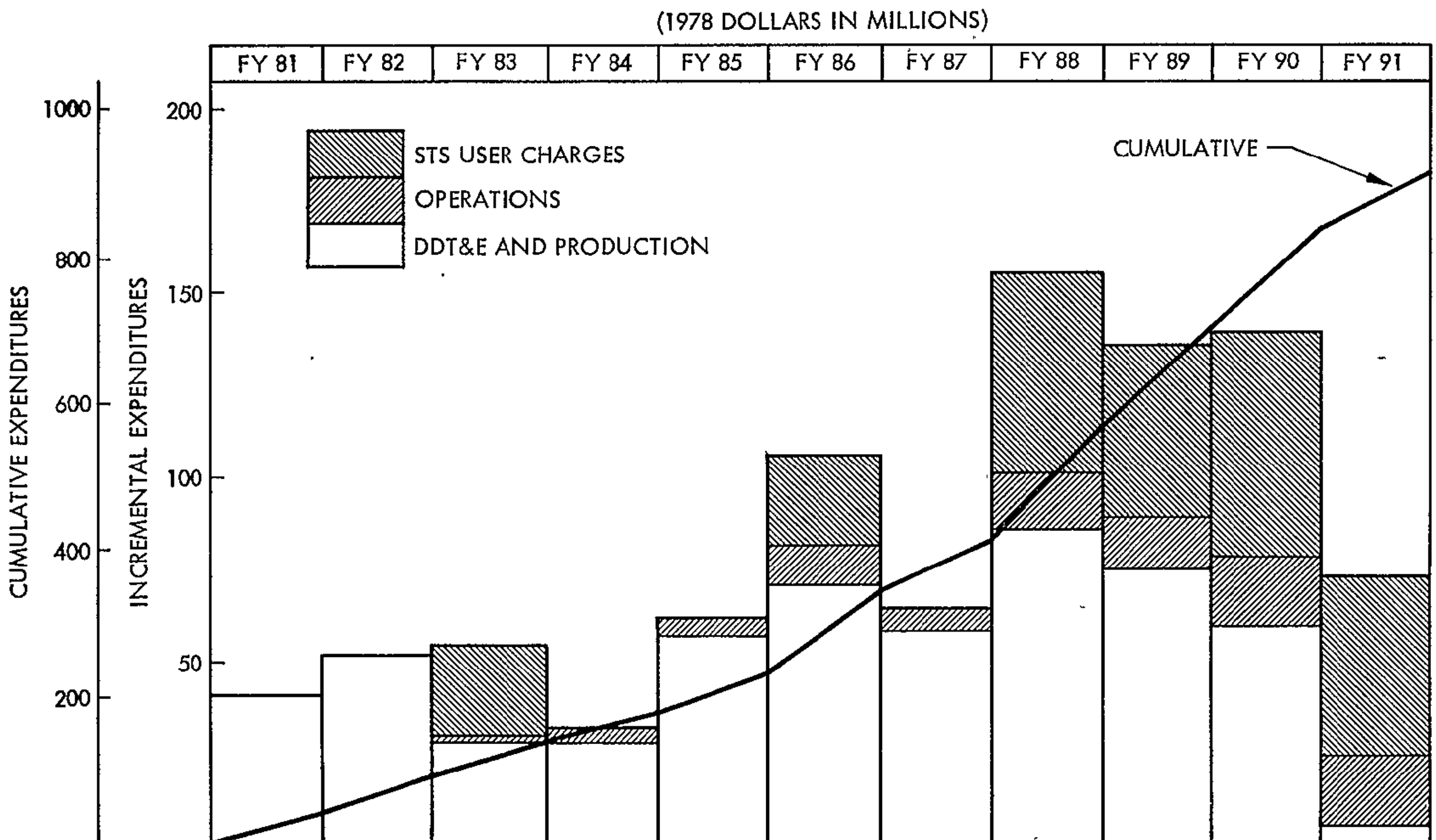
The projected funding requirements for Scenario III are presented in Figure 12. This scenario requires development of only two PM sizes, 25 kW and 50 kW. One PM is produced at the 25 kW size. It is refurbished and reflown twice. Three 50 kW PMs are produced.

Peak funding for Scenario III is approximately $133 million in FY 1990.

