LMSC D614944 – 1
27 JANUARY 1979
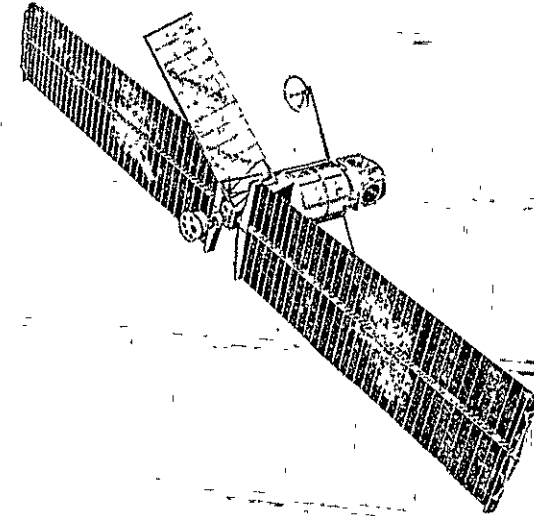
25 kW POWER MODULE
EVOLUTION STUDY

NASA
George C. Marshall
Space Flight Center

VOLUME 1 POWER MODULE EVOLUTION
PART III : CONCEPTUAL DESIGNS FOR POWER MODULE EVOLUTION · FINAL REPORT

LOCKHEED MISSILES & SPACE COMPANY, INC.

FINAL REPORT

25 kW POWER MODULE EVOLUTION STUDY

PART III: CONCEPTUAL DESIGNS FOR POWER MODULE EVOLUTION

VOLUME 1: POWER MODULE EVOLUTION

27 January 1979

Submitted to the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA 35812

CONTRACT NAS8-32928

DPD 555

DR NO. MA-04

LOCKHEED MISSILES & SPACE COMPANY, INC.
SUNNYVALE, CALIFORNIA

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 system 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-D641921A 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.

- 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 1, Power Module Evolution, of the Part III Final Report. It meets the requirements of Contract No. NAS8-32928 Data Procurement Document, Data Requirement MA-04, Final Study Report.

  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

ACKNOWLEDGEMENTS

PART III FINAL REPORT

VOLUME I: POWER MODULE EVOLUTION

.CONTENTS

SECTION 1
INTRODUCTION

1.1 PURPOSE/SCOPE

This Power Module Evolution Document describes requirements and recommendations for evolving a Power Module vehicle from 25 kW through 50 kW to 100 kW capability. Design, performance, and interface descriptions of recommended 25, 50, and 100 kW configurations are provided. Considerations for larger Power Modules up to 250 kW are described conceptually.

1.2 OBJECTIVE

The objective of this document is to present a description of candidate Power Module configurations which will directly support an evolutionary scenario allowing growth from 25 to 100 kW. This growth rationale is structured to support a nominal scenario for sortie mission support to the Orbiter and to free-flying payloads during the 1983-1990 era.

1.3 BACKGROUND

The Power Module is conceived as a significant support element to the NASA Space Transportation System. It is designed to be compatible with the STS concepts, Shuttle vehicle, and operational regime for the 1983-1990 era. The Power Module is being proposed by NASA MSFC as a first step to provide increased capability for on-orbit power, attitude control, and thermal heat rejection to the Orbiter and other docked payloads. Its major purpose is to provide supporting services for both a Shuttle-tended mode (sortie) and a Shuttle non-tended mode (free flying). In this dual role it will augment the baseline Shuttle Orbiter capability and will provide a basis for development of larger, more capable orbiting systems.

The 25 kW Power Module Evolution Study was instituted by NASA MSFC to define how a 25 kW Power Module can be evolved in evolutionary steps to meet future mission requirements. Growth evolution scenarios for a Power Module were developed to satisfy payload support mission requirements from 1983 through 1990. The scenarios ranged from minimum through maximum support in terms of fulfilling payload requirements. To effect a concept design, the study focused on a "so-called" nominal scenario to establish the support requirements. This scenario is described in detail in section 2.1 of this document. From this nominal support scenario, a candidate 25 kW Power Module was defined and subsequent 50 kW and 100 kW configurations were developed using modular growth concepts.
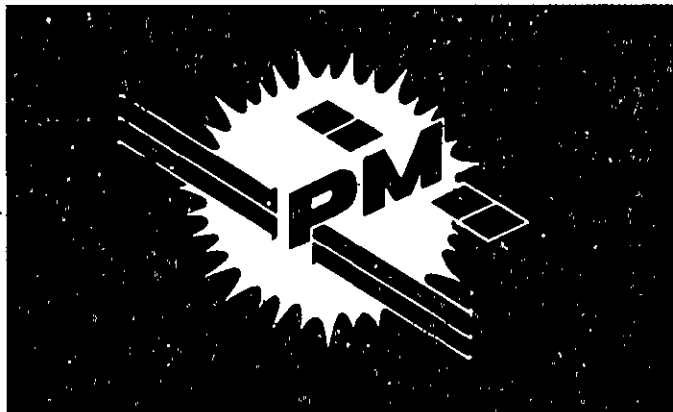
SECTION 2
REQUIREMENTS
EVOLUTION

2.1 COMPOSITE PAYLOAD REQUIREMENTS

2.2 SYSTEM REQUIREMENTS

The chief objective of this analysis was to derive candidate evolutionary systems based on logical growth stages that will support integrated (mixed discipline) payloads at optional levels of capabilities.

2.1 COMPOSITE PAYLOAD REQUIREMENTS

It was obvious from the mission requirements studies that all mission requirements could not be met simultaneously within reasonable budget. Therefore, sharing resources and program stretchout are inevitable for most disciplines. All subsequent charts in this section present the derivation and details of this analysis.

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SUMMARY PAYLOAD POWER REQUIREMENTS

- The next two charts represent desired payload power requirements by orbit and time. These requirements were coordinated with LMSC scientists and MSFC personnel. The results shown (from Part 1 of this study) have been updated and modified. The power needs for any given year are shown in the last two charts. These power needs are met by PEP/sortie and/or 1 to 4 Power Modules of four different sizes (see capabilities chart on adjacent page). Where power requirements exceeded reasonable evolutionary Power Module development (size and quantity), time sharing, where practical, was used as a restraint to permit highest mission potential. NOTE: Cumulative totals include orbiter if attached to PM.

- Early year utilization of the PEP/sortie, either single or in parallel with the PM, provides a capability to build experience and confidence in new payloads and checkout payloads requiring simultaneity of operation prior to operational readiness. This approach also minimizes interruptions of ongoing payload operations. Later use of the PEP/sortie is not readily identifiable.

Alphabets P, A, B, C, and D adjacent to discipline powers are used to identify potential power source assignments (PM numbers A, B, C, and D). See the bottom (capability) chart for any given orbit or year. Power sources identified as PM numbers A, B, C, and D are a means of record keeping. These letters correspond to letters identifying PMs shown on the PM Growth Scenario (Desired Capabilities Case chart).
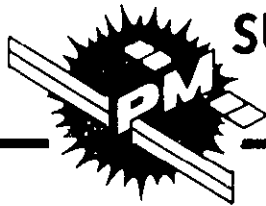
SUMMARY PAYLOAD POWER REQUIREMENTS AND CAPABILITIES PROVIDED

PAYLOAD POWER REQUIREMENTS

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	25A	25A	25A	25A	25A	33A	33A	33A 93C								
SOLAR TERRESTRIAL OBSERVATORY									10A 10P	15A 15P	*20A 15P	*20A	*23A	*28A	*28A	*28A
PUBLIC SERVICE				*15B		*20B										
SPACE SCIENCE	2P	2P	5P	*10B	*10B	*10B	*10B	*10B	2A 2P	2A 2P	*2A 2P	*15A	*15A	*15A	*15A	*15A
LIFE SCIENCE	5P	5P	5P	7B	7B	7B	7B	25-*40B								
EARTH OBSERVATION									5A	5A	*10A	*10A	*10A	*10A	*10A	*10A
SPACE CONSTRUCTION DEMO	5P	5P	5P													
CONSTRUCTION BASE				*15B	*15B	ʹ15B	*15B	*15B								
HABITAT				10B	10B	10A 10B	10A 10B	10A 20B				10A	10A	10A	10A	10A
DEPOT								*50B								
SPACECRAFT MAINTENANCE					*10B	*10B	*10B	*10B								
WORKSHOP				7B	7B	7A 7B	7A 7B	7A 7B 7C				7A	7A	7A	7A	7A
ORBITER**	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
TOTAL	51	51	54	103	98	143	123	301-316	43	53	63	76	79	84	84	84

CAPABILITIES PROVIDED (DESIRED CAPABILITIES SCENARIO)

	83	84	85	86	87	88	89	90	83	84	85	86	87	88	89	90
PEP/SORTIE	15	15	15	TBD	TBD	TBD	TBD	TBD	15	15	15	TBD	TBD	TBD	TBD	TBD
PM #A	25	25	25	25	25	50	50	50	25	25	25	50	50	50	50	50
PM #B				50	50	100	100	150								
PM #C								100								

SYMBOLS. P = TIME SHARED PEP/SORTIE
* = TIME SHARED TO CORRESPOND TO PM OUTPUT
** = SORTIE MODE; SHARES PM OR PEP WITH PAYLOADS

NOTE: REVISED FROM PART II FINAL REPORT

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SUMMARY PAYLOAD POWER REQUIREMENTS AND CAPABILITIES PROVIDED (CONT'D)

PAYLOAD POWER REQUIRE-MENTS

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						47A	47A	47A								*50D
PUBLIC SERVICE												40A	40A 50B	40A 50B	40A 50B 210C	40A 50B 210C
SPACE SCIENCE	2P	2P	2P	2A	3A	3A	3A	5A				10	10A	10A	10A	10A
LIFE SCIENCE																
EARTH OBSERVATION	10P	10P	20A 10P	20A	20A	20A	20A	20A				10A	10A	10A	10A	10A
SPACE CONSTRUCTION																
CONSTRUCTION BASE																
HABITAT						10A	10A	10A								10D
DEPOT																*50D
SPACECRAFT MAINTENANCE																
WORKSHOP						7A	7A	7A								7D
ORBITER **	14	14	14	14	14	14	14	14								
TOTAL	26	26	46	36	37	101	101	103				60	110	110	320	437

CAPABILITIES PROVIDED (DESIRED CAPABILITIES SCENARIO)

	83	84	85	86	87	88	89	90	83	84	85	86	87	88	89	90
PEP/SORTIE	15	15	15	TBD	TBD	TBD	TBD	TBD								
PM #A			25	25	25	100	100	100				Δ60	Δ60	Δ60	Δ60	Δ60
PM #B													Δ50	Δ50	Δ50	Δ50
PM #C															Δ210	Δ210
PM #D																Δ100

SYMBOLS: P = TIME SHARED PEP/SORTIE
* = TIME SHARED TO CORRESPOND TO PM OUTPUT
** = SORTIE MODE; SHARES PM OR PEP WITH PAYLOADS
Δ = 25 kW DERIVATIVE HARDWARE

NOTE: REVISED FROM PART II FINAL REPORT

POWER MODULE GROWTH SCENARIO
(DESIRED CAPABILITIES CASE)

- This scenario was a direct evolvement from the payload power requirements summary and represents desired Power Module capabilities for each orbit location and time period between 1983 and 1990.

- The requirements for the different sizes and quantities of Power Modules are based on assumed payload availability (without technology development encumbrances or cost) and on work from Part 1 of this study.

- The chart further shows the following:

    - 1983 start date; first 25 kW PM available
    - PMs added, replaced, or grown on-orbit
    - Material processing at 28.5° (min. launch/retrieval cost)
    - 1982-1991 shuttle sorties augmented by PEP for LEOs
    - Manned OTV not available until 1990
    - Solar Power Satellite missions are additive to the results of this study
    - Space construction demo/base supports public service/science
    - GEO PMs derived from basic LEO PM designs

POWER MODULE GROWTH SCENARIO
(DESIRED CAPABILITIES CASE)

ORBIT	1983	1984	1985	1986	1987	1988	1989	1990

LEO 28.5
- SCD • SS
- LS
SORTIE ONLY
B 50 kW
• CB • SS • PS
• LS
ADD SM
B 100 kW
• CB • PS
• LS • SM • SS
B 150 kW
• DEPOT • LS
• SM • CB
• SS
C 100 kW
• MPS
A 25 kW
• MPS
A 50 kW
• MPS

LEO 50 TO 57°
A 25 kW
• STO • EO
• SS
A 50 kW
• STO
• EO
• SS
SORTIE ONLY
• STO
• SS

LEO POLAR
A 25 kW
• EO
ADD SS
A 100 kW
• STO
• EO
• SS
D 100 kW
• STO
• DEPOT
SORTIE ONLY
• SS
• EO

GEO
A 60 kW
• PS
• EO
• SS
B 65/50 kW
• PS
C 270/210 kW
• PS

Legend:

Symbol	Description
POWER MODULE	
+	DOCKING MODULE – UNPRESS
⊕	DOCKING WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP / AVAILABLE ALL YEARS
H	MANNED HABITAT – FREE-FLYER MODE
✕	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SL	SKYLAB
IM	SKYLAB INTERFACE MODULE

- MP – MATERIAL PROCESSING
- STO – SOLAR TERRESTRIAL OBSER
- PS – PUBLIC SERVICE
- SS – SPACE SCIENCE
- EO – EARTH OBSERVATION
- CB – CONSTRUCTION BASE FOR
  - SPS – SPACE POWER SYSTEM
  - GEO PLATFORM
  - OTHERS
- SM – SPACECRAFT MAINTENANCE ASSEMBLY
- A, B, C, D – DESIGNATES PM's AND CORRELATES WITH DESIGNATIONS ON SUMMARY POWER REQUIREMENTS

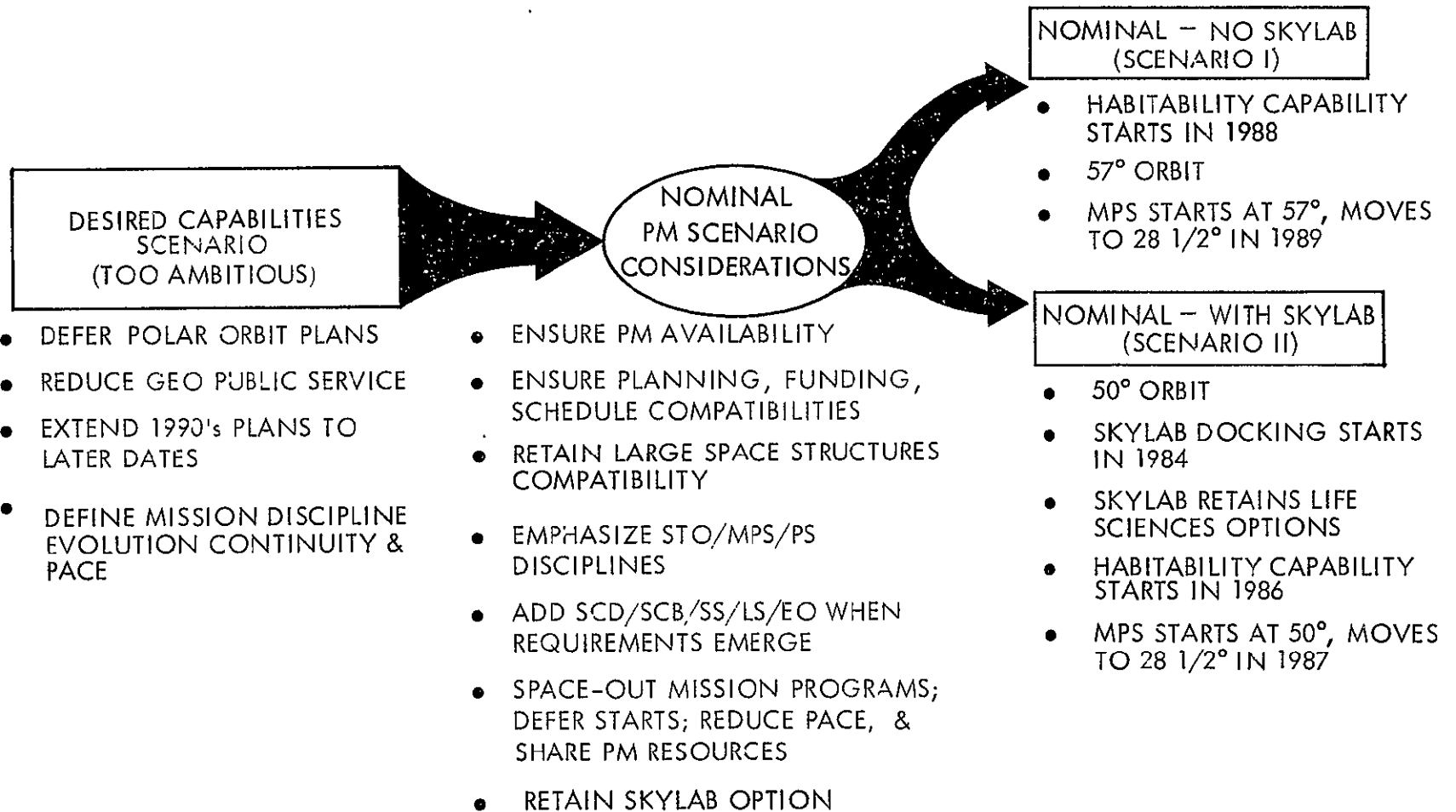NOMINAL PM SCENARIO DEVELOPMENT

The adjacent chart presents an overview of key considerations and restraints in the evolvement of the nominal PM scenarios. The two subsequent charts show the resulting nominal scenarios, i.e., no SKYLAB and with SKYLAB.

NOMINAL PM SCENARIO DEVELOPMENT

DESIRED CAPABILITIES
SCENARIO
(TOO AMBITIOUS)

NOMINAL
PM SCENARIO
CONSIDERATIONS

NOMINAL - NO SKYLAB
(SCENARIO I)

- HABITABILITY CAPABILITY STARTS IN 1988
- 57° ORBIT
- MPS STARTS AT 57°, MOVES TO 28 1/2° IN 1989

NOMINAL - WITH SKYLAB
(SCENARIO II)

- 50° ORBIT
- SKYLAB DOCKING STARTS IN 1984
- SKYLAB RETAINS LIFE SCIENCES OPTIONS
- HABITABILITY CAPABILITY STARTS IN 1986
- MPS STARTS AT 50°, MOVES TO 28 1/2° IN 1987

- DEFER POLAR ORBIT PLANS

- REDUCE GEO PUBLIC SERVICE

- EXTEND 1990's PLANS TO LATER DATES

- DEFINE MISSION DISCIPLINE EVOLUTION CONTINUITY & PACE

- ENSURE PM AVAILABILITY

- ENSURE PLANNING, FUNDING, SCHEDULE COMPATIBILITIES

- RETAIN LARGE SPACE STRUCTURES COMPATIBILITY

- EMPHASIZE STO/MPS/PS DISCIPLINES

- ADD SCD/SCB/SS/LS/EO WHEN REQUIREMENTS EMERGE

- SPACE-OUT MISSION PROGRAMS; DEFER STARTS; REDUCE PACE, & SHARE PM RESOURCES

- RETAIN SKYLAB OPTION

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PROGRAM SCENARIO I
(NOMINAL — NO SKYLAB)

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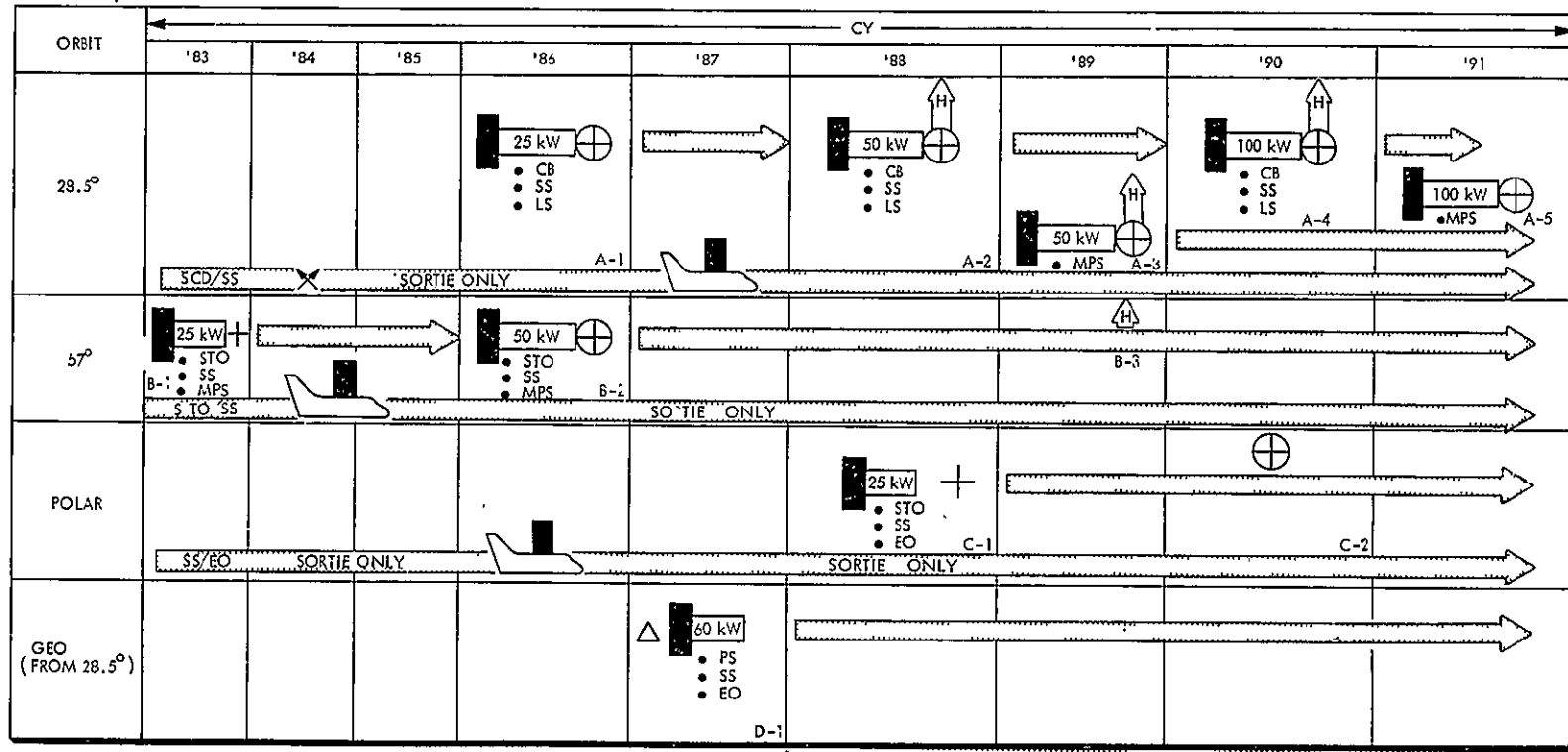| ORBIT	CY								
	'83	'84	'85	'86	'87	'88	'89	'90	'91

28.5°
- 25 kW
  - CB
  - SS
  - LS   A-1
- 50 kW (H)
  - CB
  - SS
  - LS   A-2
- 50 kW (H)
  - MPS   A-3
- 100 kW (H)
  - CB
  - SS
  - LS   A-4
- 100 kW
  - MPS   A-5

SCD/SS ✕ SORTIE ONLY

57°
- 25 kW
  - STO
  - SS
  - MPS   B-1
- 50 kW
  - STO
  - SS
  - MPS   B-2
- (H)   B-3

STO/SS SORTIE ONLY

POLAR
- 25 kW
  - STO
  - SS
  - EO   C-1
- ⊕   C-2

SS/EO SORTIE ONLY SORTIE ONLY

GEO (FROM 28.5°)
- △ 60 kW
  - PS
  - SS
  - EO   D-1

Legend:

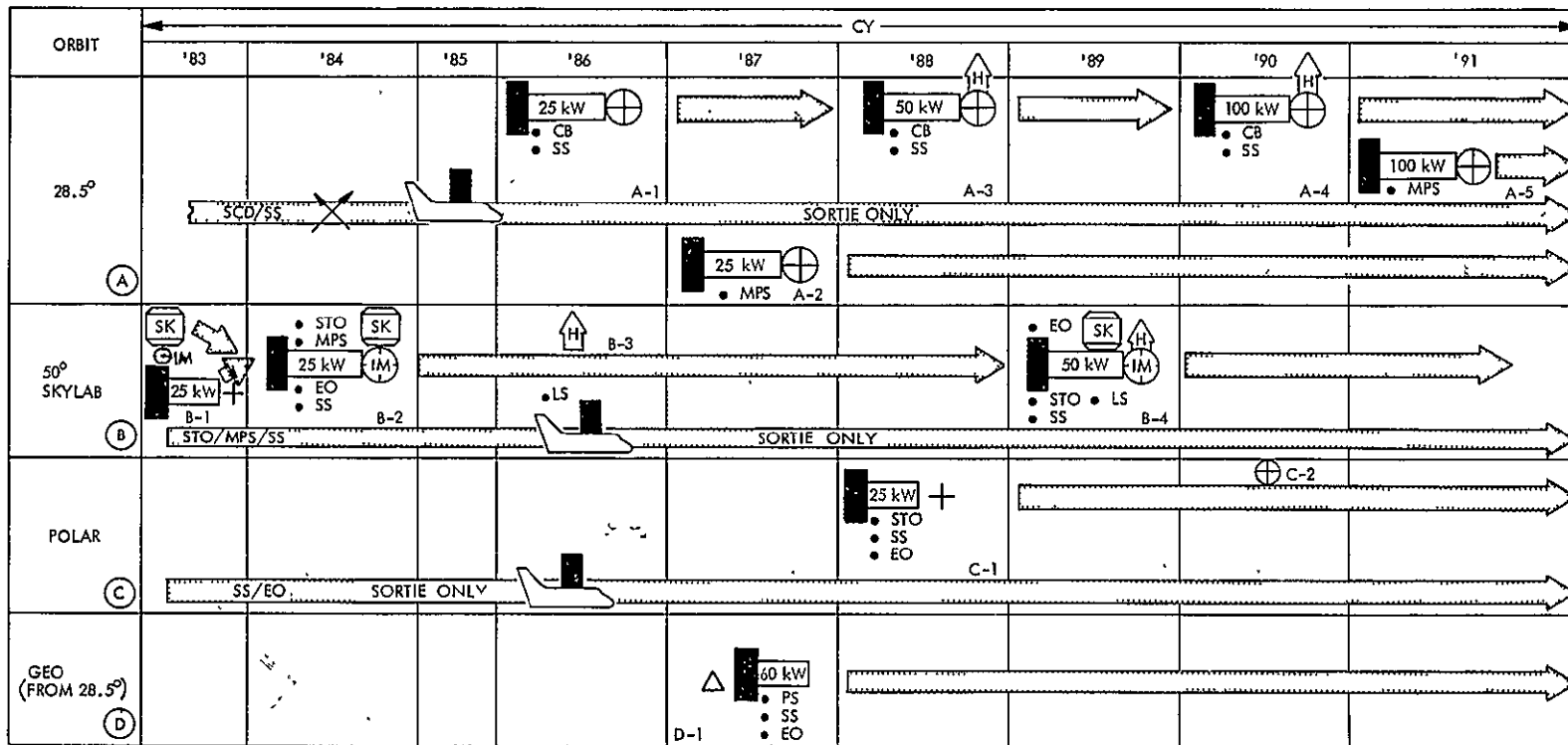| Symbol	Meaning
POWER MODULE	
+	DOCKING MODULE – UNPRESS
⊕	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
(H)	MANNED HABITAT – FREE-FLYER MODE
✕	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SK	SKYLAB

- MP — MATERIAL PROCESSING
- STO — SOLAR TERRESTRIAL OBSER
- PS — PUBLIC SERVICE
- SS — SPACE SCIENCE
- EO — EARTH OBSERVATION
- CB — CONSTRUCTION BASE FOR:
  - SPS – SPACE POWER SYSTEM
  - GEO PLATFORM
  - OTHERS
- SCD – SPACE CONSTRUCTION DEMO
- LS – LIFE SCIENCE

IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

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PROGRAM SCENARIO II
(NOMINAL – WITH SKYLAB)

Legend:

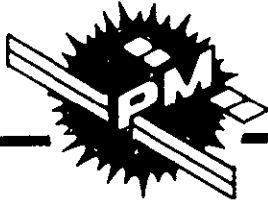| Symbol	Description
▬	POWER MODULE
+	DOCKING MODULE – UNPRESS
⊕	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
H	MANNED HABITAT – FREE-FLYER MODE
X	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SK	SKYLAB
IM	SKYLAB INTERFACE MODULE

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  - SPS – SPACE POWER SYSTEM
  - GEO PLATFORM
  - OTHERS
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- LS – LIFE SCIENCE

IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

MINIMUM AND AMBITIOUS SCENARIO DEVELOPMENT

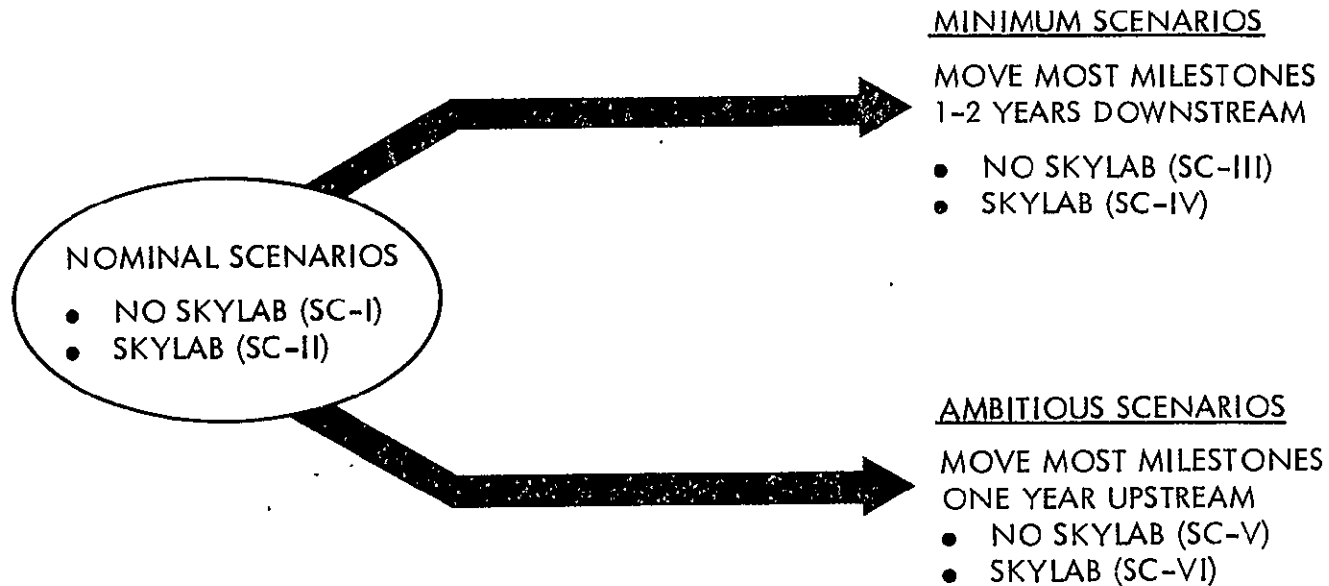Essentially there are three categories of program scenarios viz., nominal, minimum and ambitious. The nominal was previously discussed. The diagram on the adjacent page depicts the approach for development of the minimum and ambitious scenarios. The subsequent four charts (Scenarios III thru VI) represent key system considerations for two cases viz., (a) minimum, and (b) ambitious, both with and without SKYLAB.

(NOMINAL/MINIMUM/AMBITIOUS)

MINIMUM SCENARIOS

MOVE MOST MILESTONES
1-2 YEARS DOWNSTREAM

- NO SKYLAB (SC-III)
- SKYLAB (SC-IV)

NOMINAL SCENARIOS
- NO SKYLAB (SC-I)
- SKYLAB (SC-II)

AMBITIOUS SCENARIOS

MOVE MOST MILESTONES
ONE YEAR UPSTREAM
- NO SKYLAB (SC-V)
- SKYLAB (SC-VI)

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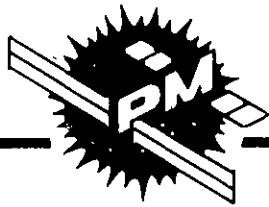
PROGRAM SCENARIO III
(MINIMUM — NO SKYLAB)
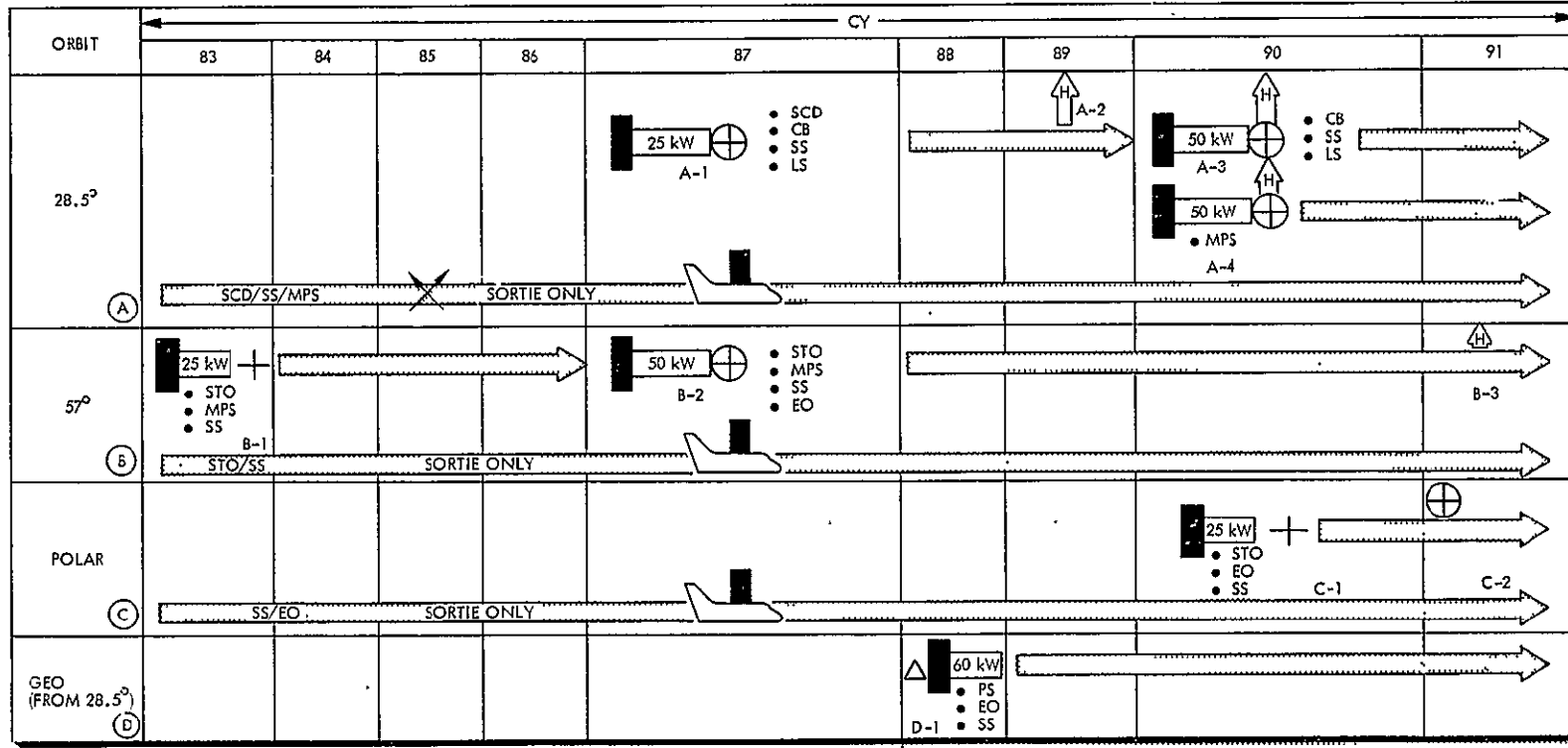
Legend:

Symbol	Description
▄▄	POWER MODULE
─┼─	DOCKING MODULE — UNPRESS
⊕	DOCKING/WORKSHOP MODULE — PRESS
◥ 15 kW	SORTIE ONLY — PEP AVAILABLE ALL YEARS
Ⓗ	MANNED HABITAT — FREE-FLYER MODE
✕	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SK	SKYLAB

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  - OTHERS
- SCD — SPACE CONSTRUCTION DEMO
- LS — LIFE SCIENCE

IMPROVED PM
EFFICIENCY
WITH ADVANCED
TECHNOLOGY
POSSIBLE

2-19

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PROGRAM SCENARIO IV
(MINIMUM — WITH SKYLAB)

CY

ORBIT	'83	'84	'85	'86	'87	'88	'89	'90	91

28.5°

25 kW ⊕
• SCD
• CB
• SS

H
A-2

50 kW ⊕
• CB
• SS
• LS

H

50 kW ⊕
• MPS
A-4

A-1

(A) SCD SS MPS ✕ SORTIE ONLY

A-3

50°

• STO
• MPS
• SS
25 kW +
B-1

25 kW ⊕
B-2

SK
IM

50 kW ⊕
• STO
• MPS
• SS
• EO
• LS

H
SK
IM
B-3

(B) STO/SS SORTIE ONLY

SK IM

25 kW +
• STO
• EO
• SS

POLAR

(C) EO/SS SORTIE ONLY

C-1 C-2

GEO
(FROM 28.5°)

△ 60 kW
• PS
• EO
• SS
D-1

(D)

Legend

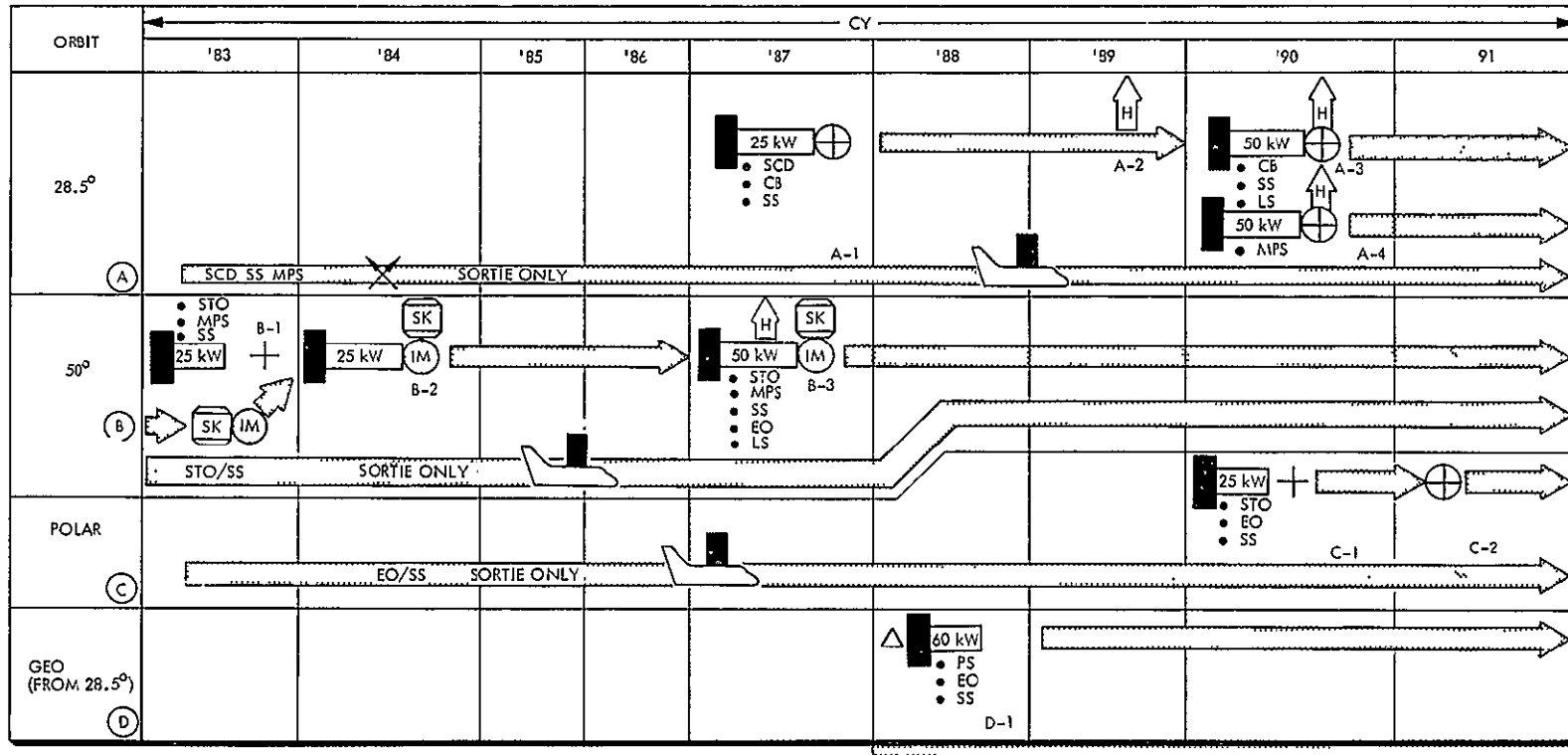| POWER MODULE |
|---|
| + DOCKING MODULE – UNPRESS |
| ⊕ DOCKING/WORKSHOP MODULE – PRESS |
| 15 kW SORTIE ONLY – PEP AVAILABLE ALL YEARS |
| (H) MANNED HABITAT – FREE-FLYER MODE |
| ✕ REQUIRES PAYLOAD STABILIZATION KIT |
| △ 25 kW DERIVATIVE HARDWARE |
| SK SKYLAB |
| IM SKYLAB INTERFACE MODULE |

• MP — MATERIAL PROCESSING
• STO — SOLAR TERRESTRIAL OBSER.
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• EO — EARTH OBSERVATION
• CB — CONSTRUCTION BASE FOR
 • SPS – SPACE POWER SYSTEM
 • GEO PLATFORM
 • OTHERS
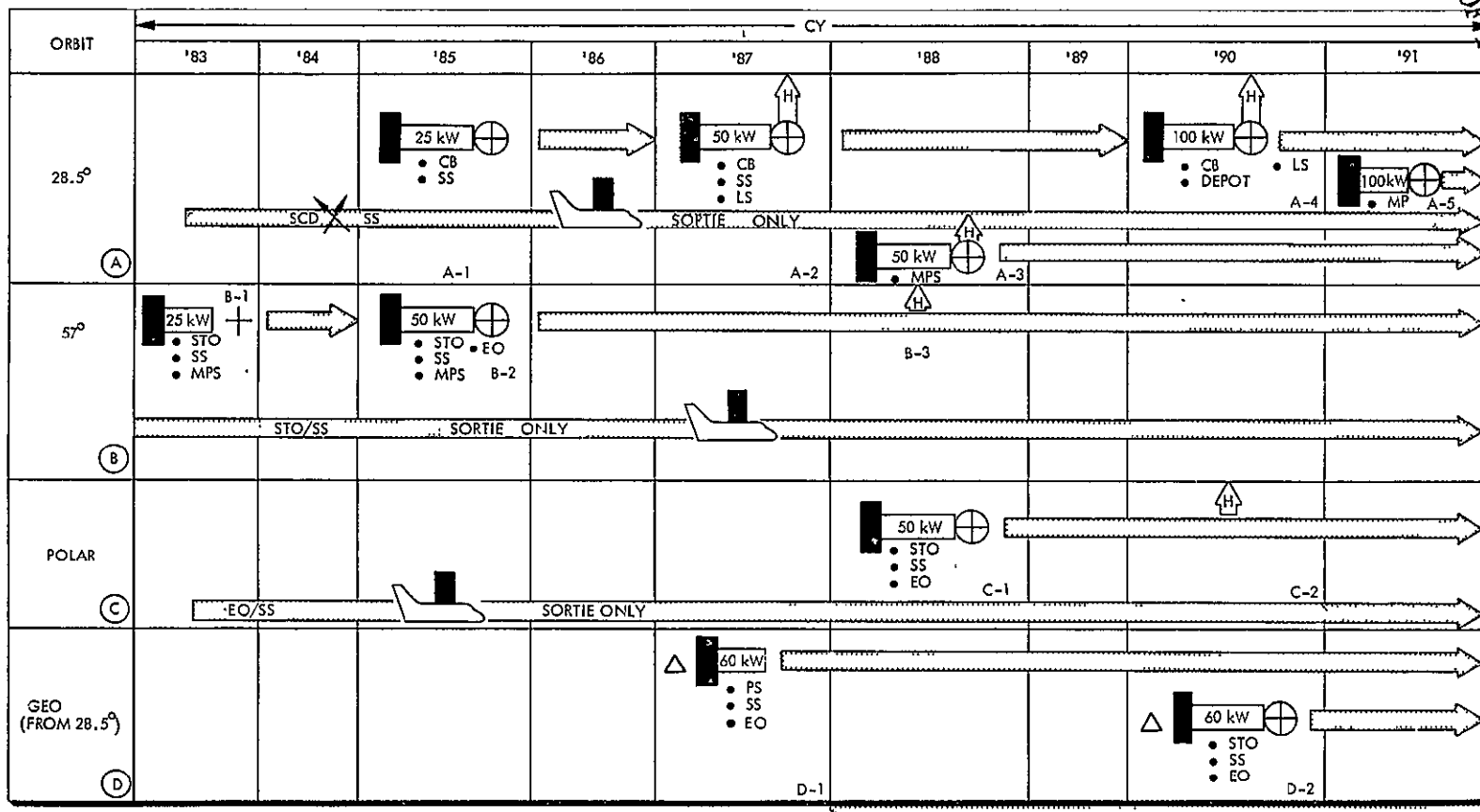• SCD – SPACE CONSTRUCTION DEMO
• LS — LIFE SCIENCE

IMPROVED PM
EFFICIENCY
WITH ADVANCED
TECHNOLOGY
POSSIBLE

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PROGRAM SCENARIO V
(AMBITIOUS WITHOUT SKYLAB)

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OF POOR QUALITY

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PROGRAM SCENARIO VI
(AMBITIOUS — WITH SKYLAB)

Symbol	Description
▭	POWER MODULE
+	DOCKING MODULE – UNPRESS
⊕	DOCKING/WORKSHOP MODULE – PRESS
15 kW	SORTIE ONLY – PEP AVAILABLE ALL YEARS
⟨H⟩	MANNED HABITAT – FREE-FLYER MODE
✕	REQUIRES PAYLOAD STABILIZATION KIT
△	25 kW DERIVATIVE HARDWARE
SK	SKYLAB
IM	SKYLAB INTERFACE MODULE

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- SS – SPACE SCIENCE
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  - SPS – SPACE POWER SYSTEM
  - GEO PLATFORM
  - OTHERS
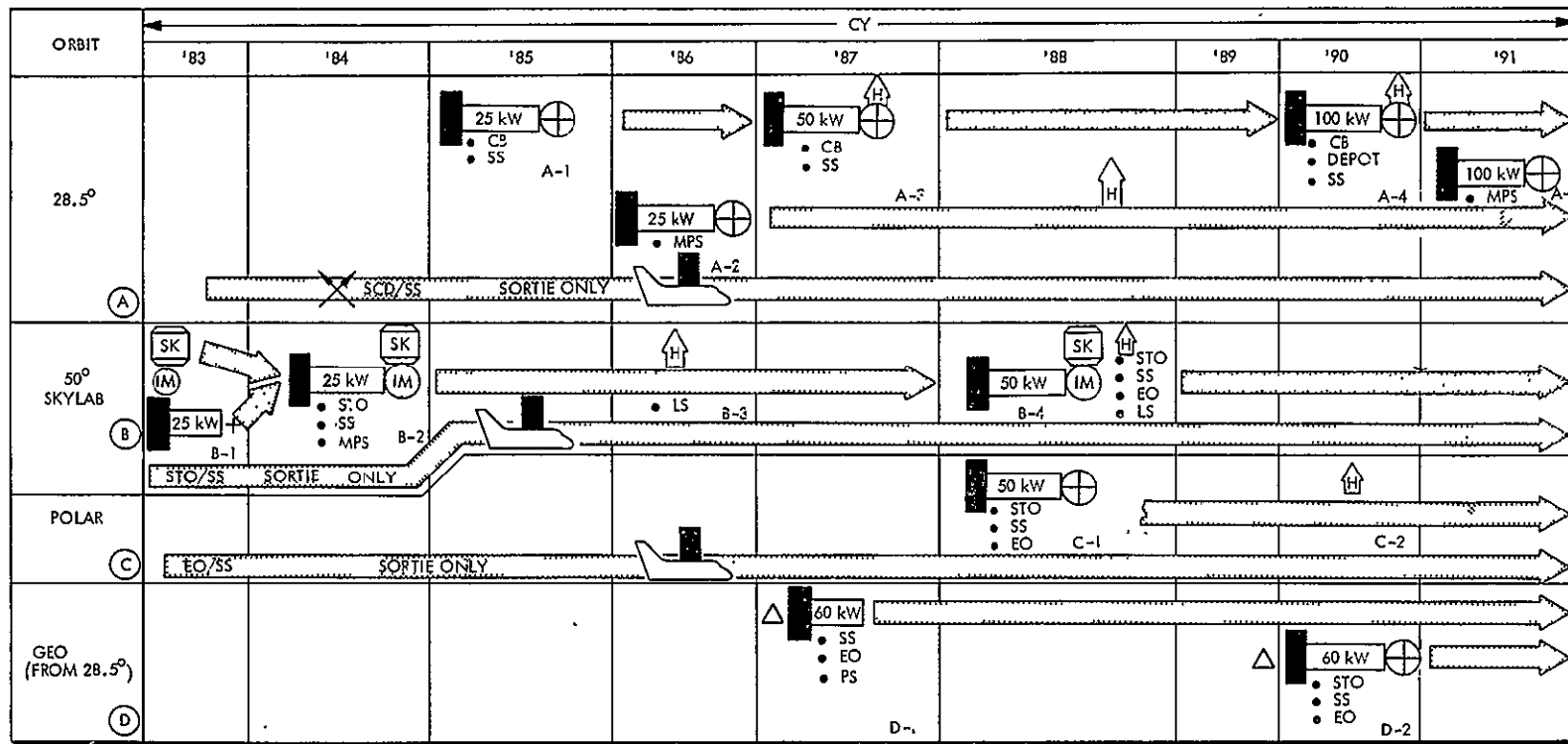- SCD – SPACE CONSTRUCTION DEMO
- LS – LIFE SCIENCE

IMPROVED PM EFFICIENCY WITH ADVANCED TECHNOLOGY POSSIBLE

COMPOSITE PAYLOAD REQUIREMENTS

● The next two charts, "Composite Payload Requirements Data", reflect PM growth (by year) and support elements if all demands (needs) are provided.

● Sortie missions shown in the scenario were not considered in this analysis.

● In cases where the payload power requirements in the scenario exceed the Power Module configuration output, available power will be time-shared.

● Each configuration change, i.e., Power Module size or other, is represented by a letter designation as an aid in following the activities from the scenarios.
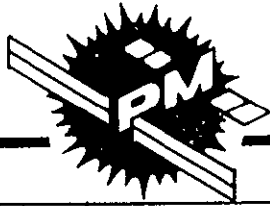
COMPOSITE PAYLOAD REQUIREMENTS

DESIRED

		POWER MODULE				DATA		SUPPORT ELEMENTS												
	PM DESIGNATION	POWER (kW)	HEAT REJECTION (kW)	STABILIZATION	MISSION DURATION	ANALOG (MHz)	DIGITAL (MBPS)	POWER MODULE QTY	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIF)	PLATFORM	REMOTE MANIPULATORS (ON PLATFORM)	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT	THERMAL CONTROL MODULE
28.5° ORBIT																				
1983–1985	A	25	TBD	±0.5°	365	4	0.01	1	X	–	X	–	–	–	–	–	–	–	–	TBD
1986–1987	A	25	TBD	±0.5°	365	4	0.01	1	X	–	X	–	–	–	–	–	–	–	–	TBD
	B	50	TBD	±0.5°	365	20	0.52	1	–	X	X	X	X	–	X	X	–	X	X	–
1988–1989	A	50	TBD	±0.5°	365	12	0.013	1	–	X	–	X	X	–	–	–	–	–	–	TBD
	B	100	TBD	±0.5°	365	28	0.52	1	–	X	X	X	X	–	X	X	–	X	X	TBD
1990	A	50	TBD	±0.5°	365	12	0.013	1	–	X	–	X	X	–	–	–	–	–	–	TBD
	B	150	TBD	±0.5°	365	28	0.031	1	–	X	X	X	X	–	X	X	X	X	X	TBD
	C	100	TBD	±0.5°	365	8	0.011	1	–	X	–	X	–	–	–	–	–	–	–	TBD
50–57° ORBIT																				
1983–1985	A	25	9	±0.5°	365	22	25.0	1	X	–	X	–	–	–	–	–	–	–	–	–
1986–1990	A	50	18	±0.5°	365	36	25.0	1	–	X	X	X	X	–	–	–	–	–	–	TBD

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COMPOSITE PAYLOAD REQUIREMENTS (CONT'D)

DESIRED

	POWER MODULE				DATA		SUPPORT ELEMENTS												
	PM DESIGNATION	POWER (kW)	HEAT REJECTION (kW)	STABILIZATION	MISSION DURATION	ANALOG (MHz)	DIGITAL (MBPS)	POWER MODULE QTY	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIF)	PLATFORM	REMOTE MANIPULATORS (ON PLATFORM)	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT	THERMAL CONTROL MODULE
90° ORBIT																				
1985–1987	A	25	10	±0.5°	365	8	10	1	X	–	X	–	–	–	–	–	–	–	–	–
1988–1990	A	100	40	±0.5°	365	40	35	1	–	X	X	X	X	–	–	–	–	–	–	TBD
GEO ORBIT																				
1986	A	60	TBD	±0.5°	365	12	5	1	–	–	–	–	–	–	–	–	–	–	X	TBD
1987–1988	B	50	TBD	±0.5°	365	NR*	NR*	1	–	–	–	–	–	–	–	–	–	–	X	TBD
	A	60	TBD	±0.5°	365	12	5	1	–	–	–	–	–	–	–	–	–	–	X	TBD
1989	B	50	TBD	±0.5°	365	NR*	NR*	1	–	–	–	–	–	–	–	–	–	–	X	TBD
	A	60	TBD	±0.5°	365	12	5	1	–	–	–	–	–	–	–	–	–	–	X	TBD
	C	210	TBD	±0.5°	365	NR*	NR*	1	–	–	–	–	–	–	–	–	–	–	X	TBD
1990	B	50	TBD	±0.5°	365	NR*	NR*	1	–	–	–	–	–	–	–	–	–	–	X	TBD
	A	60	TBD	±0.5°	365	12	5	1	–	–	–	–	–	–	–	–	–	–	X	TBD
	D	100	TBD	±0.5°	365	37	25	1	–	X	–	X	X	–	X	X	–	–	X	TBD
	C	210	TBD	±0.5°	365	NR*	NR*	1	–	–	–	–	–	–	–	–	–	–	X	TBD

NR – NOT REQUIRED; *USES PAYLOAD CHANNELS

GROWTH SYSTEM CAPABILITIES ANALYSIS
28.5° ORBIT

- The analyses data shown is centered around Program Scenario I (Nominal — No SKYLAB), 1983-1991. It covers PM and support elements for which payload development and testing originates in preparation for launch and GEO operations. The element requirements are used for system and subsystem designs and trade analysis to derive the evolutionary growth options.

- Each configuration change, i.e., PM size or other, is represented by a letter and dash number designation as an aid in following the activities from the scenario.

GROWTH SYSTEM CAPABILITIES ANALYSIS

28.5° ORBIT

COMPOSITE (DESIRED)	PM DESIGNATION	POWER (kW)	HEAT REJECTION (kW)	STABILIZATION	MISSION DURATION	ANALOG (MHz)	DIGITAL (MBPS)	POWER MODULE QTY	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIF)	PLATFORM	REMOTE MANIPULATORS (ON PLATFORM)	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT	THERMAL CONTROL MODULE
1983–1987	A	25	TBD	±0.5°	365	4	0.01	1	X	–	X	–	–	–	–	–	–	–	X	TBD
	B	50	TBD	±0.5°	365	20	0.52	1	–	X	–	X	X	X	X	X	–	X	X	TBD
1988–1989	A	50	TBD	±0.5°	365	12	0.013	1	–	X	–	X	X	–	X	–	–	–	X	TBD
	B	100	TBD	±0.5°	365	28	0.52	1	–	X	–	X	X	X	X	X	–	–	X	TBD

SCENARIO 1 (NOMINAL – NO SKYLAB)   NOMINAL SYSTEM CAPABILITIES

COMPOSITE (DESIRED)	PM DESIGNATION	POWER (kW)	HEAT REJECTION (kW)	STABILIZATION	MISSION DURATION	ANALOG (MHz)	DIGITAL (MBPS)	POWER MODULE QTY	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIF)	PLATFORM	REMOTE MANIPULATORS (ON PLATFORM)	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT	THERMAL CONTROL MODULE
1986–1987	A–1	25	TBD	±0.5°	365	12	0.015	1	–	X	X	–	–	X	X	–	–	X	X	–
1988	A–2	50	TBD	±0.5°	365	20	0.017	1	–	X	X	X	X	–	X	X	–	X	X	TBD
1989	A–2	50	TBD	±0.5°	365	20	0.017	1	–	X	X	X	X	X	X	X	–	X	X	TBD
	A–3	50	TBD	±0.5°	365	12	0.013	1	–	X	–	X	X	–	–	–	–	–	X	TBD

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GROWTH SYSTEM CAPABILITIES ANALYSIS (CONT'D)

28.5° ORBIT

COMPOSITE (DESIRED)	PM DESIGNATION	POWER (kW)	HEAT REJECTION (kW)	STABILIZATION	MISSION DURATION	ANALOG (MHz)	DIGITAL (MBPS)	POWER MODULE QTY	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIF)	PLATFORM	REMOTE MANIPULATORS (ON PLATFORM)	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT	THERMAL CONTROL MODULE
1990	A	50	TBD	±0.5°	365	12	0.013	1	-	X	-	X	X	-	X	-	-	-	X	TBD
	B	150	TBD	±0.5°	365	28	0.031	1	-	X	-	X	X	X	X	X	X	X	X	TBD
	C	100	TBD	±0.5°	365	8	0.011	1	-	X	-	X	-	-	X	-	-	-	X	TBD
SCENARIO I (NOMINAL – NO SKYLAB)						NOMINAL SYSTEM CAPABILITIES														
1990	A-4	100	TBD	±0.5°	365	20	0.017	1	-	X	X	X	X	X	X	X	-	X	X	TBD
	A-3	50	TBD	±0.5°	365	12	0.013	1	-	X	-	X	X	-	-	-	-	-	X	TBD
1991	A-4	100	TBD	±0.5°	365	20	0.017	1	-	X	X	X	X	-	X	-	-	X	X	TBD
	A-3	50	TBD	±0.5°	365	12	0.013	1	-	X	-	X	X	-	-	-	-	-	X	TBD
	A-5	100	TBD	±0.5°	365	8	0.011	1	-	X	-	X	-	-	-	-	-	-	X	TBD

2-33

GROWTH SYSTEM CAPABILITIES ANALYSIS

57° ORBIT

The analysis points to the availability of higher power (greater than 25 kW) for key disciplines in 1986 and introduction of manned habitation in 1989. The element requirements are used for system and subsystem designs and trade analysis to derive the evolutionary growth options.

GROWTH SYSTEM CAPABILITIES ANALYSIS

57° ORBIT

COMPOSITE (DESIRED)	PM DESIGNATION	POWER (kW)	HEAT REJECTION (kW)	STABILIZATION	MISSION DURATION	ANALOG (MHz)	DIGITAL (MBPS)	POWER MODULE QTY	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIF)	PLATFORM	REMOTE MANIPULATORS (ON PLATFORM)	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT	THERMAL CONTROL MODULE
1983–1985	A	25	9	±0.5°	365	22	25	1	X	–	X	–	–	–	–	–	–	–	–	TBD
1986–1990	A	50	18	±0.5°	365	36	25	1	–	X	X	X	X	–	–	–	–	–	–	TBD
SCENARIO I (NOMINAL – NO SKYLAB)						NOMINAL SYSTEM CAPABILITIES														
1983–1985	B-1	25	10	±0.5°	365	12	20	1	X	–	X	–	–	–	–	–	–	–	–	–
1986–1988	B-2	50	19	±0.5°	365	20	20	1	–	X	X	X	–	–	–	–	–	–	–	TBD
1989–1991	B-3	50	19	±0.5°	365	24	20	1	–	X	X	X	X	–	–	–	–	–	–	TBD

GROWTH SYSTEM CAPABILITIES ANALYSIS
POLAR ORBIT

- This analysis reflects considerable delay (1988) in Power Module utilization. However, utilization appears to be early enough to study the scientific phenomena associated with the approaching solar cycle of 1990-91.

GROWTH SYSTEM CAPABILITIES ANALYSIS

POLAR ORBIT

COMPOSITE (DESIRED)	POWER MODULE							SUPPORT ELEMENTS												
	PM DESIGNATION	POWER (kW)	HEAT REJECTION (kW)	STABILIZATION	MISSION DURATION	ANALOG (MHz)	DIGITAL (MBPS)	POWER MODULE QTY	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIF)	PLATFORM	REMOTE MANIPULATORS (ON PLATFORM)	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT	THERMAL CONTROL MODULE
1985–1987	A	25	10	±0.5°	365	8	10	1	X	–	X	–	–	–	–	–	–	–	–	–
1988–1990	A	100	40	±0.5°	365	40	35	1	–	X	X	X	X	–	–	–	–	–	–	TBD
SCENARIO 1 (NOMINAL – NO SKYLAB)	NOMINAL SYSTEM CAPABILITIES																			
1988–1989	C-1	25	10	±0.5°	365	20	23	1	X	–	X	–	–	–	–	–	–	..	–	–
1990–1991	C-2	25	10	±0.5°	365	24	23	1	–	X	X	X	–	–	–	–	–	–	–	–

GROWTH SYSTEM CAPABILITIES ANALYSIS

GEO ORBIT

- With the demand for 25-40 kW by Public Services in 1987, time sharing of power will be required among all payloads. This orbit uses a 25 kW PM derivative which incorporates advanced technology.

GROWTH SYSTEM CAPABILITIES ANALYSIS

GEO ORBIT

COMPOSITE (DESIRED)	PM DESIGNATION	POWER (kW)	HEAT REJECTION (kW)	STABILIZATION	MISSION DURATION	ANALOG (MHz)	DIGITAL (MBPS)	POWER MODULE QTY	PAYLOAD DOCKING MODULE (U)	PAYLOAD DOCKING MODULE (P)	PALLETS	WORKSHOP	MANNED HABITAT	EXTERNAL TANK (MODIF)	PLATFORM	REMOTE MANIPULATORS (ON PLATFORM)	TANK FARM	TELEOPERATOR	PAYLOAD STABILIZATION KIT	THERMAL CONTROL MODULE
1986	A	60	TBD	±0.5°	365	12	5	1	-	-	-	-	-	-	X	-	-	X	X	TBD
1987–1988	B	50	TBD	±0.5°	365	NR*	NR*	1	-	-	-	-	-	-	-	-	-	-	X	TBD
	A	60	TBD	±0.5°	365	12	5	1	-	-	-	-	-	-	X	-	-	X	X	TBD
1989	B	50	TBD	±0.5°	365	NR*	NR*	1	-	-	-	-	-	-	-	-	-	-	X	TBD
	A	60	TBD	±0.5°	365	12	5	1	-	-	-	-	-	-	X	-	-	X	X	TBD
	C	210	TBD	±0.5°	365	NR*	NR*	1	-	-	-	-	-	-	-	-	-	-	X	TBD
1990	B	50	TBD	±0.5°	365	NR*	NR*	1	-	-	-	-	-	-	-	-	-	-	X	TBD
	A	60	TBD	±0.5°	365	12	5	1	-	-	-	-	-	-	X	-	-	X	X	TBD
	D	100	TBD	±0.5°	365	37	25	1	-	X	-	X	X	-	X	X	-	X	X	TBD
	C	210	TBD	±0.5°	365	NR*	NR*	1	-	-	-	-	-	-	-	-	-	-	X	TBD
SCENARIO I (NOMINAL)					NOMINAL SYSTEM CAPABILITIES															
1987–1990	D-1	60	8	±0.5°	365	12	5	1	-	-	-	-	-	-	X	-	-	X	X	TBD

NR – NOT REQUIRED
*USES PAYLOAD CHANNELS

2.2 SYSTEM REQUIREMENTS

- Power Module system requirements are specified by NASA in three documents as follows:

    - Project Requirements

        25 kW Power Module Project Requirements NASA,
        MSFC, March 1978

    - Design Requirements

        Power Module System Design Requirements Document
        NASA, MSFC-SPEC-582 Rev. A, May 1, 1978

    - Interface Requirements

        25 kW Power Module — Shuttle/Payloads
        Interface Requirements/Definition Document
        NASA, MSFC — October 11, 1977

- Power Module System Requirements taken from these documents are summarized in the next two charts.
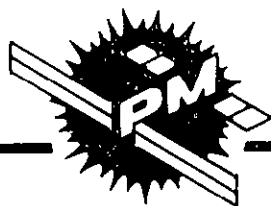
SYSTEM INTERFACE/OPERATIONS REQUIREMENTS SUMMARY

	ITEM	REQUIREMENT
OPERATIONS	LIFE	5-YR, 50 PERCENT DUTY CYCLE
	IOC	DEMONSTRATE CAPABILITY FOR INITIAL FLIGHT
	FLIGHT MODES (3)	ORBITER/PAYLOAD SORTIE SUPPORT; FREE-FLYER SUPPORT; PM ORBIT STORAGE
	RENDEZVOUS/ BERTHING	• CREW SUPPORT • OPERATE RMS; PERFORM MAINTENANCE, INSPECTION, EQUIPMENT CHANGE, AND UMBILICAL HOOK-UPS • ACTIVATE, ENABLE, MONITOR STATUS, CHECKOUT PM SYSTEMS
INTERFACES	ORBITER	COMPATIBLE WITH ORBITER PHYSICAL CONSTRAINTS (INCLUDING STA 660 LIMITATION)
	THERMAL	ORBITER PAYLOAD-FREE FLYING PAYLOAD VIA FLUID INTERFACE
	ELECTRICAL	• ORBITER BUS COMPATIBLE: ORBITER-CONTROLLED, ORBITER AND POWER MODULE NOT PARALLELED ON SAME ORBITER BUS • FAIL-SAFE AGAINST BUS OVER-LOAD; SINGLE POINT GROUND
	COMMUNICATION & DATA HANDLING	• HARDWIRE BETWEEN PM AND ORBITER-BERTHED CONFIGURATION • SEPARATE FROM POWER CABLES • TDRS
	UMBILICAL MATING	• AUTOMATED, EVA, OR RMS
	GROUND OPERATIONS	• KENNEDY SPACE CENTER SPACE TRANSPORTATION SYSTEM • GSE

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PERFORMANCE/DESIGN
REQUIREMENTS SUMMARY

ITEM	REQUIREMENT
ON-ORBIT REPAIR/MAINTENANCE	EVA IN BERTHED MODE
EVA	DOCKED TO ORBITER FOR PM REPAIR/MAINTENANCE
POWER (25 kW)	ORBITER/PAYLOAD: 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
CONTROL MOMENT GYROS (CMGs)	• STABILIZATION TO ORBITER/PAYLOAD IN SORTIE MODE: PM STABILIZATION FOR BERTHING • ATTITUDE CONTROL FOR PAYLOAD IN FREE-FLYER MODE • CMG DESATURATION
COMMUNICATION	TDRS /ORBITER COMPATIBLE
THERMAL REJECTION	ALL POWER MODULE HEAT AND UP TO 40 PERCENT OF PAY-LOAD HEAT
POWER MODULE STATUS	COMMAND AND CONTROL STATUS: (1) TO ORBITER FOR RENDEZVOUS, (2) TO ORBITER WHEN DOCKED IN SORTIE MODE, AND (3) TO GROUND IN FREE-FLYER MODE
REFURBISHMENT	ON-ORBIT RECOVERY, RETURN TO EARTH FOR GROUND REFURBISHMENT, AND RELAUNCH
ORBIT ALTITUDE MAINTENANCE	ORBITER REBOOST FOR DRAG MAKE-UP
DEPLOYMENT, BERTHING, AND RECOVERY OPERATIONS	ORBITER REMOTE MANIPULATOR SYSTEM: STABILIZE POWER MODULE: RETRACT SOLAR ARRAYS AND RADIATORS
SAFETY	FAIL-SAFE DESIGN
TRANSPORTATION (GROUND)	GOVERNMENT, CONTRACTOR, AND COMMERCIAL CARRIERS
STORAGE	CONTROLLED ENVIRONMENT, EXTENDED PERIODS
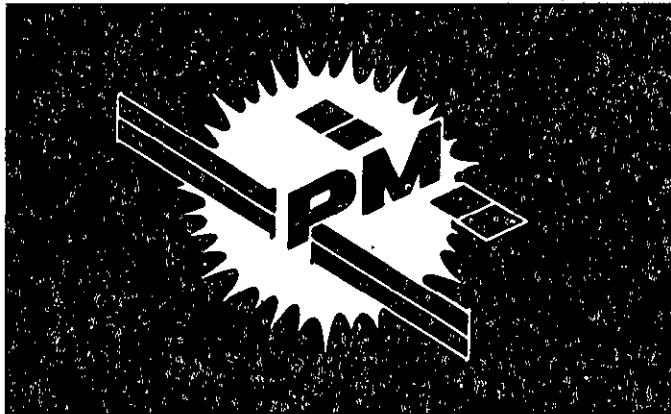
SECTION 3
RECOMMENDED POWER
MODULE EVOLUTION

3.1 SYSTEM DESCRIPTION

3.2 PM GROWTH OPTIONS

3.3 PM RECOMMENDED GROWTH STEPS

3.4 GEO DERIVATIVE CONFIGURATIONS

POWER MODULE EVOLUTIONARY SYSTEM

- The Power Module Evolutionary System consists of four basic elements: the Power Module programs, the STS services element, the payloads to be supported, and the support elements as required for various payload users. Of these four elements, the most significant one from the growth aspect is the Power Module program. The Power Module contains the hardware and services as described in the Work Breakdown Structure definition contained in Volume 6 of this Part III Final Report.

- The STS services element, including ground and flight operations and logistics, is well documented and described in the NASA 07700 series of documents issued by Johnson Space Center, references 1, 2, 3, 4, 5, 6, 7. Launch services, including facilities and operations, is described in the KSC Launch Site Accommodations Handbook for STS payload, reference 8. Support elements are described in specific documentation relating to each element. Payload descriptions will be provided in payload description documents (TBD). General capabilities of payload disciplines are given in the 25 kW Final Report Part 1 Payload Requirements and Growth Scenarios, 1 August 1978. (LMSC report number D-614921 A).

- The evolutionary approach begins with the 25 kW Power Module Program to support initial program requirements at minimum funding early in the scenario. As user needs build up, a 50 kW Power Module Program is implemented to augment on-orbit user support while retaining the initial 25 kW capability. Later in the scenario a 100 kW Power Module capability is implemented as a program, adding to previously established on-orbit support capabilities for 25 and 50 kW.

- The Power Module spacecraft are launched and deployed by the Space Transportation System Orbiter vehicle with support by the Johnson and Kennedy Space Centers for mission control and launch support respectively.
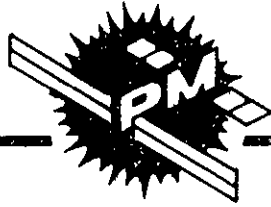
POWER MODULE EVOLUTIONARY SYSTEM

- POWER MODULE PROGRAMS

  - 25 kW PROGRAM
  - 50 kW PROGRAM
  - 100 kW PROGRAM

- STS SERVICES

  - ORBITER (DEPLOY, REVISIT, RETRIEVE)
  - JSC (MISSION CONTROL)
  - KSC (LAUNCH, LOGISTICS SUPPORT)

- PAYLOADS (SHARED WHEN COMPATIBLE)

  - MATERIAL PROCESSING (MPS)
  - SOLAR TERRESTRIAL OBSERVATION (STO)
  - PUBLIC SERVICE (PS)
  - SPACE SCIENCE (SS)
  - EARTH OBSERVATION (EO)
  - OTHERS

- SUPPORT ELEMENTS (AS REQUIRED BY USER)

  - DOCKING MODULE   — SKYLAB
  - PRESSURIZED MODULE (WORKSHOP)   — TRS
  - MANNED HABITAT   — PALLETS

3-3

3.1.1 Power Module System Operation

POWER MODULE SYSTEM OPERATIONS – MISSION PHASES

- The scope of the Power Module System Operations is shown on the next two charts. Seven different flight operating modes are depicted indicating the major flight performance functions and operating interfaces. Operational elements of the Space Transportation System, communications links with the TDRS network, and Orbiter, Power Module, and payload ground control centers will be required to support these mission phases as shown. During those flights when the Orbiter is involved (PM placement and verification; Orbiter sortie, PM maintenance/growth and PM recovery), primary mission control is under Shuttle authority. Communications and command control shall be exercised by the Shuttle Mission Control Center (MCC) at the Johnson Space Center. For PM ground control it is assumed that a Power Module Operations Control Center (PMOCC) will be operating and supportive to MCC. A Payload Operations Control Center (POCC) may be supporting MCC depending on the complement of the flight payloads.

- When the PM is operating in the free-flyer orbit storage (inactive) mode, it is assumed that command and control functions will be directed through a PMOCC. General status and flight performance/planning data for the PM will be furnished to Shuttle MCC and the Goddard Space Flight Center POCC as required.

- In the active free-flyer mode, the PM provides support to attached payloads. For this case it is assumed that direct PM operations are controlled by the PMOCC. Control of attached payloads will be the responsibility of the POCC working through the PMOCC.

25kW POWER MODULE SYSTEM
OPERATIONS—MISSION PHASES

PLACEMENT AND PM VERIFICATION

- DEPLOY
- BERTH
- CHECKOUT
- RELEASE
- PM STATUS AND CONTROL

FREE FLYER STANDBY ORBIT STORAGE

- POWER DOWN (HOUSEKEEPING)
- S/A RETRACT (PARTIAL)
- RADIATORS RETRACT (PARTIAL)
- PM STATUS AND CONTROL

ORBITER SORTIE SUPPORT

- RENDEZVOUS
- BERTH
- ORBITER SUPPORT (ACS, POWER, THERMAL)
- P/L ATTACH/REMOVAL

TDRSS

ORBITER/ POWER MODULE

ORBITER/ PAYLOAD

TDRSS

STDN

- LAUNCH
- PM CARGO
- PM SSE

JSC PMOCC

JSC MCC

GSFC POCC

ORBITER RETURN

TDRSS

.TDRSS

JSC MCC

PMOCC

GSFC POCC

TDRSS

ORBITER/ POWER MODULE

ORBITER/ PAYLOAD

TDRSS

STDN
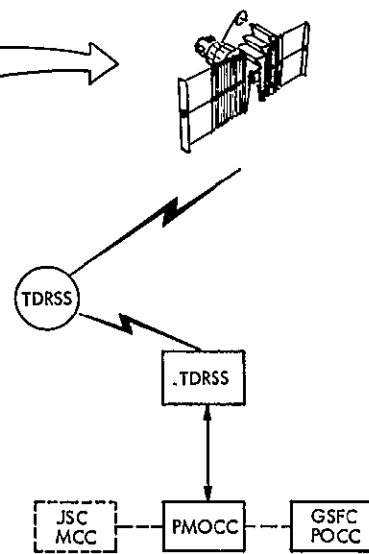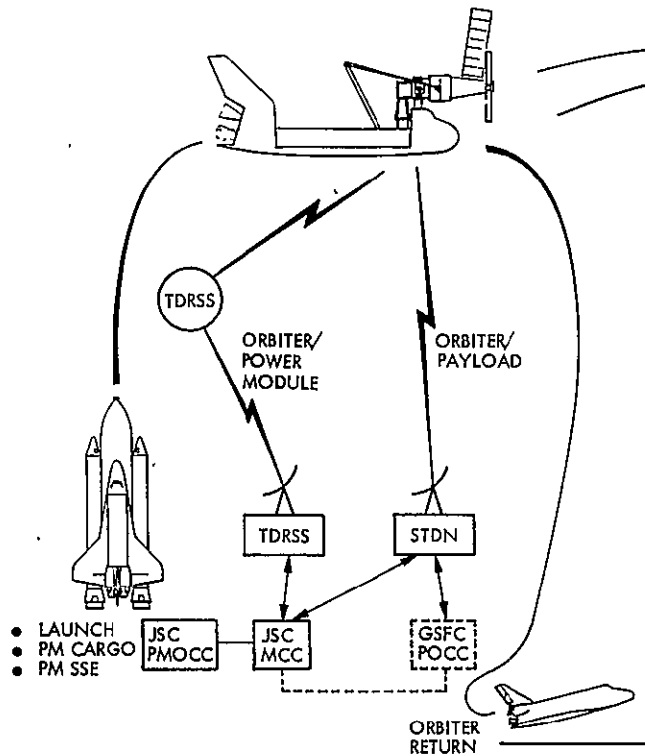
- LAUNCH
- PAYLOAD CARGO
- PM SSE

JSC PMOCC

JSC MCC

GSFC POCC

ORBITER RETURN
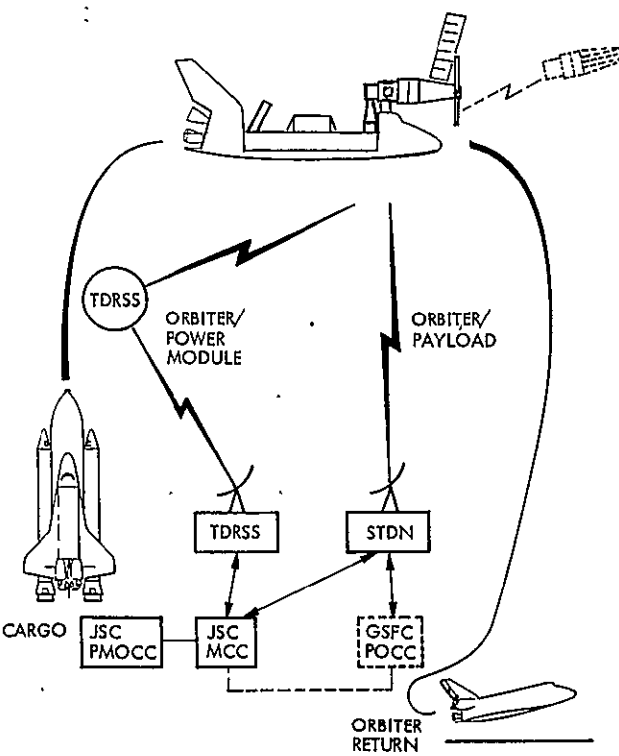
POWER MODULE SYSTEM OPERATIONS-MISSION PHASES

● Sortie Mode Support

Where the payloads remain in the Orbiter bay, payload tending and support in the sortie mode has long-term, almost-continuous operational implications i.e., early planning, preflight, flight and post flight with the orbiter. It is necessary that the payloads be compatible with the Orbiter berthing with the PM. Direct real-time support will be maintained by the POCC.

● Delivery/Revisit

During this mode of Orbiter flight rapid on-orbit service of payloads delivered to free-flyers or changeout of experiments or products are essential. It is necessary that the payloads be compatible with the Orbiter and Orbiter berthing with the PM.

25kW POWER MODULE SYSTEM
OPERATIONS—MISSION PHASES

LMSC-D614944-1

FREE FLYER
PAYLOAD
SUPPORT

- ATTITUDE CONTROL
- POWER
- THERMAL
- PAYLOAD DATA THROUGHPUT
- PM STATUS & CONTROL
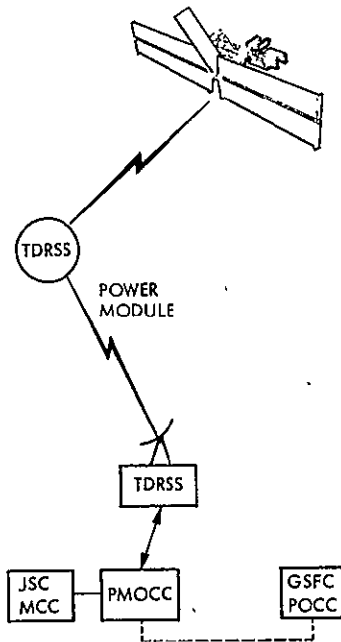
ON ORBIT
MAINTENANCE

- RENDEZVOUS
- BERTH
- EVA ORU CHANGEOUT
- CHECKOUT
- PM STATUS & CONTROL

ON ORBIT
GROWTH

- RENDEZVOUS
- BERTH
- EVA ORU CHANGEOUT
- CHECKOUT
- PM STATUS & CONTROL

PM RECOVERY
RETURN

- RENDEZVOUS
- RECOVER
- STOW/SECURE IN
  CARGO BAY

TDRSS

POWER
MODULE

TDRSS

JSC
MCC — PMOCC

GSFC
POCC

TDRSS

ORBITER/
POWER
MODULE

ORBITER/
PAYLOAD

- LAUNCH
- PM SPARES/
  GROWTH KIT
- PM SSE

TDRSS

STDN

JSC
PMOCC

JSC
MCC
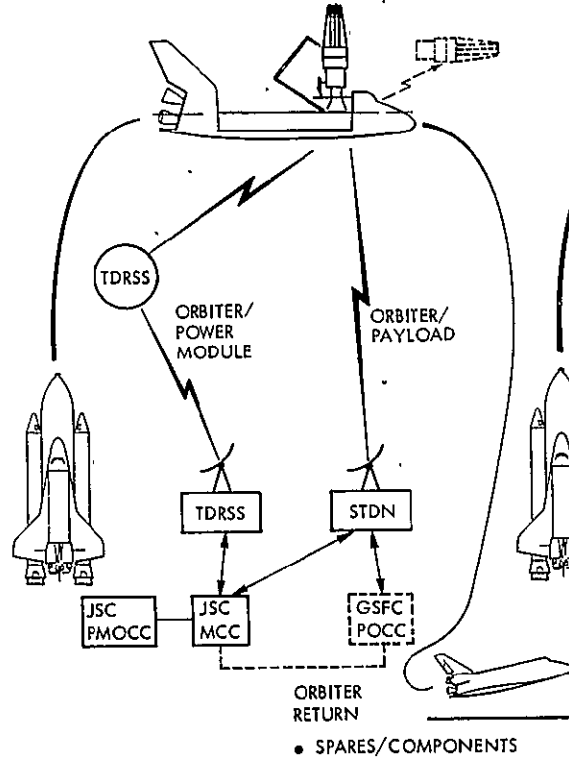
GSFC
POCC

ORBITER
RETURN

- SPARES/COMPONENTS

TDRSS

ORBITER/
POWER
MODULE

ORBITER/
PAYLOAD

- LAUNCH
- PM SSE

TDRSS

STDN

JSC
PMOCC

JSC
MCC

GSFC
POCC

ORBITER
RETURN

- POWER MODULE
- PM SSE

3-7

- There are two key systems required in the conduct of on-orbit space power operations—class Orbiter and PM.

- Each system will require long-range, near-term, and on-line mission flight planning. The next three charts delineate the Orbiter utilization based on Scenario I (1983-1991) in 3 orbits (28.5^o, 57° and Polar). All mission planning for the Orbiter-PM must include flight utilization analyses similar to these presented here.

- Assuming two types of Orbiter missions (sorties and delivery/revisit), the analysis indicates a modest schedule frequency. The Orbiter utilization rate (synonymous with PM hookups/berthings) ranges from 9 to 29 flights/year. This number is within the STS model capability of 60 flights/year. The utilization rate stated above is not NASA approved and no attempt was made to redesignate or modify numbers of planned flights/year appearing in the model.
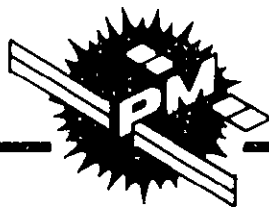
SCENARIO 1 28.5° ORBIT

LMSC-D614944-1

		DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS			
		91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91

CB
- SORTIE FLIGHT (7-DAYS)
- DELIVERY/REVISIT FLIGHT (7-DAYS)
- MISSION DURATION — 30-180

SS
- SORTIE FLIGHT (7-14 DAYS)
- DELIVERY/REVISIT FLIGHT (7 DAY)
- MISSION DURATION — 30-90 DAYS — 2-5 YRS

MPS
- SORTIE FLIGHT (7 DAY)
- DELIVERY/REVISIT FLIGHT (7 DAY)
- MISSION DURATION (DAYS) — 280 — 280 — 280

LS
- SORTIE FLIGHT (7 DAY)
- DELIVERY/REVISIT FLIGHT (7 DAY)
- MISSION DURATION — 60-90

POWER MODULE CAPABILITY (KW): 25 — 50 — 100 — 50 — 100

POTENTIALLY SHARED SORTIE FLT TOTALS/YR △: 1 0 1 1 | 1 0 1 0 | 1 0 0 1 | 1 0 1 2 | 1 2 1 0 | 1 1 1 1

POTENTIALLY SHARED D/R FLT TOTALS/YR △: 2 1 1 2 | 2 0 1 1 | 2 1 0 1 | 2 2 2 2 | 3 1 1 3 | 3 1 3 1

YEAR	83	84	85	86	87	88	89	90	91
NO. OF HOOKUPS/YR				9	6	6	12	12	12

☐ = ≈91 DAY SPAN

☒ = 1 FLIGHT

▨ = 1 FLT IN MPS ONLY

△ ASSUMES PAYLOAD FLIGHT SHARING

3-9

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ORBITER FLIGHT UTILIZATION ANALYSIS (CONT'D)

SCENARIO 1   57% ORBIT

		DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS			
		91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91

STO
- SORTIE FLIGHT (14-30 DAY)
- DELIVERY/REVISIT FLIGHT (7-14 DAYS)
- MISSION DURATION — 1-3 YRS / 3-5 YRS

MPS
- SORTIE FLIGHT (7 DAY)
- DELIVERY/REVISIT FLIGHT (7 DAYS)
- MISSION DURATION (DAYS): 280, 280, 280, 280, 280, 280, 280, 280, 280

S/S
- SORTIE FLIGHT (7-14 DAY)
- DELIVERY/REVISIT FLIGHT (7 DAY)
- MISSION DURATION — 30-90 DAYS / 2-5 YRS

POWER MODULE CAPABILITY (KW): 25 → 50

POTENTIALLY SHARED SORTIE FLT TOTALS/YR △	1	0	0	1	1	1	1	1	2	0	2	2	2	2	1	1	1	1	2	0	1	1	1	1	1	0	1	1	0	1	1	1	1	1	0	1
POTENTIALLY SHARED D/R FLT TOTALS/YR △	2	2	2	1	1	1	3	3	1	2	1	2	1	3	1	3	2	1	1	2	1	3	1	2	1	1	2	2	3	1	0	3	1	3	3	0

YEAR	83	84	85	86	87	88	89	90	91
NO. OF HOOKUPS/YR	9	12	12	14	10	11	9	10	10

□ = ≈91 DAY SPAN

☒ = 1 FLIGHT

▨ = 1 FLT IN MPS ONLY

△ ASSUMES PAYLOAD FLIGHT SHARING

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ORBITER FLIGHT UTILIZATION ANALYSIS (CONT'D)

SCENARIO 1 POLAR ORBIT

ORIGINAL PAGE IS OF POOR QUALITY

		DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS				DAYS			
		91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91
STO	SORTIE FLIGHT (14-30 DAY)																					X		X	X				X	X		X	X		X	
	DELIVERY/REVISIT FLIGHT																					X		X		X	X		X		X		X		X
	MISSION DURATION																					← 1 – 3 YRS →															
SS	SORTIE FLIGHT (7 DAY)																					X		X		X		X				X			
	DELIVERY/REVISIT FLIGHT																					X		X	X					X				X
	MISSION DURATION																					← 30 – 90 DAYS →					← 2-5 YRS →									
EO	SORTIE FLIGHT (7-14 DAY)																					X		X		X	X	X				X			
	DELIVERY/REVISIT FLIGHT (7 DAY)																					X		X		X		X							
	MISSION DURATION																					← 3 – 5 YRS →															
	POWER MODULE CAPABILITY (KW)																					25															
	POTENTIALLY SHARED SORTIE FLT TOTALS/YR △																					1	1	0	1	1	1	1	2	1	1	0	1	1	2	1	0
	POTENTIALLY SHARED D/R FLT TOTALS/YR △																					1	1	1	1	0	2	1	0	1	1	0	2	1	1	0	1

☐ = ≈91 DAY SPAN

☒ = 1 FLIGHT

YEAR	83	84	85	86	87	88	89	90	91
NO. OF HOOKUPS/YR						7	8	7	7

△ ASSUMES PAYLOAD FLIGHT SHARING

3.1.2 Power Module System Interfaces

POWER MODULE INTERFACES

- The Orbiter/Power Module major interfaces are identified in both the launch and
  sortie mode configurations. The launch interfaces will be identical to those of
  the Space Telescope in the cargo bay and will be monitored on the Orbiter payload
  monitor console. The RMS standard end effector and grapple to the PM is also
  identical to the ST Program.

- In the sortie mode, the communications, power, and thermal fluid loops are
  direct-coupled to the Orbiter and automated/manual override interface
  connections.

3-14

POWER MODULE INTERFACES

RMS
GRAPPLE

HIGH GAIN ANTENNA

POWER
MODULE

BERTHING STRUCTURE

ELECTRICAL UMBILICAL

THERMAL UMBILICAL

RMS

ORBITER PRIMARY ANTENNA

ORBITER CONTROL AND MONITOR

SORTIE MODE ORBITER INTERFACE

3 TRUNNIONS WITH
SPREADER BARS AND
1 KEEL FITTING

BERTHING SYSTEM
EXTENDED

POWER
MODULE

CONTROL AND MONITOR

ELECTRICAL UMBILICAL

LAUNCH CONFIGURATION
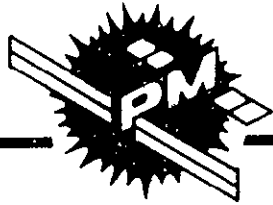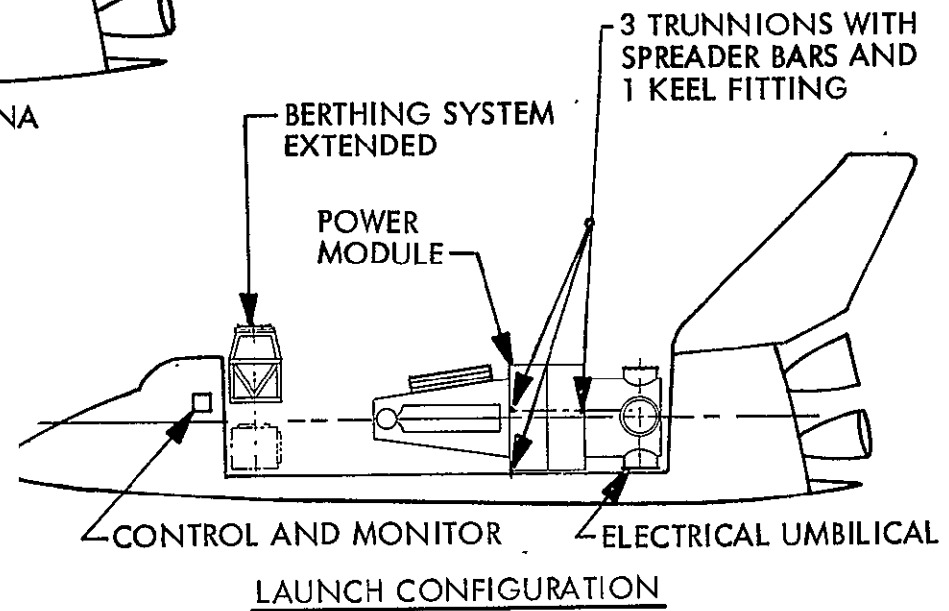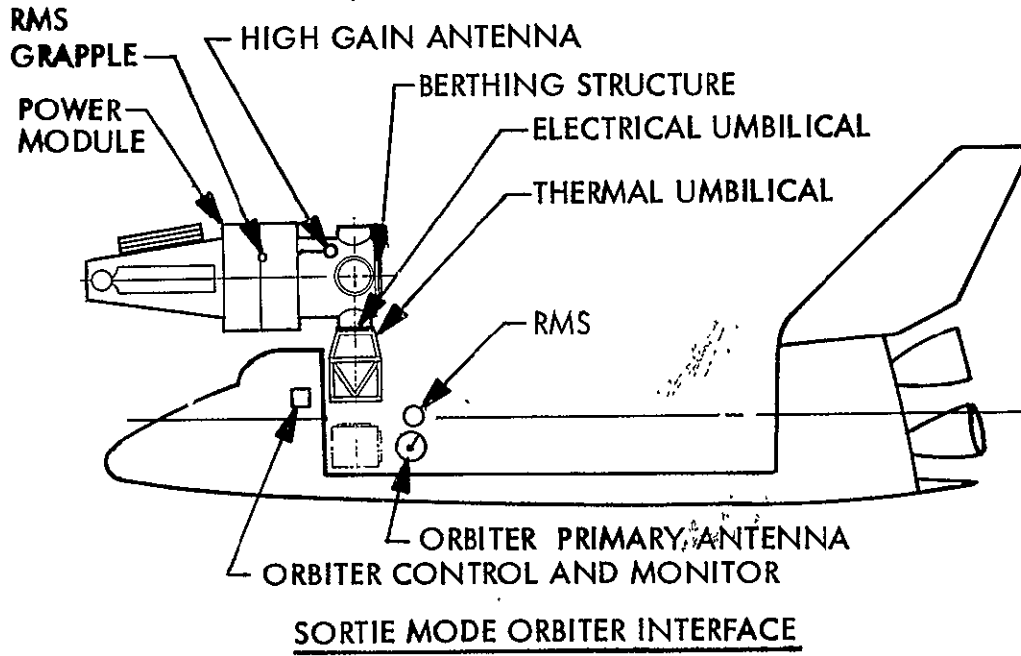
3.1.3 Power Module System Performance

The information presented in this section relates to systems performance of the PM in inertial and earth oriented modes with general applicability to solar, stellar, and low-g missions.

ELECTRICAL PERFORMANCE FOR ORBIT- SUN RELATIONSHIPS

The variation of solar beta angle is a major element affecting performance. The chart shows the variation in beta angle and eclipse time for a year of on-orbit operation. Launch date is taken to be 21 January to a 235 nmi circular orbit at 55° inclination. Six curves are shown, reflecting varying launch hours. It is seen that the beta angle represents the sum of two fluctuations. One of these results from the annual movement of the earth about the sun and, superimposed on it, is a cycle with a period of approximately 67 days due to orbit precession.
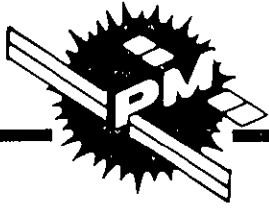
ORBIT—SUN RELATIONSHIPS
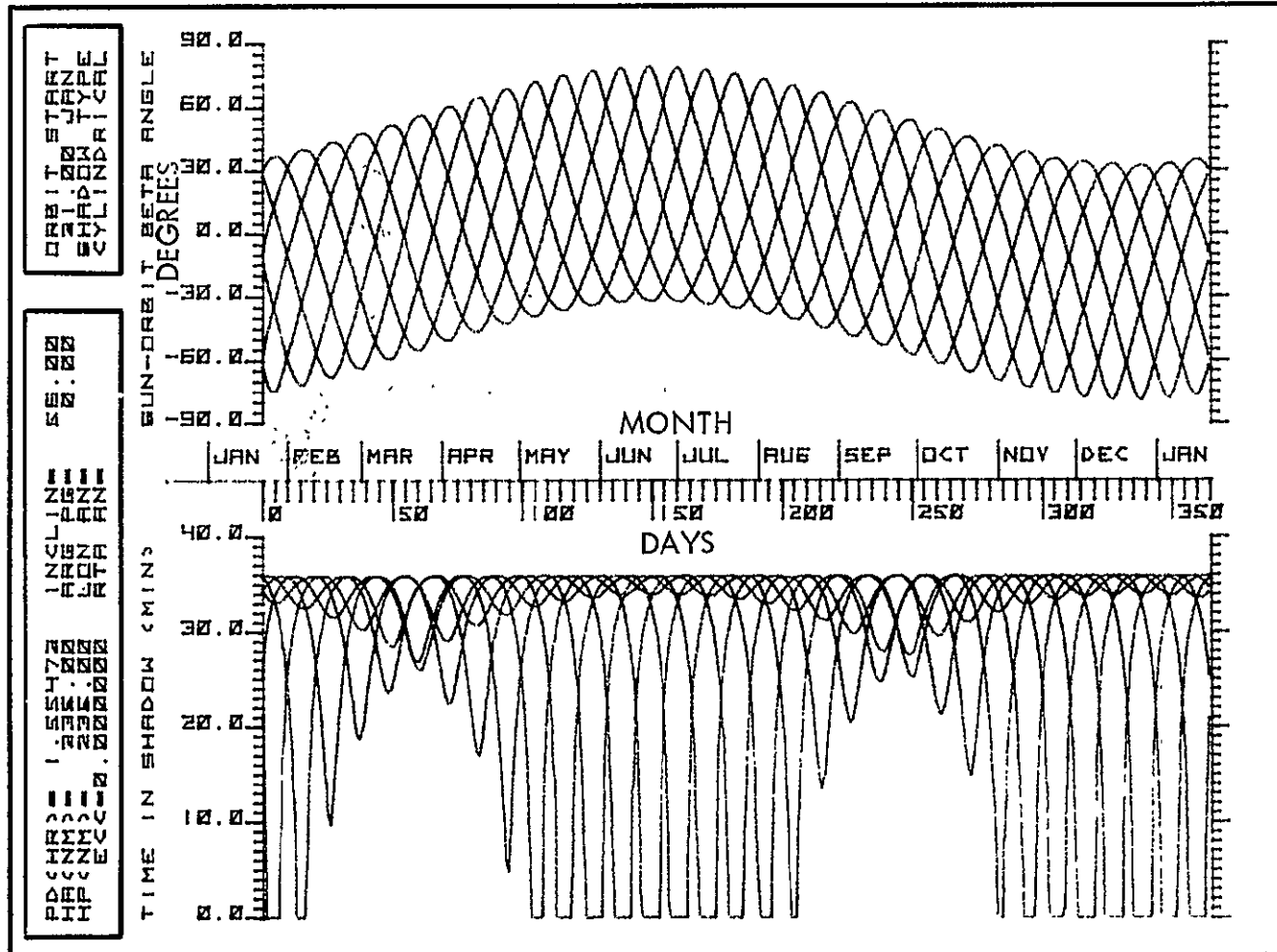
CAPABILITIES FOR INERTIAL AND ORIENTED MISSIONS

The next two charts (inertial and earth oriented missions) present data on the capability of the Power Module to supply power to an external payload. In a single-degree-of-freedom system in an inertial attitude, this is determined by the angle between the sun and the array axis of rotation (vehicle Y-axis) and the solar beta angle. Data are presented for the system in which the output is restricted to 25 kW and for a potential modification to the power control apparatus to permit the load to receive all of the power generated.

These data take into account Power Module housekeeping requirements, transmission losses, and battery losses, but do not reflect the effects of solar cell temperature or refraction at low angles of incidence nor limitations due to allowable battery depth of discharge.

Electrical Performance For Stellar Observation Missions

System capability in stellar observation missions will depend both on the location of the star being examined and on the solar Beta angle. For analytic convenience, star locations are specified in terms of latitude (angle between the satellite-star line and the orbit plane) and star longitude (angle between the projections of the satellite-sun and satellite-star lines onto the orbit plane).

Power available from the Power Module varies widely over the stellar sphere. Large sky areas can be viewed at full power. In view of the variations through the year of the viewing parameters, it is reasonable to expect that, by appropriate scheduling of observations, any star could be viewed with full power available.

CAPABILITIES FOR INERTIALLY ORIENTED MISSIONS

POWER TO ORBITER/PAYLOAD (kW) — MINIMUM VEHICLE *

OUTPUT RESTRICTED TO 25 kW MAX

SUN – Y AXIS ANGLE (DEG)	BETA ANGLE (DEG)								
	0	10	20	30	40	50	60	70	80
0	0	0	0	0	0	0	0	0	0
10	3	3	3	3	3	3	4	6	6
20	7	7	7	8	8	9	10	15	15
30	12	12	12	12	13	13	15	22	22
40	15	16	16	16	17	18	20	25	25
50	19	19	19	19	20	21	24	25	25
60	21	22	22	22	23	24	25	25	25
70	23	24	24	24	25	25	25	25	25
80	25	25	25	25	25	25	25	25	25
90	25	25	25	25	25	25	25	25	25

OUTPUT NOT RESTRICTED

ANGLE DEG	BETA ANGLE (DEG)								
	0	10	20	30	40	50	60	70	80
0	0	0	0	0	0	0	0	0	0
10	3	3	3	3	3	3	4	6	6
20	7	7	7	8	8	9	10	15	15
30	12	12	12	12	13	13	15	22	22
40	15	16	16	16	17	18	20	29	29
50	19	19	19	19	20	21	24	35	35
60	21	22	22	22	23	24	28	40	40
70	23	24	24	24	25	27	30	43	43
80	25	25	25	26	27	28	32	46	46
90	25	26	26	26	27	29	32	46	46

*FOR PURPOSES OF THE ANALYSIS THE MINIMUM VEHICLE IS ESSENTIALLY EQUIVALENT TO THE MSFC PHASE A BASELINE, AND FURTHER DEFINED IN VOLUME 5 OF THIS PART III FINAL REPORT, PAGE 3-25.