7.4 ADDITIONAL SELECTED SCENARIO.

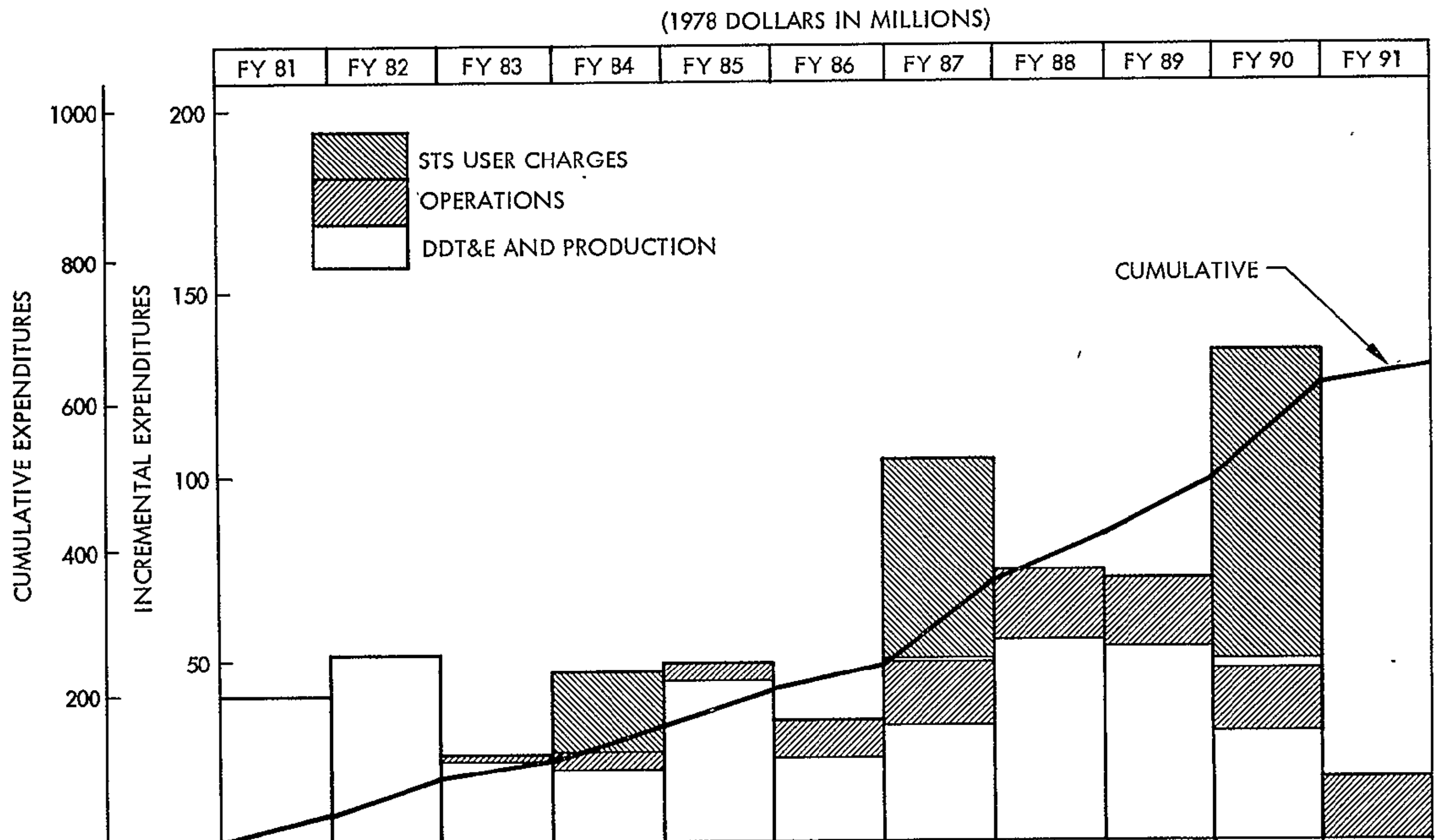
A more ambitious scenario, Program V (Without Skylab), was costed for comparison purposes. The projected funding requirements for Scenario V are presented in Figure 12A. This scenario requires six power modules, one at 25 kW, three at 50 kW, and two at 100 kW.

Peak funding for Scenario V is $131 million in fiscal year 1988, which is the same peak year as for Scenarios I and II. However, the cumulative expenditures for Scenario V build up more rapidly than for the others, exceeding $500 million by FY 1987.