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CAPABILITIES FOR
EARTH ORIENTED MISSIONS

POWER TO ORBITER/PAYLOAD (kW) — MINIMUM VEHICLE

VIEW ANGLE FROM VERTICAL (DEG)	BETA ANGLE (DEG)				
	0	20	40	60	80

XPOP, ZLV ±90° ROLL

	0	20	40	60	80
0	12	16	21	25	25
30	14	17	22	25	25
60	16	19	23	25	25
90	16	19	23	25	25

XVV, ZLV ±90° PITCH

	0	20	40	60	80
0	25	24	20	15	6
30	25	24	20	15	6
60	25	24	20	15	6
90	25	24	20	15	6

ZLV, YPSL

	0	20	40	60	80
0	25	25	25	25	25

XLV, ZPOP

	0	20	40	60	80
90	12	16	21	25	25

25 kW LIMIT IMPOSED BY POWER CONTROL CIRCUITRY

Thermal Subsystem Performance

In both solar and stellar observation missions the thermal system is seen to have adequate capability to reject all of the heat generated. Therefore heat rejection will not limit mission performance while in inertial or earth oriented modes.

HEAT REJECTION PERFORMANCE
THE NEXT 3 CHARTS SHOW HEAT REJECTION PERFORMANCE FOR THE TCS

The following three charts show the total orbit average heat rejection capability of the Power Module and the orbiter radiators in inertial and earth-oriented missions. A maximum 21.5 kW heat rejection capability is required by the orbiter and the Power Module for internally generated heat (12.5 kW for the orbiter without fuel cell operation and from 9 kW to 5 kW for the Power Module at low and high beta angles respectively). These host requirements must be subtracted from the listed totals to determine the heat rejection available for payloads.
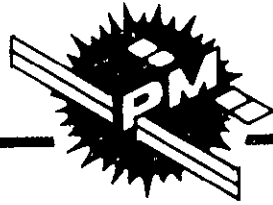
HEAT REJECTION CAPABILITY
INERTIAL POINTING MODES

MODES	CONDITIONS	HEAT REJECTION (kW)	
		PM	PM + ORB
XPOP, YPSL	ZSI β = 0°	18.7	42.5
	MXSi β = 70°	22.4	54.1
ZPOP, YPSL	MXSI, YPOP β = 0°	22.4	54.1
XIOP, ZSL ± 30° PITCH	ZSI β = 0°, 0 PITCH	18.7	42.5
ZSI, XIOP	ZSI, YPOP, β = 0°	18.7	42.5
	YLV, ZPOP (90° ROLL) β = 0°	20.6	51.6
	ZSI, ZPOP β = 70-90°	16.3	34.5

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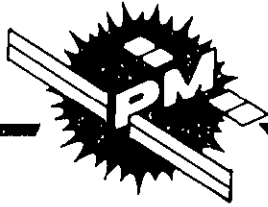
CAPABILITIES FOR
EARTH ORIENTED SORTIE MISSIONS

TOTAL HEAT REJECTION

(XPOP, ZLV ±90° ROLL)

$0°$ ROLL – LOW BETA: 41.5 kW
$0°$ ROLL – HIGH BETA: 39.1 kW
$90°$ ROLL – LOW BETA: 37.5 kW
$90°$ ROLL – HIGH BETA: 34.0 kW

(XVV, ZLV ±90° PITCH)

$0°$ PITCH – LOW BETA: 41.5 kW
$0°$ PITCH – HIGH BETA: 30.9 kW
$90°$ PITCH – LOW BETA: 51.6 kW
$90°$ PITCH – HIGH BETA: 51.6 kW

(ZLV, YPSL)

LOW BETA: 41.5 kW
HIGH BETA: 30.9 kW

XLV, ZPOP

LOW BETA: 50.5 kW
HIGH BETA: 47.8 kW

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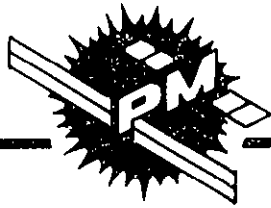
CAPABILITIES FOR EARTH ORIENTED FREE FLYER MISSIONS

TOTAL HEAT REJECTION

XPOP, ZLV ±90° ROLL

0° ROLL – LOW BETA:	20.6 kW
0° ROLL – HIGH BETA:	19.5 kW
90° ROLL – LOW BETA:	16.6 kW
90° ROLL – HIGH BETA:	15.9 kW

XVV, ZLV ± 90° PITCH

0° PITCH – LOW BETA:	20.6 kW
0° PITCH – HIGH BETA:	15.9 kW
90° PITCH – LOW BETA:	20.6 kW
90° PITCH – HIGH BETA:	20.6 kW

ZLV, YPSL

LOW BETA:	20.6 kW
HIGH BETA:	15.9 kW

XLV, ZPOP

LOW BETA:	16.6 kW
HIGH BETA:	20.6 kW

THERMAL CONTROL SUBSYSTEM PERFORMANCE CHARACTERISTICS

- The table shows the nominal performance for the Power Module thermal control subsystem. The heat rejection levels correspond to the spacecraft attitudes resulting in a solar incidence angle of 30° on the radiator panels.

- When the panels are edge-lit by the sun, the total heat rejection can be increased 27% which results in an approximate 50% increase in Payload cooling capacity.
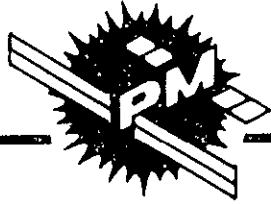
THERMAL CONTROL SUBSYSTEM
CHARACTERISTICS

LAUNCH DATE	1983	1986	1987	1988/89	1990/91
FLIGHT VEHICLE	FV-1	FV-2	FV-3	FV-4/-5	FV-6
POWER (kW)	25	25	60	50	100
RADIATOR AREA (FT^2)	675	675	675	1,350	1,350
RADIATOR PANELS	10	10	10	20	20
FREON-21 FLOW RATE (LB/HR)	5,000	5,000	5,000	10,000	10,000
HEAT REJECTION CAP.[1] (kW)	22.1 ±4	22.1 ±4	27.0 ±2	40.8 ±5	48.4 ±6
PM REQUIREMENTS (kW)	9	9	5	18	36
AVAIL. FOR PAYLOADS (kW)	13.1	13.1	22.0	22.8[2]	12.4[2]
WEIGHTS – (LB)[4]					
RADIATOR PANELS	945	945	945	1,890	1,620[5]
P/L HEAT EXCHANGER AND CONTROL	120	120	240	240	120
REMAINING COOLANT LOOP COMPONENTS	949	949	949	989	1,139[3]
TOTAL	2,014	2,014	2,134	3,119	2,879

NOTES:
1) HEAT REJECTION INCLUDES EFFECTS OF BETA ANGLE, SUN INCIDENT AT 30° AND EARTHSHINE VARIATIONS.
2) 10 kW COOLING REQUIRED TO SUPPORT 3-MAN HABITAT MODULE.
3) RADIATOR DEPLOYMENT MECHANISM INCLUDES RADIATOR EXTENSION HARDWARE.
4) ESTIMATED WEIGHTS, CONTINGENCY VALUES NOT INCLUDED.
5) 1990 RADIATOR PANEL TECHNOLOGY WEIGHT REDUCTION FROM 1.4 LB/FT^2 TO 1.2 LB/FT^2

Attitude Control Subsystem Performance

The ability to hold attitude is limited by the ability of the CMGs to absorb the momentum generated in countering gravity gradient torques. These latter may be cyclical, averaging zero over the full orbit, or bias, representing forces tending to rotate the vehicle in a constant direction. These torques depend on the vehicle attitude and its attitude mode (i.e., inertial or earth oriented).

ATTITUDE CONTROL PERFORMANCE

The next four charts relate to earth oriented and inertial modes (both sortie and free flyer) and depict the magnitude of torques, number of CMGs required, and holding times.

CAPABILITIES FOR EARTH ORIENTED
SORTIE MISSIONS

ATTITUDE HOLDING — MINIMUM VEHICLE
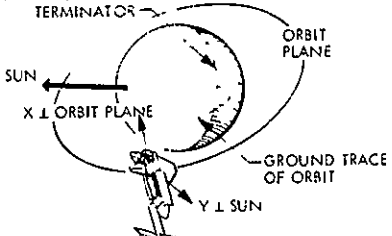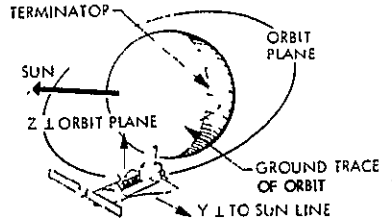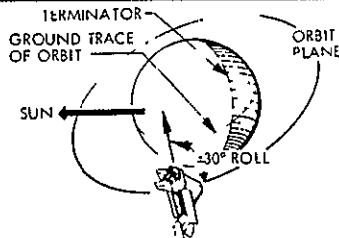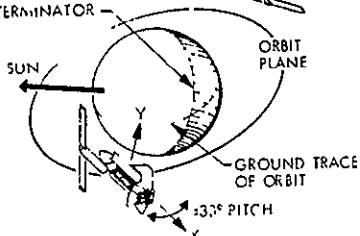
X POP, ZLV ± 90° ROLL   SMALL BIAS TORQUE ABOUT X AXIS IF ROLLED. TWO ORBITS TO SATURATION AT 45° ROLL (3CMG ACS)
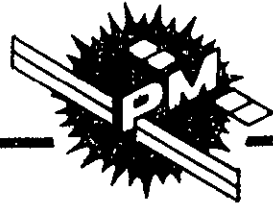
XVV, ZLV ± 90° PITCH   NO GRAVITY GRADIENT TORQUES AT 0° PITCH OR 90° PITCH. LARGE GRAVITY GRADIENT TORQUES IF PITCHED, FIVE MINUTES TO CMG SATURATION AT 45° PITCH (3 CMG ACS)

ZLV, YPSL   APPARENT LARGE TORQUES — CROSS COUPLING OF YAW AND ROTATION AT ORBITAL RATE

XLV, ZPOP   NO GRAVITY GRADIENT TORQUES

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MODES	CONDITIONS
XPOP, YPSL	NO BIAS TORQUES, SMALL CYCLIC TORQUES. 3 CMG'S ADEQUATE FOR LONG TERM HOLDING
ZPOP, YPSL	NO BIAS TORQUES, CYCLIC TORQUES LIMIT HOLD TIME TO 8.5 MIN. (3 CMG ACS) 4 CMG ACS ADEQUATE FOR LONG TERM HOLDING
XPOP, YPSL ±30° ROLL	IF NOT PITCHED, 4 CMG ACS ADEQUATE FOR LONG TERM HOLD. 30° PITCH CAUSES BIAS TORQUES THAT SATURATE CMG'S IN A FEW MINUTES.
XIOP, ZSL ±30° PITCH	4 CMG ACS REQUIRED TO HANDLE CYCLICAL TORQUES. +1 CMG FOR BIAS TORQUES + DESATURATION ONCE/ORBIT

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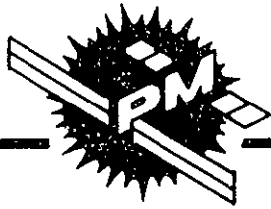
CAPABILITIES FOR EARTH ORIENTED FREE FLYER MISSIONS

ATTITUDE HOLDING – MINIMUM VEHICLE

XPOP, ZLV $\pm 90°$ ROLL

SMALL BIAS TORQUE ABOUT X AXIS IF ROLLED. EIGHTY MINUTES TO SATURATION AT $45°$ ROLL (3CMG ACS)

XVV, ZLV $\pm 90°$ PITCH

NO GRAVITY GRADIENT DISTURBING TORQUES AT $0°$ PITCH OR $90°$ PITCH. GRAVITY GRADIENT TORQUES IF PITCHED. 58 MINUTES TO CMG SATURATION AT $45°$ PITCH (3CMG ACS)

ZLV, YPSL

APPARENT LARGE TORQUES FOR $\beta < 30°$ DUE TO CROSS COUPLING OF YAW AND ROTATION AT ORBITAL RATE

NO GRAVITY GRADIENT DISTURBING TORQUES

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ATTITUDE HOLDING CAPABILITY
INERTIAL FREE FLYER POINTING MODES

MODES	CONDITIONS
XPOP, YPSL 	3 CMG ACS ADEQUATE FOR LONG TERM HOLD
ZPOP, YPSL 	3 CMG ACS ADEQUATE FOR LONG TERM HOLD

XIOP, ZSL ±30° PITCH

HOLD TIMES WITH 3 CMG ACS:

β (DEG)	PITCH (DEG)	TIME (MIN)
0	0	∞
0	30	∞
30	0	187
30	30	195
45	0	161
45	30	150

ZSI, XIOP

HOLD TIME (3 CMG ACS)

ANGLE BETWEEN Z AXIS & ORBIT PLANE (DEG)	HOLD TIME (MIN)
0	∞
30	187
45	161

ROLL AXIS RESPONSE TO CMG UNBALANCE TORQUES

As shown on the chart, the magnitude of the displacement (θ) and displacement rate ($\dot{\theta}$) in the roll response to the CMG unbalance disturbance was so small for both bandwidths that this response did not aid in the discrimination of bandwidths.

ROLL AXIS RESPONSE TO CMG UNBALANCE TORQUES

- AT 150 Hz (CMG WHEEL FREQUENCY)
- 22 LB FORCE, 2 CMG, EACH AT 1.4 FT ARM
- VIBRATION MOMENT = 61.6 FT-LB

$f_{BW}^{(1)}$	Hz	0.01	0.001	0.01	0.001
CONFIGURATION	—	PM	PM	PM + ORBITER	PM + ORBITER
I	SLUG-FT^2	286,445 $\longrightarrow$		1.5×10^6 $\longrightarrow$	
$\theta(S)/T_D(S)$	$\dfrac{DEG}{FT-LB}$	2.03×10^{-9}	2.03×10^{-9}	3.87×10^{-10}	3.87×10^{-10}
$\dot{\theta}(S)/T_D(S)$	$\dfrac{DEG/SEC}{FT-LB}$	1.91×10^{-6}	1.91×10^{-6}	3.65×10^{-7}	3.65×10^{-7}
θ	DEG	1.25×10^{-7}	1.25×10^{-7}	2.38×10^{-8}	2.38×10^{-8}
$\dot{\theta}$	DEG/SEC	1.18×10^{-4}	1.18×10^{-4}	2.25×10^{-5}	2.25×10^{-5}

1. f_{BW} — CONTROL SYSTEM BANDWIDTH

TRANSIENT RESPONSES OF POWER MODULE CONFIGURATIONS

- The long-term response to the crew motion disturb-
  ance clearly indicates that the 0.001 Hertz bandwidth
  is unacceptable.

- A structural natural frequency of 0.04 Hz is considered
  compatible with the f_{BW} = 0.01 Hz control system
  bandwidth.

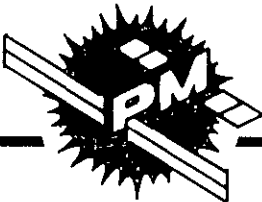# TRANSIENT RESPONSES OF POWER MODULE CONFIGURATIONS

- CREW MOTION STEP TORQUE DISTURBANCE INPUT = 22.5 LB X 50 FT = 1125 FT-LB IN PITCH (SORTIE MODE)
- SOLAR ARRAY STEP TORQUE DISTRUBANCE INPUT = 5 FT-LB IN PITCH.

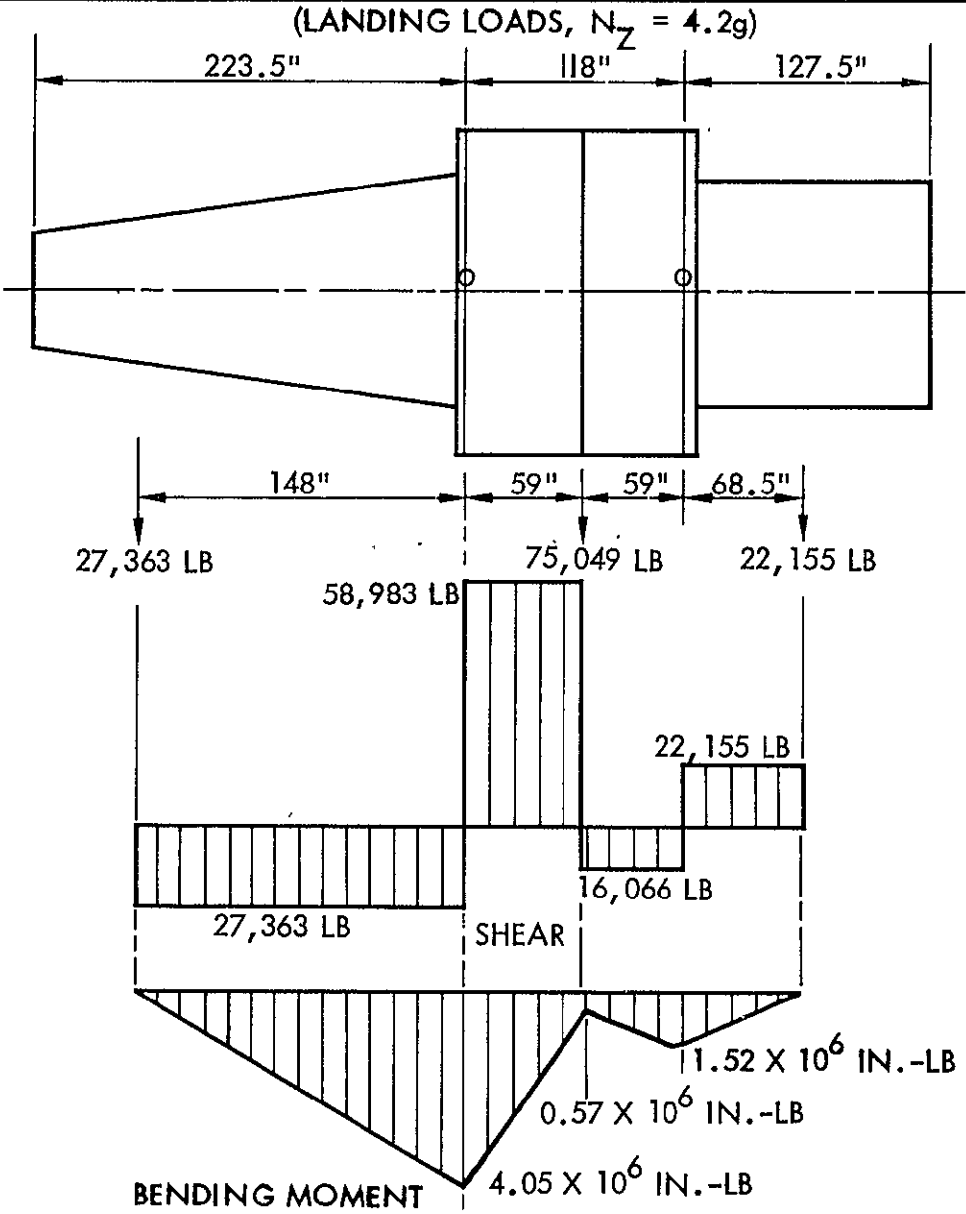|		f_{BW} (Hz)					
		0.01	0.001	0.01	0.001	0.01	0.001
CONFIG-URATION	---	PM	PM	PM	PM	PM + ORBITER	PM + ORBITER
AXIS	---	ROLL	ROLL	PITCH	PITCH	PITCH	PITCH
I (SLUG-FT^2)		286,445 ⟶		96,628 ⟶		10^7 ⟶	
θ/T_D	SHORT TERM	NOT APPLICABLE	±.0023 @t = 20 SEC	NOT APPLICABLE	±.014 @t = 20 SEC	NOT APPLICABLE	±.00013 @t = 20 SEC
$\left(\dfrac{\text{DEG}}{\text{FT-LB}}\right)$	LONG TERM	0.191 @t = 110 SEC	18.8 @t = 1100 SEC	0.567 @t = 110 SEC	55.8 @t = 1100 SEC	0.0055 @t = 110 SEC	0.54 @t = 1100 SEC
θ	SHORT TERM	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	±.07	NOT APPLICABLE	±.00065 ±.146
(DEG)	LONG TERM	NOT APPLICABLE	NOT APPLICABLE	2.84	279	0.0275 6.2	2.7 607

f_{BW} — CONTROL SYSTEM BANDWIDTH

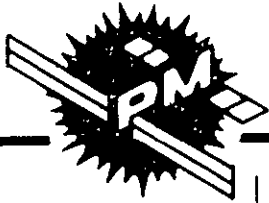CONFIGURATION 25-1 STRUCTURAL PERFORMANCE

- The evaluation of the Space Shuttle attachment structure for both the 25 kW Power Module and the 50 kW Power Module was accomplished utilizing computerized techniques.

- The most severe design conditions involving eight mission phases were investigated. These are: lift-off, high-q boost, maximum boost, orbit alone, entry and descent, pitch maneuvers, yaw maneuvers, and landing.

- The critical shear and bending moment diagrams, shown in the next two charts for the 25 kW Power Module and 50 kW Power Module, are for Nz loading associated with the 4.2 g landing loading and are intended to depict the load distribution to the primary trunnion system and the stabilizing trunnion system for this loading condition.

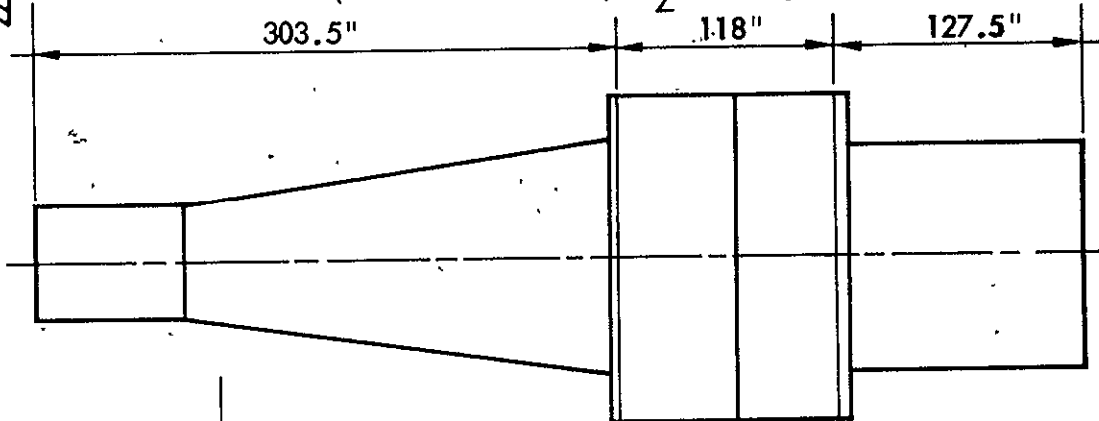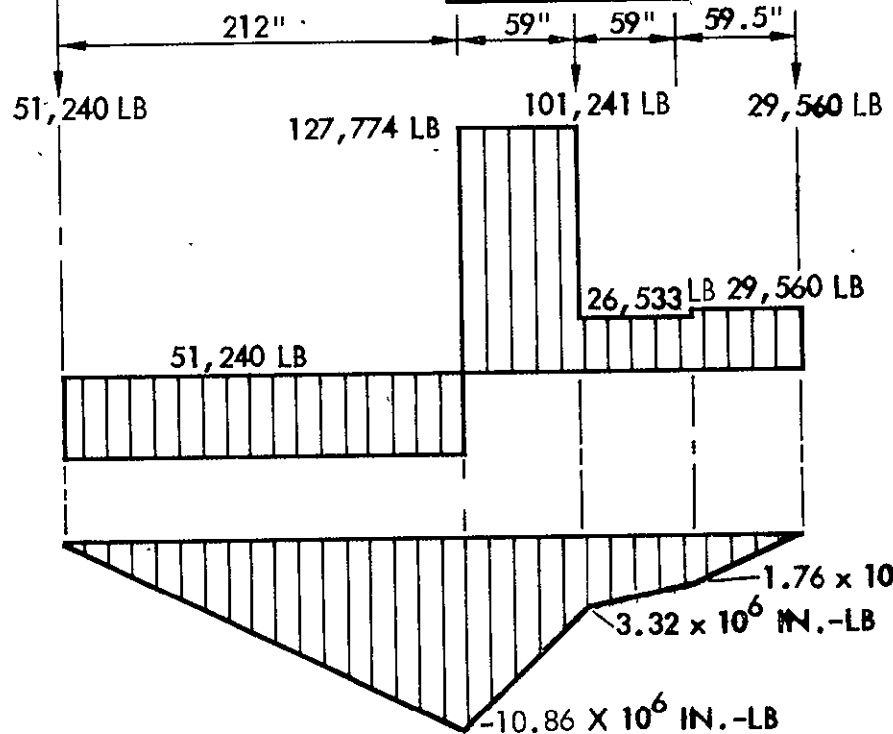# CONFIGURATION 25-1
SHEARS AND BENDING MOMENTS

(LANDING LOADS, N_z = 4.2g)

223.5" | 118" | 127.5"

148" | 59" | 59" | 68.5"

27,363 LB   75,049 LB   22,155 LB

58,983 LB

22,155 LB

16,066 LB

27,363 LB   SHEAR

1.52×10^6 IN.-LB

0.57×10^6 IN.-LB

4.05×10^6 IN.-LB

BENDING MOMENT

3-43

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CONFIGURATION 50-1
SHEARS AND BENDING MOMENTS

(LANDING LOADS, N_Z = 4.2 g)

303.5" 118" 127.5"

212" 59" 59" 59.5"

51,240 LB 127,774 LB 101,241 LB 29,560 LB

26,533 LB 29,560 LB

SHEAR

51,240 LB

−1.76 x 10^6 IN.-LB

3.32 x 10^6 IN.-LB BENDING MOMENT

−10.86 X 10^6 IN.-LB

3.2 POWER MODULE GROWTH OPTIONS

POWER MODULE GROWTH CONCEPTS
25 kW TO 100 kW

- Viable candidate configurations for Power Module evolutionary growth, from 25 kW to 100 kW, are illustrated on the chart. The single-vehicle growth paths are identified by the solid line arrows, while growth simply by use of two Power Modules is shown with the dashed line arrows. The configuration growth path recommended to satisfy Program Scenario I is identified by the crosshatched solid line arrows.

- The recommended evolution utilizes two sizes of solar array blankets, the "A" type (4 meter) at 13.2 x 130 feet and the "B" type (6 meter) at 19.8 x 130 feet. The "B" type, which is required in 1986 or later, utilizes technology which provides twice the power-generation output with only 1.5 times the area. The 50-2 configuration, using existing technology with the smaller blanket, is usable to meet initial 50 kW requirements, if facilities for fabrication of the "B" type blanket are not yet available. However, the use of more mechanical elements and more difficult stowage in the Orbiter, makes this option technically less desirable. The blankets are used in either two or four pairs, with a single deployment mast per pair. Optional growth configuration trade off considerations are discussed in Volume I of this Part III Final Report, page 2-51.
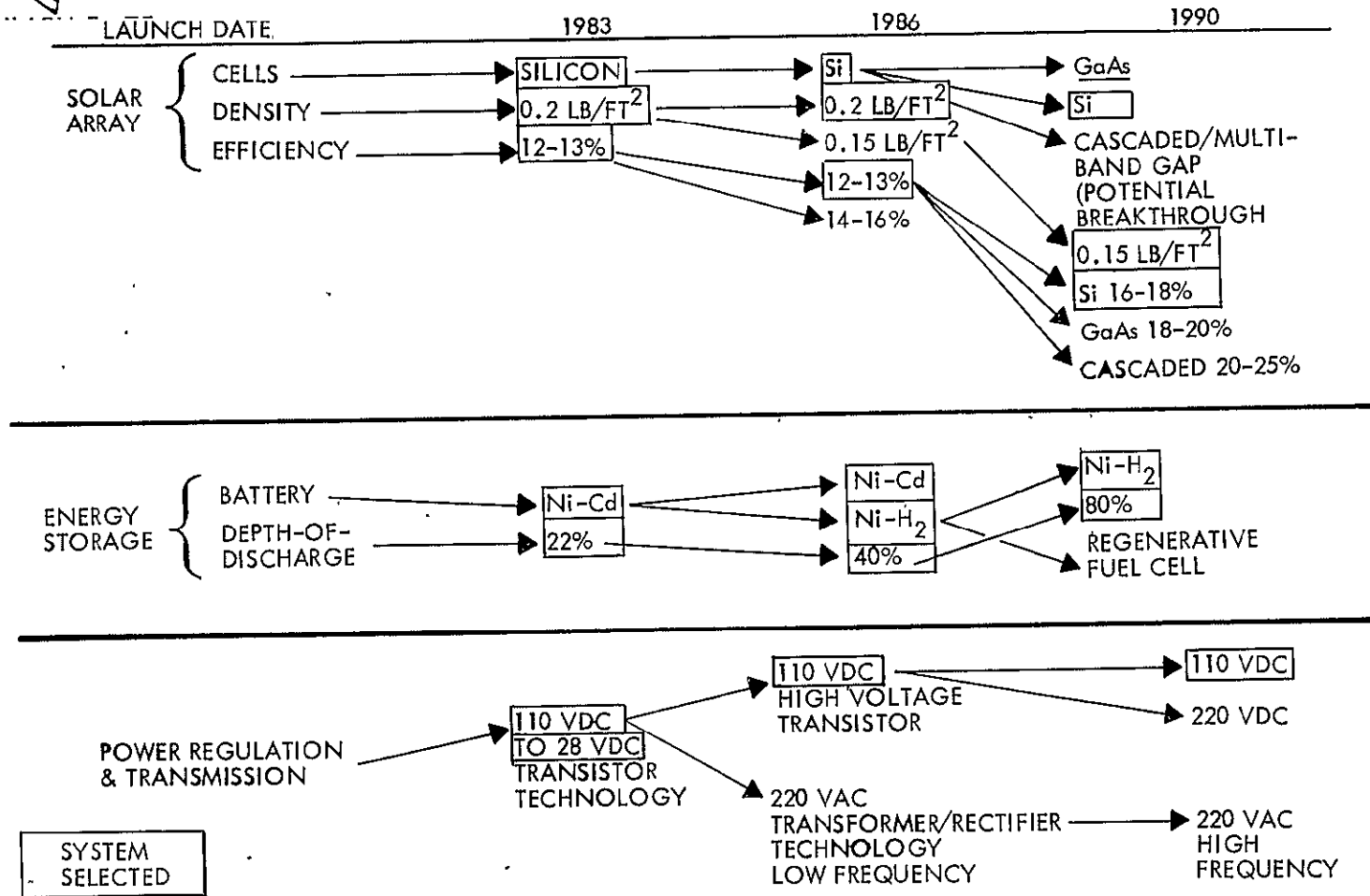
POWER MODULE GROWTH CONCEPTS
25kW TO 100kW

25 KW — 50 KW — 100 KW

Ⓐ Ⓐ

OR

50-1

Ⓑ Ⓑ

NEW SOLAR
ARRAY SUPPORT
BEAM

Ⓑ

Ⓑ

100-1

NEW SOLAR
ARRAY SUPPORT
BEAM

Ⓑ Ⓑ

Ⓐ

Ⓐ

ATTITUDE
CONTROL
SYSTEM

NEW
MODULAR
KITS

THERMAL
RADIATORS

ELECTRICAL
POWER

NEW SOLAR ARRAY
SUPPORT BEAM

Ⓐ Ⓐ

25-1

2 NEW PANEL
SUPPORT BEAMS

Ⓐ Ⓐ

Ⓐ Ⓐ

50-2

- - - ▶ MULTIPLE
POWER MODULES

——▶ SINGLE
POWER
MODULE

+++++▶ RECOMMENDED EVOLUTION

3-47
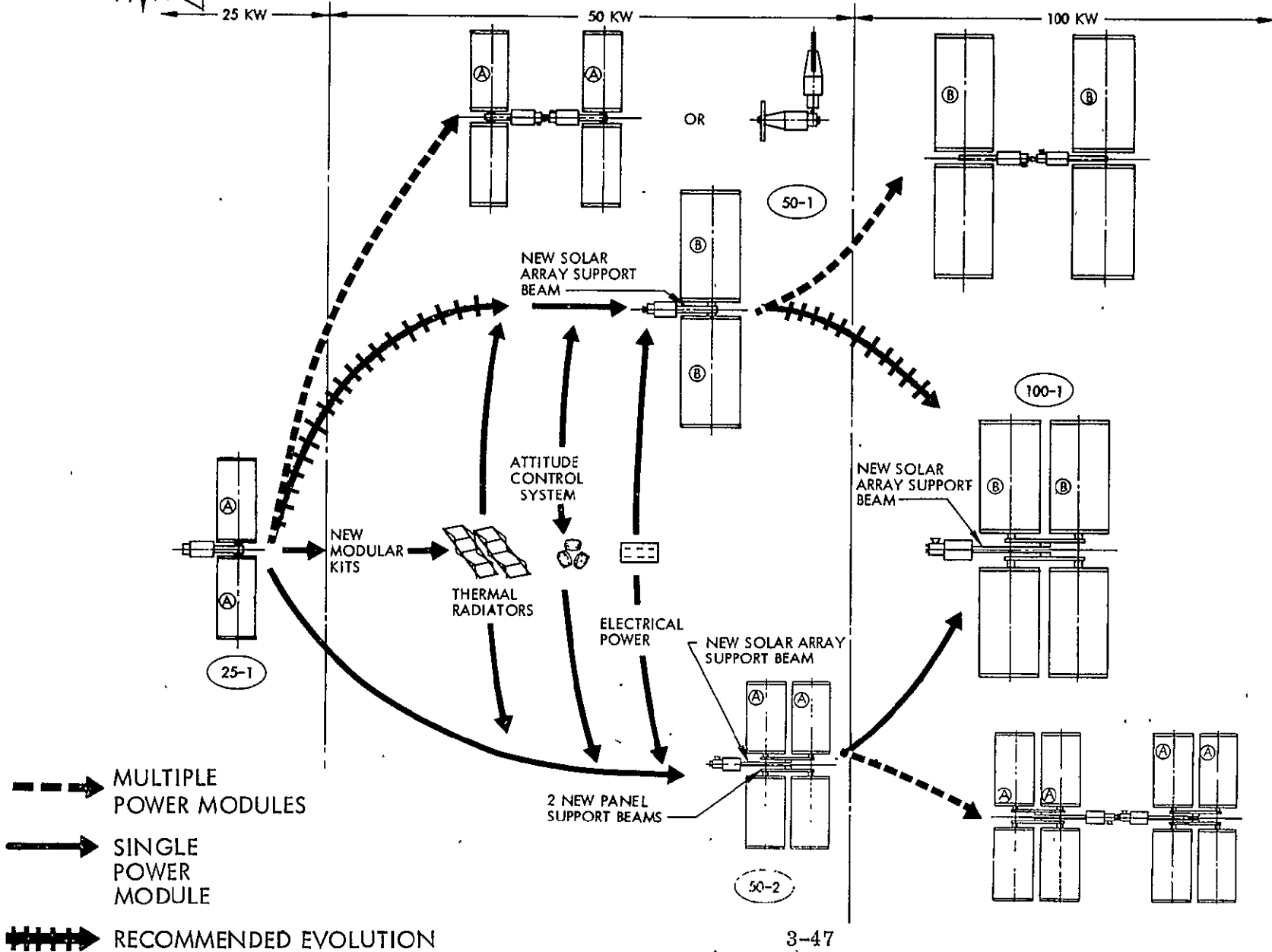
- The utilization of space will require low cost, reliable energy generation and storage methods. The accompanying chart indicates the projection of power system technology expected to be available for Power Module use. The component technology advancements represented will require astute scheduling into the Power Module Evolution.

- The advanced components are expected to save substantial dollars by two methods: (1) Substantially increasing the life, thus lowering $/KWH delivered; and (2) weight, volume, and/or efficiency improvements will lower component cost and/or STS charges. These two areas are not mutually independent. For example, replacement of nickel – cadmuim batteries every two to three years on each Power Module is an alternative to using high energy density nickel – hydrogen batteries. The weight for this replacement for Scenario I would require an additional ≈100,000 lb of batteries to be launched for replacement throughout the 1980's (72,000 lb every 2.5 years thereafter, even with no additional Power Module Vehicles being built). This amounts to more than $50M dollars of additional STS charges. Thus, the use of Ni-H$_2$ batteries capable of long life at high depths of discharge will result in substantial savings of millions of dollars.

- Also, the cost of the solar array is dictated mainly by the array area. If, as we project, the cell efficiency goes up and the power system efficiency improves, a 50 percent decrease in array area would result for the later power modules.

- Accordingly, a planned method of incorporating these changes is needed essentially at the start of the program. The method proposed here is to provide nearly identical mechanical elements. Thus, a 50 AH Ni-H$_2$ battery should be designed to replace a 60 AH Ni-Cd battery. Also, a mechanical solar array building block should be able to incorporate higher efficiency solar cells or stronger deployment masts to accommodate increases in solar array area and stiffness.

- Power Module component design ideally would interchange (fit, form, and function) within a common Power Module System. Added elements will be necessary to meet placement and/or orientation constraints. EPS elements of this nature include scale up as necessary for orientation drive and power transfer assemblies (ODAPT) and positioning booms which provide spacecraft separation.

LEO POWER SYSTEM
EVOLUTIONARY PATHS

LAUNCH DATE	1983	1986	1990

SOLAR ARRAY
- CELLS — SILICON → Si → GaAs
- DENSITY — 0.2 LB/FT^2 → 0.2 LB/FT^2 → Si
- EFFICIENCY — 12-13% → 0.15 LB/FT^2
  - 12-13%
  - 14-16%

CASCADED/MULTI-BAND GAP (POTENTIAL BREAKTHROUGH

0.15 LB/FT^2

Si 16-18%

GaAs 18-20%

CASCADED 20-25%

ENERGY STORAGE
- BATTERY — Ni-Cd → Ni-Cd / Ni-H$_2$ → Ni-H$_2$
- DEPTH-OF-DISCHARGE — 22% → 40% → 80%

REGENERATIVE FUEL CELL

POWER REGULATION & TRANSMISSION → 110 VDC TO 28 VDC TRANSISTOR TECHNOLOGY

110 VDC HIGH VOLTAGE TRANSISTOR → 110 VDC

220 VDC

220 VAC TRANSFORMER/RECTIFIER TECHNOLOGY LOW FREQUENCY → 220 VAC HIGH FREQUENCY

SYSTEM SELECTED

3.3 POWER MODULE RECOMMENDED GROWTH STEPS

PM SYSTEM LEVEL GROWTH CONSIDERATIONS

The major driver in the concept for growth of the PM system is to maintain a commonality of hardware elements which can be used through the life cycle of the programs. Other system-level considerations for evolutionary growth are shown on the next two charts.

SYSTEM LEVEL CONSIDERATIONS

CONSIDERATION	DESIGN APPROACH	RECOMMENDED DESIGN	ADVANTAGES
CONFIGURATION	MINIMIZE LENGTH	• FOLDED SOLAR ARRAYS • SHORT EQUIPMENT STRUCTURE	• PROVIDES SPACE FOR PAYLOADS
	CLOSELY COUPLED MODULES	• 4 POINT BERTHING ATTACH • NO BOOM EXTENDED MASS • NO ARTICULATED BOOMS (EXCEPT SOLAR BLANKETS)	• DETERMINATE SYSTEM • HIGH STABILITY • STATE-OF-ART CONTROL SYSTEM • EASIEST MAINTENANCE
	GOOD SYSTEM FIELD OF VIEW	• SOLAR ARRAYS & THERMAL RADIATORS ON ONE END WITH SOLAR PAYLOAD; STELLAR, EARTH, & 0-G PAYLOADS ON OPPOSITE END	• SATISFIES MULTIPLE PAYLOAD SENSOR VIEWING NEEDS
ORIENTATION VERSATILITY	ATTITUDE SENSING	STAR TRACKER (ADD) WIDE ANGLE SUN SENSOR	• ACCOMMODATES ALL CONCEPTUALIZED CONFIGURATIONS IN REQUIRED OPERATING MODES & ORIENTATIONS
	DESATURATION	DESATURATION MAGNETS (ADD)	
	ABILITY FOR MORE CMGs	PROVIDE ACCOMMODATIONS FOR 6 CMGs	
MAINTENANCE AND RETURN TO EARTH	• MODULAR DESIGNS • DEVELOPED CONCEPTS • SIMPLICITY • ORBITER COMPATIBILITY	• INCORPORATE CONCEPTS, DESIGNS & PROCEEDURES BEING DEVELOPED ON SPACE TELESCOPE • USE DEVELOPED ORBITER INTERFACES • MINIMIZE COMPLEX BOOMS & MECHANISMS	• USES DEVELOPED TECHNIQUES AND PROVIDES COMMONALITY IN PROCEDURES FOR EVA • EXTENDS ACTIVE LIFE OF EACH PM • PM CAN BE REUSED IN MULTIPLE ORBITS

3-51

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SYSTEM LEVEL CONSIDERATIONS (CONT'D)

CONSIDERATION	DESIGN APPROACH	RECOMMENDED DESIGN	ADVANTAGES
MINIMIZE COSTS	MAXIMUM USE OF DEVELOPED HARDWARE	• EXISTING EQUIPMENTS	• MINIMIZES RD & T COSTS • PROVIDES EARLIEST FLIGHT TO USERS
	SIMPLIFIED INTERFACES	• BERTHING	• DEFERS DEVELOPMENT OF ORBITER DOCKING MODULE AND ASSOCIATED SSE
GROWTH	COMMONALITY OF MAJOR PM ELEMENTS	• MAJOR STRUCTURES IDENTICAL FOR 25 TO 100 kW PM WITH PLANNED TECHNOLOGY AVAILA-BILITY	• SIGNIFICANT SAVINGS IN TRANSPORTATION • PROVIDES IMPROVED SYSTEM CONFIGURATIONS TO THE USERS
REBOOST	MINIMIZE REQUIREMENT	• OPERATING ALTITUDES DEFINED TO MINIMIZE REQUIREMENTS AND SATISFY USERS • PROVIDE BERTHING PORT FOR TRS • USE ORBITER FOR BACKUP OPTION	• USER REQUIREMENTS SATISFIED • MINIMUM PROGRAM COSTS

MODULAR GROWTH

- The right side of the chart displays the structural assemblies which are recommended to be "common" for the 25, 50 and 100 kW Power Modules. Add-on solar array/structural extensions are illustrated on the left side.

- The key factor which supports the feasibility of the "common-structure" growth concept is the utilization of battery technology advances, compatible with growth scenario requirements, which dictates use of the same-size battery installations for all three power module sizes.

- By designing the common structure for the most adverse load conditions for the three power modules, a relatively small weight penalty is incurred in the smallest vehicle. Total vehicle weight changes +16 percent between the 25 and 50 kW Power Modules, and +20 percent between the 50 and 100 kW vehicles.

MODULAR GROWTH

COMMON ELEMENTS THROUGH 100 kW SIZE

GROWTH/CHANGE STRUCTURES ← → COMMON STRUCTURES

GRAPPLING FIXTURE – 2 PL

CMGs

ELECTRIC POWER RACK

BERTHING STRUCTURE AND MECHANISMS

25 kW

ACS & C&DH EQUIPMENT RACK

SOLAR ARRAY SUPPORT STRUCTURE & THERMAL SUBSYSTEM

STRUCTURAL EXTENSION

100 kW

STRUCTURAL INTERFACE PLANE

3-55
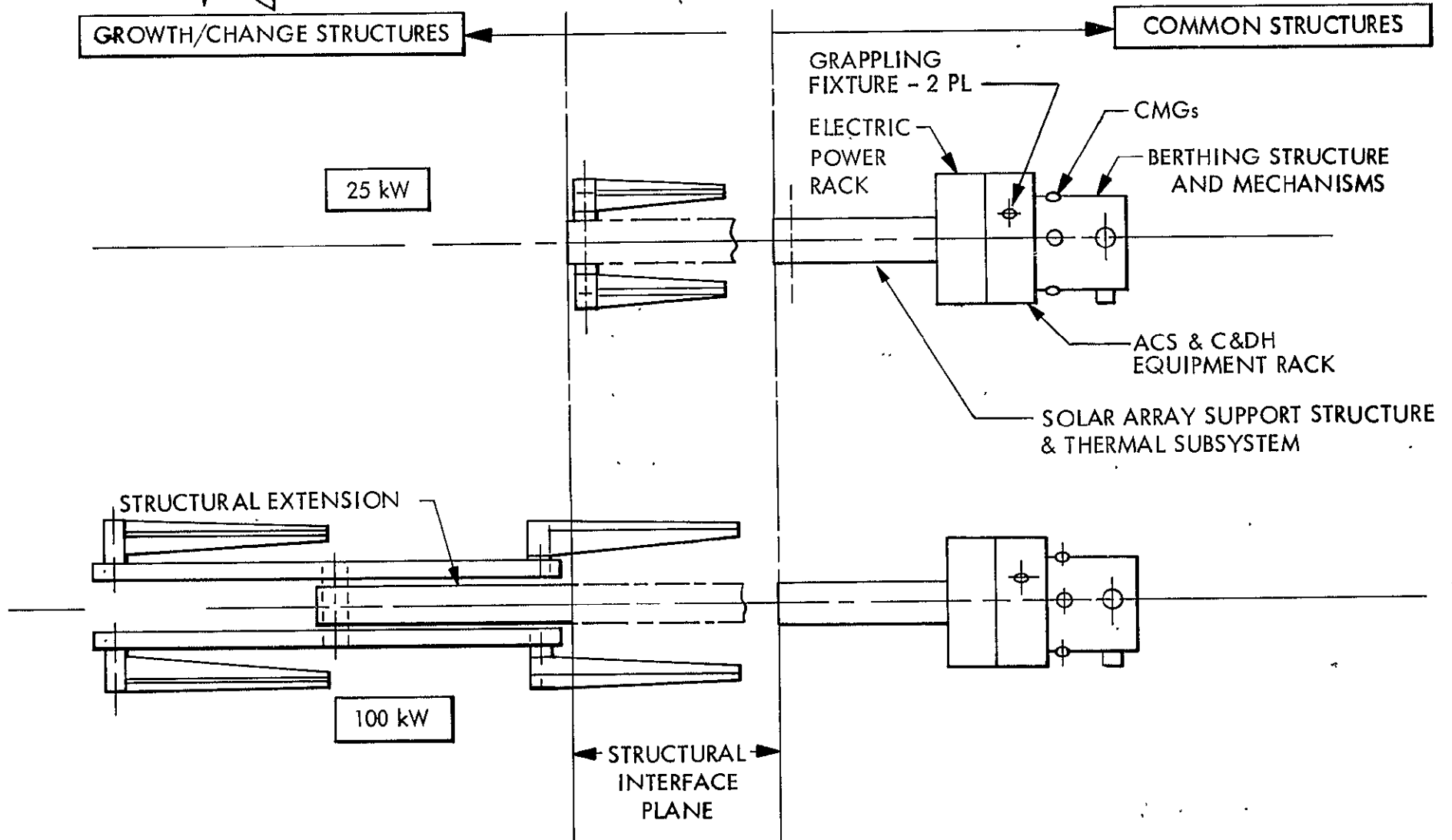
POWER MODULE BASIC DIMENSIONS

- Basic dimensions for the 25, 50, and 100 kW Power
  Module family of vehicles is shown here.

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POWER MODULE GROWTH SUMMARY

A summary of the subsystem configuration for the 25,
50, and 100 kW Power Modules is shown on the chart.
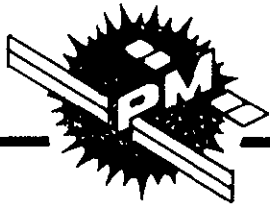
POWER MODULE GROWTH SUMMARY

| VEHICLE	STRUCTURES			ELECTRICAL POWER			THERMAL CONTROL SYSTEM	ATTITUDE CONTROL SYSTEM NUMBER REQUIRED					COMM & DATA HANDLING
	SOLAR ARRAY SUPPORT STRUCTURE	EQUIPMENT RACK ELEMENT	BERTHING STRUCTURE	SOLAR ARRAY	BATTERIES	ELECTRONICS		CMGs	GYROS	HORIZON SENSORS	SUN SENSORS	MAGNETIC TORQUERS	
25 kW	SEMI-MONOCOQUE (SHEET METAL EXTRUSION) 220 0 IN LONG	AN ASSEMBLY OF TWO SIMILAR RACKS EACH RACK 168 0 IN DIA X 62 5 IN LONG	TUBULAR SHEET METAL STRUCTURE 120.0 IN DIA	2 WINGS (4 BLANKETS) EACH WING 9.04M WIDE (29.66 FT)	60AH TYPE 40 BATTERIES NiCd SEASAT PACKAGED/ INTO 12 REPLACE-ABLE MODULES 20% DOD	DEVELOP HIGH POWER BUILDING BLOCK TYPE I^2 REGULATOR AND BATTERY CHARGE CONTROLLER /DESIGN FOR 100 AMPERE CAPABILITY)	INSTALLED ON SOLAR ARRAY SUPPORT STRUCTURE RADIATOR PANELS 68M^2 (731.6 FT^2)	3	9*	4	5	4	TWO-HI-GAIN ANTENNAS INSTALLED ON BERTHING STRUCTURE OTHER EQUIPMENT IN AFT RACK DATA SYSTEM DUAL REDUNDANT. DATA BUS WITH REMOTE UNITS. NSSC-II COMPUTER – 256Kbs.
									*9 GYROS ON FIRST FLIGHT VEHICLE, ONE 3-AXIS PACKAGE ON SUBSEQUENT VEHICLES				
50 kW	SAME AS 25 kW PLUS 80.0 IN LONG BOOM	SAME AS 25 kW	SAME AS 25 kW	2 WINGS (4 BLANKETS) EACH WING 39 6M LONG (130 FT) X 13 44M WIDE (44.10 FT)	50AH N$_4$-H$_2$ BATTERIES PACKAGED INTO 12 SIMILAR REPLACEABLE UNITS, INSTALLATION SAME AS 25 kW. 40% DOD	INTERCHANGEABLE DIMENSIONALLY AND WITH RESPECT TO WEIGHT WITH 25 kW	INSTALLATION SIMILAR TO 25 kW RADIATOR PANELS 131M^2 (1350 FT^2) OTHER EQUIPMENT SAME AS 25 kW EXCEPT FOR MODIFIED PAYLOAD HEAT EXCHANGER	3-6	3-AXIS	4	5	4	SAME AS 25 kW EXCEPT PROVIDE ADDITIONAL REMOTE TLM AND COMMAND UNITS
100 kW	SAME AS 50 kW PLUS 360.0 IN LONG BOOM PLUS TWO SOLAR ARRAY SUPPORT BEAMS	SAME AS 25 kW	SAME AS 25 kW	4 WINGS (8 BLANKETS) EACH WING 39.6M LONG (130 FT) X 13.44M WIDE (44.10 FT)	SAME AS 50 kW 80% DOD	NEW TECHNOLOGY COMPONENTS FOR HIGH CURRENT WILL BE REQUIRED	SAME AS 50 kW	6	3-AXIS	4	5	4	SAME AS 50 kW

DERIVED SYSTEM CONFIGURATIONS

- The chart illustrates, at equivalent scale, each of the Power Module/ Payload satellite configurations analyzed in Part III. Both Power Module and satellite designations are identified.