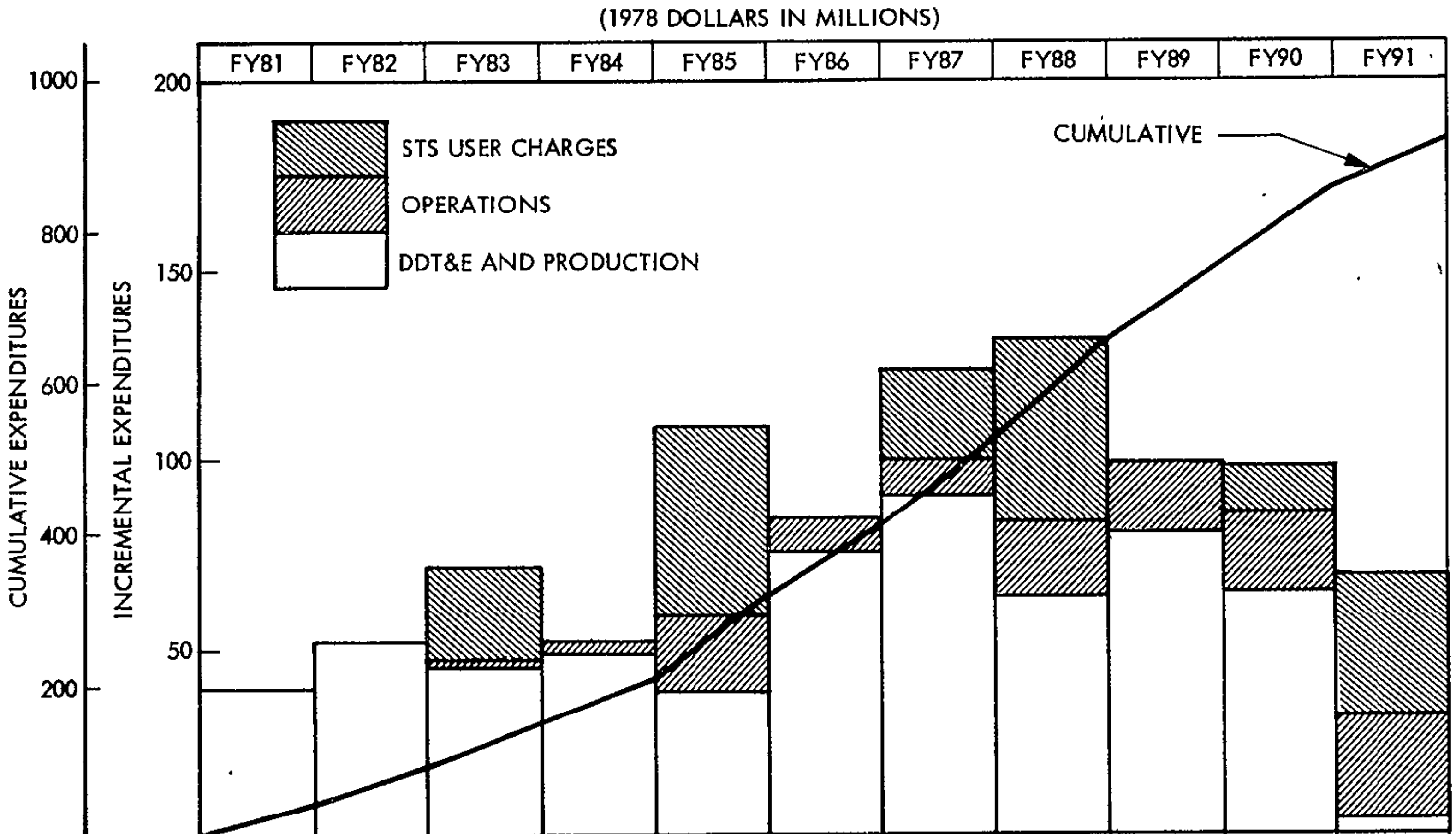
	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
INCREMENTAL	40	51	53	31	61	105	63	155	135	139	71
CUMULATIVE	40	91	144	175	236	341	404	559	694	833	904

Figure 11. Funding Requirements for Scenario II



	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
INCREMENTAL	40	51	24	47	49	33	104	73	71	133	17
CUMULATIVE	40	91	115	162	211	244	348	421	492	625	642

Figure 12. Funding Requirements for Scenario III



	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91
INCREMENTAL	40	51	71	51	109	84	124	131	99	98	69
CUMULATIVE	40	91	162	213	322	406	530	661	760	858	927

Figure 12A. Funding Requirements for Scenario V

Section 8

DESIGN SUPPORT STUDIES DATA

During the course of this study a series of comparative cost analyses was performed to help evaluate major alternatives in PM configuration and evolution. This section summarizes some key findings of these analyses.

8.1 TRADE STUDIES

Figure 13 summarizes some of the key design and implementation trade studies in which cost was a criterion for selection. These trade results are organized by subsystem and present the alternatives, comparative costs, and important findings.

8.2 GROWTH OPTIONS

Figure 14 summarizes key trades involving evolution of the PM system.

Trade	Option 1						Option 2						Outcome
	Description of Alternative	Cost ($Millions, 1978)					Description of Alternative	Cost ($Millions, 1978)					
		Design & Devel	Proto-Flight	Production	Δ STS Charges	Total Cost		Design & Devel	Proto-Flight	Production	Δ STS Charges	Total Cost	
Body Structure	Refurbished Existing ATM Equipment Racks	1.26	0.43	4.36	N/A	6.05	Space Telescope Equipment Racks (Mod.)	0.30	1.28	1.22	N/A	2.80	Option 2 is $3.25M Cheaper at Equal Capability
Docking Concept	Docking Module With Separate Adapter	4.69	2.68	2.54	N/A	9.91	Unified Berthing Structure	3.39	1.15	1.09	N/A	5.63	Option 2 is $4.28M Cheaper at Equal Capability
Radiator Concept	Orbiter Curved Radiator Panels	1.48	1.53	1.45	N/A	4.46	STP80-2 Type Flat Panels With Heat Pipes	0.72	2.00	1.90	N/A	4.62	Concepts are Roughly Equal in Cost But Option 2 is More Efficiently Packaged
Attitude Sensing	NASA Standard Star Trackers (3)	N/A	0.9	0.9	N/A	1.8	ITHACO Horizon Sensors (2)	N/A	0.6	0.6	N/A	1.2	Option 2 is $0.6M Cheaper at Equal Capability
C&DH Concept	Minimum System, STDN Compatible, 4 kbps	1.63	3.20	3.04	N/A	7.87	256 kbps System, TDRS Compatible	1.86	6.71	6.56	N/A	15.13	Option 2 is $7.26M More Expensive But Meets User Needs

Figure 13. Summary of Design Trades

Trade	Option 1						Option 2						Outcome
	Description of Alternative	Cost ($Millions, 1978)					Description of Alternative	Cost ($Millions, 1978)					
		Design & Devel	Proto-Flight	Production	Δ STS Charges	Total Cost		Design & Devel	Proto-Flight	Production	Δ STS Charges	Total Cost	
50 kW Power Capability	Two 25 kW Power Modules on Orbit Per Using Payload	N/A	N/A	97.2	48.6	145.8	Single 50 kW PM per Using Payload	18.3	N/A	76.4	24.3	119.0	Option 2 is $26.8M Cheaper for First 50 kW Use (Comparable Savings for Subsequent Uses)

Figure 14. Summary of Growth Option Trades.

Section 9

REFERENCES

The following documents are referenced in Volume 3:

REF.	TITLE
1	MSC-D614944-6, Final Report, 25 kW Power Module volution Study, Part III: Conceptual Design for ower Module Evolution, Volume 6: WBS and Dictionary, ated 27 January 1979.
2	ASA JSC-11802, Space Transportation System eimbursement Guide, February 1978.
3	MSC-D614944-4, Final Report, 25 kW Power Module volution Study, Part III: Conceptual Design for ower Module Evolution, Volume 4: Design Analysis, ated 27 January 1979.
4	pecial Supplement (Limited Access) to LMSC-D614944-3, inal Report, 25 kW Power Module Evolution Study, Part II: Conceptual Design for Power Module Evolution, olume 3: Cost Estimates, dated January 1979.
5	MSC-D614944-2, Final Report, 25 kW Power Module volution Study, Part III: Conceptual Design for ower Module Evolution, Volume 2: Program Plans, ated 27 January 1979.

APPENDIX A

NASA COST DATA FORMS

This appendix contains expanded cost and technical data on the LMSC recommended PM evolution. The cost data are based on Mission Scenario I, a nominal user program with no Skylab support. However, costs for the geosynchronous PM shown in Section I have been omitted.

Organization of this appendix is as follows. Figure A-1 presents NASA Forms A, which display cost data in matrix form by WBS and by program. Figures A-2 and A-3 are NASA Forms B which display technical characteristics for the 25 kW, 50 kW and 100 kW Power Modules, respectively. Figures A-4 through A-6 present the funding distribution of the Power Module program in the format of NASA Form C. Figure A-4 summarizes DDT&E cost; Figure A-5, Production Cost; and Figure A-6, Operations Cost.

The production phase costs shown in Figures A-1 and A-6 represent the cost of producing any required PM flight articles above and beyond the protoflight unit that is developed and tested in the DDT&E phase.

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COST ESTIMATE DATA FORM A

(Thousands of Dollars, 1978)

SCENARIO I: NOMINAL PROGRAM, NO SKYLAB

WBS NUMBER	COST ELEMENT	DDT&E ϕ			PRODUCTION ϕ			OPERATIONS ϕ			SCENARIO TOTAL
		ENG DES & DEV	PROTOFLIGHT UNIT	SUB TOTAL	FIRST PRODUCTION UNIT	QTY	SUB TOTAL	OPERATIONS	SUSTAIN-ING	SUB TOTAL	
1.0	Power Module System	(105,105)	(241,351)	(346,456)	–	–	(184,561)	(326,040)	(8,131)	(334,171)	(865,188)
1.1	25 kW Power Module Program	(65,778)	(49,118)	(114,896)	–	–	–	(133,099)	(3,156)	(136,255)	(251,151)
1.1.1	Power Module	(65,778)	(49,118)	(114,896)	–	–	–	(56,353)	(3,156)	(59,509)	(174,405)
1.1.1.1	System/Project Mgt.	(18,166)	(576)	(18,742)	–	–	–	–	(765)	(765)	(19,507)
1.1.1.1.1	Program Management	3,467	114	3,581	–	–	–	–	478	478	4,059
1.1.1.1.2	SE&I	13,870	455	14,325	–	–	–	–	239	239	14,564
1.1.1.1.3	Deliverable Data	829	7	836	–	–	–	–	48	48	884
1.1.1.2	PM Spacecraft	(46,452)	(48,542)	(94,994)	–	–	–	–	(2,391)	(2,391)	(97,385)
1.1.1.2.1	Structures	6,302	3,602	9,904	–	–	–	–	–	–	9,904
1.1.1.2.2	Thermal Control	3,929	2,709	6,638	–	–	–	–	478	478	7,116
1.1.1.2.3	Attitude Control	5,627	3,462	9,089	–	–	–	–	478	478	9,567
1.1.1.2.4	Comm. & Data Handling	1,865	6,706	8,571	–	–	–	–	478	478	9,049
1.1.1.2.5	Electrical Power	21,416	28,649	50,065	–	–	–	–	957	957	51,022
1.1.1.2.6	Propulsion	–	–	–	–	–	–	–	–	–	–
1.1.1.2.7	Software	2,364	–	2,364	–	–	–	–	–	–	2,364
1.1.1.2.8	Space Support Equipment	1,600	1,320	2,920	–	–	–	–	–	–	2,920
1.1.1.2.9	Integration/Assy/Test	–	2,094	2,094	–	–	–	–	–	–	2,094
1.1.1.2.10	GSE	3,349	–	3,349	–	–	–	–	–	–	3,349
1.1.1.3	Operations	(1,160)	–	(1,160)	–	–	–	(56,353)	(0)	(56,353)	(57,513)
1.1.1.3.1	Requirements/Plans	1,160	–	1,160	–	–	–	–	–	–	1,160
1.1.1.3.2	Launch Site Operations	–	–	–	–	–	–	3,987	–	3,987	3,987
1.1.1.3.3	Mission Control Operations	–	–	–	–	–	–	5,941	–	5,941	5,941
1.1.1.3.4	PM Maintenance/Refurb.	–	–	–	–	–	–	46,425	–	46,425	46,425