- The configurations are grouped by orbit: 28.5°, 57.0°, polar, and geosynchronous. Payload disciplines supported by each satellite configuration are also identified.

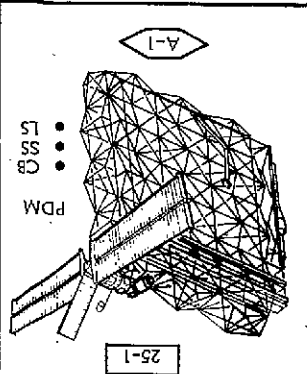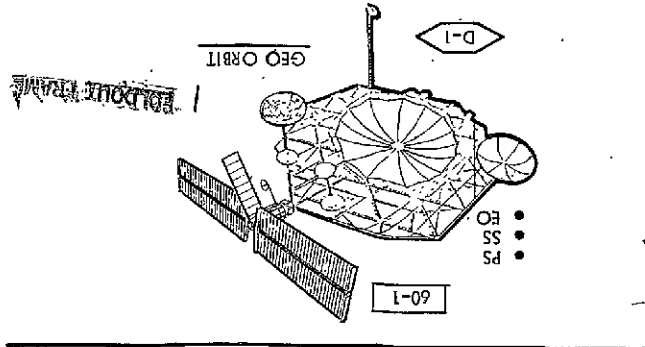Note: No time relationship is implied by the grouping shown on the chart.

NOT RELEASED

PICTORIAL SCENARIO 1 POWER MODULE
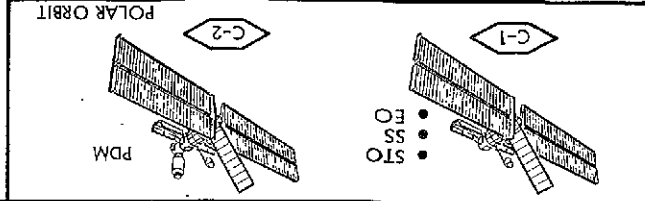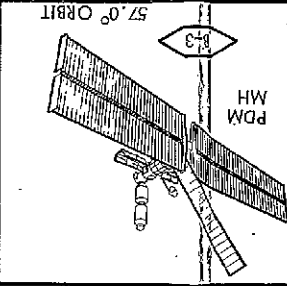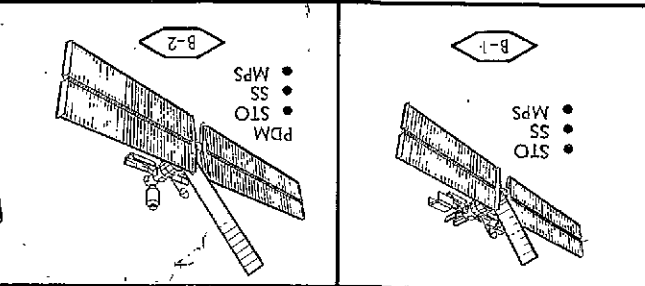
LMSC-D614070

FOLDOUT FRAME 1

FOLDOUT FRAME 2
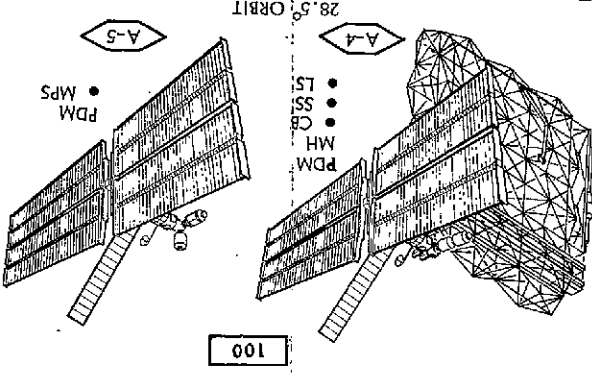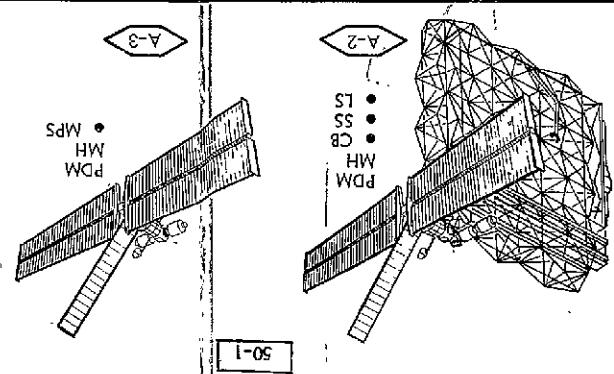
LEGEND:

| | POWER MODULE CONFIGURATION |
| | SATELLITE CONFIGURATION |

- PDM — PRESSURIZED DOCKING MODULE
- MH — MANNED HABITAT
- MPS — MATERIAL PROCESSING
- STO — SOLAR TERRESTRIAL OBSER
- PS — PUBLIC SERVICE
- SS — SPACE SCIENCE
- EO — EARTH OBSERVATION
- CB — CONSTRUCTION BASE FOR:
  - SPS — SPACE POWER SYSTEM
  - GEO PLATFORM
  - LEO PLATFORM
  - OTHERS
- SCD — SPACE CONSTRUCTION DEMO
- LS — LIFE SCIENCE

28.5° ORBIT

A-1 25-1
- PDM
- CB
- SS
- LS

A-2 50-1
- PDM
- MH
- CB
- SS
- LS

A-3
- PDM
- MH
- MPS

A-4 100
- PDM
- MH
- CB
- SS
- LS

A-5
- PDM
- MPS

57.0° ORBIT

B-1
- PDM
- STO
- SS
- MPS

B-2
- PDM
- STO
- SS
- MPS

B-3
- PDM
- MH

POLAR ORBIT

C-1
- PDM
- STO
- SS
- EO

C-2
- PDM
- EO

GEO ORBIT

D-1 60-1
- PS
- SS
- EO

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ELECTRICAL POWER SUBSYSTEM GROWTH

- Power systems have been conceptualized for each of the Scenario I vehicles, utilizing the expected technology available in the applicable time periods. The results of this effort are summarized in the chart.

- As can be seen from the estimated weights of the power system components, power system specific performance is projected to improve to over 4 watts/pound, from the 1.5 watts/pound produced by the initial power module.

- The main emphasis was placed on power systems for low earth orbit (LEO). However, it can be seen that for a geosynchronous (GEO) vehicle the power system specific performance is greatly improved, to a level of approximately 8 watts/pound.

- On of the evolutionary features of the Power Module is the concept of recovery from orbit, refurbishment on the ground, and subsequent reuse as a flight vehicle. The initial flight vehicle (FV-1) to be launched in 1983, can be recovered, refurbished, and launched again in 1986. This is shown in Volume 2, page 2-13 of the Part III Final Report. Details of the Electrical Power Subsystem refurbishment are discussed in Volume 4, page 3-18 and 3-19 of the Part III Final Report.

- Another evolutionary feature of the PM is the concept of growth on orbit (increasing capability), accomplished by the addition of a growth kit. The 50 kW PM launched in 1988 (FV-4) can be increased to a 100 kW capability in 1990 by the use of an on-orbit installed 50-100 kW growth kit as shown in Volume 2, page 2-13 of the Final Report. The 50-100 kW growth kit is described on pages 6-4 and 6-5 of this Volume 1. The on-orbit growth sequence, which is supported by EVA operations, is described in Volume 4, pages 6-48 and 6-49 of the Part III Final Report.
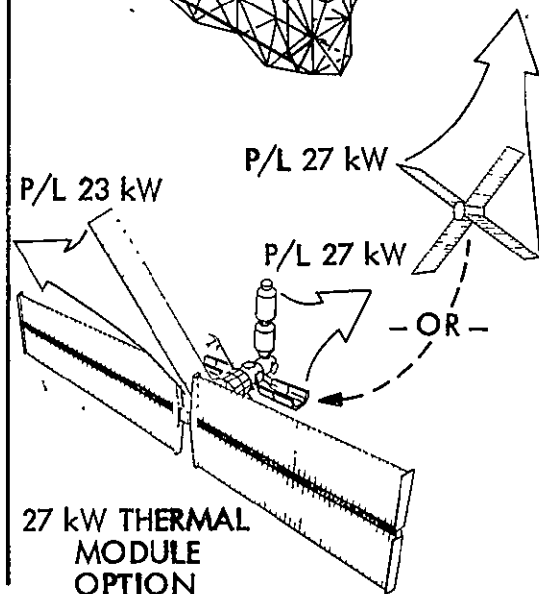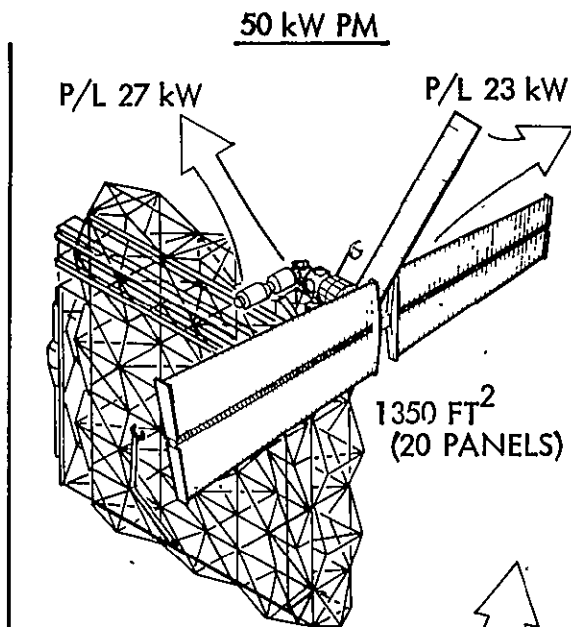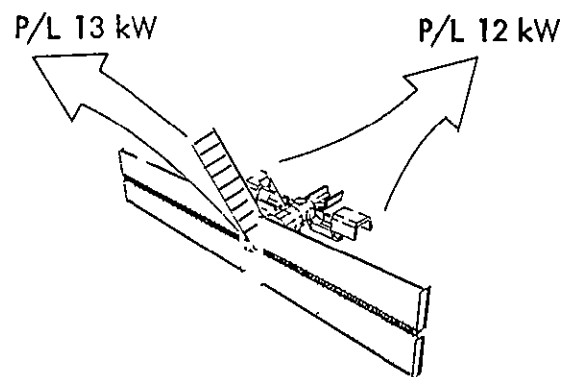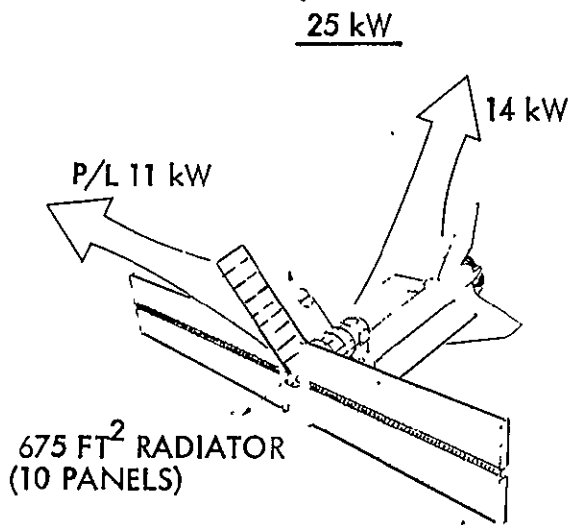
ELECTRICAL POWER SUBSYSTEM GROWTH

ORBIT	LEO							GEO
LAUNCH DATE	1983	1986	1986/88/89	1988	1990	1990 (5)	1991	1987
POWER – kW	25	25	50	25	50-100(KIT)[1]	100-1'	100-1[6]	60
CELL TYPE, #/FT^2	Si, 0.2	Si, 0.2	Si, 0.2	Si, 0.15	Si, 0.15	Si, 0.15	Si, 0.15	Si, 0.15
CELL EFF – %	12-13	12-13	14-16	16-18	16-18	16-18	16-18	12-13
BATTERY	Ni-Cd	Ni-H$_2$	Ni-H$_2$	Ni-H$_2$	Ni-H$_2$	Ni-H$_2$	Ni-H$_2$	H$_2$-O$_2$RFC[3]
DoD – %	20	20	40	20	80	80	80	50
VOLTAGE, DC REG	110/28	110/28	110	110	110	110	110	110
WEIGHTS – #								
SOLAR ARRAY	2,400	2,400	4,800	1,800	3,600	8,400	7,200	1,800
ADAPT[2]	200	200	250	200	300	550	300	200
BATTERIES	7,440	6,400	6,400	6,400	6,400	12,800	6,400	3,200[3]
ELECTRONICS	1,395	1,395	1,395	1,395	2,055	3,450	2,055	660
PWR DISTRIBUTION	630	630	880	630	1,145	2,025	1,145	200
CABLING	500	500	500	500	500	1,000	500	300
CONTINGENCY – 25%	3,141	2,881	3,556	2,731	3,500	7,056	4,400	1,590
TOTAL	15,706	14,406	17,781	13,656	17,500	35,281	22,000	7,950
VEHICLE [4] CONFIGURATION	FV-1/B-1	FV-1R1 A-1	FV-2/B-2 FV-4/A-2 FV-5/A-3	FV-1R2 C-1/C-2	FLIGHT KIT	FV-4/A-4	FV-6/A-5	FV-3/D-1

1. THE 50-100 kW KIT ALLOWS ON-ORBIT BUILDUP TO 100 kW (WEIGHTS SHOWN ARE FOR KIT COMPONENTS ONLY).
2. ORIENTATION DRIVE AND POWER TRANSFER ASSY.
3. REGENERATIVE FUEL CELL (WEIGHT INCLUDES FUEL CELLS, ELECTROLYZER, TANKAGE, REGULATORS, REACTANTS)
4. VEHICLE DESIGNATORS CORRESPOND TO FLIGHT VEHICLES AS SHOWN IN VOLUME 2 OF THIS PART III FINAL REPORT, PAGES 2 - 13. CONFIGURATION DESIGNATORS REPRESENT CONFIGURATIONS SHOWN ON PAGES 3 - 62 IN VOLUME I OF THIS PART III FINAL REPORT.
5. VEHICLE WEIGHT ON-ORBIT AFTER 50-100 kW KIT INSTALLATION.
6. THE 100 kW GROUND LAUNCHED CONFIGURATION.

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POWER MODULE HEAT REJECTION GROWTH

25 kW

P/L 11 kW

14 kW

675 FT^2 RADIATOR
(10 PANELS)

P/L 13 kW

P/L 12 kW

50 kW PM

P/L 27 kW

P/L 23 kW

1350 FT^2
(20 PANELS)

P/L 27 kW

P/L 27 kW

P/L 23 kW

– OR –

27 kW THERMAL
MODULE
OPTION

1080 FT^2 RADIATOR
REQ'D FOR 70 ±30°F CONTROL

100 kW

P/L 88 kW

P/L 12 kW

1350 FT^2 RADIATOR
(20 PANELS)

P/L 88 kW

P/L 12 kW

88 kW
HI-TEMP
THERMAL
MODULE
FOR MPS
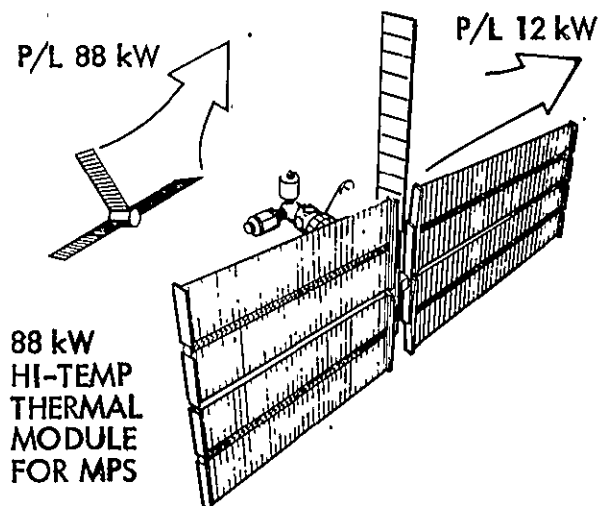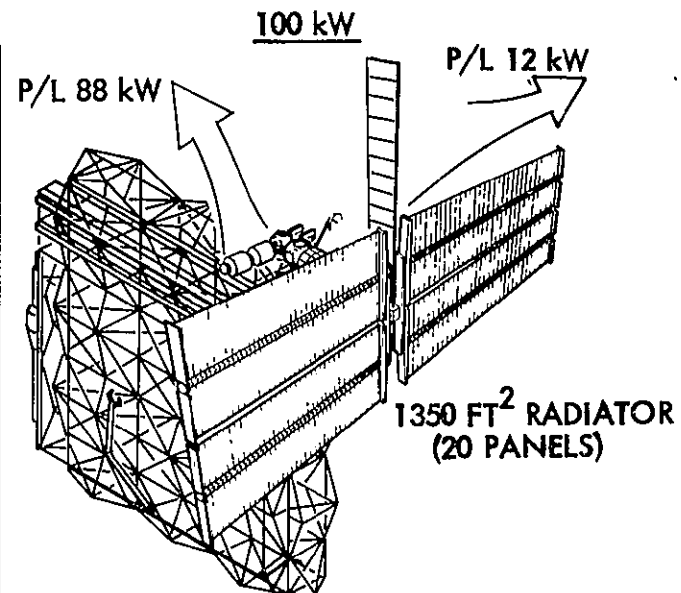
1640 FT^2 RADIATOR
AREA REQ'D FOR
170 ±50°F CONTROL

ATTITUDE CONTROL SUBSYSTEM GROWTH ACTUATOR SIZING

- The driving condition for the number of CMGs required is the control of the gravity gradient cyclic torques in the Perpendicular to Orbit Plane (POP) orientation.
  One CMG is required for redundancy.
  One CMG is adequate for control of disturbances (other than gravity gradient).

- The analysis showed that with three CMGs on the 25 kW and 50 kW Power Modules, and 6 CMGs on the 100 kW Power Module inertial orientations were possible for the configurations in Scenario 1. Configurations A-1, A-2, and A-4, reference page 3-63, cannot be flown inertially because of their size.

ATTITUDE CONTROL SUBSYSTEM
ACTUATOR SIZING

LMSC-D614944-1

- POSSIBLE INERTIAL ORIENTATIONS

CONFIGURATION	POWER LEVEL kW	NUMBER OF CMGs REQUIRED	INERTIAL ORIENTATIONS POSSIBLE					
			FREE-FLYING			SORTIE		
			X POP	Y POP	Z POP	X POP	Y POP	Z POP
A-1	25	3						
A-2	50	3						
A-3	50	3	X	X	X	X		
A-4	100	6			X			
A-5	100	6		X		X		X
B-1	25	3	X	X	X	X		
B-2	50	3	X	X	X	X		
B-3	50	3	X	X	X	X		
C-1	25	3	X	X	X	X		
C-2	25	3	X	X	X	X		

- ANY PRINCIPAL AXIS ALONG THE LOCAL VERTICAL

- RESULTS: VEHICLE SIZE   NUMBER OF CMGs

VEHICLE SIZE	NUMBER OF CMGs
25 kW	3
50 kW	3
100 kW	6

RECOMMENDED ATTITUDE CONTROL SUBSYSTEM GROWTH

- A wide angle 4π steradian sun sensing system is used to provide a line of position to the sun for attitude determination. These sensors also provide the ability to reacquire the sun in a contingency mode.

- A magnetic torquing system, identical to that used on Space Telescope, provides contingency stabilization for retrieval. This system will also provide additional desaturation capability.

- Horizon sensors provide the additional data required to compute three-axis attitude.

- To accommodate stabilization of the larger sortie-mission configurations, and at the same time augment feasibility of growth on-orbit, provision for 6 CMGs is recommended.

- If attitude determination capability on the order of arc minutes is required, star sensors can be added to future Power Modules.
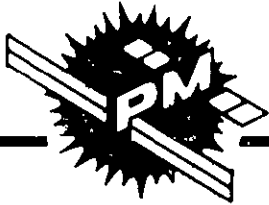
RECOMMENDED ATTITUDE CONTROL SUBSYSTEM GROWTH

LMSC-D614944-1

RECOMMENDATION	RATIONALE	
	FOR FIRST MISSION	FOR GROWTH
WIDE ANGLE SUN SENSOR	FOR ATTITUDE DETERMINA-TION	FOR ATTITUDE DETERMIN-ATION
MAGNETIC TORQUING SYSTEM	• PROVIDE CONTINGENCY RETRIEVAL STABILIZATION • PROVIDE ADDITIONAL DESATURATION CAPA-BILITY	• PROVIDE CONTINGENCY RETRIEVAL STABILIZATION • PROVIDE ADDITIONAL DESATURATION CAPA-BILITY
HORIZON SENSOR	PROVIDE ATTITUDE DETER-MINATION CAPABILITY	PROVIDE ATTITUDE DETER-MINATION CAPABILITY
CMGs (PROVISION FOR SIX)	PROVIDE ADDITIONAL MIS-SION ORIENTATION CAPA-BILITY	FOR GROWTH CONFIGU-RATIONS
STAR SENSORS	NOT APPLICABLE	PROVIDE IMPROVED ATTITUDE DETERMINATION CAPABILITY

RECOMMENDED C&DH SUBSYSTEM GROWTH

- The high gain antennas will provide RF link closure for data rates above approximately 4 KBS to 256 KBS. For data rate transmission above 256 KBS, a Ku band kit can be added. Provision for growth can be accommodated by incorporating a dual S and Ku band antenna feed on the first Power Module.

- The recommended 256 KBS data rate capability will support payload housekeeping and scientific rates (below approximately 192 KBS) plus PM housekeeping data rates for 25 kW, 50 kW, and 100 kW PM systems.

- The NSSC-II recommendation for the on-board computer is based on an IBM study which compared the NSSC-1 and NSSC-II computers. Special emphasis was given to the key drivers of memory growth, speed, and general performance.

RECOMMENDED C&DH SUBSYSTEM GROWTH

RECOMMENDATION	RATIONALE	
	FOR FIRST MISSION	FOR GROWTH
HIGH GAIN ANTENNAS, S-BAND (STEERABLE)	REQUIRED FOR SOLAR TERRESTRIAL DATA AND PM DATA > 4 KBS	Ku BAND KIT ALLOWS DATA RATE GROWTH TO 300 MBS
NSSC II COMPUTER	IMPROVED SPEED FOR EARLY PAYLOAD SYSTEM REQUIREMENTS	FOR HANDLING MORE ACS AND MEMORY REQUIREMENTS
256 KBS DATA RATE CAPABILITY	TO SUPPORT EARLY PAYLOAD SYSTEM RQMTS	Ku BAND KIT TO MEET EXPANDED PAYLOAD & PM DATA RATE RQMTS
DISTRIBUTED DATA BUS SYSTEM (REMOTE TELEMETRY & COMMAND UNITS)	MINIMIZES WIRES CROSSING DOCKING INTERFACES	MINIMIZE WIRES CROSSING PAYLOAD/POWER MODULE INTERFACES. GROWTH BY ADDING REMOTE UNITS

STRUCTURAL SUBSYSTEM/EQUIPMENT INSTALLATION GROWTH

● The following two drawings show the equipment installation growth for the 25, 50, and 100 kW configuration Power Modules. Additional details of these installations are shown in paragraphs 4.1.2, 5.1.2, and 6.1.2 respectively of this Volume I of the Part III Final Report.

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3.4 POWER MODULE GEO DERIVATIVE CONFIGURATIONS

### POWER MODULE DERIVED GEO CONCEPT

- The 25 kW Power Module Evolutionary Study examined the many desires for the Geostationary Platform. Users include Communications, Space Science, Navigation, and Solar Terrestial Observations. These System configurations require further conceptual definitions. However, it is suggested that the 25 kW Power Module Program will provide a significant contribution to the Geostationary Program by having many directly applicable components to be incorporated into the GEO System concepts.

- This figure shows a PM concept for use in GEO. It is assumed that cooling will be provided by attached payloads, since heat sources will probably be widely distributed. A Regenerative Fuel Cell (RFC) energy storage system will probably be optimum for GEO, and has the advantage of reducing system weights by factors of 2 and 3 respectively over $Ni-H_2$ and Ni-Cd battery systems.

- At GEO the eclipse is near the equinox and is a maximum of 72 minutes. Eclipse will be at local midnight at a time when traffic is near the lowest level and therefore full power capability will not be needed. Low cycle life is required with long recharge times available, thus allowing the reduction in electrolyzer amount. Weight characteristics of the electrical power subsystem of the GEO PM are given on page 3-65 of this Volume I, Part III Final Report.

POWER MODULE DERIVED GEO CONCEPT

GEO POWER MODULE
CHARACTERISTICS
SUMMARY

- POWER 60 kW
- C&DH — NASA STANDARD
  COMPONENTS

PM
SOLAR
ARRAY

PM
EQUIP. MODULE

BERTHING
ATTACH POINTS
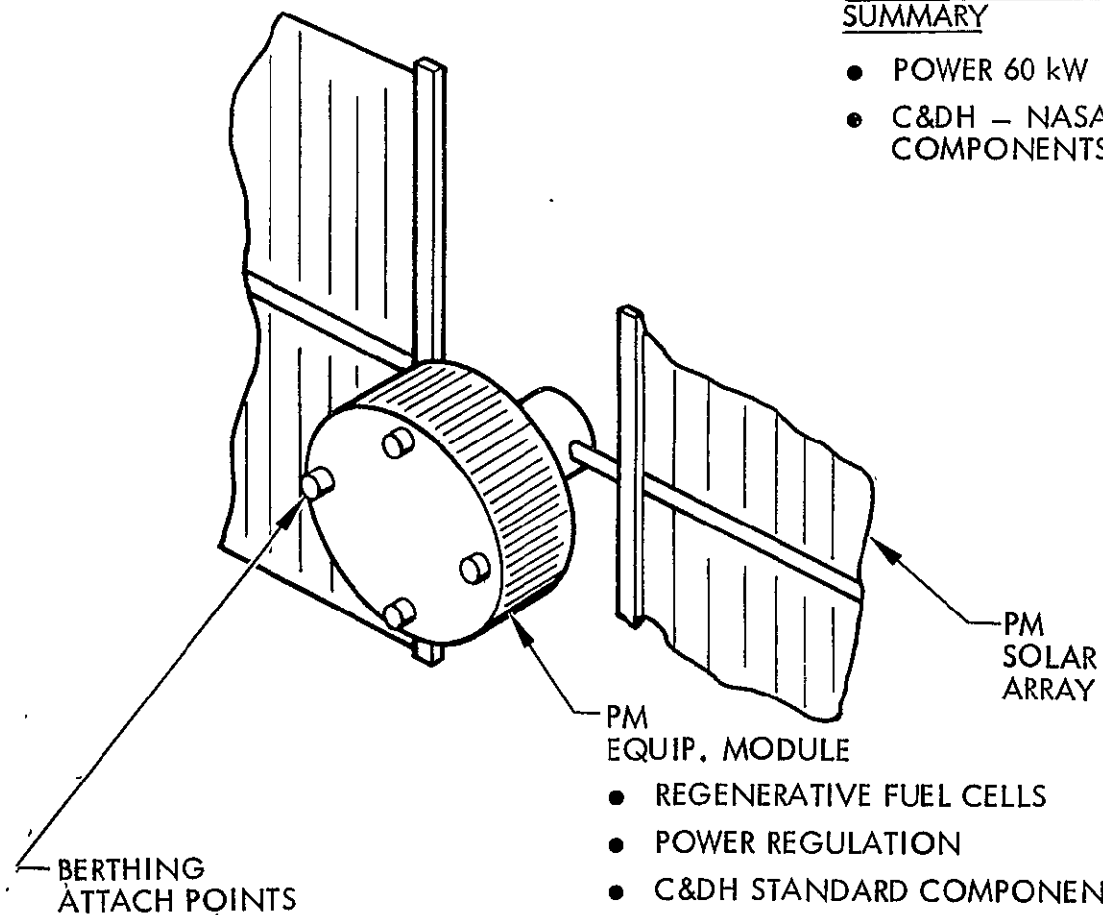
- REGENERATIVE FUEL CELLS
- POWER REGULATION
- C&DH STANDARD COMPONENTS
- SINGLE DEGREE OF FREEDOM
  TRACKING SYSTEM
- ACS COMPONENTS
- COMPUTER
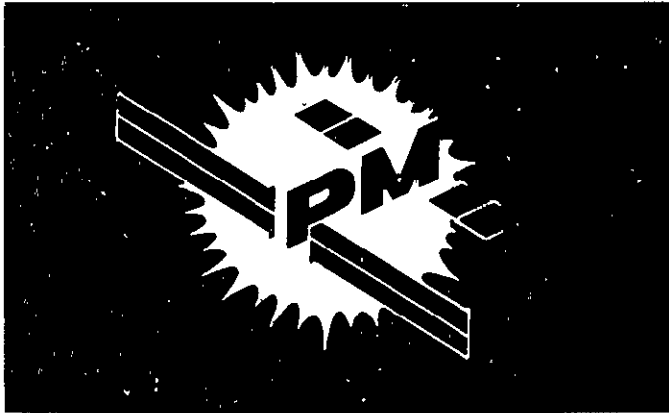
SECTION 4
25kW POWER MODULE

RECOMMENDED 25 kW POWER MODULE

CONFIGURATION – DEPLOYED

- The 25 kW Power Module configuration is shown here. This vehicle includes five basic subsystems as follows:

    - Structures
    - Electrical Power
    - Thermal
    - Attitude Control
    - Communication and Data Handling

- Subsystem design guidelines have emphasized compatibility with Shuttle Orbiter interfaces and operations, replicability of equipment, flexibility for growth and maintenance on orbit, and low cost design.

RECOMMENDED 25 kW POWER MODULE
CONFIGURATION — DEPLOYED

THERMAL RADIATORS 68M^2

(731.6 FT^2)

EQUIPMENT STRUCTURE

HI-GAIN
ANTENNA
2 PLACES

BERTHING STRUCTURE
PAYLOAD/ORBITER
INTERFACES — 5 PLACES

CMGs (3 PLACES)

SOLAR POINTING PAYLOAD
MOUNTING INTERFACE

83.97M
(275.5 FT)

9.04M
(29.66 FT)

SOLAR ARRAY (60KW)
160.0M^2 (1722 FT^2)

4-3
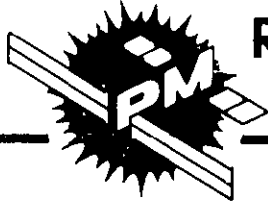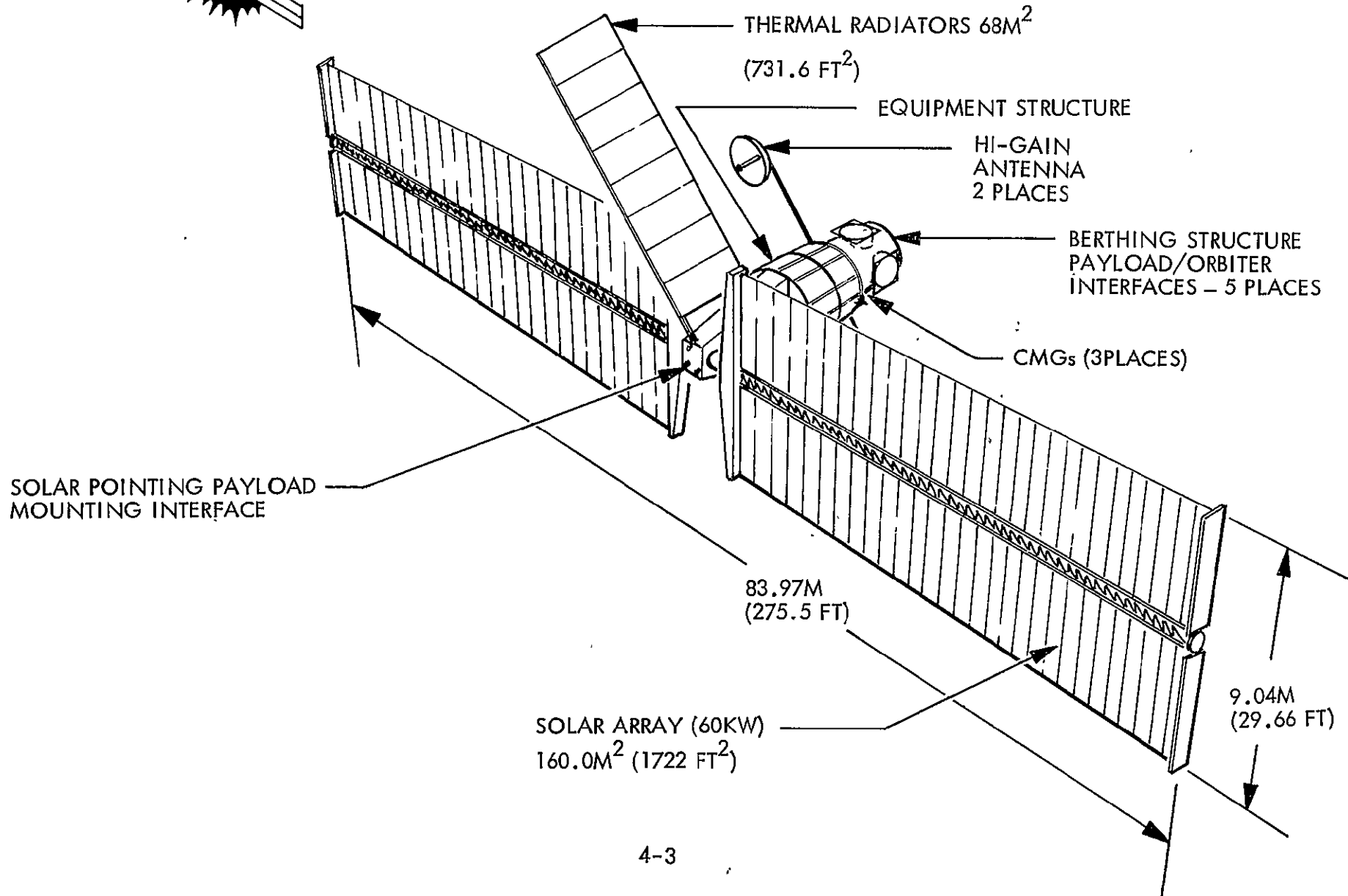
25 kW POWER MODULE – ORBITER PAYLOAD
BAY INSTALLATION

Configuration sizing compatibility in the Orbiter cargo bay is shown in the chart and the Orbiter payload installation drawing. This PM configuration can be carried on one Orbiter flight; while still allowing space in the Orbiter for an additional Spacelab-type pallet. Space forward of Orbiter station 660 is reserved for Orbiter use.

25kW POWER MODULE—
ORBITER PAYLOAD BAY INSTALLATION

TRUNNION

TRUNNION

HI-GAIN ANTENNA-2 PLACES

469.00

SPACELAB PALLET

RADIATORS

GRAPPLE
RMS INTERFACE
NS & FS

POWER MODULE

BERTHING PLATFORM

ST 582

CONTROL & MONITOR PANEL

ORBITER STA 660.00

ORBITER STA 939.20

KEEL FITTING

ELECTRICAL UMBILICAL

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LMSC-D61494-1

25KW POWER MODULE
CONT 25-1-ORBITER
PAYLOAD INSTALLATION

LOCKHEED MISSILES & SPACE COMPANY, INC
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

NOTES:
1. ATTACH TRUNNION FITTING (NON DEPLOYABLE PAYLOAD) PER SHUTTLE ORBITER/CARGO STANDARD INTERFACES ICD NO. 2-19001, FIGURE 3.3.1.2.1-1 BY NASA - JOHNSON SPACE CENTRE.

2. TRUNNIONS REQUIRE BRIDGE STRUCTURE TO DISTRIBUTE LOAD TO CARGO BAY SILL FITTING.

ELECTRICAL UMBILICAL
KEEL FITTING
ORBITER STA 835.20
WIRE TRAY TYPICAL
ORBITER STA 660.00
POWER MODULE
GRAPPLE
MMS INTERFACE NSA-FS
SPACELAB PALLET
AFT FLIGHT DECK
582.0

SORTIE MISSION BERTHING
BERTHING PLATFORM
BERTHING POSITION (EXTENDED PLATFORM) SEE DWG 81690
EXTENDED POSITION
LMAX ARC OF DEPLOYED SOLAR ARRAY
SOLAR ARRAY
BERTHING STRUCTURE
RADIATOR - 10 PANELS

TRUNNION
TRUNNION

LMSC-D61494-1

A ADDED - SORTIE MISSION BERTHING, NOTE 1

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4.1   OUTBOARD AND INBOARD PROFILES

4.1.1 Outboard Profile

25 kW POWER MODULE — OUTBOARD PROFILE

- The 25 kW Power Module outboard profile is shown in the chart. The vehicle is composed of four major structural components:

  - Solar array support structure

  - Forward equipment rack

  - Aft equipment rack

  - Berthing support structure

- The solar array support structure is of closed shear box or semi-monocoque construction. It also supports and contains the thermal radiator system.

- Both forward and aft equipment racks are constructed from ring frame assemblies, radial webs, and longerons attached to an inner tubular structure. Built into the equipment rack structure are the trunnion fittings and keel fitting that support the Power Module in the Orbiter payload compartment.

- The berthing support structure is of semi-monocoque construction and is of the same diameter as the inner tubular structure in the equipment racks. Five berthing ports are built into this structure — four at equal spaces around the diameter and one on the aft face.

25kW POWER MODULE
OUTBOARD PROFILE

SOLAR ARRAY WING — 2 PL

SOLAR ARRAY PYLON

TRUNNION FITTING

FORWARD EQUIPMENT RACK

AFT EQUIPMENT RACK

BERTHING STRUCTURE

29.0

58.0

RADIATORS THERMAL CONTROL SYSTEM

GRAPPLING FIXTURE 2 PL

125.0

124.0

HI-GAIN ANTENNA - 2 PLACES

168.0 DIA

196.0

62.5

88.0

120.0 DIA

BERTHING PORT – 5 PL

60.0

14.0

BERTHING TRUNK

84.0

TRUNNION FITTINGS

356.0 DIA

220.0

KEEL FITTING

469.0 REF
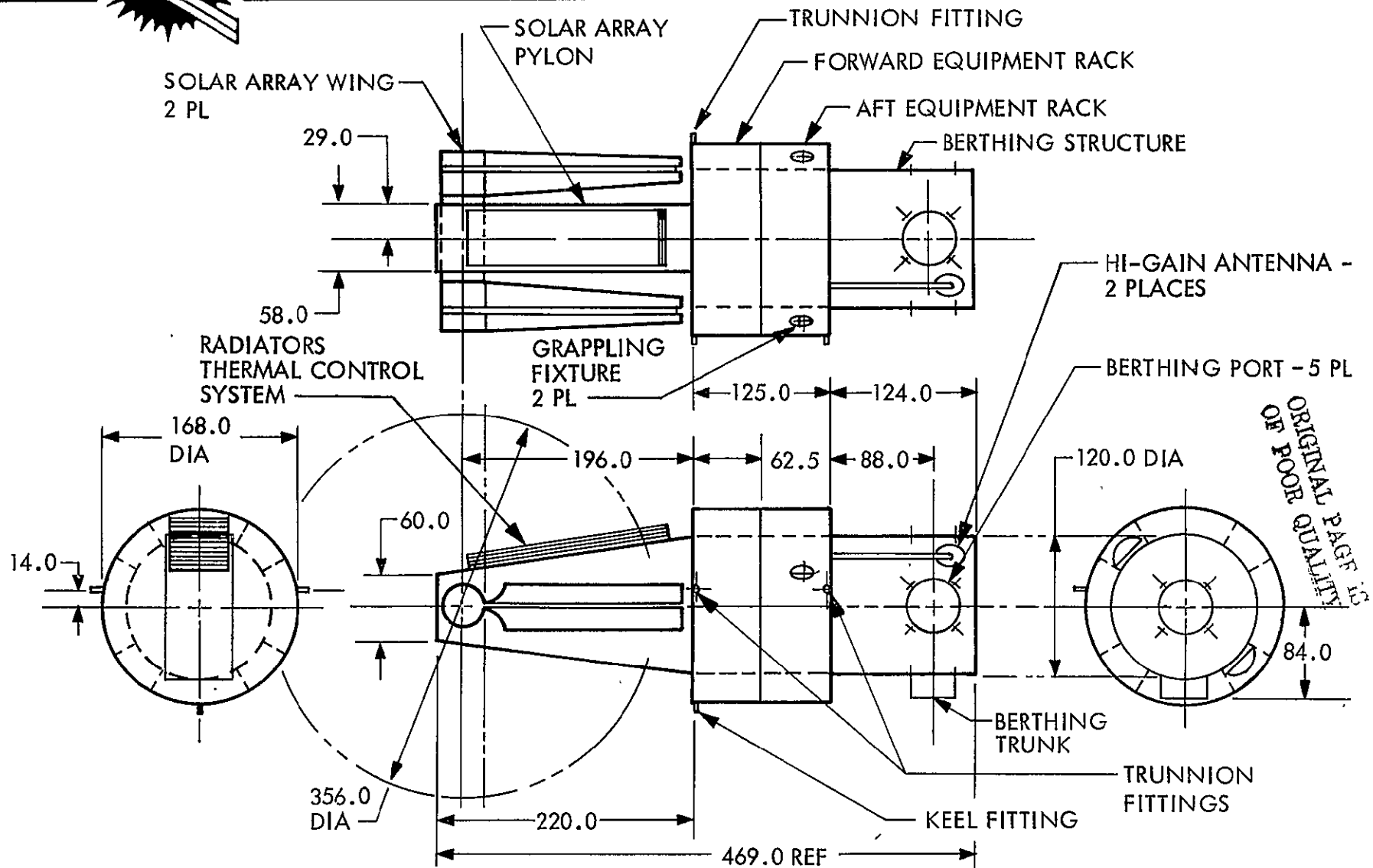
ALL DIMENSIONS IN INCHES

4.1.2 Inboard Profile

25 kW POWER MODULE INBOARD PROFILE

● The inboard profile is shown in the next chart. For equipment installation the concept of subsystem modularity is maintained. The electrical power subsystem equipment is located in the forward equipment rack. Communications and data handling subsystem equipment including magnetic torquers and electronics, rate gyros, horizon sensors, and electronics are located in the aft equipment rack. The control moment gyros (3) are located in the berthing module.

● This subsystem compartment allocation provides enhancement for growth and maintenance on orbit.

25kW POWER MODULE INBOARD PROFILE

MAGNETIC TORQUERS
(HIDDEN)

ACS
EQUIPMENT

S-BAND
HI-GAIN
ANTENNA (2)

ELECTRICAL
POWER SYSTEM
NiCd BATTERIES

THERMAL
RADIATORS

CMGs
ATTITUDE CON-
TROL SYSTEM (3)

BERTHING
MECHANISM

COMMUNICATION
AND DATA HANDLING

SOLAR ARRAY
WINGS-4M BLANKETS

THERMAL CONTROL
SYSTEM EQUIPMENT
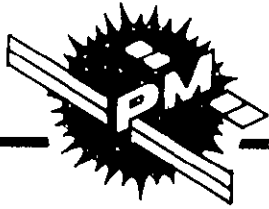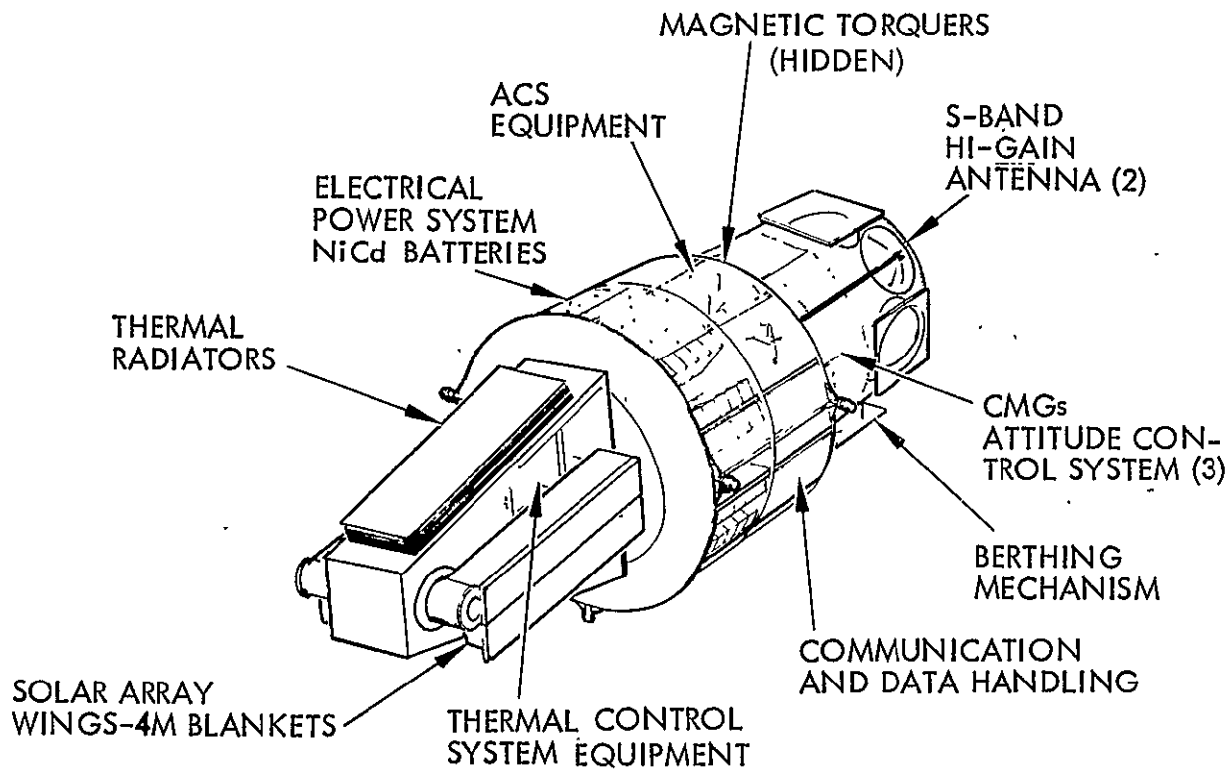
25 kW POWER MODULE EQUIPMENT INSTALLATION

- Equipment installation details for the 25 kW Power Module are shown in the drawing.

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4.2 WEIGHTS

Detailed weights data for the 25 kW Power Module subsystems are included in the following subsystem descriptions. A summary weight statement of the Power Module is shown below. Detail mass properties data is given in Volume 4, paragraph 2.2 of the Part III Final Report.

<div align="center">

25 kW POWER MODULE WEIGHT SUMMARY

ITEM	WEIGHT (LB)
Structure and Mechanical	7430
Electrical Power	12565
Thermal Control	2014
Attitude Control	2138
C & DH	428
Subtotal	24575
Contingency — 25%	6144
TOTAL	30719

</div>

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4.3 SUBSYSTEM DESIGN DESCRIPTION

4.3.1 Structures

Functions/Requirements

The major functional elements of the structure assembly are:

- Solar array support structure
- Equipment racks (two)
- Berthing structure

This structure assembly will provide for the optimum structural arrangement to satisfy the installation and support of power module peculiar equipment, the orbiter installation and berthing attachment and release requirements, and payload berthing and attachment.

Structural configuration trade-off studies are described in Volume 4, page 3-10, of Part III Final Report and Reference 10, pages 20-6 through 2C-21.

Subsystem Description

25 kW POWER MODULE STRUCTURE

The chart illustrates the major structural elements.
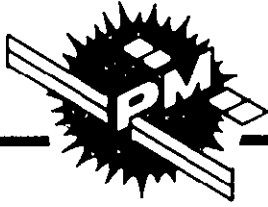
25 kW POWER MODULE STRUCTURE

SOLAR ARRAY SUPPORT STRUCTURE

- SHEAR BOX STRUCTURE
- PROVIDES FOR GROWTH
- READILY ACCOMMODATES EQUIPMENT
- APPLICABLE TO 25, 50, AND 100 kW STRUCTURE

EQUIPMENT RACK

- DESIGN AND TOOLING AVAILABLE
- ORBITER ENVIRONMENT QUALIFIED
- SOME REDESIGN REQUIRED
- PROVIDES FOR GROWTH
- SPACE FOR GROWTH EQUIPMENT
- APPLICABLE TO 25, 50, AND 100 kW STRUCTURE

BERTHING STRUCTURE

- MONOCOQUE STRUCTURE
- PROVIDES FOR EQUIPMENT GROWTH
- PROVIDES BERTHING AND SORTIE INTERFACE
- APPLICABLE TO 25, 50, AND 100 kW STRUCTURE

BERTHING STRUCTURE   120.0 DIA

120.0 DIA

2 EQUIPMENT RACKS   168.0 DIA

122.0

120.0 DIA

SOLAR ARRAY SUPPORT STRUCTURE

116.0

60.0

122.5

58.0

220.0
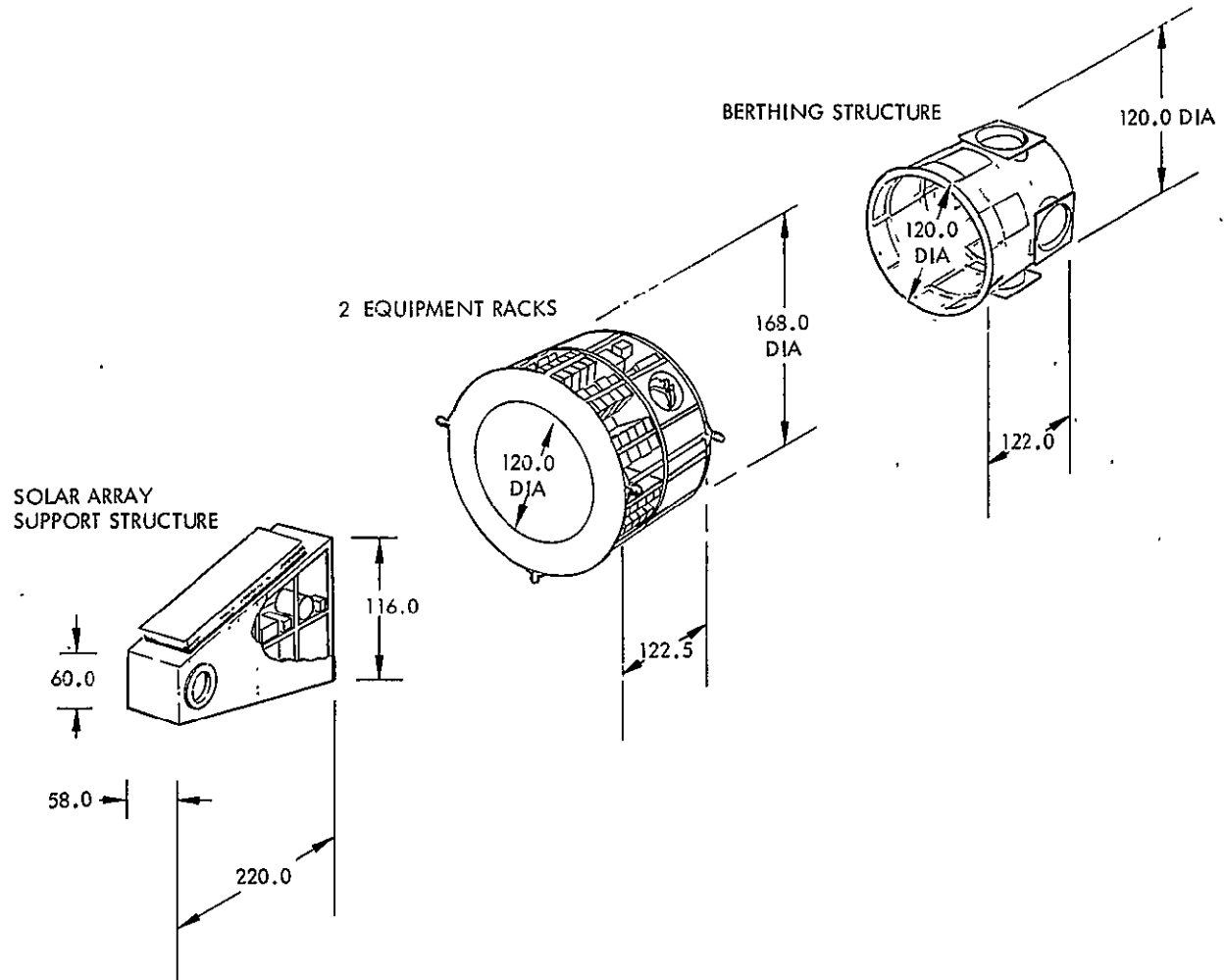
DIMENSIONS IN INCHES

SOLAR·ARRAY SUPPORT STRUCTURE

- The Solar Array Support Structure is a semi-monocoque configuration of light alloy shear panels and structural members; design details are shown in this drawing. At its forward end are housed the drive assemblies of the two solar array wing assemblies. On its forward face are mounted the support brackets and tilt mechanism for the solar pointing package, and on its upper surface are attached the extendable radiators of the thermal protection system. The remainder of the TPS equipment and items associated with the electrical power system and solar pointing package are installed within the structure-access doors being provided for servicing, at its aft end the structure is attached to the forward face at the equipment rack section. At this interface are situated electrical and fluid connections.