Figure A-1

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COST ESTIMATE DATA FORM A

(Thousands of Dollars, 1978) (Cont.)

SCENARIO I: NOMINAL PROGRAM, NO SKYLAB

WBS NUMBER	COST ELEMENT	DDT&E ϕ			PRODUCTION ϕ			OPERATIONS ϕ			SCENARIO TOTAL
		ENG DES & DEV	PROTOFLIGHT UNIT	SUB TOTAL	FIRST PRODUCTION UNIT	QTY	SUB TOTAL	OPERATIONS	SUSTAIN-ING	SUB TOTAL	
1.1.2	STS Services	–	–	–	–	–	–	(76,746)		(76,746)	(76,746)
1.1.2.1	Launch	–	–	–	–	–	–	72,900		72,900	72,900
1.1.2.2	On-Orbit Services	–	–	–	–	–	–	366		366	366
1.1.2.3	Retrieval	–	–	–	–	–	–	3,480		3,480	3,480
1.2	50 kW Power Module Program	(18,568)	(77,552)	(96,120)	(76,430)	1	(76,430)	(89,751)	(3,253)	(93,004)	(265,554)
1.2.1	Power Module	(18,568)	(77,552)	(96,120)	(76,430)	1	(76,430)	(40,907)	(3,253)	(44,160)	(216,710)
1.2.1.1	System/Project Mgt.	(799)	(740)	(1,539)	(740)	1	(740)	–	(788)	(788)	(3,067)
1.2.1.1.1	Program Management	154	146	300	146	1	146	–	493	493	939
1.2.1.1.2	SE&I	618	585	1,203	585	1	585	–	246	246	2,034
1.2.1.1.3	Deliverable Data	27	9	36	9	1	9	–	49	49	94
1.2.1.2	PM Spacecraft	(17,479)	(76,812)	(94,291)	(75,690)	1	(75,690)	–	(2,465)	(2,465)	(172,446)
1.2.1.2.1	Structures	2,059	4,190	6,249	3,981	1	3,981	–		–	10,230
1.2.1.2.2	Thermal Control	489	5,135	5,624	4,878	1	4,878	–	493	493	10,995
1.2.1.2.3	Attitude Control	720	3,989	4,709	6,692	1	6,692	–	493	493	11,894
1.2.1.2.4	Comm. & Data Handling	325	6,545	6,870	6,218	1	6,218	–	493	493	13,581
1.2.1.2.5	Electrical Power	10,776	53,273	64,049	50,609	1	50,609	–	986	986	115,644
1.2.1.2.6	Propulsion	–	–	–	–	–	–	–		–	–
1.2.1.2.7	Software	236	–	236	–	–	–	–		–	236
1.2.1.2.8	Space Support Equipment	–	–	–	–	–	–	–		–	–
1.2.1.2.9	Integration/Assy./Test	–	3,680	3,680	3,312	1	3,312	–		–	6,932
1.2.1.2.10	GSE	2,874	–	2,874	–	–	–	–		–	2,874
1.2.1.3	Operations	(290)	–	(290)	–	–	–	(40,907)		(40,907)	(41,197)
1.2.1.3.1	Requirements/Plans	290	–	290	–	–	–	–		–	290
1.2.1.3.2	Launch Site Operations	–	–	–	–	–	–	2,658		2,658	2,658
1.2.1.3.3	Mission Control Operations	–	–	–	–	–	–	5,771		5,771	5,771
1.2.1.3.4	PM Maintenance/Refurb.	–	–	–	–	–	–	32,478		32,478	32,478

Figure A-1 (Continued)

1 FOLDOUT FRAME

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COST ESTIMATE DATA FORM A

(Thousands of Dollars, 1978) (Cont.)

SCENARIO I: NOMINAL PROGRAM, NO SKYLAB

WBS NUMBER	COST ELEMENT	DDT&E Φ			PRODUCTION Φ			OPERATIONS Φ			SCENARIO TOTAL
		ENG DES & DEV	PROTOFLIGHT UNIT	SUB TOTAL	FIRST PRODUCTION UNIT	QTY	SUB TOTAL	OPERATIONS	SUSTAIN-ING	SUB TOTAL	
1.2.2	STS Services	–	–	–	–	–	–	(48,844)	–	(48,844)	(48,844)
1.2.2.1	Launch	–	–	–	–	–	–	48,600	–	48,600	48,600
1.2.2.2	On-Orbit Services	–	–	–	–	–	–	244	–	244	244
1.2.2.3	Retrieval	–	–	–	–	–	–	–	–	–	–
1.3	100 kW Power Module Program	(20,759)	(114,681)	(135,440)	(108,131)	–	(108,131)	(103,190)	(1,722)	(104,912)	(348,483)
1.3.1	Power Module	(20,759)	(114,681)	(135,440)	(108,131)	–	(108,131)	(29,286)	(1,722)	(31,008)	(274,579)
1.3.1.1	System/Project Mgt.	(2,310)	(876)	(3,186)	(876)	1	(876)	–	(417)	(417)	(4,479)
1.3.1.1.1	Program Management	446	173	619	173	1	173	–	261	261	1,053
1.3.1.1.2	SE&I	1,785	692	2,477	692	1	692	–	130	130	3,299
1.3.1.1.3	Deliverable Data	79	11	90	11	1	11	–	26	26	127
1.3.1.2	PM Spacecraft	(17,289)	(113,805)	(131,094)	(107,255)	1	(107,255)	–	(1,305)	(1,305)	(239,654)
1.3.1.2.1	Structures	3,241	5,254	8,495	4,991	1	4,991	–	–	–	13,486
1.3.1.2.2	Thermal Control	448	4,695	5,143	4,460	1	4,460	–	261	261	9,864
1.3.1.2.3	Attitude Control	1,570	9,721	11,291	9,234	1	9,234	–	261	261	20,786
1.3.1.2.4	Comm. & Data Handling	325	6,545	6,870	6,217	1	6,217	–	261	261	13,348
1.3.1.2.5	Electrical Power	5,703	81,832	81,832	77,740	1	77,740	–	522	522	165,797
1.3.1.2.6	Propulsion	–	–	–	–	–	–	–	–	–	–
1.3.1.2.7	Software	1,159	–	1,159	–	–	–	–	–	–	1,159
1.3.1.2.8	Space Support Equipment	840	632	1,472	–	–	–	–	–	–	1,472
1.3.1.2.9	Integration/Assy./Test	–	5,126	5,126	4,613	1	4,613	–	–	–	9,739
1.3.1.2.10	GSE	4,003	–	4,003	–	–	–	–	–	–	4,003
1.3.1.3	Operations	(1,160)	–	(1,160)	–	–	–	(29,286)	–	(29,286)	(30,446)
1.3.1.3.1	Requirements/Plans	1,160	–	1,160	–	–	–	–	–	–	1,160
1.3.1.3.2	Launch Site Operations	–	–	–	–	–	–	3,322	–	3,322	3,322
1.3.1.3.3	Mission Control Operations	–	–	–	–	–	–	3,055	–	3,055	3,055

Figure A-1 (Continued)

COST ESTIMATE DATA FORM A

(Thousands of Dollars, 1978) (Cont.)

SCENARIO I: NOMINAL PROGRAM, NO SKYLAB

WBS NUMBER	COST ELEMENT	DDT&E ∅			PRODUCTION ∅			OPERATIONS ∅			SCENARIO TOTAL
		ENG DES & DEV	PROTOFLIGHT UNIT	SUB TOTAL	FIRST PRODUCTION UNIT	QTY	SUB TOTAL	OPERATIONS	SUSTAIN-ING	SUB TOTAL	
1.3.1.3.4	PM Maintenance/Refurb.	–	–	–	–	–	–	22,909	–	22,909	22,909
1.3.2	STS Services	–	–	–	–	–	–	(73,904)	–	(73,904)	(73,904)
1.3.2.1	Launch	–	–	–	–	–	–	73,400	–	73,400	73,400
1.3.2.2	On-Orbit Services	–	–	–	–	–	–	504	–	504	504
1.3.2.3	Retrieval	–	–	–	–	–	–	–	–	–	–

Figure A-1 (Continued)