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EQUIPMENT RACK

- The equipment rack consists of two equipment sections presently used in the space systems module (space telescope program) spliced into one unit. Equipment rack structural details are shown in this drawing. This section of the SSM is composed of radial web assemblies on either end of a 120.0 inch diameter inner shell; the web assemblies are interconnected by longitudinal diaphragms situated at 30° spacing. Keel and trunnion fittings for installation on the power module into the orbiter payload bay are attached to this rack structure. Minor modifications will be required to adapt the structure for the 25 kW power module.

Battery modules, control assemblies, bus regulators and other items of the electrical power system are installed in the forward section of the rack and the aft section houses the communication and data handling module and items associated with the attitude control system. Hinged access doors offer environmental protection, and facilitate maintenance to items on this aft section.
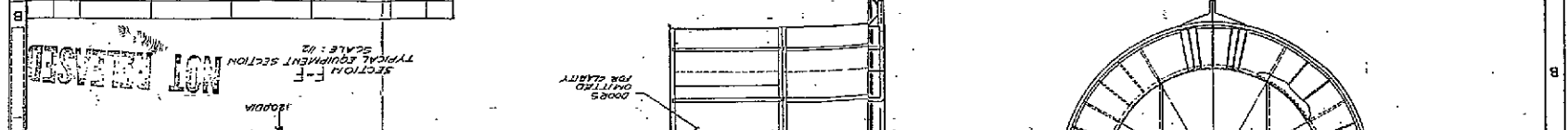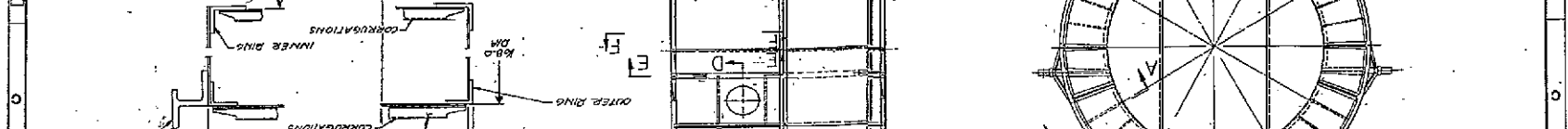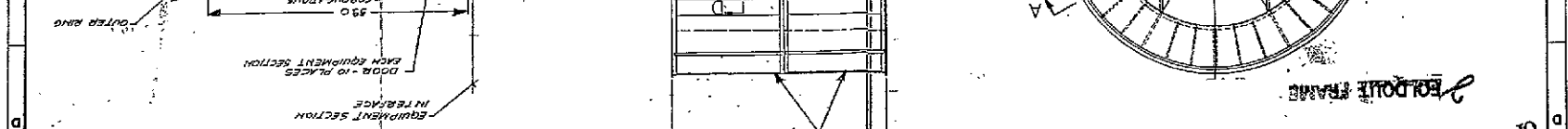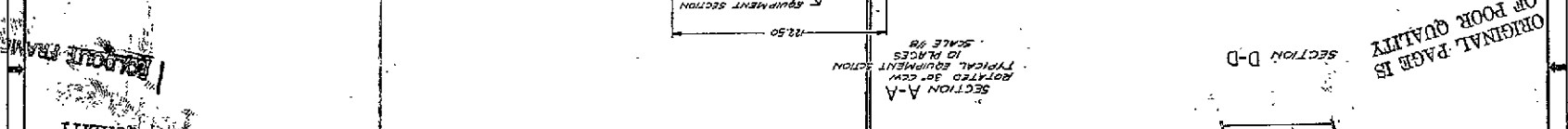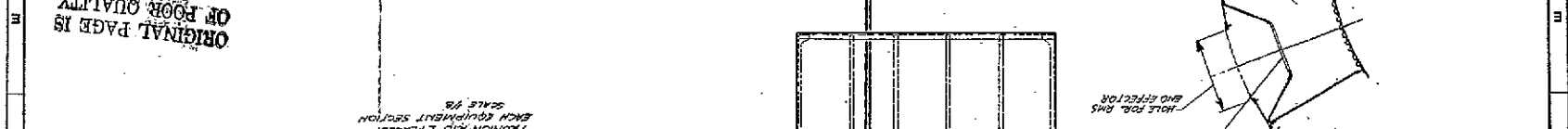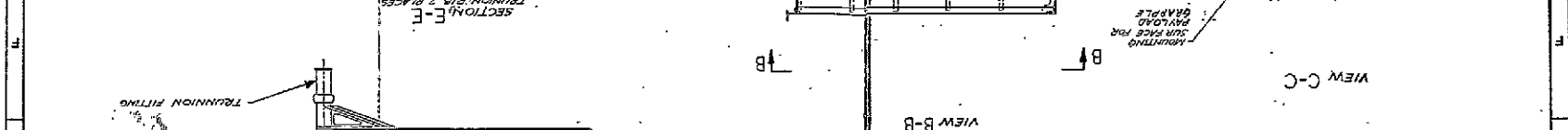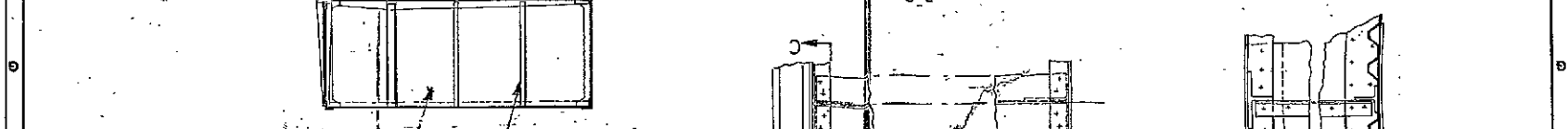
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BERTHING STRUCTURE

- The berthing structure is a frame and rib stiffened shell of 120.0 inch diameter which attaches at its forward face to the aft face of the equipment rack. Structural details of the berthing structure and the berthing concept are shown on these two drawings. Built into its bottom surface is an extended collar supporting the orbiter sortie interface. Four other berthing interfaces are supplied at 0°, 90°, and 270° around the shell, and on the aft face of the structure.

  Cutouts and supporting beams for six control moment gyros are 60° spacing around the shell diameter. Support brackets and fold-out mechanisms for two hi-gain antennas are installed diametrically opposite each other on the outside of the shell.

A-6

NOT RELEASED

BERTHING STRUCTURE
POWER MODULE

FOLDOUT FRAME

FOLDOUT FRAME

SECTION A-A

LONGERON-12 PLACES

6 PL CMG MOUNT
BRACKETS-U REQD

3X2X10 ANGLE-AL
AFT RING

3X1X.75 ZEE
AL-7 PLACES

2.5X2.5X.D ANGLE-AL LONGERONS
TYPICAL

.050 WEB
AL TYP AL

ORBITER STA 935.20

122.0
DIA

ORBITER-DATUM (REF)

ORBITER SPACE INTERFACE
EXTENSION COLLAR BASE

POWER MODULE
EQUIP RACK

CUT-OUT 6 PL
FOR CMG
60° SPACING

AFT BULKHEAD
STABILIZER(?)

BERTHING PART
4 PLACES

120.0 DIA
64.0
42.0 TYP

4 POINT BERTHING INTERFACE 74.0 DIA
SIMILAR TO ST CONCEPT

68.0
124.0

ZONE	REV		SPECIFICATION	MATL	NO

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN
INCHES TOLERANCES ON:
FRACTIONS ± 1/16
DECIMALS .X ± .1
.XX ± .03
.XXX ± .010
ANGLES ± 2 DEG

BERTHING STRUCTURE
POWER MODULE

LOCKHEED MISSILES & SPACE COMPANY INC
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

DWN 10-24-78

SIZE A CODE IDENT DRAWING NO D614053 REV

SCALE 1/20 SHEET 1 of 2

LMSC-D614944-1

ZONE	LTR	DESCRIPTION	DATE	APVD
	A	ADDED CUT-OUTS AND STRUCTURE	11-9-78	

REVISIONS

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COMPONENT CHARACTERISTICS

- A summary of structure subsystem weights and characteristics of the structures components are given in the table.
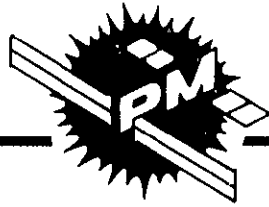
STRUCTURES AND MECHANICAL SUBSYSTEM COMPONENT CHARACTERISTICS

STRUCTURES AND MECHANICAL SUBSYSTEM COMPONENT CHARACTERISTICS

ITEM NO.	COMPONENT	NO. REQ'D	PWR (WATTS)	SIZE (L X W X H) IN.	UNIT WT (LBS)	TOTAL WT (LBS)
1	STRUCTURE ASSEMBLY SOLAR ARRAY SUPPORT BOOM	1	N/A	220 X 58 X 60/116	880	880
2	STRUCTURAL ASSEMBLY, FWD SECTION EUIPMENT RACK	1		62.5 X 168 DIAM.	1435	1435
3	STRUCTURAL ASSEMBLY, AFT SECTION EQUIPMENT RACK	1		62.5 X 168 DIAM.	1465	1465
4	STRUCTURAL ASSEMBLY, BERTHING MODULE	1		12.4 X 168 DIAM.	3200	3200
5	MECHANISMS	TBD		TBD	450	450

Functions/Requirements

The major functional elements of the electrical power subsystem (EPS) are: solar array assembly, power control, and energy storage (battery system). These elements are integrated so that the PM is capable of operating in LEO for 5 years. The EPS furnishes power required for the PM subsystems in sortie, free-flyer, and orbit storage modes. In addition, 25 kW power is provided at the payload interface for either sortie or free-flyer modes of flight.

Subsystem Description

ELECTRICAL POWER SUBSYSTEM BLOCK DIAGRAM

The figure is a simplified block diagram of the EPS, identifying its major elements and functional interfaces.

- The basic power producing, processing, and storage is divided into twelve equal elements. These elements are monitored and controlled by the Power Interface Distributor.

- The Power Interface Distributor (PID) provides the central management point of the entire distribution system and provides all system management functions. Currents, voltages, and energy are monitored from this point.

- Power for the Power Module is distributed from the PID to DC/DC transformer regulators such that all PM power is isolated from the power distributed to users. A main distribution box provides monitoring and management of the PM power. Auxiliary distribution boxes are used as required throughout the PM spacecraft.
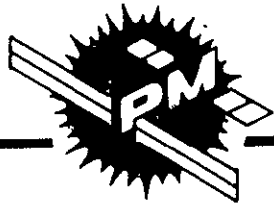
ELECTRICAL POWER SUBSYSTEM BLOCK DIAGRAM

SOLAR ARRAY SYSTEM

SOLAR ARRAY DISTRIBUTOR

PPG POWER PROCESSING GROUP

POWER INTERFACE DISTRIBUTOR

BERTHING DISTRIBUTOR

TYPICAL OF 12 SEGMENTS

TYPICAL OF 12 SEGMENTS

DC/DC CONV.

DC/DC CONV.

DC/DC CONV.

MAIN POWER DISTRIBUTOR FOR PM

FWD RACK DIST.

MID RACK DIST.

AFT RACK DIST.

SPECIAL CASE (i.e., DIST)

PPG DETAIL

BUCK CHARGE REGULATOR – p^3 –

REMOTE POWER CONTROLLER – RPC –

BUCK CHARGE REGULATOR – p^3 –

BATTERY POWER TRANSFER SWITCH

Solar Arrays

The solar array element is comprised of the solar array wings, drive assembly and deployment/retraction boom and mechanisms. Design details of the solar arrays are described in Reference 9.

The solar array drive assembly and solar array wings are attached to the Power Module forward support structure. The solar array panels are extendable/retractable and form an extended wing array 9 meters (30 feet) wide by 83.5 meters (271 feet) long. The SA has a single degree of rotation about the longitude axis for solar pointing and provides 60 kW peak output with 25 kW continuously to the user.

25 kW S/A EXTENSION SEQUENCE

The figure shows the sequencing of the array panels as they are extended or retracted by the extension/retraction mast.

25kW S/A EXTENSION SEQUENCE

CONTAINER

CONTAINER

MAST
CANNISTER

STOWED

CANNISTER

1.93M
(6.34FT)

CONTAINERS OPEN

9.17M
(30.09 FT)

START DEPLOYMENT

GUIDE WIRE

TENSION BAR

EXTENSION/RETRACTION MAST

COVER

40 M
(131.33 FT)

FULLY DEPLOYED

9.04 M (BLANKET)
(29.66 FT)

4-41
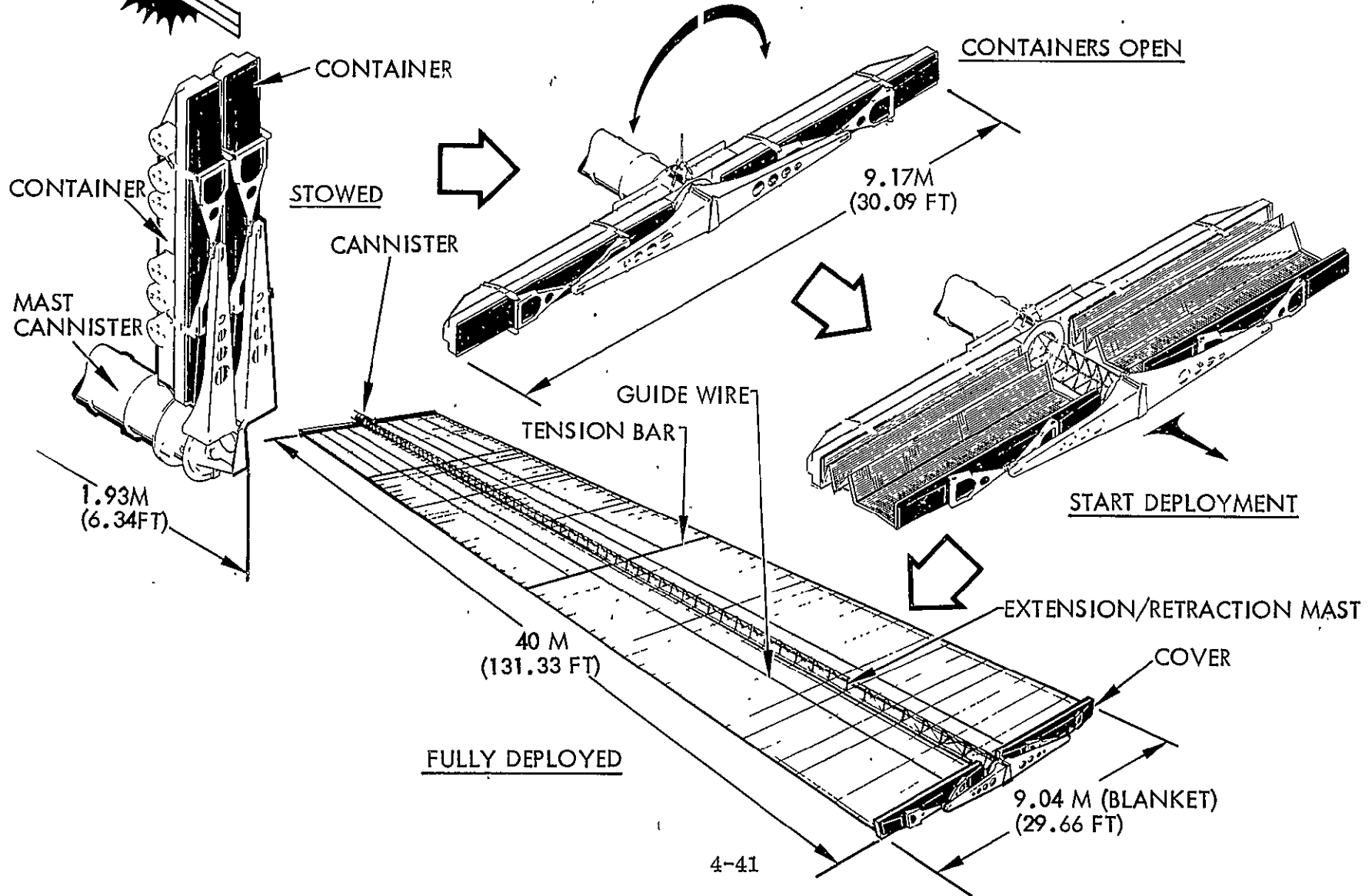
Solar Array Mast Capabilities

Analysis has shown it is feasible to use a common mast envelope for growth from 25 kW to 100 kW using a modular building block solar array system.

Characteristics of the mast are shown. The SEP-
type-technology deployment mast, capable of pro-
viding sufficient blanket tension to meet a greater-
than 0.04 Hz natural frequency requirement as
discussed in Volume 4, section 2, page 2-34 of
this Part III Final Report, is the baseline design.

SOLAR ARRAY MAST CAPABILITIES

60 IN. MAST OVERALL HT.

26 IN. DIA
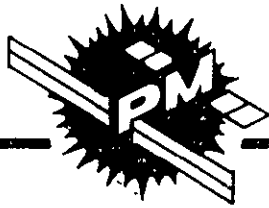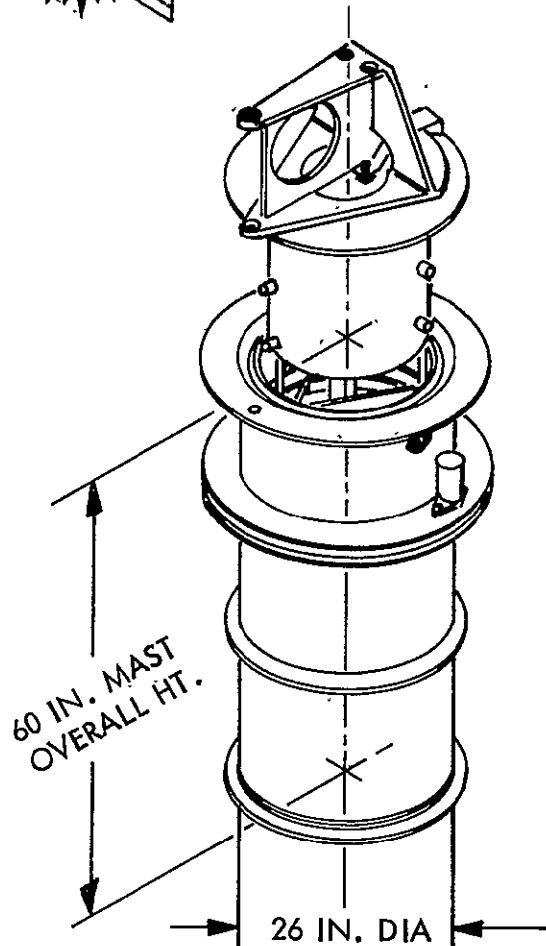
CONTINUOUS FIBERGLASS LONGERON

R = 11.0 IN.
WT = 180 LB.
G LEVEL = .004

$EI = 100 \times 10^6$ LB-IN^2

$M_{cr} = 330$ LB-FT

75 IN. MAST OVERALL HT.

26 IN. DIA
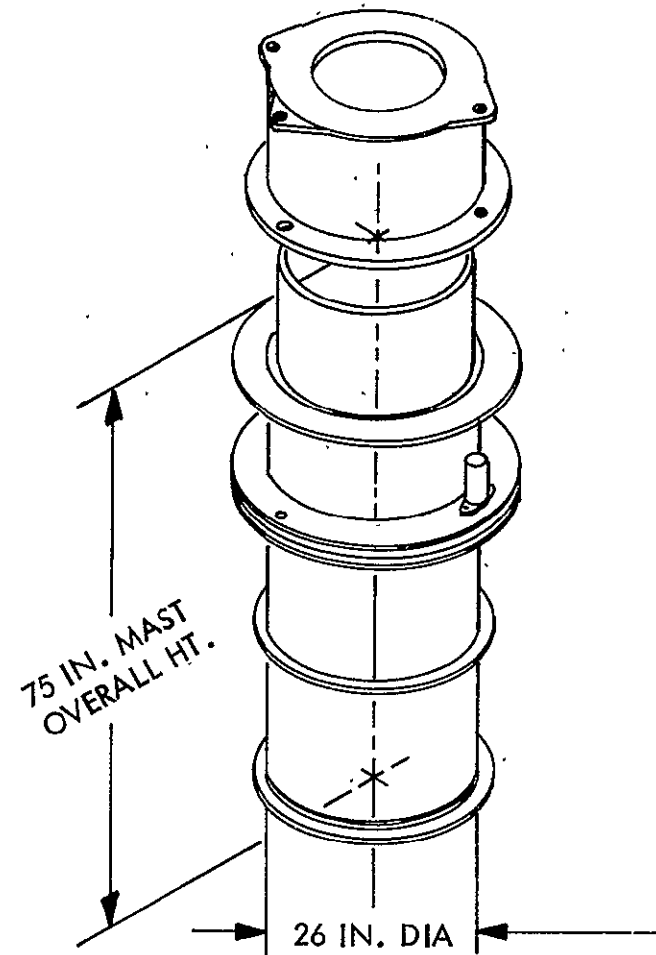
ARTICULATED STEEL LONGERON

R = 11.0 IN.
WT = 590 LB.
G LEVEL = .04

$EI = 300 \times 10^6$ LB-IN^2

$M_{cr} = 3300$ LB-FT

<u>Power Control</u>

EPS POWER CONTROL DIAGRAM

● Power from the solar array is partitioned into twelve segments. Control of this power is effected in the power processing group (PPG) shown in the chart. The PPG provides input regulation, charge control for energy storage, and output regulation to the power distribution system. The dedication of each of 12 solar array segments to one of 12 power processing groups follows from the application of 60 Ah nickel-cadmium batteries at approximately 20 percent depth-of-discharge (DOD). The use of 12 power source-energy storage elements can remain constant with evolutionary system growth, since battery DOD is conveniently programmed to increase with growth to 50 and 100 kW.

● The PPG will deliver regulated 28 VDC power to the power interface distributor (PID). Power to each docking berth will be provided by the berthing distributor. Power Module power requirements will be provided through PID and transformer coupled dc/dc converters, for isolation and conversion, to a main power distributer (MPD). From the MPD, power will be provided to a distributor box in the Power Module equipment rack.

● The buck regulator (P^3) provides three basic functions: (1) tracks the peak power point of the solar array, (2) converts solar array excess voltage into storable ampere-hours, (3) and controls the battery charge. This regulator both maximizes solar array energy and controls battery energy throughout the daylight portion of the orbit.

● The second major element of the PPG is the bus regulator. Here the choice of most efficient regulator is a function of the input-to-output voltage ratio. For this study LMSC has chosen to deliver regulated 28 volt power to the power interface distributor and then to the berthing distributor. This concept presumes that power is transferred to users through our berthing ports at only one voltage level. For example, the Orbiter (PEP electronics) would then provide any additional voltage conversion for Orbiter use while attached to the PM.

EPS POWER CONTROL

POWER SOURCE

S/A

DRIVE &
POWER
TRANSFER

S/A
DIST.

TYPICAL OF
12 ELEMENTS

RPC — REMOTE POWER
CONTROLLER

POWER PROCESSING GROUP

"p^3" BUCK
CHARGE
REGULATOR

150-180 VDC

REMOTE
POWER
CONTROLLER
(RPC)

"p^3" BUCK
REGULATOR

28±1 V.DC
TO POWER
INTERFACE
DISTRIBUTOR

BPTS

BATTERY POWER
TRANSFER SWITCH
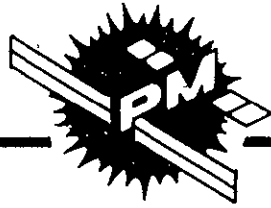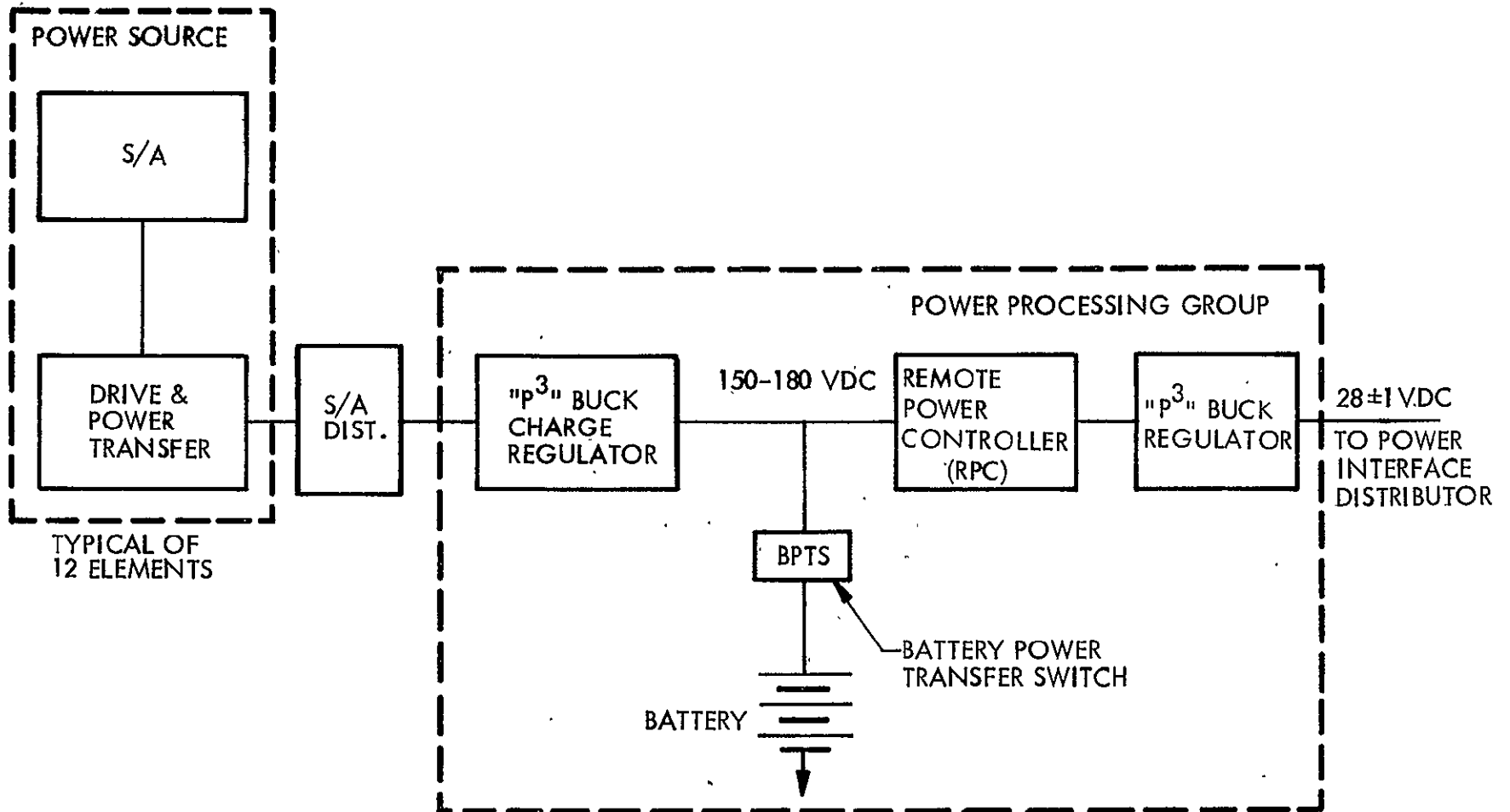
BATTERY

TYPICAL OF 12 ELEMENTS

EPS Component Characteristics

EPS weight for the first 25 kW system, based on 12-13 percent efficiency solar cells and 20 percent DOD Ni-Cd batteries, is shown below.

25 kW EPS CHARACTERISTICS/WEIGHT SUMMARY

Power (kW)	25
Cell Type (Lb/Ft^2)	Si, 0.2
Cell Efficiency (%)	12-13
Battery Type	Ni-Cd
DOD (%)	20
Voltage, DC Reg.	110/28
Weights	(Lb):
Solar Array	2,400
Solar Array Drive	200
Batteries	7,440
Electronics	1,395
Power Distribution	630
Wire Harness	500
Subtotal	12,565
Contingency-25%	3,141
TOTAL	15,706

25 kW POWER MODULE ELECTRICAL POWER SUBSYSTEM COMPONENTS LIST

EPS component characteristics are shown in the table. Components are selected to meet the performance requirements for the 25 kW PM in 1983 and subsequent evolutionary growth to 50 and 100 kW.

25kW POWER MODULE ELECTRICAL POWER SUBSYSTEM COMPONENTS CHARACTERISTICS LIST

ITEM NO.	COMPONENT	NO. REQ'D	PWR (WATTS)	SIZE (L X W X H) (IN.)	UNIT WT (LB)	TOTAL WT (LB)
1	BATTERY MODULE (TYPE 40) (Ni-Cd)	60	**	25 X 9 X 10	124	7440
2	BATTERY CONTROL ASSY	12		12 X 24 X12	55	660
3	BUS REGULATOR	12		12 X 24 X 12	55	660
4	SOLAR ARRAY WING	2		130 FT X 30 FT	1200	2400
5	SOLAR ARRAY DRIVE ASSY	2		TBD	100	200
6	POWER TRANSFER ASSY	2		TBD	100	200
7	DRIVE ELECTRONICS	1		12 X 12 X 12	30	30
8	DC/DC CONVERTERS	3		12 X 12 X 9	15	45
9	POWER INTERFACE DISTRIBUTOR	1		40 X 17 X 10	150	150
10	MAIN POWER DISTRIBUTOR	1		17 X 17 X 8	50	50
11	SOLAR ARRAY DISTRIBUTOR	1		17 X 17 X 8	30	30
12	BERTHING DISTRIBUTOR	1		30 X 17 X 10	100	100
13	RACK DISTRIBUTORS	3		17 X 17 X 8	30	90
14	REMOTE POWER CONTROLLERS	30		4 X 7 X 5	< 0.5	10
15	POWER CABLES				500	500

Subsystem Performance Characteristics

EPS system power requirements are based on delivering 25 kW of power to external loads and 1.9 kW to meet PM demands. This 26.9 kW requirement will be met for a 5 year mission by the subject EPS.

25 kW EPS PERFORMANCE CHARACTERISTICS

- Performance characteristics for the major EPS components are shown in the figure.

- The basic 25 kW solar array size (29 ft x 275 ft) provides a 13 percent margin in power at end of life (EOL), based on the power conversion efficiency and line loss assumption made. This margin may be treated as a measure of overall reliability, since up to 3 of 12 S/A-battery strings could fail so long as the power interface distributor can redistribute the power to the loads.

- "p^3" regulator efficiency is assumed to be 97 percent in regulation of S/A output and 88 percent in the conversion to 28 volts.

- The Eagle-Picher RSN-55-3 Ni-Cd battery cell (which was developed for and is used by Lockheed in other programs) is a measured 60 Ah cell. Based on measured values from flight experience, the DODs can be treated as actual performance capability.

25kW EPS PERFORMANCE CHARACTERISTICS

SOLAR ARRAY
730 M^2
(2 WINGS)
204 PANELS

180 VDC
66.3 kW (BOL)
62.2 kW (EOL)

LINE & POWER
TRANSFER
$\eta = 0.965$
(WITH DIODE)

64. kW (BOL)
60 kW (EOL)

"P^3" BUCK
CHARGE
REGULATOR
(12)
$\eta = 0.97$

23.2 kWh ↓   ↑18.6 kWh (2)

NiCd
BATTERY
110 – 60Ah
CELLS
(12)
19% DOD
$\eta = 0.80$

155-170 VDC
62.1 kW (BOL)
58.2 kW (EOL)

BOL – BEGINNING OF LIFE
EOL – END OF LIFE

RPC
(12)
$\eta = 0.99$

39.9 kW (BOL)
36.0 kW (EOL)

"P^3" BULK
REGULATOR
(12)
$\eta = 0.88$

28 VDC
35.1 kW (BOL)
30.7 kW (EOL)

RPC
(12)
$\eta = 0.99$
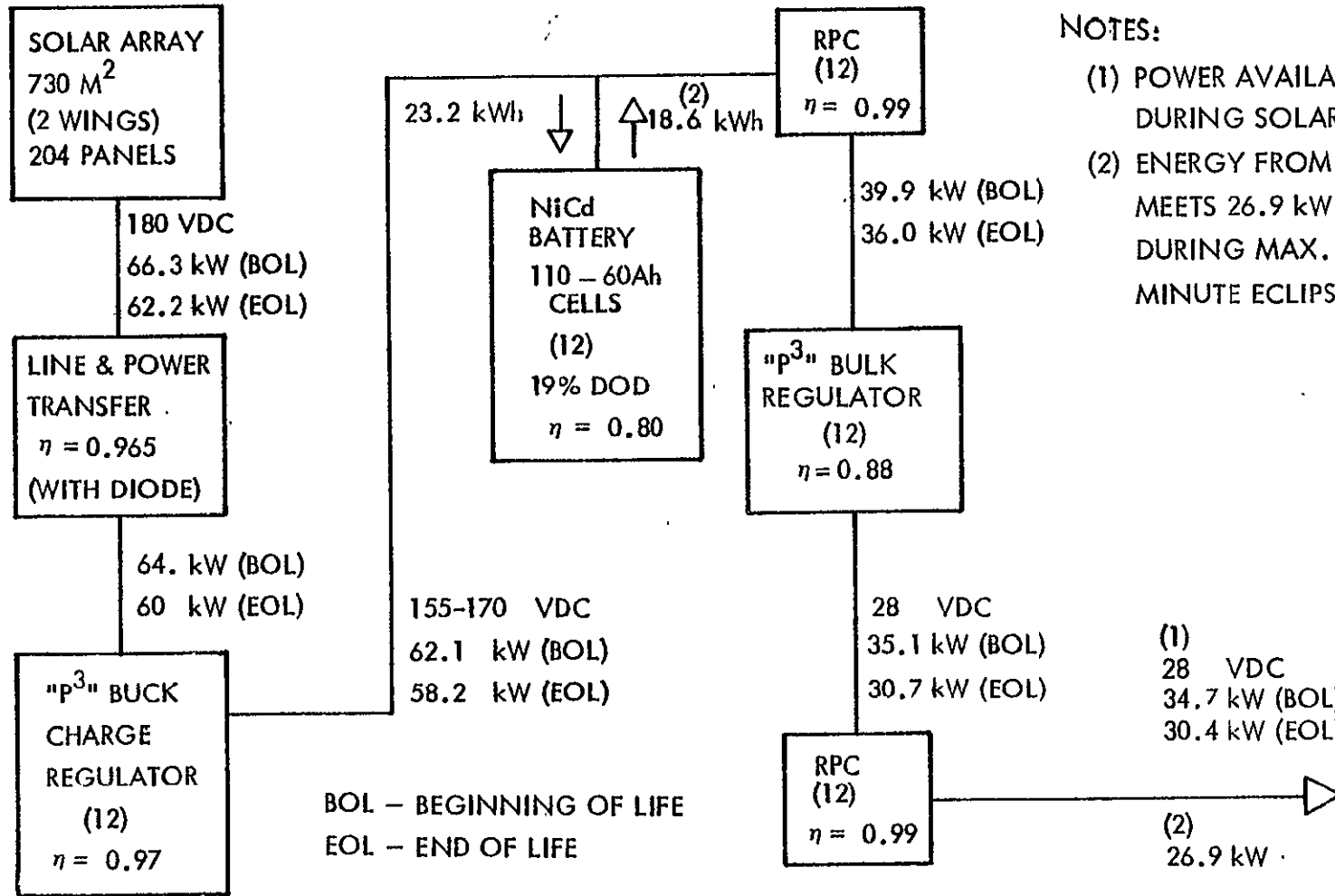
NOTES:
(1) POWER AVAILABLE
DURING SOLAR ILLUMINATION
(2) ENERGY FROM BATTERIES
MEETS 26.9 kW DEMAND
DURING MAX. 35.7
MINUTE ECLIPSE

(1)
28 VDC
34.7 kW (BOL)
30.4 kW (EOL)

(2)
26.9 kW

4.3.3 25 kW Thermal Control Subsystem

The Power Module thermal control subsystem (TCS) is based on a Freon-21 pumped coolant loop and deployable radiators for rejecting heat. This approach provides the necessary control flexibility to handle the wide range of equipment tasking and component locations and substitutions. Extensive use has been made of coolant-loop components and technology developed for the Shuttle Orbiter. A hybrid heat pipe/fluid loop header radiator design has been selected to replace the existing Orbiter all fluid radiators. This substitution was chosen to provide reliability for radiators exposed to the potentially hazardous micro-meteoroid environment.

Functions/Requirements

The thermal control subsystem is designed to maintain Power Module temperature within limits while simultaneously providing some heat rejection capability for the attached payloads. The major functional elements of the TCS are: (1) deployable heat rejection radiators, (2) pumped Freon-21 coolant-loop and flow control, (3) battery and equipment mounting cold plates, (4) payload heat exchange and flow control. The functions are similar to those of the Shuttle Orbiter thermal control and the technology developments for the Orbiter have been incorporated into the Power Module system where possible.

Early definition of the Power Module battery, power conversion, and spacecraft guidance and communications component requirements provided the minimum heat rejection design requirements. Existing electrical component design and anticipated battery charge and discharge cycles result in a total of 9 kW internally generated heat load in the Power Module. The batteries are to be controlled to approximately 50°F for efficient operation and the remaining equipments can typically be operated at a room temperature level of 70 ±50°F.

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POWER MODULE THERMAL CONTROL SYSTEM

● The figure is a block diagram showing the major elements of the TCS Freon-21 coolant loop for the Power Module. It is a dual-loop system designed to maintain the batteries and electrical components at 50 to 110°F temperatures in all attitudes and operational environments. A payload heat exchanger is included in the system to provide payload cooling for up to 40 percent of the supplied electrical power. Minor check valves, filters, etc. are not included in the diagram.

● The primary components in the coolant loop include the cold plates which provide a structural tray for the batteries and heat dissipating components and through their sandwich type construction function as a heat exchanger. The hot Freon-21 is then pumped through the deployed radiators using one of the two pumps shown in each loop's pump package. These pumps are identical to the 2500 pound/hour pumps developed for the Shuttle Orbiter. The pumps have an expected life of 23,000 hours, which is less than the five-year requirement for the Power Module. Therefore, it is expected that it will be necessary to switch to the redundant pump in each loop prior to completing a five-year mission.

● The hot Freon-21 then enters the deployed radiator panels where the heat can be rejected to space. These panels include a Freon-21 manifold which transfers heat to the evaporator section of the attached heat pipes. The heat pipes distribute the heat over the extended radiator panels. The temperature of the liquids returning to the spacecraft equipment sections will be 40°F or less. The temperature is dependent on the system heat load and the external environment. The PM equipment section inlet temperature of 40°F is maintained by an automatic mixing valve which senses the radiator outlet temperature and subsequently allows some of the coolant to bypass the radiators.

● The coolant pumps will operate continuously, with the mixing valve controlling the equipment section inlet temperature to 40°F regardless of equipment tasking levels or spacecraft attitude. With each pump package pumping 2500 pound/hour flow, the dual-loop cold plates are provided 5000 pounds of Freon per hour. In the event of a failure of either coolant loop, sufficient flow will be maintained to provide cooling for the PM equipment. In the event the pump package in one loop and the radiator elements of the other simultaneously fail, a normally closed cross-over valve will function to maintain operation.

POWER MODULE THERMAL CONTROL SYSTEM

FLOW CONTROL
MIXING VALVE

FLOW CONTROL
MIXING VALVE

40°F

40°F

GSE HEAT
EXCHANGER

10 PANELS
18 TO 24 KW
TOTAL HEAT
REJECTION

RADIATOR

RADIATOR

BATTERY
COLD PLATES
4 kW

OPTIONAL HEAT REJEC.
FROM PM SURFACES

51°F

PAYLOAD HEAT
EXCHANGER
9 kW TO 15 kW

≈ 60°F

ORBITER OR
PAYLOAD HEAT

90°F

PM EQUIPMENT
COLD PLATES
5 kW

OPTIONAL HEAT REJEC.
FROM PM SURFACES

103°F

NOTE:
FLUID TEMPERATURES SHOWN
FOR 5,000 LB/HR FLOWRATE

DUAL PUMP PACKAGES
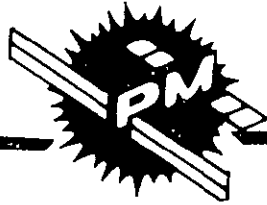
HEAT PIPE RADIATOR DESIGN CONCEPT

A heat pipe radiator design concept is shown in the figure. This concept is recommended for the 1/4 inch diameter heat pipes. The heat pipes distribute the heat over the extended radiator panels. The liquid temperatures returning to the spacecraft equipment sections will be 40°F or less. This temperature is dependent on the system heat load and the external environment. The PM equipment section inlet temperature of 40°F is maintained by an automatic mixing valve which senses the radiator outlet temperature and subsequently allows some of the coolant to bypass the radiators.

The Freon manifold is located in the center of the panel to reduce the condenser length of the heat pipes thereby preventing boilout in the condenser at the design heat rejection levels. The radiator panel shown is designed for a 6 kW load whereas the 5 ft by 13.5 ft panels selected for the final design will be capable of approximately 3 kW heat rejection. The heat pipe evaporator sections are angled across the manifold to increase the contact length while minimizing the width of the manifold exposed to the meteoroid environment.

HEAT PIPE RADIATOR DESIGN CONCEPTS

15 FT

B

B

A

A

2 IN. RADIUS BEND

10 FT

9 IN.

COOLANT
RETURN

COOLANT
SUPPLY INLET

EVAPORATOR SECTION

1.9 IN.

1 IN.

5/8 IN.

1/4 IN.

COMPACT HEAT
EXCHANGER
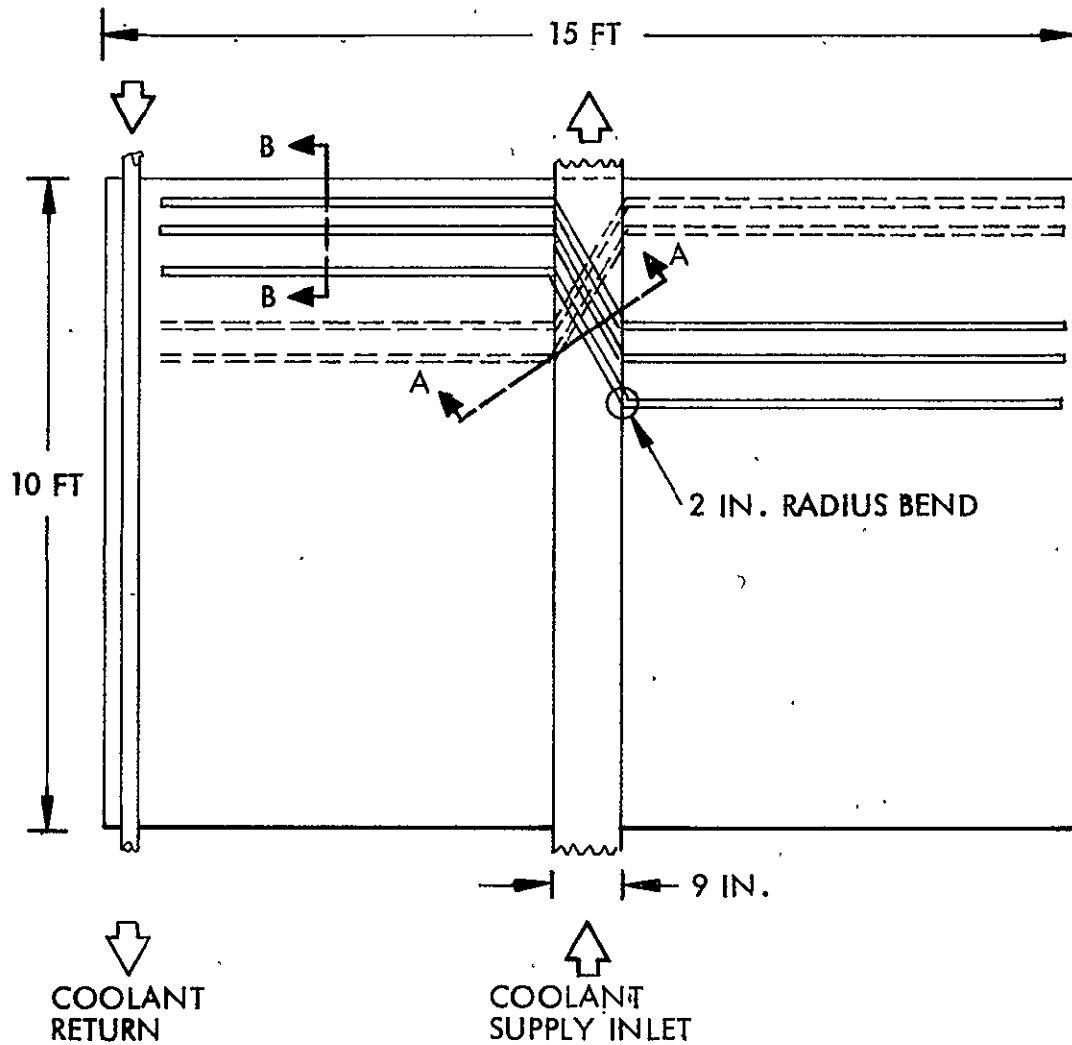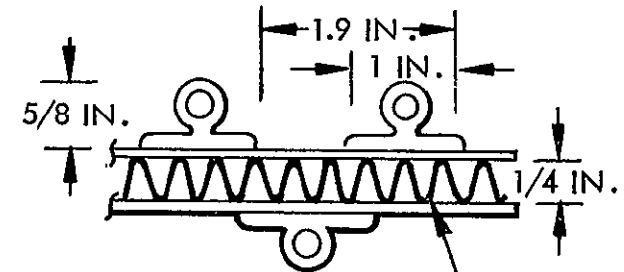
SECTION A-A

CONDENSER SECTION

4.8 IN.

1/2 IN.

FLAT
SURFACE

RADIATOR PANEL
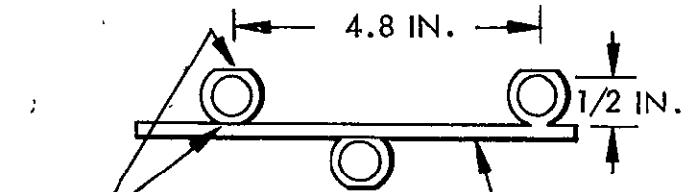
SECTION B-B

Component Characteristics

A summary of TCS weights is given below.

25 kW TCS WEIGHT SUMMARY

ITEM	WEIGHT (LBS)
Radiator, Structure, Motors	1035
Cold Plates, Lines	565
Pumps, Controls	177
Insulation, Paint	100
Heat Exchangers	137
Subtotal	2014
Contingency - 25%	504
TOTAL	2518

25 kW POWER MODULE THERMAL CONTROL SUBSYSTEM COMPONENTS LIST

Characteristics of the TCS components are given in the table.
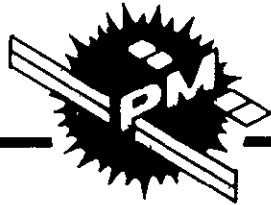
25kW POWER MODULE
THERMAL SUBSYSTEM PHYSICAL CHACTERISTICS

ITEM NO.	COMPONENTS	NO. REQ'D	PWR (WATTS)	SIZE (L X W X H) (IN.)	UNIT WT (LB)	TOTAL WT (LB)
1	RADIATOR	10		162.0 X 60.0 X 0.925	94.5	945
2	COLD PLATES	24		TBD	21.7	520
3	PUMP, ACCUMULATOR, CHECK VALVE, INVERTER	2	500(AC)	7.9 X 3.5 X 3.5 13.1 (D) X 27.2	58.0	116
4	PRESSURE TRANSDUCERS	2		TBD	5.0	10
5	FLOW CONTROL ASSEMBLY (MIXER VALVE)	2	57.5	24 X 20 X 9	25.5	51
6	PAYLOAD H_X	1		TBD	120.0	120.0
7	GSE H_X	1		TBD	17	17.0
8	LINES FASTENERS, CONNECTORS, FILTERS, SOLENOID VALVES	TBD			45	45
9	INSULATION	N/A			100	100
10	HEATERS	1	TBD		TBD	TBD
11	MOTOR AND MECHANISM TO DEPLOY THE RADIATORS	20	TBD		2.0 (EST)	40.0
12	FREON 21	N/A			TBD	
13	RADIATOR SUPPORT STUCTURE	1			50	50

Subsystem Performance

The coolant loop schematic in the TCS block diagram (Page 4-53) shows the location of the cold plates and the payload heat exchanger. The batteries are most efficient at approximately 50°F and are "first in line" in the coolant loop. At maximum charge/discharge operation the batteries are expected to generate 4 kW of waste heat. This will result in a Freon temperature rise of 11°F at 5000 lb/hr. The payload heat exchanger which is downstream from the batteries, will have an inlet temperature of 51°F. It will return 60°F coolant to the payloads. A maximum PM coolant temperature rise of 39°F will occur in the heat exchanger, resulting in 93°F coolant available to the remaining Power Module equipment. The temperature rise in the payload heat exchanger is directly proportional to the payload heat load.

The thermal analysis of the heat rejection levels of the radiator panels was based on calculating the absorbed solar, albedo, and earthshine energy on the panel surfaces. The solar and earthshine heat input to the radiators significantly influenced the radiator rejection performance. The direct radiant energy exchange between the 80°F (orbit-average) to 120°F solar arrays and the radiators was shown to significantly affect radiator performance. Based on this analysis, the radiators are deployed away from the solar arrays and oriented to minimize the solar heat load. Optimum radiator locations included a tradeoff between thermal, fields-of-view, and mechanical design considerations.

The ten-panel radiator system of 5 x 13.5 ft panels (total area of 675 ft) will reject from 18 to 24 kW. The variation in heat rejection is the result of variations in solar incidence angles and spacecraft orientation as it affects incident earthshine. With the Power Module dissipating a maximum of 9 kW, a surplus capability of 9 to 15 kW is available for payload cooling. The 9 to 15 kW is reduced approximately 1 kW in the sortie mode because of orbiter surface influences.

POWER MODULE HEAT REJECTION PERFORMANCE

A summary of the radiator performance is shown in the figure for the 25 kW configuration. The heat rejection values correspond to maximum Power Module dissipation and the average minimum radiator capability. The total radiator capability of 19.5 kW will be increased approximately 25 percent if the radiators are edge-lit by the sun, with a resulting 50 percent increase in payload cooling.

POWER MODULE HEAT REJECTION PERFORMANCE

CONFIGURATION	FREON-21 MASS FLOW RATE (LB/HR)	HEAT REJECTION (kW)			FREON TEMP (^{o}F)		RADIATOR AREA (FT^2)	NO. OF PANELS/ CONFIGURATION (3)
		PM	P/L[1]	TOTAL[2]				
25 kW	5,000	9	13.1	22.1	58	40/98	675	10

NOTES: (1) HEAT REJECTION AVAILABLE TO PAYLOAD MAY BE USED FOR MANNED HABI-TAT CONTROL. 10 kW ESTIMATED FOR 3-MAN OCCUPANCY.

(2) TOTAL HEAT REJECTION INCLUDES EFFECTS OF BETA ANGLE, SUN INCIDENT UP TO 30°, AND EARTHSHINE.

(3) WITH THE 10 PANEL RADIATOR CONFIGURATION THERE IS VERY LITTLE HEAT REJECTION DIFFERENCES BETWEEN THE PM IN SORTIE AND FREE-FLYING MODES.

Thermal Interface

The payloads will reject heat from the Power Module radiators through the payload heat exchanger in the PM coolant loop. This heat exchanger is designed to extract 15 kW from the payload coolant loop. This level of payload cooling applies with a 110°F payload inlet temperature and 60°F return temperature. The payload heat exchanger design is based on the fuel cell heat exchanger developed by Hamilton Standard for the Orbiter. This unit is modified to accept up to four separate payloads, with each payload varying in cooling requirements and priority. It is anticipated that the individual payloads will provide their own coolant loop control to match available cooling. However, the Power Module interface will assume ultimate payload cooling availability through a flow control module.

PAYLOAD HEAT EXCHANGER INTERFACE

The functions of this control module shown in the figure include monitoring payload loop temperatures and flow rates and bypassing the heat exchanger to protect against payload overload. Alternate control concepts have been provided by Hamilton Standard; however, the one shown results in the highest flexibility and hardware simplicity.

PAYLOAD HEAT EXCHANGER INTERFACE

ORBITER
OR PAYLOAD

POWER MODULE

FLOW
METER

TEMP
SENSOR

PM COOLANT
RETURN TO
RADIATORS

90°F
(MAX

BYPASS FLOW
CONTROL VALVE

~110°F INLET
ORBITER OR
PAYLOAD HEAT
60°F OUTLET

PAYLOAD HEAT
EXCHANGER
9 kW TO 15 kW

51°
POWER MODULE
COOLANT LOOP
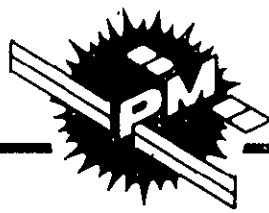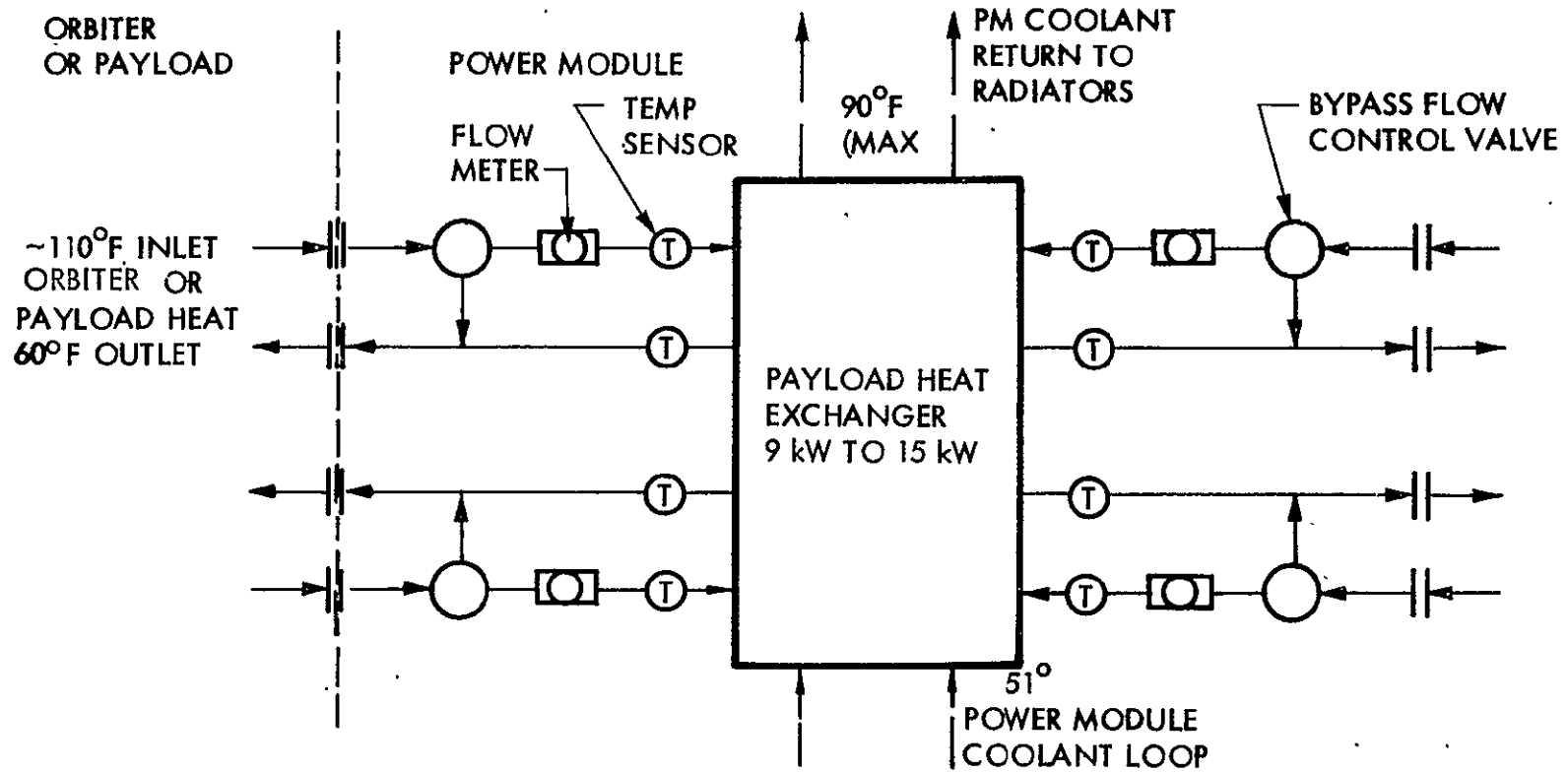
4.3.4 Attitude Control Subsystem

Function/Requirements

The Attitude Control Subsystem (ACS) provides for three-axis attitude determination and vehicle pointing for solar array, experiment, and antenna pointing, and three-axis stability for vehicle control and experiment performance for both the free-flying and sortie modes. In addition, stabilization of the free-flying Power Module for retrieval by the Orbiter Remote Manipulator System is provided. An ancillary stability capability permits retrieval under contingency conditions.

Subsystem Description

25 kW POWER MODULE ATTITUDE CONTROL SUBSYSTEM BLOCK DIAGRAM

The ACS functional block diagram is shown in the chart. The ACS is comprised of elements for three functions:

- Primary pointing and stability
- Attitude determination.
- Contingent stability and desaturation

The primary pointing and stability system utilizes gyros to sense vehicle rates, a double gimbal CMG momentum exchange system for vehicle actuation, and information from the attitude determination element for vehicle pointing. Desaturation is provided by the Orbiter in the sortie mode, and primarily by gravity gradient torques in the free-flying mode.

The attitude determination element employs both sun and earth sensors. Contingent stability is provided by a magnetic torquing system, which also can be used to assist in the desaturation of the momentum exchange system. Critical to the ACS is the Command and Data Handling Subsystem which provides real time and stored commands, vehicle pointing and stability computations, CMG steering logic, desaturation logic, and redundancy management.

ATTITUDE CONTROL SUBSYSTEM
FUNCTIONAL BLOCK DIAGRAM

CONTINGENT
STABILITY &
DESATURATION

MAGNETOMETER
& ELECTRONICS

4 MAGNETIC TORQUERS
& ELECTRONICS

ATTITUDE
DETERMINATION

2 HORIZON SENSOR
SYSTEMS

1 WIDE ANGLE SUN
SENSING SYSTEM

2 POINTING
SUN SENSORS

COMMAND &
DATA HANDLING
SUBSYSTEM &
ELECTRICAL POWER

PRIMARY
POINTING
& STABILITY

9 RATE GYROS

SIGNAL CONDITIONER
& INTERFACE UNIT

3 CMGs &
ELECTRONICS

ACS
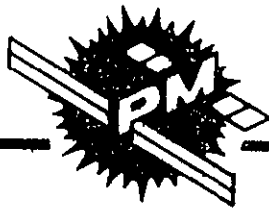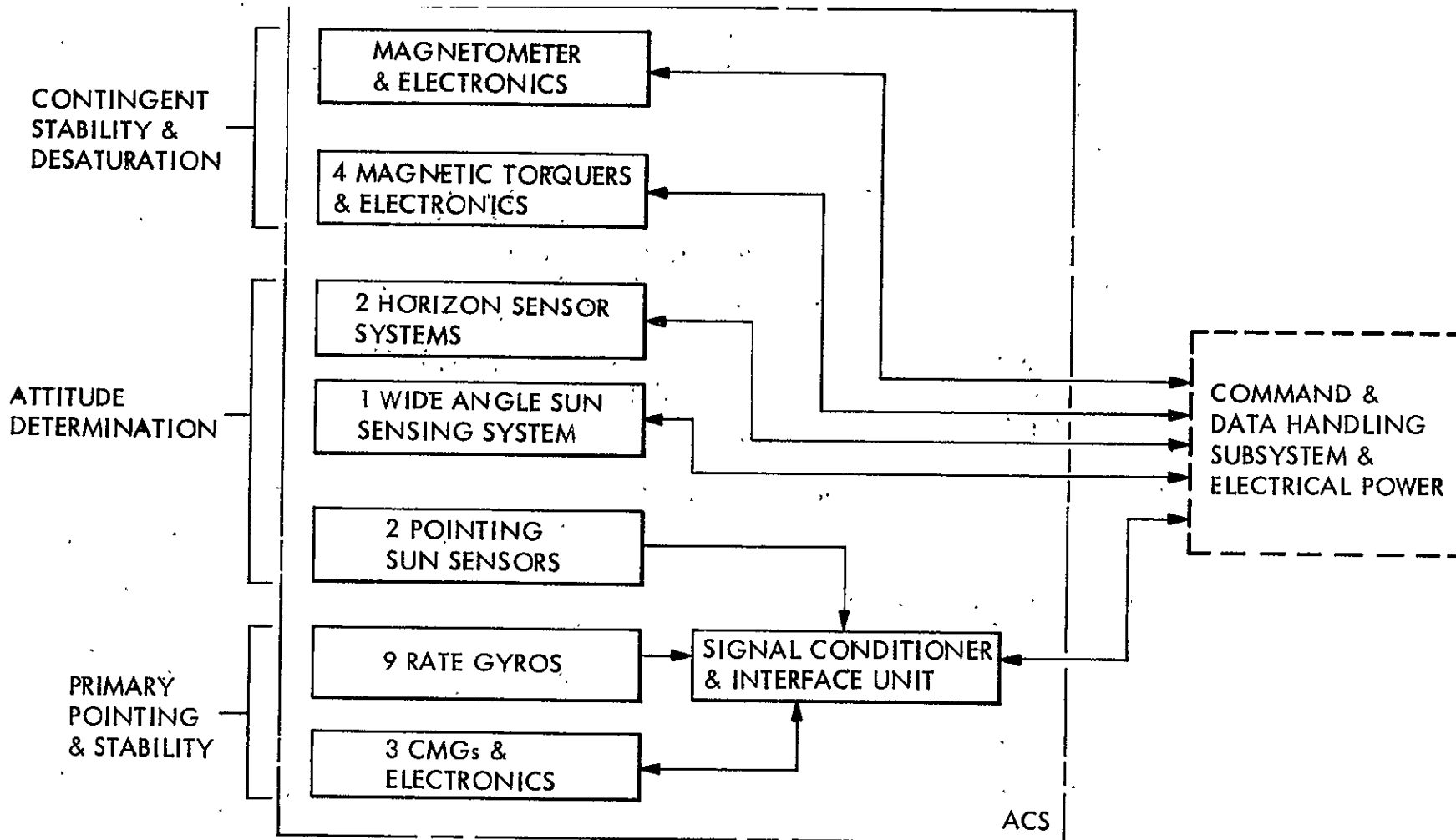
Component Characteristics

The components were principally selected as flight-proven hardware which will minimize mission risk, or provide commonality with existing programs. The pointing sun sensors, rate gyros, and CMGs were components of the Skylab ATM attitude and pointing control subsystem. It is currently planned to refurbish the CMGs by replacing the rotors, providing unlimited gimbal freedom, and improving the rotor lubrication system.

The wide-angle sun sensing system has flown on the Naval Research Laboratory NTS-1. The horizon sensors are currently being developed for an early Spacelab mission. The magnetic torquing system uses components of the Space Telescope pointing control system. The signal conditioner and interface unit is a new component required to make the existing ATM hardware compatible with the command and data handling subsystem.

ACS weights for the 25 kW System are given below:

25 kW ACS WEIGHT SUMMARY

ITEM	WEIGHT (LB)
CMGs and Inverters	1416
Rate Gyros	104
Signal Conditioner and Interface Units	90
Horizon Sensors/Electrical	54
Magnetic Torquers/Electrical	456
Miscellaneous	18
Subtotal	2138
Contingency-25%	535
TOTAL	2673

25 kW POWER MODULE ATTITUDE CONTROL SUBSYSTEM COMPONENT CHARACTERISTICS LIST

The physical characteristics of the ACS components are summarized in the table.

25kW POWER MODULE ATTITUDE CONTROL SUBSYSTEM COMPONENT CHARACTERISTICS LIST

ITEM NO.	COMPONENT	MANUFACTURER	REQ'D	POWER (WATTS)	SIZE (L X W X H) IN.	UNIT WT (LB)	MTBF (HR)
1	SUN SENSOR #1	BALL	1	N/A	6.9 X 6.5 X 3	3.7	0.20×10^6
2	SUN SENSOR #2	BALL	1	N/A	6.9 X 6.5 X 3	3.7	0.20×10^6
3	SS ELECTRONICS ASSY #1	BALL	1	1.2	5 X 5 X 2	1.33	0.58×10^6
4	SS ELECTRONICS ASSY #2	BALL	1	1.2	5 X 5 X 2	1.33	0.58×10^6
5	ATM RATE GYRO #1 X-1	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
6	ATM RATE GYRO #2 X-2	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
7	ATM RATE GYRO #3 X-3	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
8	ATM RATE GYRO #4 Y-1	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
9	ATM RATE GYRO #5 Y-2	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
10	ATM RATE GYRO #6 Y-3	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
11	ATM RATE GYRO #7 Z-1	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
12	ATM RATE GYRO #8 Z-2	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
13	ATM RATE GYRO #9 Z-3	MARTIN/KEARFOTT	1	19-45	12 X 8.76 X 5.5	11.5	19,000
14	CMG #1	BENDIX	1	Note 1	39" SPHERE	420.0	28,000
15	CMG #2	BENDIX	1	Note 1	39" SPHERE	420.0	28,000
16	CMG #3	BENDIX	1	Note 1	39" SPHERE	420.0	28,000

NOTES: 1. EACH CMG RECEIVES ITS POWER FROM A CMG INVERTER ASSEMBLY ONLY.

2. IF CMG WHEEL IS AT OPERATING SPEED, NO TORQUE IS BEING EXERTED ON VEHICLE, BEARING HEATERS OFF, EACH CMG INVERTER ASSEMBLY DRAWS APPROX 160 WATTS, 28 VDC. HEATERS REQUIRE 52 WATTS PER CMG. VEHICLE TORQUING REQUIRES 0-160 WATTS, ADDITIONAL.
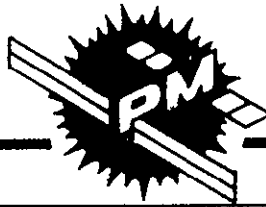
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25kW POWER MODULE ATTITUDE CONTROL SUBSYSTEM COMPONENT CHARACTERISTICS LIST (CONT.)

ITEM NO.	COMPONENT	MANUFACTURER	REQ'D	POWER (WATTS)	(L X W X H)(IN.)	UNIT WT (LB)	MTBF (HR)
17	CMG INVERTER ASSEMBLY (CMG #1)	BENDIX	1	NOTE 2	25 X 22.5 X 3.5	52.0	58,000
18	CMG INVERTER ASSEMBLY (CMG #2)	BENDIX	1	NOTE2	25 X 22.5 X 3.5	52.0	58,000
19	CMG INVERTER ASSEMBLY (CMG #3)	BENDIX	1	NOTE 2	25 X 22.5 X 3.5	52.0	58,000
20	X AXIS HORIZON SENSOR #1	ITHACO	1	N/A	3.6 DIA X 5 L	2.0	
21	Z AXIS HORIZON SENSOR #1	ITHACO	1	N/A	3.6 DIA X 5 L	2.0	58,000
22	ELECTRONICS PACKAGE #1	ITHACO	1	6.0	6.4 X 6.4 X 5.6	5.0	
23	X AXIS HORIZON SENSOR #2	ITHACO	1	N/A	3.6 DIA X 5 L	2.0	
24	Z AXIS HORIZON SENSOR #2	ITHACO	1	N/A	3.6 DIA X 5 L	2.0	58,000
25	ELECTRONICS PACKAGE #2	ITHACO	1	10.0	6.4 X 6.4 X 5.6	5.0	
26	MAGNETOMETER	SCHONSTED	1	N/A	2.75 X 2.75 X 4.69	1.5	
27	MAGNETOMETER ELECTRONICS	SCHONSTED	1	2.0	5.37 X 6.5 X 3	2.5	24,000
28	MAGNETIC TORQUER ELECTRONICS	PRIME	1	122.0	9 X 9 X 12	16.0	316,000
29	MAGNETIC TORQUERS	ITHACO	4	N/A	4 X 4 X 92	109.0	14.3×10^6
30	WIDE ANGLE SUN SENSOR	ADCOLE	5	5.0	3.18 X 3.18 X 0.8	0.56	
31	WIDE ANGLE SUN SENSOR ELECTRONICS	ADCOLE	1	0.12	3.5 X 4.5 X 1.16	0.65	570,000
32	SIGNAL CONDITIONING AND INTERFACE UNIT (CHARACTERISTICS ESTIMATED)	PRIME	2	20.0	12 X 18 X 8	45.0	6,000

1. EACH CMG RECEIVES ITS POWER FROM A CMG INVERTER ASSEMBLY ONLY.

2. IF CMG WHEEL IS AT OPERATING SPEED, NO TORQUE IS BEING EXERTED ON VEHICLE, BEARING HEATERS OFF, EACH CMG INVERTER ASSEMBLY DRAWS APPROX 160 WATTS, 28 VDC. HEATERS REQUIRE 52 WATTS PER CMG. VEHICLE TORQUING REQUIRES 0-160 WATTS, ADDITIONAL.

Subsystem Performance Characteristics

ATTITUDE CONTROL SYSTEM REQUIREMENTS

The Attitude Control Subsystem (ACS) conforms to the requirements of the Power Module System Design Requirements Document, MSFC-SPEC-582, Revision A, May 1, 1978. In addition, Orbiter pointing accuracy and stability performance requirements, as described in reference 6, were used as guidelines. The ACS requirements are summarized in the chart.

ATTITUDE CONTROL
SUBSYSTEM REQUIREMENTS

- SHUTTLE EQUIVALENT POINTING ACCURACY AND STABILITY FOR
STO AND SPACE SCIENCE EXPERIMENTS, FOR A 25 kW POWER MODULE
IN BOTH FREE-FLYING AND SORTIE MODES
  - POINTING ACCURACY ±0.5 DEGREE (3 SIGMA) HALF-CONE ANGLE
  - STABILITY (DEADBAND) ±0.1 DEGREE PER AXIS
  - STABILITY RATE ±0.01 DEGREE PER SECOND PER AXIS

- 10^{-5} G ENVIRONMENT FOR MATERIAL PROCESSING, FOR BOTH FREE-
FLYING AND SORTIE MODES

- ±0.5 DEGREE (3 SIGMA) HALF-CONE ANGLE POINTING ACCURACY
FOR ANTENNA POINTING

- DESATURATION CAPABILITY IN FREE-FLYING MODE

- RETRIEVAL CAPABILITY
  GRAPPLE POINT   LIMIT CYCLE AMPLITUDE: ±3 INCHES
                  LIMIT CYCLE RATE: 0.1 DEGREE PER SEC

- 4π STERADIAN SENSOR FOR SOLAR ACQUISITION

- SENSORS FOR SOLAR POINTING

Primary Pointing and Stability Element

This element of the ACS, comprised of nine rate gyros and three CMGs, uses input data from the attitude sensors. In addition to the hardware, there is a software requirement imposed on the digital computer which is an element of the C&DH subsystem.

ATTITUDE CONTROL SUBSYSTEM SOFTWARE REQUIREMENTS

The ACS software requirements are shown in the chart.
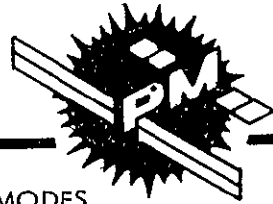
SOFTWARE REQUIREMENTS

MODES

ATTITUDE HOLD

MANEUVER

COMMAND

SOFTWARE

DISTURBANCE TORQUES	VEHICLE	ATTITUDE SENSORS	BODY POSITION	VEHICLE 3-AXIS CONTROL LAW	TORQUE COMMANDS	CMG STEERING LAW	GIMBAL RATE COMMANDS	CMGs
		RATE GYROS	RATES			REDISTRIBUTION		
						DESATURATION		

TORQUES

4-71
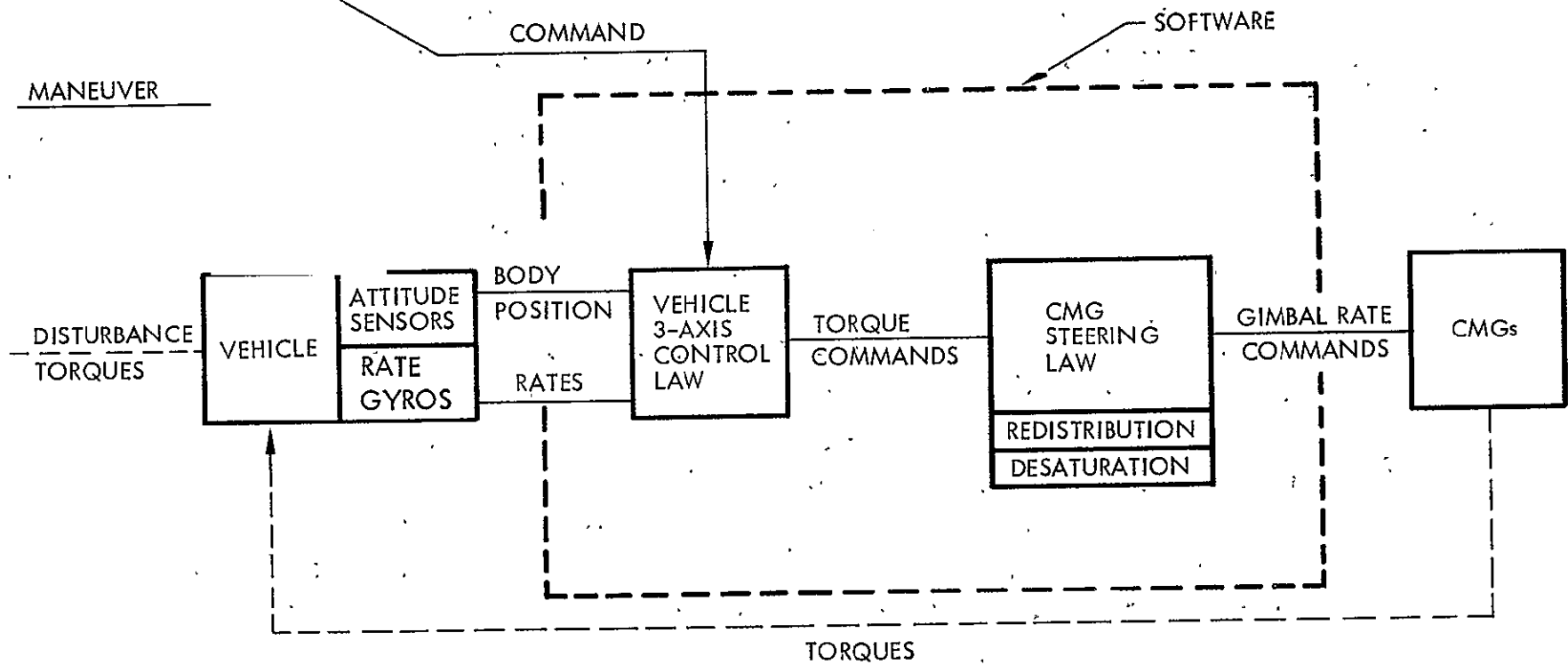
RATE GYROSCOPE PERFORMANCE CHARACTERISTICS

- The ATM rate gyro package consists of a single Kearfott rate integrating gyro (King Series, C702519018) and associated electronics which allow it to operate in a rate mode. It is designed to operate over two selectable ranges of rate inputs. The low range, the fine mode, has a scale factor of 450 volts per degree per second for inputs up to 0.1 degree per second. The coarse mode has a scale factor of 45 volts per degree per second for inputs up to 1.0 degree per second. These scale factors result in rate output commands of 0 ± 45 VDC to be supplied from each package.

- Self-test provisions permit the gyro to be torqued electrically by a test signal with no rate input. The resulting gyro output checks the servo loop including the range change operation.

- The electronics include a 4.8 kHz generator, AC amplifier, 3-phase inverter, demodulator, power supply, torquer driver, and heater control.
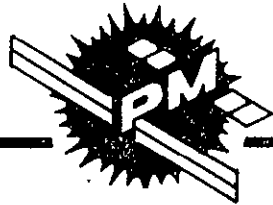
RATE GYROSCOPE
PERFORMANCE CHARACTERISTICS

ELECTRICAL

RATE (MAXIMUM)
COARSE MODE   ±1 DEG/SEC
FINE MODE   ±0.1 DEG/SEC

MAXIMUM VOLTAGE OUTPUT – EITHER MODE   0 TO ±45 VDC
NULL UNCERTAINTY   2.0 MILLIVOLT

TRANSFER FUNCTION
COARSE MODE

$$\frac{45 \text{ VDC/DEG/SEC}}{\left(\frac{S}{180}\right)^2 + \frac{2\,(0.7)\,S}{180} + 1}$$

FINE MODE

$$\frac{450 \text{ VDC/DEG/SEC}}{\left(\frac{S}{50}\right) + \frac{2\,(0.8)\,S}{50} + 1}$$

NULL DRIFT RATE.
COARSE MODE (COMPENSATED)   0.1 DEG/HOUR
FINE MODE (COMPENSATED)   0.1 DEG/HOUR

BANDPASS
COARSE MODE   26 ±4 Hz
FINE MODE   8 ±1 Hz

SPIN-UP TIME   90 SECONDS

POWER:
RUNNING   12 WATTS (ESTIMATED)
HEATER   0 TO 25 WATTS

NULL DRIFT RATE
COARSE MODE (COMPENSATED)   0.1 DEG HR
FINE MODE (COMPENSATED)   0.1 DEG HR

BANDPASS
COARSE MODE   26 4 Hz
FINE MODE   8 ±1 Hz
SPIN-UP TIME   90 SEC

POWER
RUNNING   12 WATTS (ESTIMATED)
HEATER   0 TO 25 WATTS

4-73

CMG CHARACTERISTICS

- Each CMG consists of an induction-motor-driven constant-momentum rotor which is gimbal supported to provide infinite rotation. The instrument is capable of producing restoring torques on a vehicle proportional to the angular rate of the gimbals. By controlling the CMG gimbal rates, attitude control of the vehicle can be achieved. Consequently, each gimbal control system contains a high-degree-of-performance rate servo which provides linear gimbal rate control.

- Processing electronics for the CMG are contained in the Electronics Assembly which is fastened to the CMG frame. The rate loop for each gimbal consists of a DC torquer, a DC tachometer, a precision speed-reduction gear train, and electronic amplifiers which provide voltage and power gain. These amplifiers are also used to implement servo compensation networks and to provide summing points for the rate command signal and the tachometer feedback signal.

- The 3-phase, 455-Hz power and 4.8-kHz excitation from each CMG Inverter Assembly (CMGIA) are fed to a corresponding CMG Electronics Assembly. The CMGIA also supplies 4.8 kHz and 800 kHz excitations and 455 Hz power.

- Each CMGIA consists of two types of electronics: (1) a static power inverter, and (2) conditioning electronics. The static power inverter comprises the following functional groups: (1) oscillator, control circuitry, and frequency drivers, (2) cycle register, (3) power amplifiers and output transformer system, (4) three-phase output filter, (5) wheel braking circuit, (6) three-phase output current assembly, (7) 800 Hz and 4.8 kHz amplifiers, (8) ±12 VDC bias supply, and (9) line filters and RFI suppression.

- A crystal oscillator is used to provide the reference signal for the 4.8 kHz and 800 Hz amplifiers. A separate oscillator is used in generating the 455 Hz outputs.

- The 4.8 kHz and 800 Hz signals are the excitations for the APCS components. To reduce the possibility of losing these outputs, a backup oscillator is provided in the same functional block with the crystal oscillator. A frequency sensing circuit automatically switches in the backup oscillator, if required.

- The conditioning electronics provide information on temperature levels of the CMG wheel bearings, CMG wheel speed, and inner and outer gimbal positions.

CMG CHARACTERISTICS

PERFORMANCE CHARACTERISTICS

MOMENTUM STORAGE	2300 FT-LB-SEC
DEGREES OF FREEDOM	2
LIFE	10,000 HR AT RUN SPEED
OUTPUT TORQUE	
RANGE	0 TO 160 FT-LB
THRESHOLD	0.160 FT-LB
GIMBAL COMMAND SENSITIVITY	1.0 VDC/DEG/SEC
GIMBAL RATES	
RANGE	0 TO 7.0 DEG/SEC
THRESHOLD	0.0046 DEG/SEC
GIMBAL RATE SERVO	
BANDWIDTH	70 RADIANS/SEC
PHASE MARGIN	70 DEG
GIMBAL PIVOT	
ACTUATOR (DC MOTOR) TORQUE (MAX)	7.0 FT-LB
TACHOMETER GAIN	1 VDC/RAD/SEC
TACHOMETER AMPLIFIER GAIN	1.013
GEAR RATIO	56.55:1
RESOLVERS SPEED	SINGLE (4.8 kHz EXCITATION)
WHEEL	
OPERATING SPEED	9027 RPM
ACCELERATION TIME	14 HR MAX TO 8700 RPM
DECELERATION TIME	4.5 TO 5.0 HR NOMINAL (DYNAMIC BRAKING), 30 TO 40 HR (COAST DOWN)

PERFORMANCE CHARACTERISTICS (CONT)

POWER REQUIREMENTS

BEARING HEATERS		
60°F TO 80°F	48 WATTS	
DURING WHEEL ACCELERATION	175 WATTS PER CMG (NOMINAL), 180 WATTS (MAX)	
WHEEL AT OPERATING SPEED	55 WATTS PER CMG (NOMINAL), 100 WATTS (MAX)	

GIMBAL FREEDOM

INNER	ELECTRICAL ±75 DEGREES	MECHANICAL ±80 DEGREES
OUTER	ELECTRICAL +215°, -125°	MECHANICAL +220°, -130°

PHYSICAL CHARACTERISTICS

SIZE (APPROXIMATE)

CMG	39-INCH SPHERE
CMG ELECTRONICS ASSEMBLY (CMGEA)	9.8 BY 8.6 BY 3.0 INCHES
CMG INVERTER ASSEMBLY (CMGIA)	25.0 BY 22.5 BY 3.5 INCHES

WEIGHT

CMG	
INNER GIMBAL & WHEEL	242.0 LB
OUTER GIMBAL	75.3 LB
FRAME	94.7 LB
CMGEA	8.2 LB
CMGIA	52.0 LB
TOTAL	472.2 LB

Attitude Determination Element

This element of the ACS includes the narrow and wide angle sun sensing systems and the horizon sensing system. The narrow angle sun sensor (including electronics) provides solar pointing error information for the control of the solar arrays. There are two narrow angle sun sensors provided, both of which are active under normal operating conditions. The combination of the wide angle sun sensing system and the horizon sensing system will provide a three-axis attitude determination with an accuracy of better than ±0.5 degree.

NARROW ANGLE SUN SENSOR PERFORMANCE CHARACTERISTICS

The sensor is an array of detectors which generates solar pointing error signals. The detector is an electro-optical device which converts solar radiant energy into an electrical current. It consists of a photovoltaic cell, a lens, and baffles which control the geometry of the input-output characteristics. The system (sensor plus electronics) will provide electrical analog signals proportional to the solar pointing error of the solar arrays and a sun presence signal to indicate when the sun is in the field-of-view of the error sensors. The performance characteristics of the narrow angle sun sensor are summarized in the chart.

NARROW ANGLE SUN SENSOR
PERFORMANCE CHARACTERISTICS

SENSOR SPECIFICATIONS

FINE NULL SENSOR (BOTH AXES)

FIELD OF VIEW	±10 DEG MINIMUM (FULL OUTPUT)
	±20 DEG (25 PERCENT OUTPUT)
LINEAR RANGE	±5 DEG MINIMUM (±6 DEG TYPICAL)
NULL ACCURACY	2 ARC MINUTES OR BETTER AT 0 ±5 mV NULL ERROR

TARGET SENSOR

FIELD OF VIEW	±9 DEG (CIRCULAR) ±1 DEG

ELECTRICAL PERFORMANCE

POWER

INPUT VOLTAGE	+28 VDC ±4 VDC
INPUT POWER	1.2 WATTS MAXIMUM

SIGNAL

TRANSFER FUNCTION

$$\frac{114.6 \text{ VOLTS/RADIAN}}{S/62 + 1}$$

ELECTRICAL PERFORMANCE (CONT)

ANGULAR SENSITIVITY	1.9 VOLTS/DEG TO 2.1 VOLTS/DEG
	(WITHIN ±3 DEG OF NULL), 2 VOLTS/DEG NOMINAL
ON-TARGET OUTPUT	+ 6 VOLTS
FREQUENCY RESPONSE	0 TO 10 Hz (3 dB) MIN
OUTPUT VOLTAGE RANGE	±12 VDC

MECHANICAL SPECIFICATIONS

WEIGHT	SENSOR: 3.7 LB
	ELECTRONICS: 1.5 LB

MAXIMUM DIMENSIONS

SENSOR PACKAGE	6.9 BY 6.5 BY 3 INCHES
ELECTRONICS PACKAGE	5 BY 5 BY 2 INCHES

WIDE ANGLE SUN SENSING SYSTEM PERFORMANCE CHARACTERISTICS

The wide angle sun sensing system is an Adcole Model 16764 system which provides spherical coverage with an average least significant bit size of 0.5 degrees and an accuracy of 0.25 degrees. This digital system consists of five two-axis sensors with 128 x 128 degree field-of-view and a package of signal processing electronics. The signal processing circuitry is shared by the five sensors; internal switching connects the sensor nearest the optical axis with respect to the sun and the processing circuitry. The system has been space qualified and successfully operated in orbit. The performance characteristics of the wide angle sun sensing system are summarized in the chart.

WIDE ANGLE SUN SENSING SYSTEM
PERFORMANCE CHARACTERISTICS

NO. OF AXES: 2

MAX. NO. OF SENSORS: 5

FIELD OF VIEW

    EACH SENSOR: 128° X 128°

    TOTAL: 4π STERADIANS

LEAST SIGNIFICANT
BIT SIZE: 0.5°

TRANSITION ACCURACY[2]: $\pm0.25^\circ$

SENSOR MODEL NO.: 16763

SENSOR SIZE: 3.18" X 3.18" X0.8" EXCLU-
SIVE OF CONNECTOR

(80.77 MM X 80.77 MM X
20.32 MM)

SENSOR WEIGHT: 0.56 LB
254 GM

ELECTRONICS SIZE: 3.5" X 4.5" X 1.16"
(88.9 MM X 114.3 MM X
29.5 MM)

ELECTRONICS WEIGHT: 0.65 LB
295 GM

OUTPUT[3]: 16 BIT PARALLEL GRAY CODE
(8 BITS PER AXIS) AND 3 BIT
PARALLEL SENSOR IDENTITY
OUTPUT (ELECTRONICS
SELECTS SENSOR THAT HAS
SUN IN FIELD OF VIEW)

OUTPUT LEVEL: TTL COMPATIBLE CAPABLE OF
DRIVING 6 LPTTL LOAD OR
1 TTL LOAD

POWER REQUIREMENTS: +12 ±0.36 VDC AT 8 MA MAX
-12 ±0.36 VDC AT 2 MA MAX

TEMPERATURE RANGE:
    OPERATING: -20°C TO $+50^\circ$C
    NON-OPERATING: -40°C TO $+65^\circ$C

PRESSURE: HARD VACUUM AS EN-
COUNTERED IN EARTH ORBIT

HUMIDITY: UP TO 100 PERCENT

ACCELERATION: 25 g

SHOCK: 40 g , 1 MS DURATION

RANDOM VIBRATION: 20-2000 Hz; 0.31 g^2/Hz;
25 g RMS; ONE MINUTE
EACH AXIS

EMI: MIL-STD-461A

EXPECTED LIFE: UNLIMITED

RADIATION EFFECTS: N ON P SILICON PHOTO-
CELLS ARE PROTECTED WITH
0.5" OF FUSED SILICA. NO
MOS DEVICES ARE USED.
OPTICAL MATERIALS UN-
AFFECTED BY PARTICLES OR
ULTRAVIOLET RADIATION

RELIABILITY: MTBF 5.7 X 10^5 HR

DESIGN STATUS: FLOWN NAVAL RESEARCH
LABORATORIES NTS-1

HORIZON SENSING SYSTEM PERFORMANCE CHARACTERISTICS

- The horizon sensing system is an Ithaco Model CSA-9530 system consisting of two heads and an electronics package. Each head is a conical-scan, two-axis sensor. One sensor is aligned with the vehicle X-axis to accommodate local vertical orientations, the other sensor is aligned with the Z-axis to be compatible with inertial orientations (XPOP). Two complete systems are provided to improve the reliability through redundancy.

- The performance characteristics of the system are summarized in the chart.

- The combination of the Wide Angle Sun Sensing System and the Horizon Sensing System will provide a three-axis attitude determination with an accuracy better than ±0.5 degree.
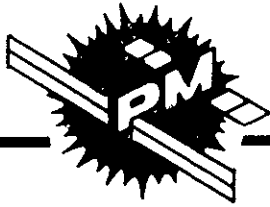
HORIZON SENSING SYSTEM
PERFORMANCE CHARACTERISTICS

ITEM	CHARACTERISTIC
GENERAL	
FIELD OF VIEW	TBD
ACCURACY (3σ)	±0.25°
ELECTRICAL	
POWER (PER SYSTEM)	10 WATTS
MECHANICAL	
WEIGHT (PER SYSTEM)	8.5 POUNDS
SIZE SENSOR PACKAGE	3.6-INCH DIAMETER BY 5-INCH LENGTH
ELECTRONICS PACKAGE	6.4 BY 6.4 BY 5.6 INCHES
RELIABILITY	
MTBF (PER SYSTEM)	58,000 HOURS

Contingent Stability and Desaturation Element

This element of the ACS is a magnetic torquing system which consists of a magnetometer, magnetometer electronics, four magnetic torquers, and a torquer electronics package. The prime function of this element is to provide the Power Module with the capability to be stabilized adequately for retrieval by the Orbiter Remote Manipulator System in the event of a failure of the primary pointing and control element. In addition, the magnetic torquing system will be used to continuously desaturate the CMGs during normal operation. At maximum coupling with the earth's magnetic field (approximately 1/2 gauss) the magnetic torquing system will exert a torque on the vehicle of approximately 0.15 foot-pounds.

MAGNETIC TORQUING SYSTEM PERFORMANCE CHARACTERISTICS

The performance characteristics of this element are summarized in the chart.

MAGNETIC TORQUING SYSTEM
PERFORMANCE CHARACTERISTICS

MAGNETOMETER AND ELECTRONICS		ELECTRICAL	
RANGE	±500 MILLIGAUSS	MAGNETOMETER AND ELECTRONICS	2 WATTS
SCALE FACTOR	0.005 VOLTS/MILLIGAUSS	TORQUERS AND ELECTRONICS	122 WATTS
ZERO BIAS	ZERO MILLIGAUSS = 2.500 ± 0.007 VDC		
ACCURACY	WITHIN 1% OF READING	MECHANICAL	
SIGNAL NOISE	LESS THAN 10 MILLIVOLTS	WEIGHT	
BANDWIDTH	10 Hz	MAGNETOMETER AND ELECTRONICS	4 POUNDS
ORTHOGONALITY	THREE AXES ARE ORTHOGONAL WITHIN ±0.25 DEG	TORQUERS (EACH)	110 POUNDS
	AND ALIGNED WITH THE INSTALLATION REFERENCE	TORQUER ELECTRONICS	16 POUNDS
	WITHIN ±0 25 DEG		
MTBF	240,000 HOURS	SIZE	
		MAGNETOMETER	2.75 X 2.75 X 4.69 INCHES
TORQUERS AND ELECTRONICS		MAGNETOMETER ELECTRONICS	5.37 X 6.5 X 3 INCHES
TORQUER OUTPUT RANGE	±4000 AMPERE-METER SQUARED	TORQUERS (EACH)	4 X 4 X 92 INCHES
SENSITIVITY	0.5 AMPERE-METER SQUARED	TORQUER ELECTRONICS	9 X 9 X 12 INCHES
OUTPUT LINEARITY	LESS THAN 5% OF COMMANDED MOMENT		
MTBF TORQUERS	14.3×10^6 HOURS		
TORQUER ELECTRONICS	316,000 HOURS		

Functional Interfaces

25 KW POWER MODULE ATTITUDE CONTROL SUBSYSTEM INTERFACES-FREE-FLYER FLIGHT MODE

In the free-flying mode, the ACS interfaces are as shown in the chart. All command and data flow between the Power Module and the ground is through the on-board C & DH and TDRSS. The ACS software is configured to accept attitude reference information from experiment sensors.

ATTITUDE CONTROL SUBSYSTEM
INTERFACES-FREE FLYER FLIGHT MODE
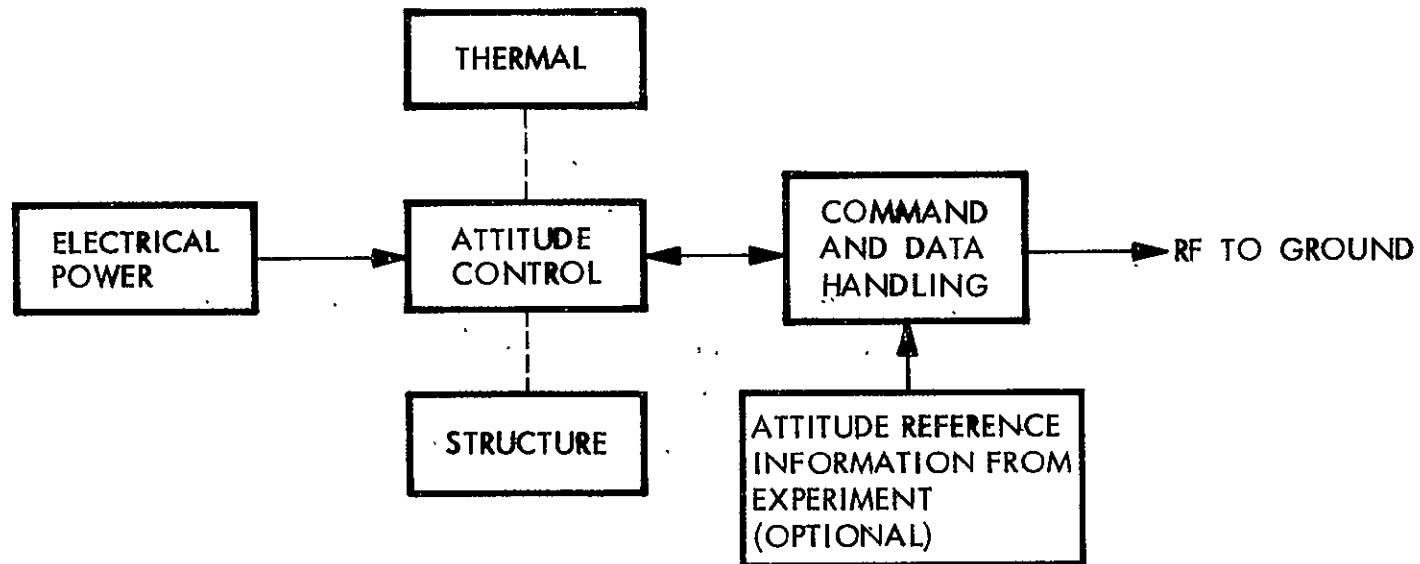
25 KW POWER MODULE ATTITUDE CONTROL SUBSYSTEM INTERFACES-SORTIE FLIGHT MODE

The ACS interfaces in the sortie mode are shown in the table. The principal functional interface derives from the requirement for the Power Module to provide the stabilization of the cluster while the Orbiter provides the necessary desaturation torques. Orbiter safety requirements require inputs to the caution and warning system, via hardwire, for display at the mission specialist station. There is a further requirement for controls and displays via hardwire at the mission specialist station to monitor and control, if necessary, any potentially dangerous conditions, e.g. wheel overspeed.

In the sortie mode there are redundant (RF and hardwire) transmission paths between the C&DH systems of both vehicles, with the Orbiter being the primary link with TDRSS and the ground.

ATTITUDE CONTROL SUBSYSTEM
INTERFACES-SORTIE FLIGHT MODE

POWER MODULE | ORBITER

THERMAL

ELECTRICAL POWER → ATTITUDE CONTROL ↔ COMMAND AND DATA HANDLING

RF

COMMAND AND DATA HANDLING → RF TO GROUND

HARDWIRE

STRUCTURE

HARDWIRE

CAUTION AND WARNING ELECTRONICS

MISSION CRITICAL CONTROLS AND DISPLAYS
HARDWIRE

MISSION SPECIALIST STATION

COMPUTER

RCS

DESATURATION TORQUES

ATTITUDE CONTROL TORQUES

STRUCTURE
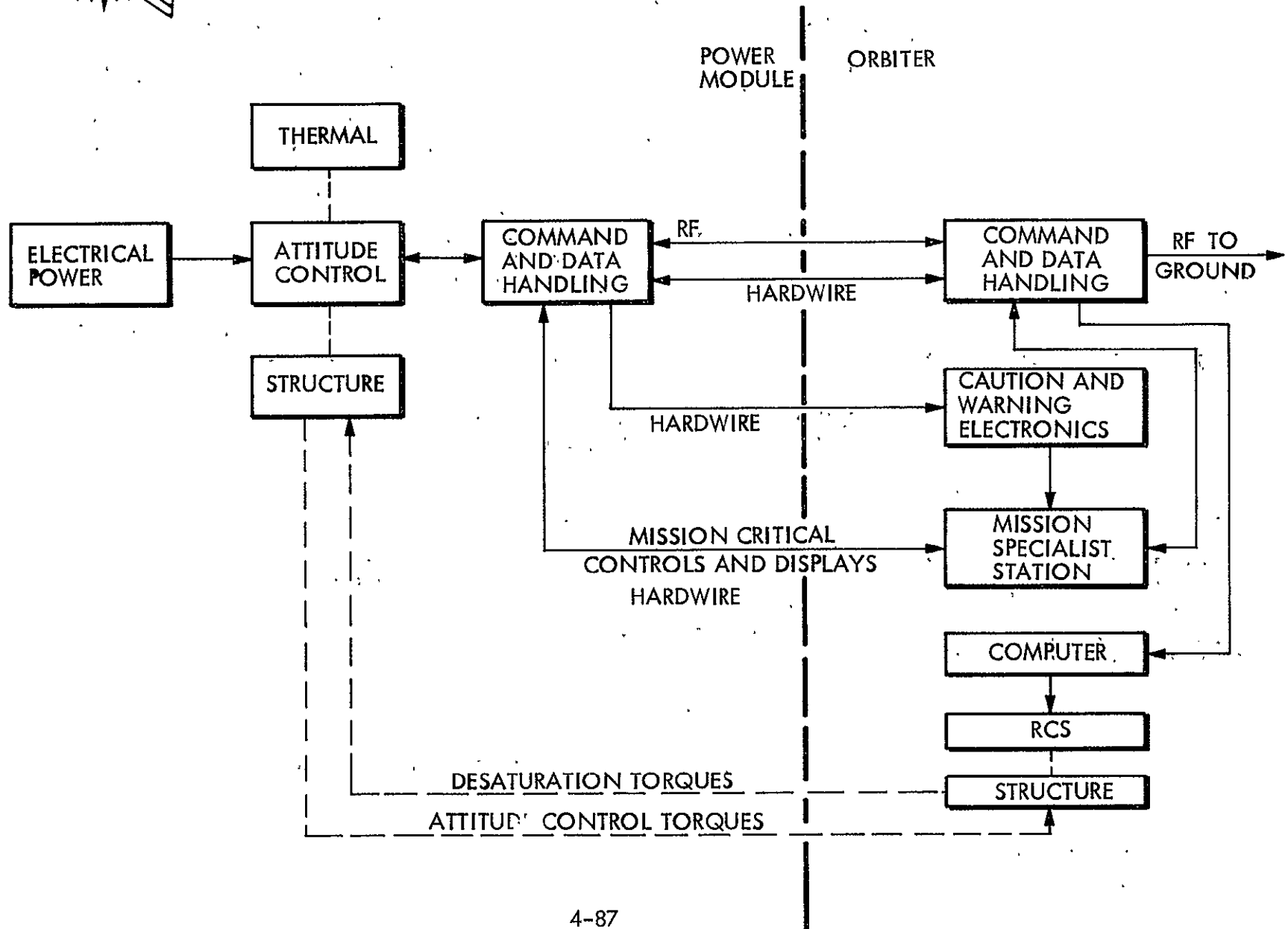
4.3.5 Communication and Data Handling Subsystem

Functions

Communications and Data Handling (C&DH) subsystem provides onboard collection and formatting of engineering data for the Power Module subsystems. It receives, decodes, stores, distributes, and executes discrete and digital commands. Commands are received via TDRS. Data is transmitted via TDRS. Data transmission and commanding are also compatible with the STS Orbiter when docked or in a free-flying mode. An onboard digital computer is used to provide telemetry formatting and commanding, PM attitude control, and hi-gain antenna tracking (if provided) for TDRS contracts.