STUDY TITLE ________
CONTRACT NO. ________

1 FOLDOUT FRAME

2 FOLDOUT FRAME

TECHNICAL CHARACTERISTICS DATA FORM B

DATE ____________
PAGE ___ OF ______

(1) WBS MATRIX IDENTIFICATION NUMBER	(2) WBS MATRIX IDENTIFICATION	(3) QUANTITY OR VALUE	(4) UNITS OF MEASURE	(5) CHARACTERISTICS	(6) NOTES
1.1.1.2	25 Kw PM Spacecraft	22,455	Pounds	Weight (Dry)	Excludes SSE, Excludes Contingency
1.1.1.2.1	Structures Subsystem	7,030	Pounds	Weight	Includes All Mechanisms Except Antenna Drive
1.1.1.2.2	Thermal Control Subsystem	2,289	Pounds	Weight (Dry)	
1.1.1.2.2.2	Radiator Assy	22.1 ± 4	Kilowatts	Total Heat Rejection	
		675	Square Feet	Radiator Surface Area	
1.1.1.2.3	Attitude Pointing & Control	0.5	Degrees	Pointing Accuracy	3-Sigma, Half-Cone Angle
	Subsystem	2,138	Pounds	Weight	
1.1.1.2.4	Communications & Data Handling	256	Kilobits/Sec.	Data Rate	
	Subsystem	428	Pounds	Weight	
1.1.1.2.4.4	Computer	32,000	Words	Memory Size	
1.1.1.2.5	Electrical Power Subsystem	25	Kilowatts	EPS Power Output	
		12,570	Pounds	Weight	
1.1.1.2.5.2	Solar Array	6,800	Square Feet	Area	
		60	Kilowatts	Peak Array Power Output	
		12.5	Percent	Solar Cell Efficiency	
1.1.1.2.7	Software	13,220	Instructions	Program Size	Machine-Level Executable Instructions (All New)
1.1.1.2.8	Space Support Equipment	2,295	Pounds	Weight	
1.2.1.2	50 Kw Power Module	29,720	Pounds	Weight (Dry)	Excludes Contingency & SSE
1.2.1.2.1	Structures Subsystem	8,150	Pounds	Weight	
1.2.1.2.2	Thermal Control Subsystem	3,872	Pounds	Weight (Dry)	
1.2.1.2.2.2	Radiator Assy.	40.8±5	Kilowatts	Total Heat Rejection	
1.2.1.2.2.2		1,350	Square Feet	Radiator Surface Area	
1.2.1.2.3	Attitude Pointing & Control	0.5	Degrees	Pointing Accuracy	3-Sigma, Half-Cone Angle
	Subsystem	2,138	Pounds	Weight	
1.2.1.2.4	Communications & Data	256	Kilobits/Sec.	Data Rate	
	Handling Subsystem	450	Pounds	Weight	
1.2.1.2.4.4	Computer	32,000	Words	Memory Size	

Figure A-2

1 FOLDOUT FRAME

STUDY TITLE ________
CONTRACT NO. ________

TECHNICAL CHARACTERISTICS DATA FORM B

DATE ________
PAGE ___ OF ________

WBS MATRIX IDENTIFICATION (1) NUMBER	(2) WBS MATRIX IDENTIFICATION	(3) QUANTITY OR VALUE	(4) UNITS OF MEASURE	(5) CHARACTERISTICS	(6) NOTES
1.2.1.2.5	Electrical Power Subsystem	50	Kilowatts	EPS Power Output	
		15,110	Pounds	Weight	
1.2.1.2.5.2	Solar Array	10,800	Square Feet	Area	
		108	Kilowatts	Peak Array Power Output	
		16	Percent	Solar Cell Efficiency	
1.2.1.2.5.3	Batteries	44.4	Pounds	Weight (Each)	Ni-H_2 Type
		40	Percent	Depth of Discharge	
1.3.1.2	100 Kw Power Module	46,679	Pounds	Weight (Dry)	Excludes Contingency & SSE
1.3.1.2.1	Structures Subsystem	9,900	Pounds	Weight	
1.3.1.2.2	Thermal Control Subsystem	4,950	Pounds	Weight (Dry)	
1.3.1.2.2.2	Radiator Assy	48.4 ± 6	Kilowatts	Total Heat Rejection	
		1,350	Square Feet	Radiator Surface Area	
1.3.1.2.3	Attitude Pointing & Control	0.5	Degrees	Pointing Accuracy	3-Sigma, Half-Cone Angle
	Subsystem	2,610	Pounds	Weight	
	Communications & Data Handling	256	Kilobits/Sec.	Data Rate	
	Subsystem	494	Pounds	Weight	
1.3.1.2.4.4	Computer	32,000	Words	Memory Size	
1.3.1.2.5	Electrical Power Subsystem	100	Kilowatts	EPS Power Output	
		28,725	Pounds	Weight	
1.3.1.2.5.2	Solar Array	21,600	Square Feet	Area	
		216	Kilowatts	Peak Array Power Output	
		16	Percent	Solar Cell Efficiency	
1.3.1.2.5.3	Batteries	44.4	Pounds	Weight (Each)	Ni-H_2 Type
		80	Percent	Depth of Discharge	
1.3.1.2.8	Space Support Equipment	1,000	Pounds	Weight	Cradle for Kit