Subsystem Description

25 kW POWER MODULE COMMUNICATION AND DATA
HANDLING SUBSYSTEM BLOCK DIAGRAM

- The C&DH subsystem functional block diagram is shown in the figure. This subsystem is comprised of five major elements:

  (1) central unit
  (2) computer
  (3) redundancy management control
  (4) communications
  (5) remote units

- The subsystem configuration is dual redundant with the exception of the redundancy management and mass storage unit. Power Module growth in the C&DH subsystem is assured by the flexibility provided in the basic design concept so that software can be modified and modular remote units can be added. In addition, remote units can also be added to payload units to collect housekeeping data and provide limited command capability.

- The C&DH subsystem employs a completely redundant data buss system for command, control, and telemetry processing. This dual redundancy throughout the subsystem assures no loss of functions due to a single failure.
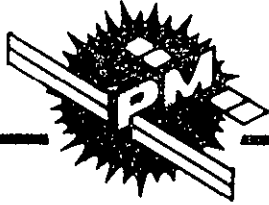
4-88

25kW POWER MODULE – COMMUNICATIONS AND DATA HANDLING SUBSYSTEM BLOCK DIAGRAM

HARDLINE STATUS TELEMETRY AND CONTROL TO/FROM SHUTTLE UMBILICAL FOR PM SHUTTLE LAUNCH – RETRIEVAL AND SORTIE MODES

NOTE: REDUNDANCY NOT SHOWN
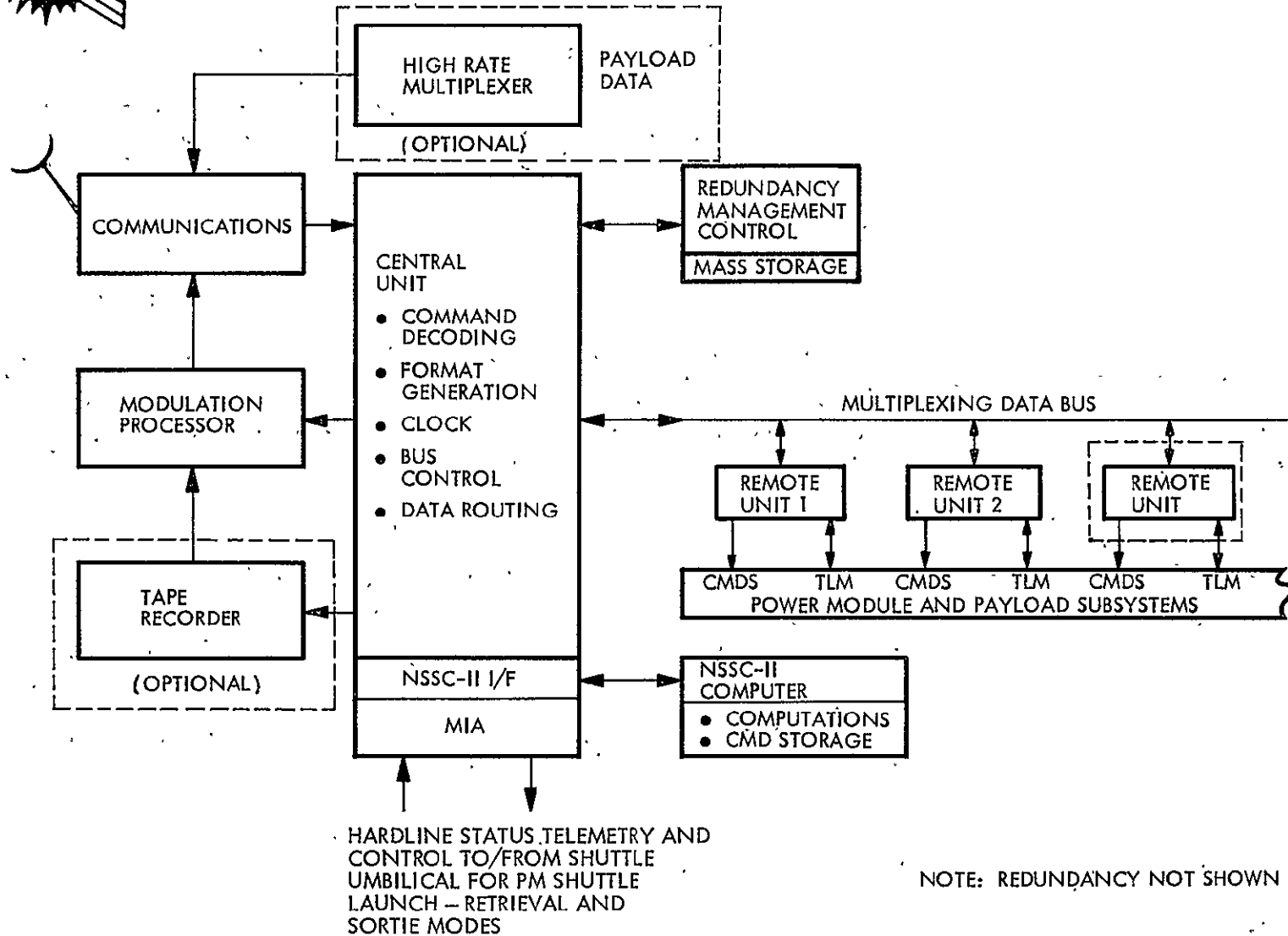
Central Unit. The central unit is the major interface element within the C and DH subsystem. This unit is designed to perform the functions of command decoding, format generation, clocking, buss control, and data routing.

Command Decoding. The central unit accepts commands from either of the redundant TDRSS transponders in the NASA Standard word format at 125 bps or 1 kbs. Power Module address, word length, and parity checks are made. The length of the command word is (TBD).

Data Format Generation. Power Module and payload data rates are (TBD). The candidate system has a 256 kbs capability.

Buss Control and Data Routing. The data collection from the remote units is controlled by generating data point addresses in accordance with microprocessor and computer generated data formats. The computer and microprocessor distributes real time and stored commands via the central unit, data buss, and remote units.

Computer and Redundancy Management. The computer performs computations, stores commands, and executes events. Its prime responsibility is to manage attitude control and redundancy management functions. Mission-critical data is stored and updated in the mass storage unit. If an active computer failure is detected, it is powered off and the standby computer is powered on and its memory loaded from the mass storage unit. Execution of the flight program continues from the standby computer. The candidate computer has 56k memory.

Communications

25 kW POWER MODULE COMMUNICATIONS SUBSYSTEM BLOCK DIAGRAM

A block diagram of the communications subsystem is shown in the figure. The C and DH communication S-band subsystem utilizes NASA standard TDRSS transponders and omni and high gain (21 db) steerable antennas. The on-board computer generates antenna pointing commands for either of the steerable antennas. The antenna is a direct-drive motor design used on Space Telescope. RF switches, diplexers, and multicouplers (which may be required) are standard units in use on several Air Force and NASA Programs.
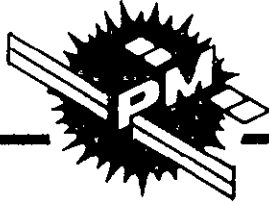
25kW POWER MODULE
COMMUNICATION SUBSYSTEM BLOCK DIAGRAM

* GROWTH ADDITION FOR DATA RATES>256 KbS
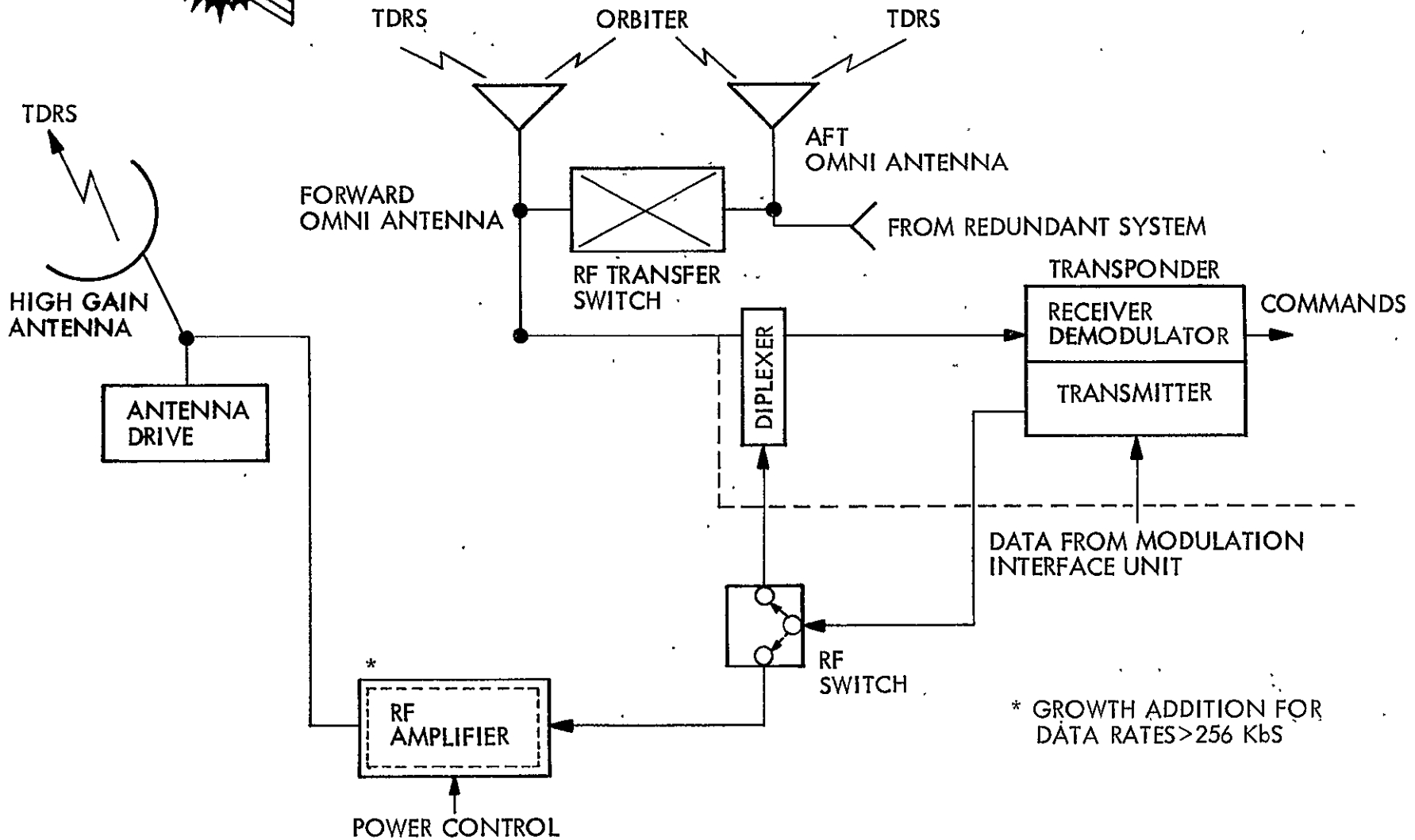
NOTE: REDUNDANCY NOT SHOWN

Remote Units

The remote units are slaved to the central unit by a part line or data buss system. The remote units accept instructions from the central unit by a unique address and respond to the instructions by performing the following functions: (1) decode and distribute discrete and serial commands to the subsystems, and (2) accept, condition, and transmit (TBD) channels of subsystem telemetry data.

Component Characteristics

A weight breakdown of the C&DH subsystem for the 25 kW Power Module is given below.

C & DH SUBSYSTEM WEIGHT SUMMARY

ITEM	WEIGHT (LB)
Transponders	31
Computer	130
Central and Remote Units	80
Antennas/Drives	116
Steering Electronics	48
Swtiches and Cables	23
SUBTOTAL	428
Contingency-25%	107
TOTAL	535

C&DH SUBSYSTEM COMPONENTS CHARACTERISTICS LIST

The physical characteristics of the C&DH subsystem are summarized in the table.
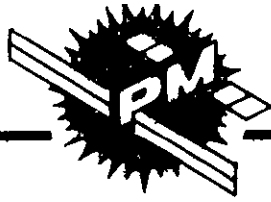
C&DH SUBSYSTEM
COMPONENTS CHACTERISTICS LIST

ITEM NO.	COMPONENTS	NO. REQ'D	PWR (WATTS)	SIZE (L X W X H) (IN.)	UNIT WT (LB)	TOTAL WT (LB)
1	TRANSPONDER	2	38	15.2 X 9.9 X 4.3	15.7	31.4
2	OMNI ANTENNA	2	–	4.0 DIA	.225	.45
3	S BAND TRACKING ANTENNA	2	–	48 DIA	10	20
4	ANTENNA DRIVE ASSEMBLY	2	TBD	8.5 DIA X 14 H	22.5	45
5	ANTENNA SUPPORT ASSEMBLY	2	–	TBD	2.1	4.2
6	ANTENNA STEERING ELECTRONICS	2	TBD	13.6 X 6.8 X 5.8	24	48
7	DEPLOY-RETRACT ASSEMBLY	2	N/A	TBD	23	46
8	NSSC-II COMPUTER	2	234	TBD; EST. VOLUME 1760 IN^3	65	130
9	REDUNDANCY MANAGEMENT UNIT	2	TBD	TBD	10	20
10	CENTRAL UNIT	2	TBD	TBD	10	20
11	REMOTE UNIT	4	TBD	TBD	10	40
12	CABLES	2	N/A	TBD	10	20
13	CIRCULATOR/ISOLATOR	2	N/A	TBD	TBD	TBD
14	RF SWITCH	2	TBD	3.5 X 2.8 X 2.1	0.6	1.2

Subsystem Performance

25 kW POWER MODULE C AND DH SUBSYSTEM COMPONENTS CHARACTERISTICS LIST

- Performance characteristics of the Communication and Data Handling Subsystem are summarized in the table. The assumption is that the MMS data handling system has been modified from 64 kbs to 256 kbs capability.

- With the 22 db gain of the S-band antenna, adequate link margins to TDRS exists with the 256 kbs data rate.
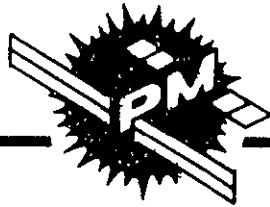
25kW POWER MODULE C&DH PERFORMANCE CHARACTERISTICS

25 KW POWER MODULE C&DH PERFORMANCE CHARATERISTICS

COMPONENT	CHARACTERISTIC
COMPUTER (NSSC-II)	56K MEMORY (BASELINE)
MEMORY	1024K BYTES (8 BITS) – CAPABILITY
SPEED	200 KOPS – CAPABILITY
RF COMMAND RATE	1 KBS
PCM DATA RATE	256 KBS (S BAND)
PCM FORMATS FIXED PROGRAMMABLE	2 TBD
ANTENNA GAIN	≈22 dB (S BAND PARABOLIC)

Functional Interfaces

25 kW POWER MODULE C AND DH SUBSYSTEM INTERFACES

- C and DH interfaces are shown in the figure.

- When the Power Module is docked to the Orbiter, up to 64 kbs of data can be interleaved with the STS operations telemetry to the ground. Portions of the data can also be displayed to the Orbiter crew if required. When in the free-flying mode, the data rate drops to 16 kbs. In either the sortie mode or free-flyer mode the Power Module can accept and execute commands via the module interface adapter when docked and via the receiver/decoder when free-flying.

SORTIE MODE

PM | ORBITER

CENTRAL UNIT — M I A

COMMANDS 1 KBS → SIGNAL PROCESSOR ← MDM → KU BAND RF SYSTEM

TELEMETRY 64 KBS → DATA INTERLEAVER → PCM MASTER UNIT

NSSC-II

FREE FLYER MODE

COMMANDS/TLM 16 KBS 1 KBS

ORBITER

TRANS-PONDER

CENTRAL UNIT

NSSC-II

SIGNAL PROCESSOR ← MDM → KU BAND RF SYSTEM

DATA INTELEAVER → PCM MASTER
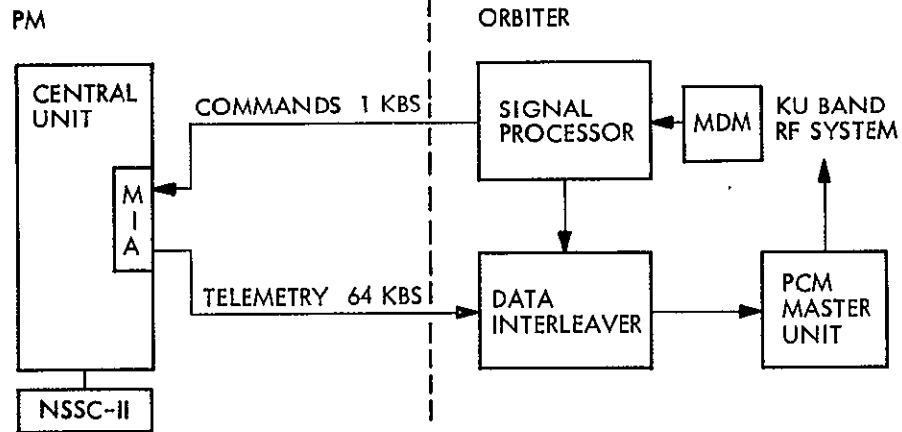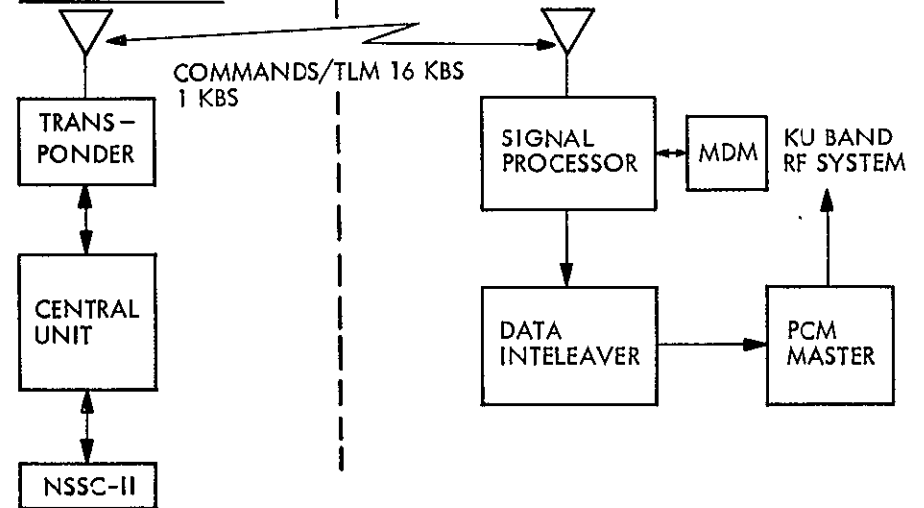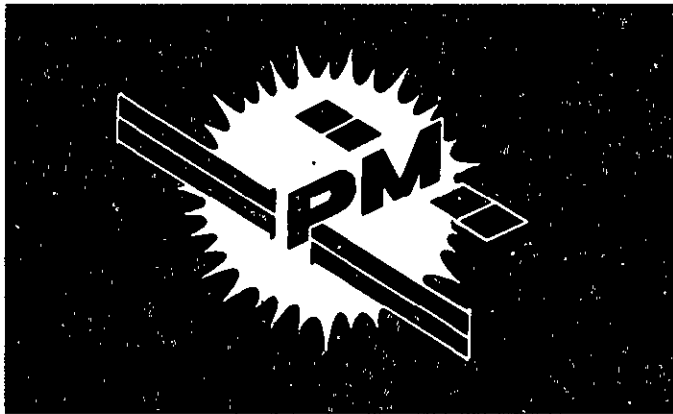
SECTION 5
50kW POWER MODULE

CANDIDATE 50kW POWER MODULE CONFIGURATION – DEPLOYED

- The 50kW Power Module, a derivative of the basic 25kW configuration and subsystems, is shown in the figure. The vehicle includes five basic subsystems.

    Structures
    Electrical power
    Thermal
    Attitude control
    Communication and data handling

- Subsystem design guidelines have emphasized compatibility with Shuttle Orbiter interfaces and operations, replicability of equipment, flexibility for growth and maintenance on orbit, and low-cost design concepts.
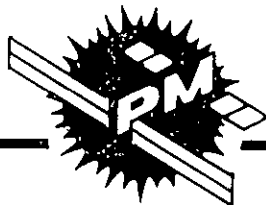
CANDIDATE 50kW POWER MODULE
CONFIGURATION—DEPLOYED
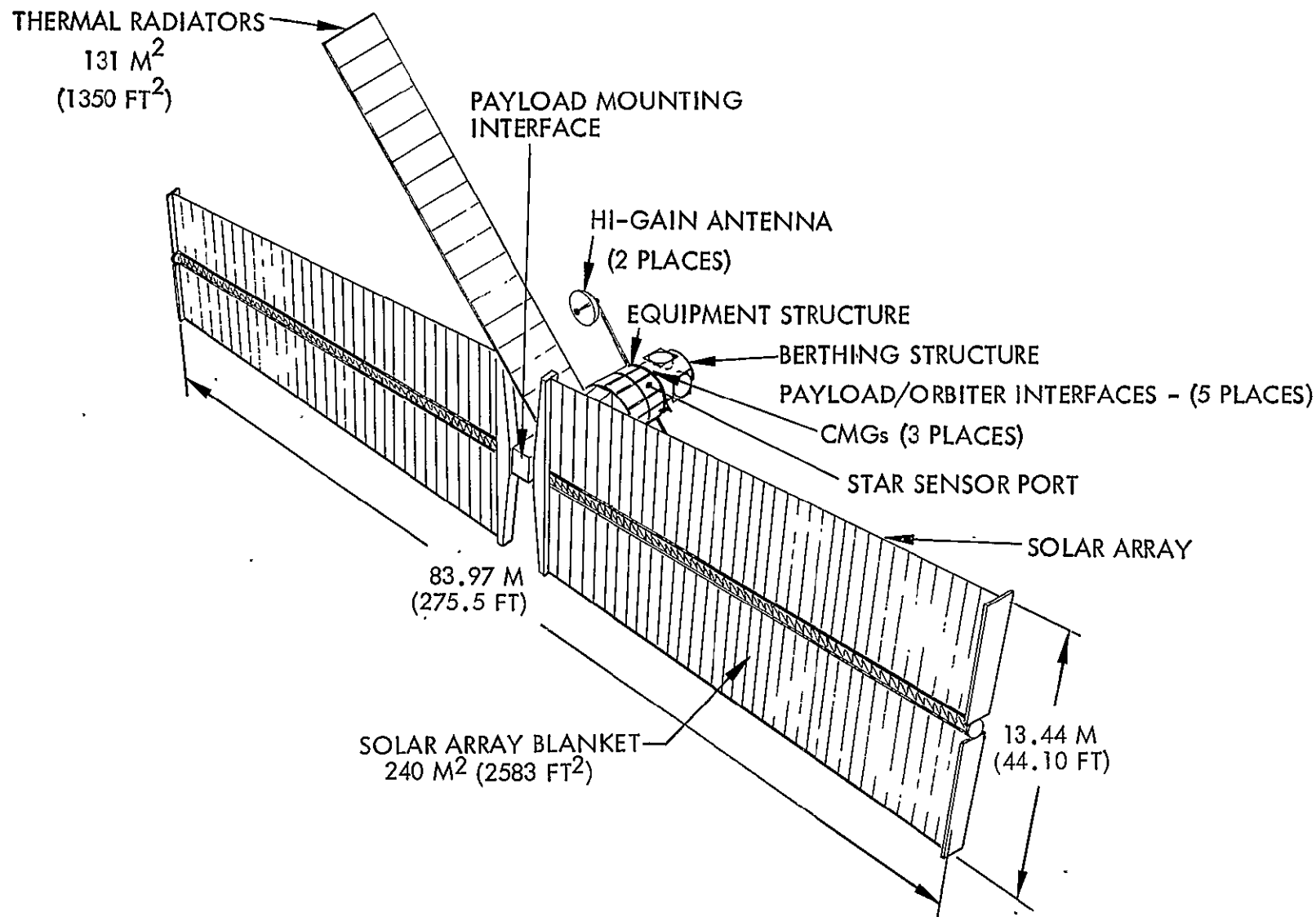
THERMAL RADIATORS
131 M^2
(1350 FT^2)

PAYLOAD MOUNTING
INTERFACE

HI-GAIN ANTENNA
(2 PLACES)

EQUIPMENT STRUCTURE

BERTHING STRUCTURE

PAYLOAD/ORBITER INTERFACES – (5 PLACES)

CMGs (3 PLACES)

STAR SENSOR PORT

SOLAR ARRAY

83.97 M
(275.5 FT)

13.44 M
(44.10 FT)

SOLAR ARRAY BLANKET
240 M^2 (2583 FT^2)

50 kW POWER MODULE – ORBITER PAYLOAD BAY INSTALLATION

* Configuration compatibility in the Orbiter cargo bay is shown in
  the figure and the accompanying drawing.

* A solar pointing package, which will contain Solar Terrestial
  Observation experiments is shown in a folded, launch – storage
  configuration. Space forward of Orbiter station 660 is reserved
  for Orbiter use.
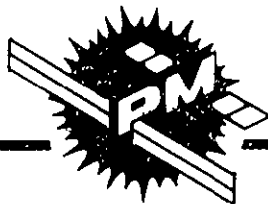
50kW POWER MODULE–
ORBITER PAYLOAD BAY INSTALLATION

TRUNNION

SOLAR ARRAY

RADIATOR

SOLAR ARRAY

BERTHING
STRUCTURE

HI-GAIN ANTENNA-
2 PLACES

SOLAR POINTING
PACKAGE & MOUNT (EPM)

BERTHING PLATFORM

STA 582.00

STA 1302.0

629.00

GRAPPLE
RMS INTERFACE
NS & FS

RADIATORS

POWER
MODULE

PM CONTROL &
MONITOR PANEL

WIRE
TRAY (TYP)

AFT STA
AIR LOCK
ORBITER STA
660.00

KEEL
FITTING

STA
572.0

118.00

ELECTRICAL UMBILICAL

TRUNNION FITTING
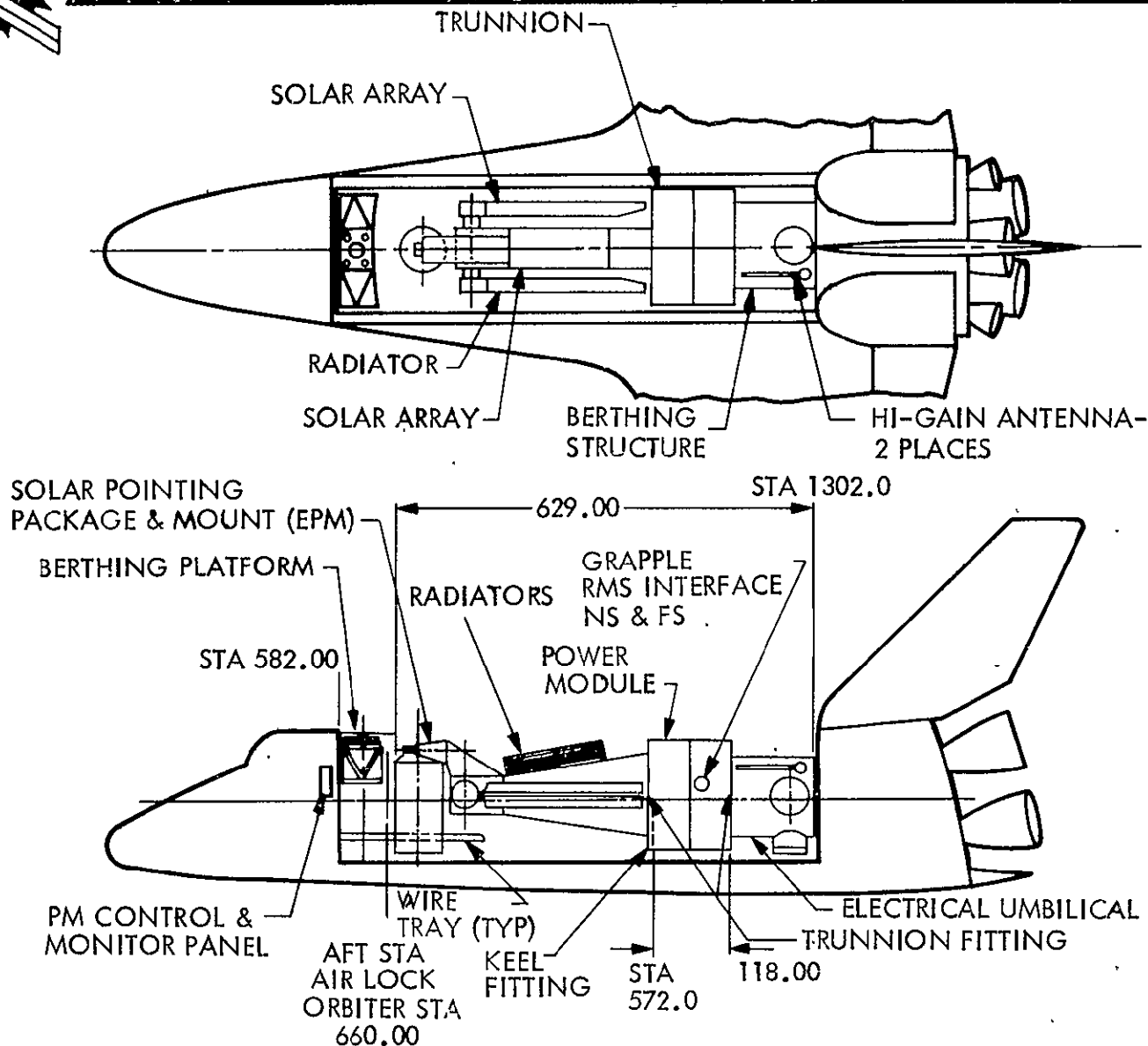
ALL DIMENSIONS IN INCHES

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5.1 OUTBOARD AND INBOARD PROFILES

● The 50 kW Power Module configuration is the same as the 25 kW Power Module with the following variations:

- Addition of an 80 inch solar array support structure extension to accommodate increased width solar array blankets.

- Use of 6 meter width solar array blankets instead of 4 meter used on 25 kW.

- Use of Ni-H$_2$ type batteries instead of Ni-Cd used on 25 kW

- Addition of thermal radiator panels (10) to accommodate increased thermal dissipation.

5.1.1 Outboard Profile

50 kW POWER MODULE OUTBOARD PROFILE

● The 50 kW Power Module outboard profile is shown in the figure. The vehicle is composed of four major structural components:

- Solar array support structure

- Forward equipment rack

- Aft equipment rack

- Berthing support structure

● The solar array support structure is of closed shear box or semi-monocoque construction to which the solar array wings are attached. The structure also carries the thermal radiator system.

● Both forward and aft equipment racks are constructed from ring frame assemblies, radial webs, and longerons attached to an inner tubular structure. Built into the equipment back structure are the trunnion fittings and keel fitting that support the Power Module in the Orbiter payload compartment.

● The berthing support structure is of semi-monocoque construction and is of the same diameter as the inner tubular structure in the equipment racks. Five berthing ports are built into this structure, four at equal spaces around the diameter and one on the aft face.

OUTBOARD PROFILE
50kW POWER MODULE

TRUNNION FITTING

SOLAR ARRAY WING
6 METER BLANKETS
2PL

SOLAR ARRAY PYLON

FORWARD EQUIPMENT RACK

AFT EQUIPMENT RACK

BERTHING STRUCTURE

29.0

58.0

168.0 DIA

14.0

60.0

TRUNNION FITTINGS

125.0

124.0

62.5

38.0

BERTHING PORT – 5 PL

120.0 DIA

84.0

KEEL FITTING

BERTHING TRUNK

SUPPORT STRUCTURE EXTENSION

80.0

220.0

549.0 REF

529.0 DIAM
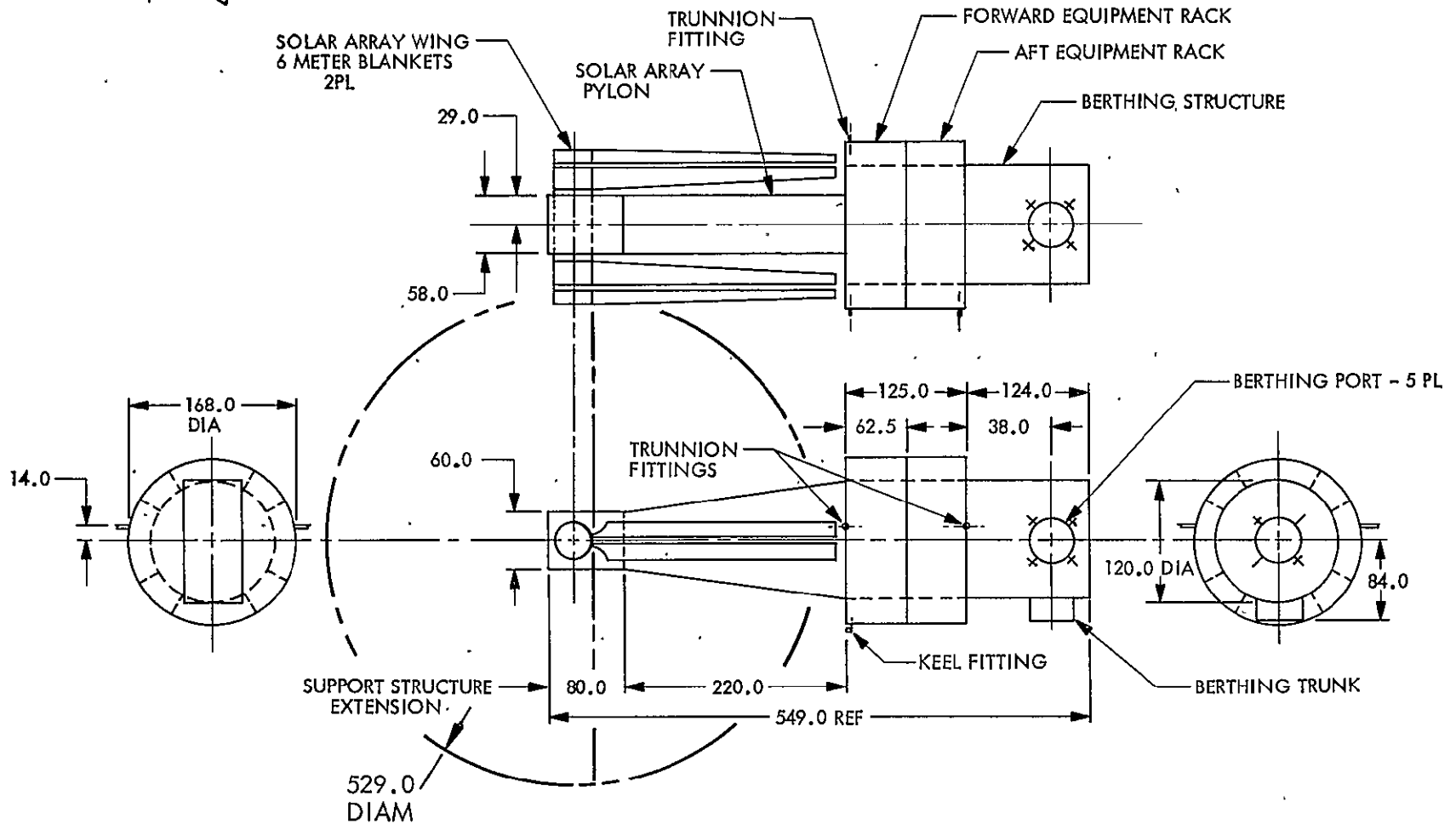
ALL DIMENSIONS IN INCHES

5.1.2 Inboard Profile

50 kW POWER MODULE EQUIPMENT INSTALLATION

- The inboard profile showing equipment installed is shown in the figure and is identical to the 25 kW PM aft of the solar array pylon/forward equipment rack interface. The concept of sub-system modularity is maintained for ease of equipment installation. The electrical power sub-system equipment is located in the forward equipment rack. Communications and data handling subsystem equipment, including magnetic torquers and electronics, rate gyros, and horizon sensors and electronics are located in the aft equipment rack. The three control moment gyros are located in the berthing module.

- As in the 25 kW PM configuration, subsystems are allocated to compartments to enhance the capability for growth and maintenance on-orbit. The 80 inch support structure extension (to accommodate 6 meter solar array blankets) is added to the forward end of the 25 kW PM solar array pylon support structure. The 10 additional thermal radiator panels are added to the thermal panel assembly for the 25 kW PM. The Ni-H$_2$ batteries are installed in the forward equipment rack in the same location used for the 25 kW batteries.

50kW POWER MODULE INBOARD PROFILE

ELECTRICAL POWER SYSTEM NiCd BATTERIES

ACS EQUIPMENT

MAGNETIC TORQUERS (HIDDEN)

S-BAND HI-GAIN ANTENNA (2)

THERMAL RADIATORS

CMGs ATTITUDE CON-TROL SYSTEM (3)

BERTHING MECHANISM

COMMUNICATION AND DATA HANDLING

THERMAL CONTROL SYSTEM EQUIPMENT

SOLAR ARRAY WINGS-6M BLANKETS
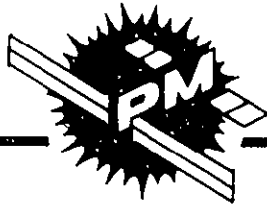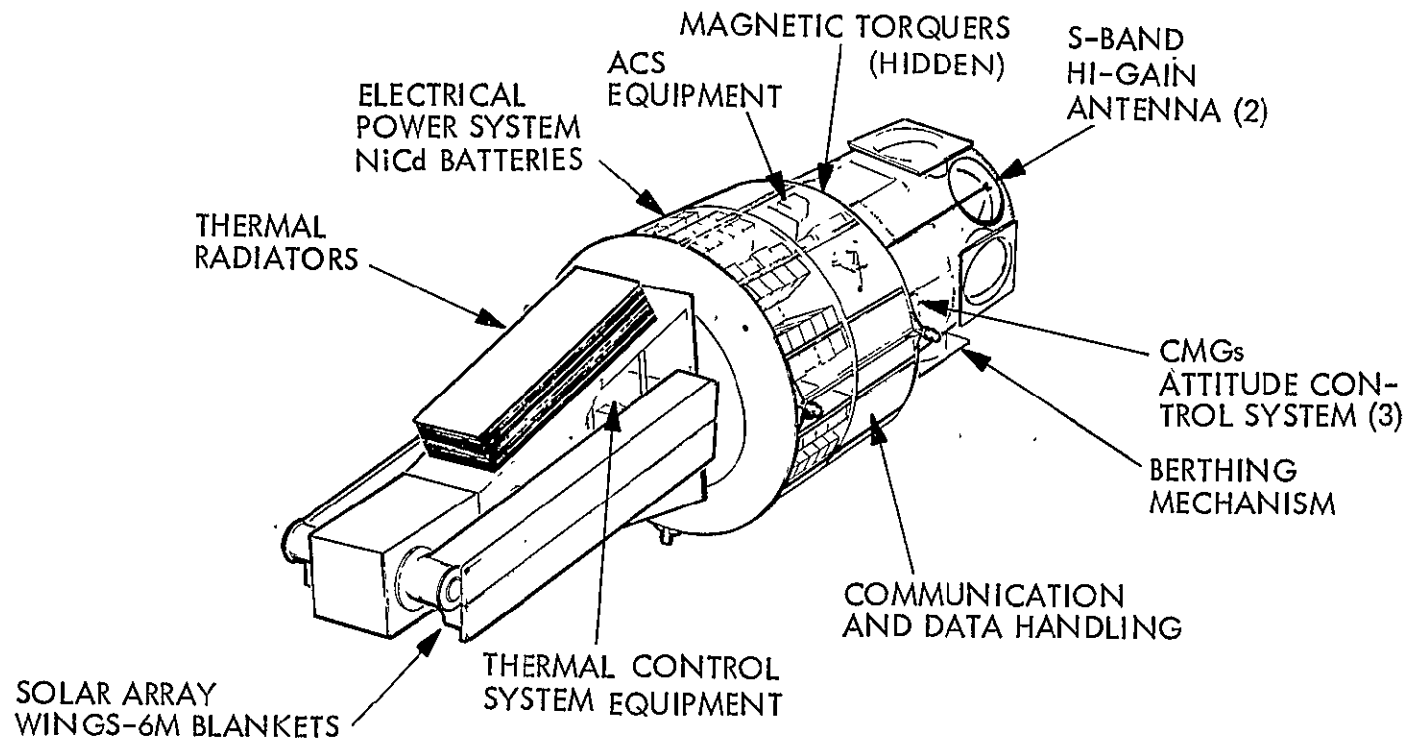
50 kW POWER MODULE EQUIPMENT INSTALLTION

- Equipment installation details for the 50 kW Power Module are shown in the drawing.

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5.2 WEIGHTS

A weight summary for the 50kW power module is shown below. Mass properties data is given in Volume 4, paragraph 2.2, of the Part III Final Report.

50kW POWER MODULE WEIGHT SUMMARY

ITEM	WEIGHT (LB)
STRUCTURE & MECHANICAL	8,150
ELECTRICAL POWER	14,225
THERMAL CONTROL	3,119
ATTITUDE CONTROL	2,138
C & DH	450
SUB TOTAL	28,082
CONTINGENCY – 25%	7,021
TOTAL	35,103

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5.3 SUBSYSTEM DESIGN DESCRIPTIONS

5.3.1 Structures

- The 50 kW Power Module structure is the same as that for the 25 kW Power Module for the forward equip-ment rack, aft equipment rack and berthing structure as described in paragraph 4.3.1 pages 4-20 through 4-37 of Volume I Part III Final Report.

- The solar array support structure is larger for the 50 kW Power Module than for the 25 kW Power Module and is shown in the figure. All structure is of shear-box design.

- The solar array support structure has basic dimensions to accommodate the 6 meter deployable solar arrays, provides structural strength, and Orbiter/sortie clearances during rotation of the solar array through 360°. The structure has provisions for mounting the thermal radiators, and the thermal subsystem mechanical and electrical components, and also provide support for the solar pointing package.

50 kW STRUCTURES
SUBSYSTEM-SOLAR ARRAY STRUCTURE
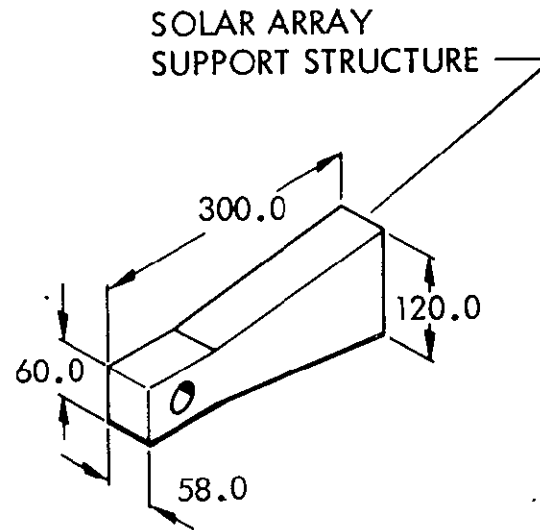
SOLAR ARRAY
SUPPORT STRUCTURE

300.0

120.0

60.0

58.0

COMPONENT CHARACTERISTICS

A summary of structure subsystem weights and characteristics of the structure subsystem components are given in the table.
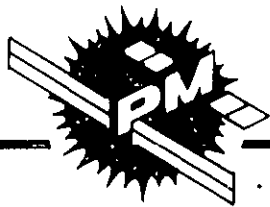
STRUCTURES AND MECHANICAL SUBSYSTEM
COMPONENT CHARACTERISTICS

ITEM NO.	COMPONENT	NO. REQ'D	PWR (WATTS)	SIZE (L X WK X H) IN.	UNIT WT (LBS)	TOTAL WT (LBS)
1	STRUCTURAL ASSY. SOLAR ARRAY SUPPORT BOOM	1	N/A	300 X 58 X 60/120	1250	1250
2	STRUCTURAL ASSY. FWD SECTION EQUIPMENT RACK	1		62.5 X 168 DIAM.	1435	1435
3	STRUCTURAL ASSY AFT SECTION EQUIPMENT RACK	1		62.5 X 168 DIAM.	1465	1465
4	STRUCTURAL ASSY. BERTHING MODULE	1		124 X 168 DIAM.	3200	3200
5	MECHANISMS	TRD		TBD	800	800

The electrical power subsystem (EPS) for the 50 kW Power Module furnishes power required for the PM subsystems and provides 50 kW power at the Orbiter and payload interfaces. Characteristics of the EPS elements (solar arrays, power control and energy storage) are described below:

Solar Arrays

Increased power over that of the basic 25 kW vehicle is achieved by increased size of the solar arrays in conformance with the recommended growth path of the Power Module as shown in para 3.2 of this document. The solar array blankets are increased in width to 19.8 ft. (6 M). In addition solar cell efficiency is projected to increase to 16% by 1986. Based on these factors, a solar array blanket area of 2550 ft.^{2} is used. A total of 4 blankets having a total area of 10,800 ft.^{2} will provide the required electrical power output.

To support the increased size of the solar array wings, the solar array support structure is increased in length by 80 inches over the 25 kW configuration to a new length of 300 inches.

Power Control

The same power control equipment can be used in the 50 kW EPS as for the 25 kW EPS because the number of solar array — battery — regulator elements remains at 12 and the current and power levels remain within hardware capability. Power distribution and cabling equipment will increase in weight.

Energy Storage

Increasing power from 25 kW to 50 kW while maintaining 12 power string elements requires doubling the depth-of-discharge of the batteries to a maximum of 40%. It is LMSC's recommendation that this requirement can be satisfied with Ni-H$_2$ batteries by 1986. The control functions for the Ni-H$_2$ battery would be the same as for the Ni-Cd, except cell pressure measurement would be added for state-of-charge indication. The structural mounting and thermal control interface for the Ni-H$_2$ battery will of necessity by changed to accommodate the new configuration.

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Subsystem Performance and Component Characteristics

EPS performance requirements for the 50 kW PM are assumed to be double that of the 25 kW PM, which will require a doubling of Solar array area and battery DOD. EPS weight for the 50 kW system, based on 16% solar cell efficiency and 40% battery DOD Ni-H_2 batteries is given below:

50kW EPS CHARACTERISTICS AND WEIGHTS

ITEM	CHARACTERISTIC
POWER (kW)	50
CELL TYPE, LB/FT^2	Si, 0.2
CELL EFF. (%)	16
BATTERY	Ni - H_2
DOD (%)	40
VOLTAGE (VDC REG)	(28) 110 OPTIONAL
WEIGHTS (LB)	
SOLAR ARRAY	4,800
SOLAR ARRAY DRIVE	250
BATTERIES	6,400
ELECTRONICS	1,395
PWR. DISTRIBUTION	880
WIRE HARNESS	500
SUBTOTAL	14,225
CONTINGENCY – 25%	3,556
TOTAL	17,781

50kW POWER MODULE ELECTRICAL POWER SUBSYSTEM COMPONENTS LIST

EPS component characteristics are shown in the table.

5.3.2-1   50 kW POWER MODULE ELECTRICAL POWER SUBSYSTEM COMPONENTS LIST

ITEM NO.	COMPONENT	REQ'D	PWR (WATTS)	SIZE (LX WX H) IN.	UNIT WT (LBS)	TOTAL WT (LBS)
1	BATTERY MODULE (Ni-H$_2$ TYPE)	12	**	52 X 27 X 10	633	6,400
2	BATTERY CONTROL ASSY	12		12 X 24 X 9	55	660
3	BUS REGULATOR	12		12 X 24 X 12	55	660
4	SOLAR ARRAY WING	2		130 X 44	1400	4,800
5	SOLAR ARRAY DRIVE ASSY	2		TBD	125	250
6	POWER TRANSFER ASSY	2		TBD	125	250
7	DRIVE ELECTRONICS	1		12 X 12 X 12	30	30
8	DC/DC CONVERTERS	3		12 X 12 X 9	15	45
9	POWER INTERFACE DISTRIBUTOR	1		40 X 17 X 10	300	300
10	MAIN POWER DISTRIBUTOR	1		17 X 17 X 8	50	50
11	SOLAR ARRAY DISTRIBUTOR	1		17 X 17 X 8	30	30
12	BERTHING DISTRIBUTOR	1		30 X 17 X 10	150	150
13	RACK DISTRIBUTORS	3		17 X 17 X 8	30	90
14	REMOTE POWER CONTROLLERS	30		4 X 7 X 5	<.5LB	10
15	POWER CABLES				500	500

**Heater Power to be determined

5.3.3 Thermal Control Subsystem

The 50 kW Thermal Control Subsystem is the same as the 25 kW TCS with added components. The 50 kW TCS configuration is achieved by adding radiator panels and an additional payload heat exchanger plus simultaneous pump operation in each of the two coolant loops. To provide payload heat rejection availability to the payloads in the 50 kW configuration, 10 additional radiator panels (67.5 ft.^{2} each) are added. This addition more than doubles the total PM heat rejection because the new panels are less influenced by solar array, PM surface, and payload surface interaction.

To maintain the Power Module battery and equipment temperatures within the desired 50 to 110°F range, the flow rate through the coolant system is approximately doubled by operating all pumps simultaneously. Subsequent flow analyses and development testing may show that the 2500 lb/hr pumps require upgrading to 3000 lb/hr capacity to handle the expected increase in pressure losses. Based on projected 23,000 hour mean-time-to-failure data on the Orbiter pumps, a pump package replacement would be scheduled to occur midway through the five-year mission.

An additional 15 kW rated payload heat exchanger would be added in parallel with the existing unit. Two payload fluid loop couplings would be provided with the necessary flow control.