Figure A-3

STUDY TITLE ____

CONTRACT NO. ____

FOLDOUT FRAME

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FUNDING SCHEDULE DATA FORM C

DATE ____

PAGE ____ OF ____

PHASE DDT&E (INCLUDING PROTOFLIGHT UNITS)

PROJECT WBS MATRIX ITEMS	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90
1.0 Power Module System	(40.1)	(51.4)	(45.9)	(47.7)	(25.9)	(26.0)	(41.7)	(31.0)	(22.7)	(14.1)
1.1. 25 kW PM Program	(40.1)	(51.4)	(23.4)							
1.1.1 Power Module	(40.1)	(51.4)	(23.4)							
1.1.1.1 System/Project Mgt.	7.2	7.5	4.0							
1.1.1.2 PM Spacecraft	32.9	43.6	18.5							
1.1.1.3 Operations		0.3	0.9							
1.2 50 kW PM Program			(22.5)	(47.7)	(25.9)					
1.2.1 Power Module			(22.5)	(47.7)	(25.9)					
1.2.1.1 System/Project Mgt.			0.4	0.6	0.5					
1.2.1.2 PM Spacecraft			22.1	47.1	25.1					
1.2.1.3 Operations					0.3					
1.3 100 kW PM Program										
1.3.1 Power Module						(26.0)	(41.7)	(31.0)	(22.7)	(14.1)
1.3.1.1 System/Project Mgt.						0.6	0.6	0.7	0.7	0.6
1.3.1.2 PM Spacecraft						25.4	41.1	30.3	21.1	13.2
1.3.1.3 Operations									0.9	0.3

Figure A-4

STUDY TITLE ________

CONTRACT NO. ________

/FOLDOUT FRAME

FOLDOUT FRAME 2

FUNDING SCHEDULE DATA FORM C

PHASE PRODUCTION

DATE ________

PAGE ____ OF ____

PROJECT WBS MATRIX ITEMS	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
1.0 Power Module System						(26.9)	(55.1)	(51.4)	(45.5)	(5.6)
1.2 50 kW Power Module Program						(26.9)	(38.5)	(11.0)		
1.2.1 Power Module						(26.9)	(38.5)	(11.0)		
1.2.1.1 System/Project Mgt.						0.2	0.3	0.2		
1.2.1.2 PM Spacecraft						26.7	38.2	10.8		
1.3 100 kW Power Module Program							(16.6)	(40.4)	(45.5)	(5.6)
1.3.1 Power Module							(16.6)	(40.4)	(45.5)	(5.6)
1.3.1.1 System/Project Mgt.							0.2	0.3	0.3	0.1
1.3.1.2 PM Spacecraft							16.4	40.1	(45.2)	5.5

Figure A-5

STUDY TITLE ______

CONTRACT NO. ______

PHASE OPERATIONS

FUNDING SCHEDULE DATA FORM C

DATE ______

PAGE ___ OF ___

PROJECT WBS MATRIX ITEMS	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91
1.0 Power Module System		(25.7)	(3.5)	(16.0)	(61.1)	(20.9)	(80.8)	(32.3)	(48.2)	(46.4)
1.1 25 kW PM Program		(25.7)	(3.5)	(3.5)	(44.8)	(3.5)	(44.8)	(3.5)	(3.5)	(3.5)
1.1.1 Power Module		(1.3)	(3.5)	(3.5)	(18.6)	(3.5)	(18.7)	(3.5)	(3.5)	(3.5)
1.1.1.1 System/Project Mgt.			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1.1.1.2 PM Spacecraft			0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1.1.1.3 Operations		1.3	3.1	3.1	18.2	3.1	18.3	3.1	3.1	3.1
1.1.2 STS Services		24.4			26.2		26.1			
1.2 50 kW PM Program				(12.5)	(16.3)	(5.3)	(17.8)	(21.0)	(10.1)	(10.1)
1.2.1 Power Module				(0.4)	(4.0)	(5.3)	(5.7)	(8.7)	(10.1)	(10.1)
1.2.1.1 System/Project Mgt.					0.2	0.1	0.1	0.2	0.1	0.1
1.2.1.2 PM Spacecraft					0.5	0.4	0.4	0.4	0.4	0.4
1.2.1.3 Operations				0.4	3.3	4.8	5.2	8.1	9.6	9.6
1.2.2 STS Services				12.1	12.3		12.1	12.3		
1.3 100 kW PM Program						(12.1)	(18.2)	(7.8)	(34.6)	(32.8)
1.3.1 Power Module							(5.8)	(7.8)	(9.6)	(7.9)
1.3.1.1 System/Project Mgt.							0.1	0.1	0.1	0.1
1.3.1.2 PM Spacecraft							0.3	0.3	0.4	0.4
1.3.1.3 Operations							5.4	7.4	9.1	7.4
1.3.2 STS Services						12.1	12.4		25.0	24.9

Figure A-6

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