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TCS Performance and Component Characteristics

The heat loads controlled by the PM coolant loop are basically double the 25 kW configuration. Battery and PM equipment will dissipate 18 kW of heat. The equipment temperature and coolant temperature increases will remain the same with a 10,000 lb/hr flow rate as those shown in paragraph 4.3.3. The total heat rejection capability will range from a minimum of 36 to 50 kW, thus providing an 18 to 32 kW cooling capacity for payloads. Similarly to the 25 kW radiators, the higher heat rejection levels correspond to spacecraft orientations which keep the panels edge-lit by the sun. Heat rejection levels are 18 kW maximum for the PM and nominal 25 kW for the payloads. Coolant loop temperature range 54°F is with a range 40/96°F. Thermal control of the manned habitat planned for the 1988 50 kW spacecraft will require 10 kW, or more, cooling capability depending on the occupancy level. This 10 kW requirement would reduce payload cooling capability by an equal amount. Heat rejection performance is given below.

50 kW POWER MODULE HEAT REJECTION PERFORMANCE

Configuration	Freon-21 Mass Flow Rate (lb/hr)	Heat Rejection (kW)			Freon Temp ($^\circ$F)		Radiator Area (FT^2)	No. Of Panels/ Configuration
		PM	P/L[1]	Total[2]				
50 kW	10,000	18	22.8	40.8	54	40/94	1,350	20

Notes: (1) Heat rejection available to payload may be used for manned habitat control. 10 kW estimated for 3-man occupancy.

(2) Total heat rejection includes effects of beta angle, sun incident up to 30°, and earthshine.

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TCS COMPONENT CHARACTERISTICS

TCS weight for the 50 kW system is given below:

50 kW TCS WEIGHT SUMMARY

ITEM	WEIGH (lb)
RADIATOR, STRUCTURE, MOTORS	2,020
COLD PLATES, LINES	565
HEAT EXCHANGERS	257
PUMPS, CONTROLS	177
INSULATION, PAINT, HEATERS	100
SUBTOTAL	3,119
CONTINGENCY — 25%	780
TOTAL	3,899

TCS components characteristics are shown in the table.

50kW POWER MODULE THERMAL CONTROL SUBSYSTEM COMPONENTS

ITEM NO.	COMPONENT	NO. REQ'D	PWR (W)	SIZE (L X W X H) (IN)	UNIT WT (LB)	TOTAL WT (LB)
1	RADIATOR	20		162.0 X 60.0 X 0.925	94.5	1,890
2	COLD PLATES	24			21.7	520
3	PUMP, ACCUMMULATOR, CHECK VALVE, INVERTER	2	500 (AC)	7.9 X 3.5 X 3.5* 13.1 (D) X 27.2**	58	116
4.	PRESSURE TRANSDUCERS	2			5	10
5	FLOW CONTROL ASSEMBLY (MIXER VALUE)	2	57.5	24 X 20 X 9	25.5	51
6	INTERFACE H_X	2		.	120	240
7	GSE H_X	1			17	17
8	LINES FASTENERS, CONNECTORS, FILTERS, SOLENOID VALVES	TBD			45	45
9	INSULATION	TBD			100	100
10	HEATERS	1	TBD		TBD	
11	MOTOR AND MECHANISM TO DEPLOY THE RADIATORS	40	TBD		2.0 (EST)	80
12	FREON 21	TBD			TBD	TBD
13	RADIATOR SUPPORT STRUCTURE	1			50 (EST)	50

*INVERTER
**ACCUMULATOR, PUMP, AND CHECK VALVE

5.3.4 Attitude Control Subsystem

The attitude control subsystem for the 50 kW Power Module is identical to that provided for the 25 kW Power Module, as described in paragraph 4.3.4 of this Volume 1, Part III Final Report.

CMG REQUIREMENTS FOR 50 KW POWER MODULES

The CMG requirements for the 50 kW configurations in Scenario I, shown in paragraph 2.1 page 2-13 of this Volume, are given in the table. The analysis is based on computing the momentum required to control the cyclic torques on the vehicle when it is in an inertial, perpendicular-to-the-orbit plane orientation, and providing two additional CMGs for maneuvering and redundancy. The analysis was for the Orbiter docked to the Power Module. It can be seen that vehicle A-2, because of its size, cannot be flown inertially, and will be constrained to local vertical orientations. The remaining three configurations can be flown in an XPOP orientation, or with any principal axis along the local vertical, with three CMGs.
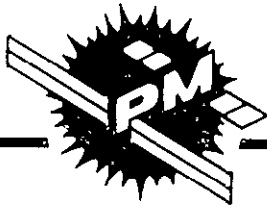
CMG REQUIREMENTS FOR
50kW POWER MODULES

CONFIGURATION NOTE 1	ORIENTATION	CMGs REQUIRED TO CONTROL CYCLE TORQUES	CMGs REQUIRED FOR MANEUVERING AND REDUNDANCY	TOTAL CMGs REQUIRED	ORIENTATION
A-2	X POP	25	2	27	} NONE
	Y POP	16	2	18	
	Z POP	10	2	12	
A-3	X POP	1	2	3	√
	Y POP	4	2	6	
	Z POP	4	2	6	
B-2	X POP	1	2	3	√
	Y POP	4	2	6	
	Z POP	4	2	6	
B-3	X POP	1	2	3	√
	Y POP	4	2	6	
	Z POP	4	2	6	

NOTE 1: CONFIGURATION DESIGNATORS REFER TO CONFIGURATIONS SHOWN ON PAGE 3-62 OF THIS VOLUME 1 OF PART III FINAL REPORT.

5.3.5 Communication And Data Handling Subsystem

The Communication and Data Handling Subsystem for the 50 kW Power Module is identical to the design for the 25 kW PM. One remote interface unit is added to support the added 25 kW capability. Refer to paragraph 4.3.5 of this Volume 1, Part II Final Report for a description of the C & DH subsystem.

A weight breakdown of the C & DH subsystem for the 50 kW Power Module is given below.

C & DH SUBSYSTEM WEIGHT SUMMARY

Item	Weight (lb)
Transponders	31
Computer	130
Central and Remote Units	100
Antennas/Drives	116
Steering Electronics	48
Switches and Cables	25
SUBTOTAL	450
Contingency — 25%	113
TOTAL	563

The baseline C & DH subsystem can be expanded readily to accommodate any additional requirements by adding remote command and telemetry units to the central unit data bus. This is illustrated in the C & DH block diagram in paragraph 4.3.5.
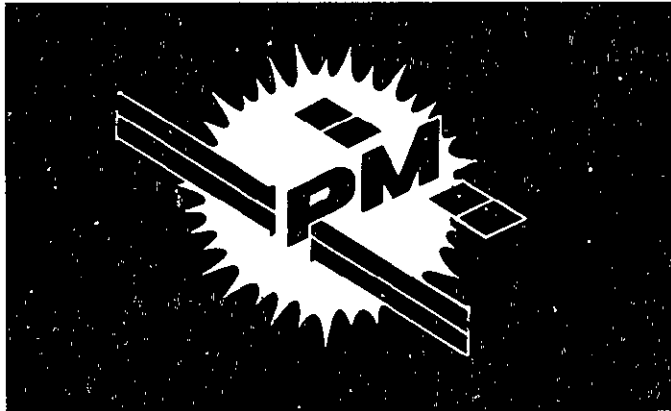
SECTION 6
100 kW POWER MODULE

CANDIDATE 100 kW POWER MODULE CONFIGURATION – DEPLOYED

- The 100 kW Power Module flight configuration is shown in the figure. This vehicle includes five basic subsystems as follows:

  Structures
  Electrical Power
  Thermal
  Attitude Control
  Communication and Data Handling

- Subsystem design guidelines have emphasized compatibility with Shuttle Orbiter interfaces and operations, replicability of equipment, and flexibility for growth and maintenance on-orbit.

- There are two configuration concepts for the 100kW PM. The 100-1' configuration is grown on orbit from an existing, in-flight 50 kW vehicle by adding a 50-100 kW growth kit. The 100-1 configuration is all ground launched.

CANDIDATE 100 kW
POWER MODULE CONFIGURATION - DEPLOYED

THERMAL RADIATORS
131 M^2
(1350 FT^2)

HI-GAIN ANTENNA
(2 PLACES)

EQUIPMENT STRUCTURE

BERTHING STRUCTURE

PAYLOAD ORBITER INTERFACES
(5 PLACES)

CMGs (~4 PLACES)

STAR SENSOR PORT

PAYLOAD MOUNTING
INTERFACE

83.97 FT
(275.5 FT)

360° ROTATIONAL
CAPABILITY

13.44M
(44.10 FT)

SOLAR ARRAY BLANKET
240 M^2 (2583 FT^2)
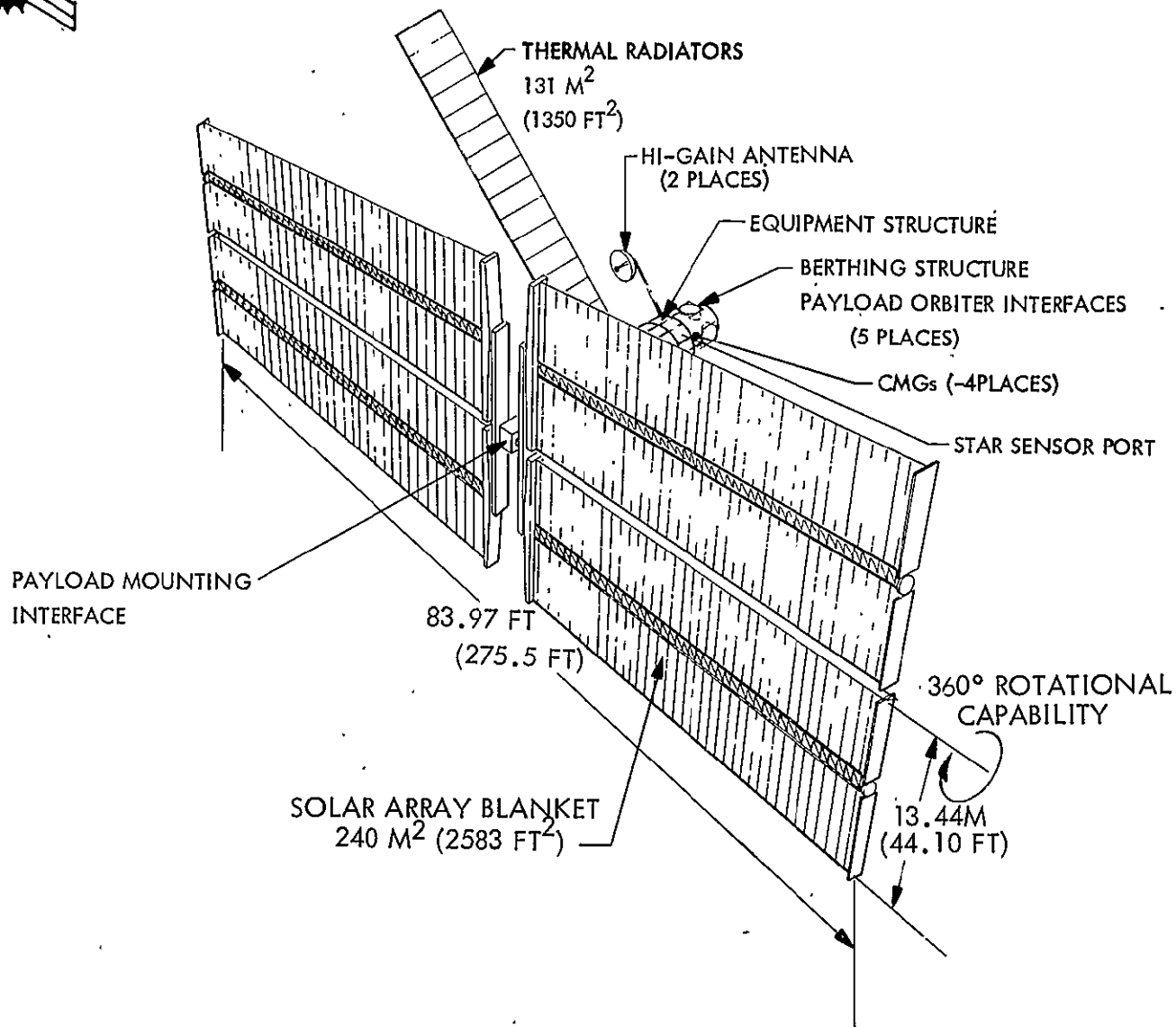
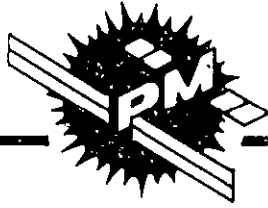100 kW POWER MODULE 100-1′ CONFIGURATION — (50-100 kW KIT)

ORBITER PAYLOAD BAY INSTALLATION

- The 100-1′ vehicle is built up on-orbit from a 50 kW in-flight vehicle. The 50-100 kW kit is transported via an Orbiter launch (partial cargo) as shown in the figure to a rendezvous orbit with the in-flight 50 kW vehicle. Following rendezvous, capture, and berthing of the 50 kW vehicle to the Orbiter, the 50-100 kW growth kit is assembled to the 50 kW vehicle to form a 100 kW flight configuration. Details of this on-orbit assembly sequence are discussed in Volume 4, paragraph 6.5, of this Part III Final Report.
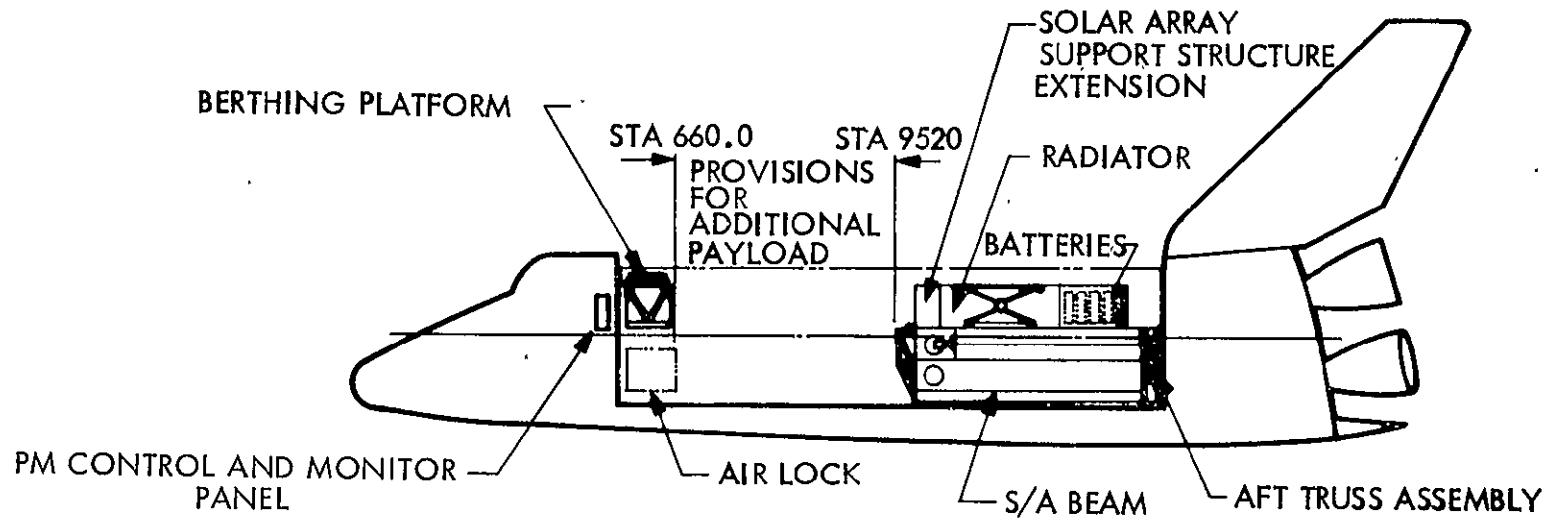
- When assembled on-orbit, the 100-1′ and 100-1 vehicles are identical with the following exceptions:

    The 100-1′ configuration is build up from a 50 kW vehicle using a 50-100 kW kit. The kit will include components of the electrical power subsystem (batteries and electronics) which are installed in the solar array extension mast as an integral system. The original complement of batteries for the 50 kW vehicle will remain in the forward equipment rack and will remain inoperative.

- The concept of increasing electrical power capability on-orbit by using a 50-100 kW kit is to package on the ground a completely integrated electrical power subsystem including batterires electronics and two solar array wings. This can be tested and verified as an intact functional subsystem prior to launch, thereby precluding the necessity of breaking into the existing system of the 50 kW PM on-orbit. Assembly on-orbit, then, can be achieved with minimum disruption of the existing system on the 50 kW PM by adding the two solar array wings from the 50 kW PM to the 50-100 kW kit (with two solar array wings) and bypassing the existing 50 kW batteries and electronics.

100kW POWER MODULE—(50-100 kW KIT) ORBITER PAYLOAD BAY INSTALLATION

SOLAR ARRAYS

SOLAR ARRAY SUPPORT STRUCTURE EXTENSION

RADIATOR

FORWARD TRUSS ASSY

TRUNNION 4 PLACES

BERTHING PLATFORM

STA 660.0   STA 9520

PROVISIONS FOR ADDITIONAL PAYLOAD

SOLAR ARRAY SUPPORT STRUCTURE EXTENSION

RADIATOR

BATTERIES

PM CONTROL AND MONITOR PANEL

AIR LOCK

S/A BEAM

AFT TRUSS ASSEMBLY
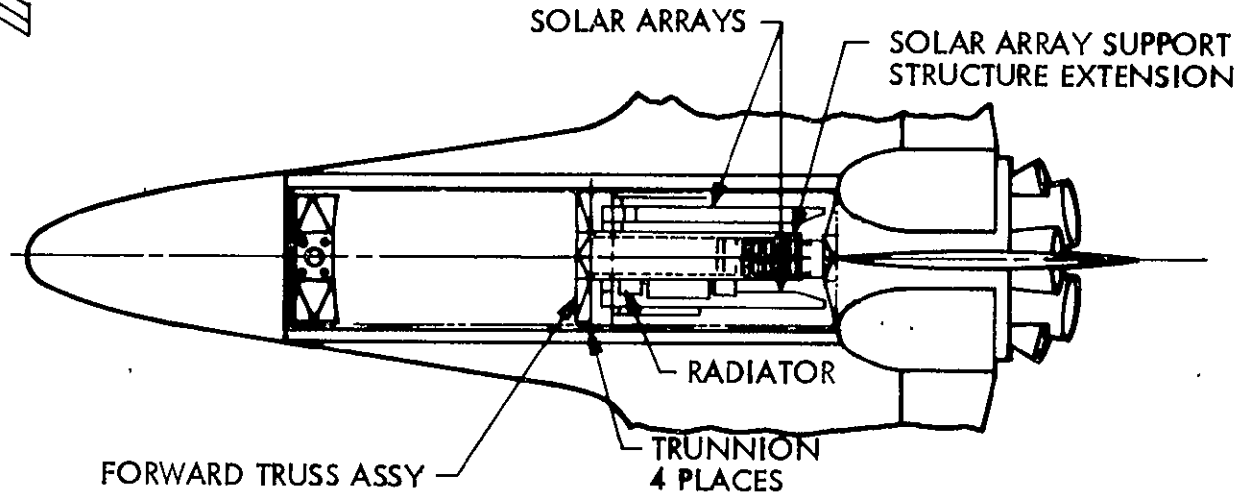
100 kW POWER MODULE 100-1 CONFIGURATION

ORBITER PAYLOAD BAY INSTALLATION

- The 100-1 vehicle is launched as a full 100 kW capability system. Because of sizing, this requires two Orbiter launches. The first Orbiter launch will carry the Power Module equipment/ berthing structure assembly (a partial cargo load) as shown in the chart. The second Orbiter launch will carry the solar array assembly (a full cargo load) as shown in the subsequent chart. In orbit, the PM equipment/berthing structure assembly will be berthed to the Orbiter and prepared for assembly operation. When the second Orbiter launch delivers the solar array assembly, it will be attached to the PM equipment assembly to form a 100 kW flight configuration.

- Configuration compatibility in the Orbiter cargo bay is shown in the two figures and two accompanying drawings. Space forward of Orbiter Station 660 is reserved for Orbiter use.

100kW POWER MODULE—EQUIPMENT/BERTHING STRUCTURE ELEMENT—ORBITER PAYLOAD BAY INSTALLATION

TRUNNION

250.0

TRUNNION

BERTHING SYSTEM

AFT FLIGHT DECK

STA 660.0

PROVISIONS FOR ADDITIONAL PAYLOAD

TRUNNION

EQUIPMENT RACK

STA 1302.0

STA 582.0

PM CONTROL AND MONITOR PANEL

KEEL FITTING

AIR LOCK

ELECTRICAL UMBILICAL

BERTHING STRUCTURE

GRAPPLE RMS INTERFACE
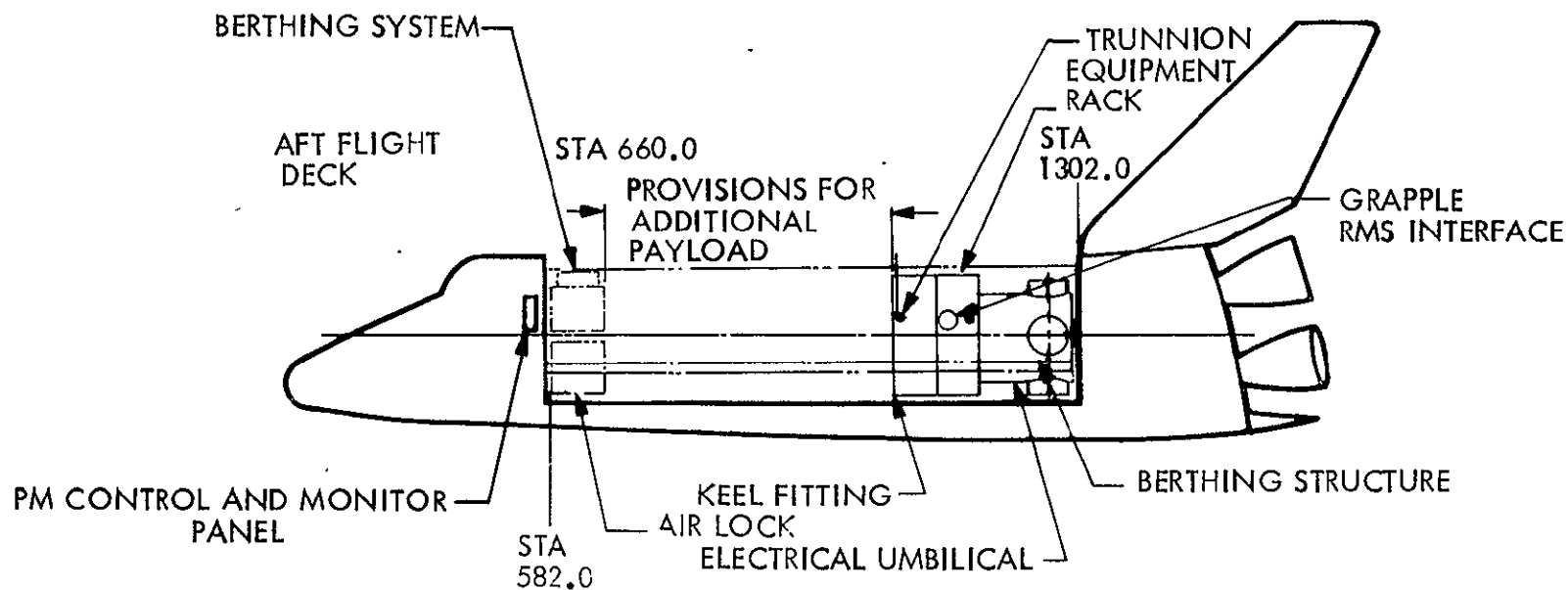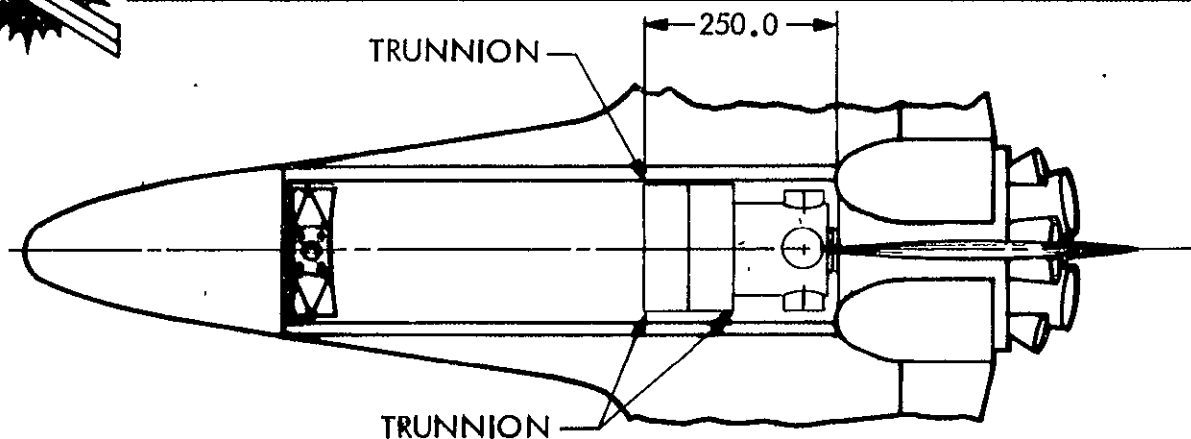
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100kW POWER MODULE—SOLAR ARRAY ASSEMBLY ELEMENT—ORBITER PAYLOAD BAY INSTALLATION

SOLAR ARRAYS

SOLAR ARRAY BEAM

TRUNNION
4 PLACES

RADIATORS

SOLAR ARRAYS

SOLAR ARRAY SUPPORT
STRUCTURE

SOLAR ARRAY BEAM

FORWARD TRUSS ASSY
(INTERFACE WITH SOLAR
ARRAY BEAMS)
TYPICAL – 2 PLACES

SOLAR ARRAY
SUPPORT
STRUCTURE

KEEL FITTING

AFT TRUSS ASSY

AIR LOCK

STA
660

ACCESS AREA
TO LATCHES
ON KEEL
STRUCTURE

KEEL TRUSS ASSEMBLY

LATCH (MANUAL
TYPICAL

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100 KW POWER MODULE
ORBITER INSTALLATION
CONFIGURATION 100-1

LOCKHEED MISSILES & SPACE COMPANY, INC
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

/3/ TRUNNIONS REQUIRE BRIDGE STRUCTURE TO DISTRIBUTE LOAD TO CARGO BAY SILL FITTING

SECTION A-A

KEEL FITTING

SOLAR ARRAY SUPPORT ASSY INTERFACE

AIR LOCK
STA 582.0
WIRE TRAY TYPICAL
BERTHING STRUCTURE
ELECTRICAL UMBILICAL
KEEL FITTING
AFT FLIGHT DECK
ADDITIONAL PAYLOAD
STA 660 PROVISIONS FOR 3.7M ADDITIONAL PAYLOAD
TRUNNION
EQUIPMENT RACK
BERTHING SYSTEM
GRAPPLE RMS INTERFACE STA 679.0
242.0

SOLAR ARRAY CLEARANCE
/3/ TRUNNION SEE SHT 2
SEE SHT 2
SOLAR ARRAY CONTAINER DEPLOYED
250.0
/3/ TRUNNION SEE SHT2

MAX ARC OF DEPLOYED SOLAR ARRAY
SORTIE MISSION BERTHING
SOLAR ARRAY
BERTHING PLATFORM EXTENDED POSITION (TRAVELLING PLATFORM) SEE DWG 6/46660
SOLAR ARRAY
RADIATOR-20 PANELS

2 FOLDOUT FRAME
FOLDOUT FRAME

UNLESS OTHERWISE SPECIFIED DIM ARE IN INCHES TOLERANCES ON:
FRACTIONS = ± 1/16
DECIMALS: .XX = ± .1
.XXX = ± .030
ANGLES = ± 2 DEG

REVISIONS
ZONE	LTR	DESCRIPTION	DATE	APVD
	A	ADDED INTERFACES, RELOCATED MODULE IN ORBITER, SORTIE MISSION BERTHING	May 12	
	B	REVISED SORTIE MISSION, REMOVED LIMIT ON ROTATION, ZIM 2U70 ADDED		

NOT RELEASED

NOTES:
1. ATTACH TRUNNION FITTING (NON DEPLOYABLE PAYLOAD)
   PER SHUTTLE ORBITER/CARGO STANDARD INTERFACES
   ICD NO. 2-19001, FIGURE 3.3.21-1
   BY NASA- JOHNSON SPACE CENTRE.
2. FORWARD, AFT AND KEEL TRUSS ASSY'S ARE REUSABLE
   SHUTTLE/ PAYLOAD TRANSPORT EQUIPMENT.

100 KW POWER MODULE
CONFIGURATION 100-1
ORBITER PAYLOAD BAY INSTAL.

LOCKHEED MISSILES & SPACE COMPANY INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

SIZE A | 6164063

LMSC-D614944-1

REVISIONS
A | REVISED 50kW TO 100 KW MOD KIT

100 KW MOD KIT

AIR LOCK
STA 660

KEEL TRUSS ASSY
KEEL FITTING
AFT TRUSS ASSY
LATCH (MANUAL)
ACCESS AREA
TO LATCHES ON KEEL STRUCTURE
SECTION B-B
KEEL TRUSS ASSY
S/A BEAMS & SOLAR ARRAYS
S/A SUPPORT STRUCTURE
S/A BEAM (FOLDED)
S/A SOLAR ARRAYS WITH SOLAR ARRAYS
SOLAR ARRAY
RADIATOR
SOLAR ARRAY SUPPORT STRUCTURE EXTENSION
KEEL FITTING
50kW TO 100 KW MOD KIT

SOLAR ARRAY SUPPORT STRUCTURE
S/A BEAM
FORWARD TRUSS ASSY
(INTERFACE WITH S/A BEAMS)
TYPICAL 2 PLACES
AFT TRUSS ASSY
RADIATOR
SOLAR ARRAY SUPPORT STRUCTURE EXTENSION
50kW TO 100KW MOD KIT

RADIATORS
SOLAR ARRAYS
S/A BEAM
SOLAR ARRAY SUPPORT STRUCTURE
TRUNNION 4 PLACES
SOLAR ARRAYS
S/A BEAM
50kW TO 100 KW MOD KIT
TRUNNION 4 PLACES
RADIATOR
S/A BEAM
SOLAR ARRAYS
SOLAR ARRAY SUPPORT STRUCTURE EXTENSION

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6.1 OUTBOARD AND INBOARD PROFILES

6.1.1 Outboard Profile

100 kW POWER MODULE OUTBOARD PROFILE

- The 100 kW Power Module outboard profile is shown for the 100-1 configuration. The vehicle is composed of four major structural components:

    Solar array support structure

    Forward equipment rack

    Aft equipment rack

    Berthing support structure

    The outboard profile for the 100-1' configuration and 100-1 configuration is identical.

- The solar array support structure is of closed shear box or semi-monocoque construction to which the solar array wings are attached. It also carries the thermal radiator system. Both forward and aft equipment racks are constructed from ring frame assemblies, radial webs, and longerons attached to an inner tubular structure. Built into the equipment rack structure are the trunnion fittings and keel fitting that support the Power Module in the Orbiter payload compartment.

- The berthing support structure is of semi-monocoque construction and is of the same diameter as the inner tubular structure in the equipment racks. Five berthing ports are built into this structure — four at equal spaces around the diameter and one on the aft face.

100kW POWER MODULE OUTBOARD PROFILE

SOLAR ARRAY WING
(6 METER BLANKETS)

TRUNNION
FITTING

FORWARD EQUIPMENT RACK

AFT EQUIPMENT RACK

BERTHING STRUCTURE

SUPPORT STRUCTURE
EXTENSION

58.0

SUPPORT BEAM
2 PL

GRAPPLING FIXTURE
2 PL

440.0   220.0   125.0   124.0

565.0   356.0   62.5   33.0

RADIATORS
THERMAL CONTROL
SYSTEM

HI-GAIN ANTENNA
2 PL

BERTHING PORT–5 PL

84.0

120 DIA

TRUNNION
FITTINGS

BERTHING TRUNK

KEEL FITTING

909.0 REF

1194.0

52° DIAM
2 PLACES
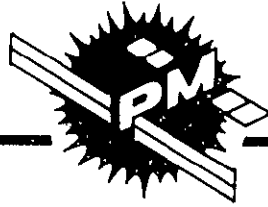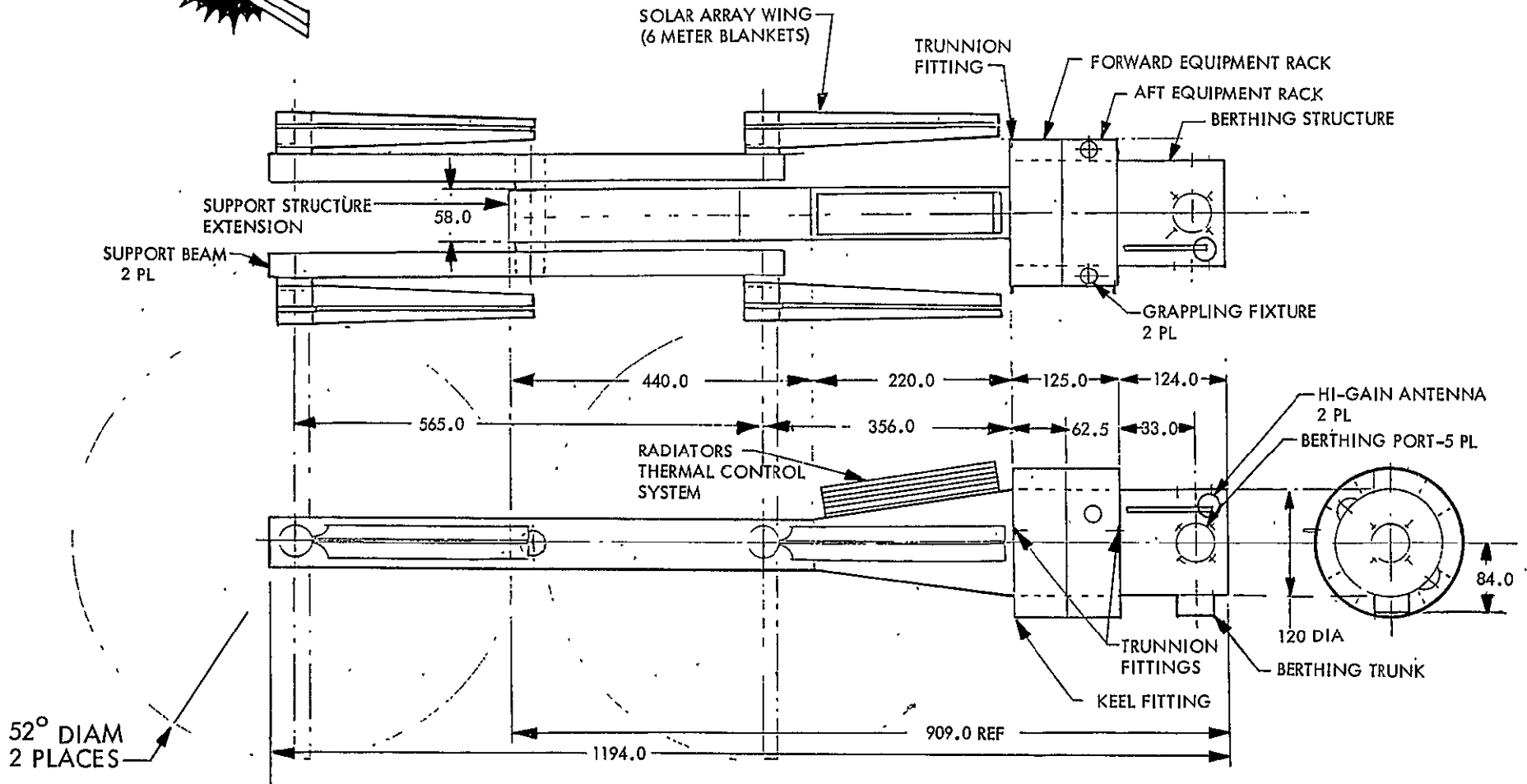
OUTBOARD PROFILE
100 kW POWER MODULE

ALL DIMENSIONS IN INCHES

6.1.2 Inboard Profile

100 kW POWER MODULE INBOARD PROFILE EQUIPMENT INSTALLATION

● The inboard profile is shown in the figure for the 100-1 configuration. For ease of equipment installation, the concept of subsystem modularity is maintained. The electrical power subsystem equipment is located in the forward equipment rack. Communications and data handling subsystem equipment, magnetic torquers and electronics, rate gyros, and horizon sensors and electronics are located in the aft equipment rack. The four control moment gyros are located in the berthing module. The basic difference in the 100-1' configuration after on-orbit assembly of the (50-100 kW) kit to the 50 kW PM, is that the major components of the new electrical power subsystem (batteries and electronics) will be located in the solar array extension structure. The batteries and electronics of the former 50 kW vehicle will remain inactive in the forward equipment rack.

● This subsystem compartment allocation provides enhancement for growth and maintenance on-orbit.
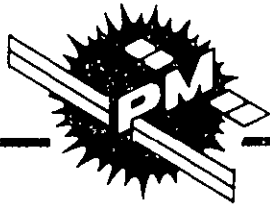
100kW POWER MODULE INBOARD PROFILE EQUIPMENT INSTALLATION - (100-1) CONFIGURATION

ACS EQUIPMENT

MAGNETIC TORQUERS

ELECTRICAL POWER SYSTEM NiH$_2$ BATTERIES

HI-GAIN ANTENNA (2)

CMG ATTITUDE CONTROL SYSTEM (4)

RADIATORS

BERTHING MECHANISM

BOOM EXTENSION

COMMUNICATION AND DATA HANDLING

THERMAL CONTROL SYSTEM EQUIPMENT

SOLAR ARRAY SUPPORT BEAMS
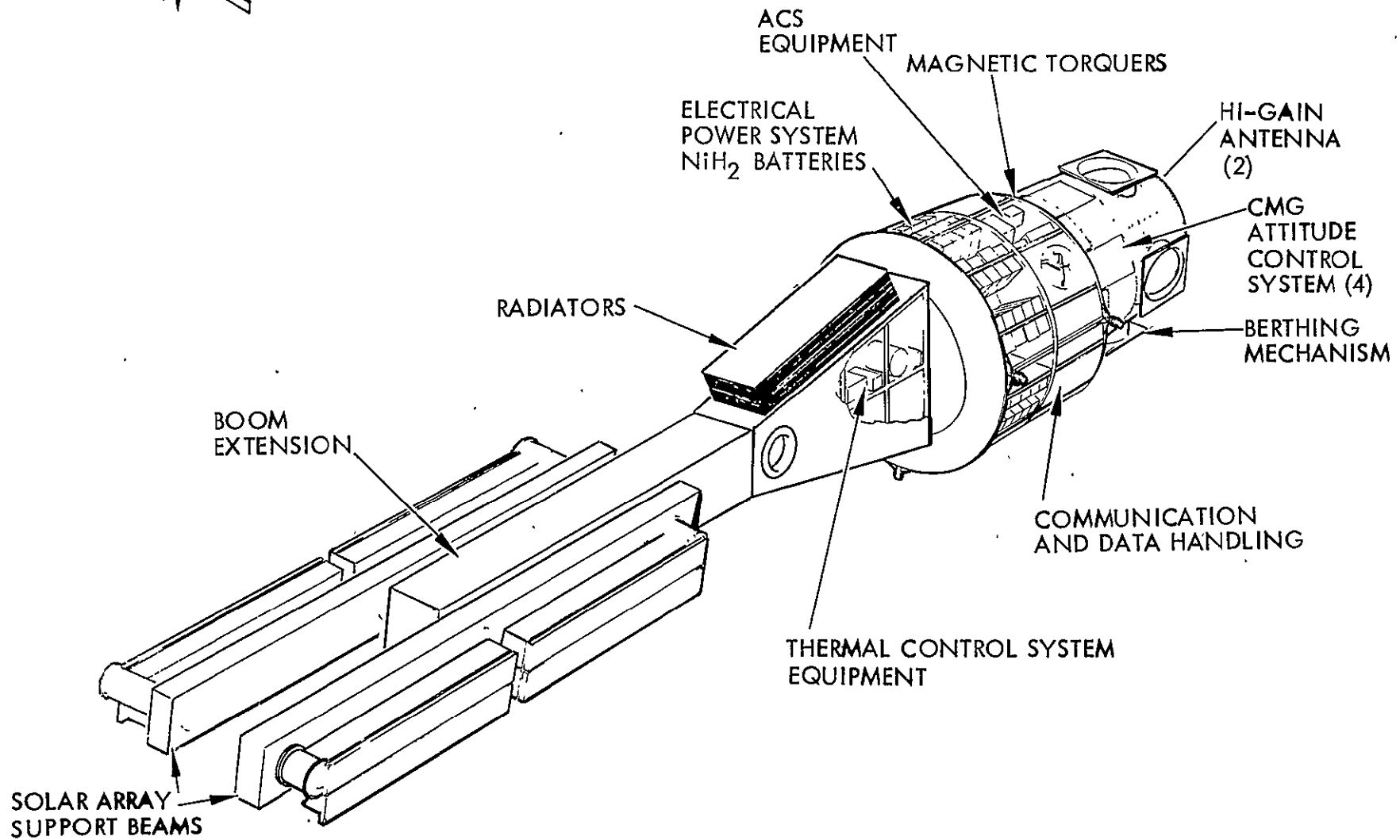
100 kW POWER MODULE EQUIPMENT INSTALLATION

● Equipment installation details for the 100-1 configuration are shown in the drawing.

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6.2 WEIGHTS

A summary weight statement for the 100 kW Power Module is shown below. Mass Properties data is given in Volume 4, paragraph 2.2 of the Part III, Final Report.

100 kW POWER MODULE WEIGHTS SUMMARY

ITEM	CONFIGURATION	
	100–1'*	100–1
WEIGHT (LB)		
STRUCTURE & MECHANICAL	9,900	10,050
ELECTRICAL POWER	28,225	17,600
THERMAL CONTROL	3,549	2,879
ATTITUDE CONTROL	2,610	2,610
C & DH	494	472
SUBTOTAL	44,778	33,611
CONTINGENCY	11,195	8,403
TOTAL	55,973	42,014

*On–orbit weight after kit assembly.

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6.3 SUBSYSTEM DESIGN DESCRIPTION

6.3.1 Structures

The structure of the forward and aft equipment racks and of the berthing structure is the same for the 100 kW PM as it is for the 25 kW PM as described in paragraph 4.3.1 pages 4-20 through 4-37 of this Volume.

CONFIGURATION 100-1 S/A STRUCTURE

- The solar array structural components are shown in the chart. All structure is of shear box design.

- The solar array support structure has basic dimensions to accommodate the deployable solar arrays and their rotation and to provide structural strength, and orbiter/clearances. The structure has provisions for mounting the solar array beams, the radiators, and the radiator mechanical and electrical components. The support section has a 58.0 X 60.0 - inch cross section that is standard for kit growth.

- The solar array beams accommodate two solar array assemblies on each beam. The beams interface with the solar array support structure and are powered to rotate and operate through 360°. A drive system similar to that for the 25 kW system, would rotate the beams for the 100 kW PM solar array wings. In this case the individual assemblies are fixed once they are deployed. A study is required to determine the cost effectiveness of making the 25 kW rotation system applicable to the 100 kW system.
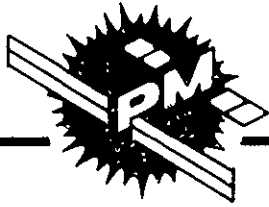
CONFIGURATION — 100–1 S/A STRUCTURE
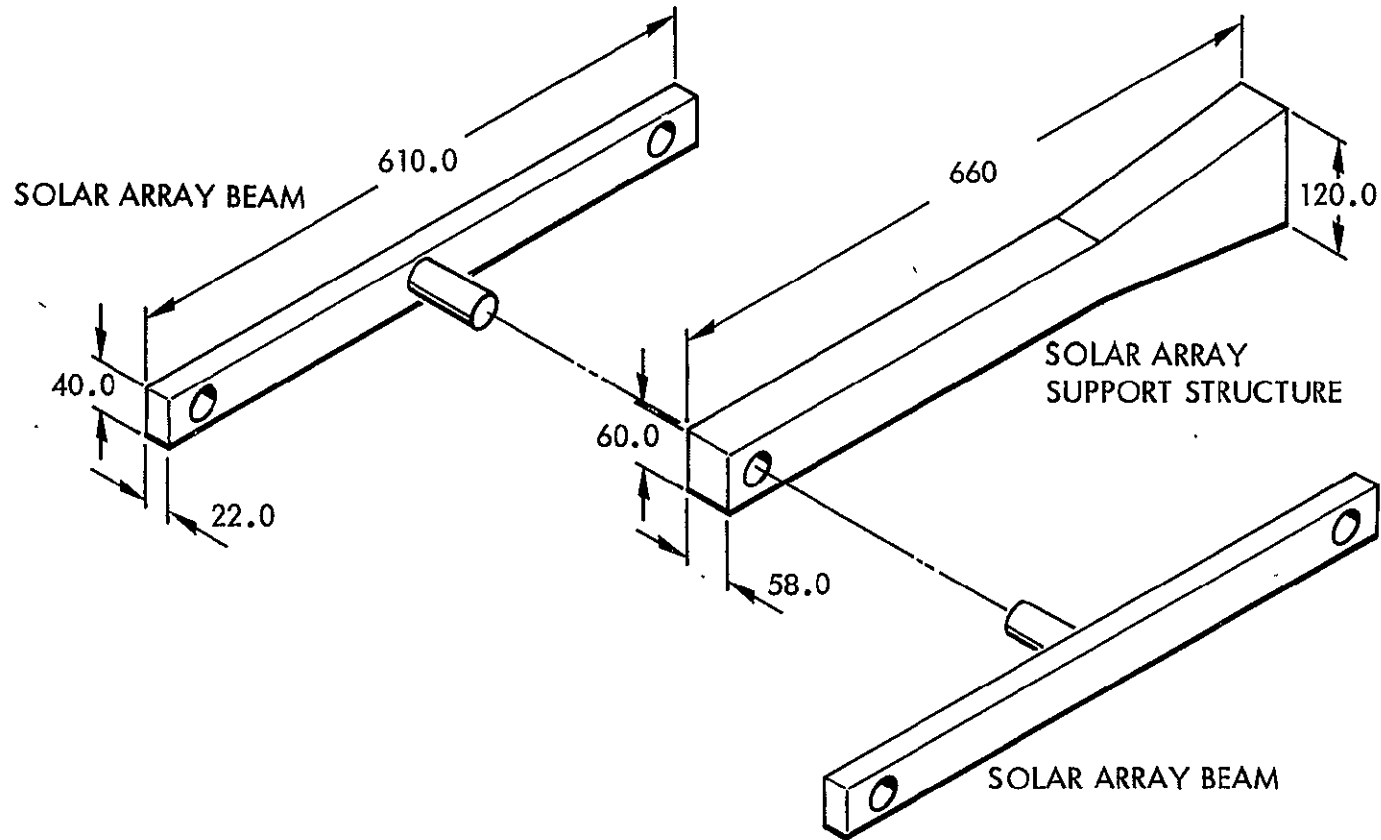
SOLAR ARRAY BEAM

610.0

40.0

22.0

660

120.0

SOLAR ARRAY
SUPPORT STRUCTURE

60.0

58.0

SOLAR ARRAY BEAM

COMPONENT CHARACTERISTICS

- A summary of structure subsystem weights and characteristics of the structures subsystem components are given in the table:

100 kW POWER MODULE STRUCTURES AND MECHANICAL COMPONENT CHARACTERISTICS

ITEM NO.	COMPONENT	NO REQD	PWR (WATTS)	SIZE (L X W X H) IN	UNIT WT (LBS)	UNIT WT (LBS)	UNIT WT (LBS)	UNIT WT (LBS)
1	STRUCTURAL ASSEMBLY, SOLAR ARRAY SUPPORT - PYLON	1	N/A	660 X 58 X 120/160	1800	1800	2150	2150
2	STRUCTURAL ASSEMBLY, SOLAR ARRAY SUPPORT - BEAM	2		610 X 22 X 40	350	700	350	700
3	STRUCTURAL ASSEMBLY, FWD EQUIPMENT RACK	1		168 DIA X 62.5	1435	1435	1435	1435
4	STRUCTURAL ASSEMBLY, AFT EQUIPMENT RACK	1		168 DIA X 62.5	1465	1465	1465	1465
5	STRUCTURAL ASSEMBLY, BERTHING MODULE	1		168 DIA X 124	3200	3200	3200	3200
6	MECHANISMS	A/R		TBD	450	450	450	450

6.3.2 100 kW Electrical Power Subsystem

The electrical power subsystem (EPS) for the 100 kW Power Module furnishes power required for the PM subsystem and provides 100 kW power at the Orbiter and payload interfaces. Characteristic of the EPS elements (solar array proven control and energy storage) are described below:

Solar Arrays

One alternative for growth to 100 kW is on-orbit growth which is achieved by adding a 50-100 kW kit to one of the 50 kW Power Modules in orbit. This on-orbit assembly sequence, described in Volume 4, paragraph 6.9, of Part III Final Report, is summarized as follows:

(1) Retraction and temporary stowage of 50 kW S/A blankets and radiators.
(2) Removal and stowage of 50 kW solar array support assembly
(3) Deployment of 50 kW "kit" which includes a 100 kW sized S/A support assembly
(4) Mounting of existing 50 kW S/A blankets on 100 kW support assembly
(5) Extension of masts with S/A blankets

The second alternative for growth to 100 kW is "launch-to-orbit" growth achieved by a 100 kW configuration launched entirely from the ground.

Solar Array Blanket Characteristics

Solar array blanket characteristics for these alternatives are given in the table.

100 kW POWER MODULE SOLAR ARRAY
BLANKET CHARACTERISTICS

	50 kW	50 kW kit	100 kW
CELL EFF (%)	16.0	16.0	16.0
BLANKET WIDTH (FT)	19.8	19.8	19.8
BLANKET LENGTH (FT)	13.0	13.0	13.0
BLANKET AREA (FT^2)	2550	2550	5100
NUMBER OF BLANKETS	4	4	8
TOTAL AREA (FT^2)	10,200	10,200	20,400
	GROWTH ON-ORBIT CONFIGURATION		GROUND LAUNCH CONFIGURATION

Power Controls

The 100 kW PM will contain a full new complement of power controls brought up with the 50-100 kW kit. Higher power ratings are required, since the number of S/A-regulator-battery power strings will remain at 12.

Advances in technology between 1983 and 1990 are expected to offer significant weight savings and high reliability. Therefore, redesign of the control electronics is planned to take advantage of these improvements.

Energy Storage

The 50-100 kW kit will contain a full new complement of $Ni-H_2$ batteries for the following reasons:

- Batteries in the on-orbit 50 kW PM will have had 4 years of operation.
- The new complement of $Ni-H_2$ batteries will represent newer technology cells along with extensive life test data to back up operation to 80 percent DoD.
- The new 100 kW PM will use the same number (12) and size of batteries as the 50 kW PM, except DoD will double from 40 to 80 percent.

The doubled DoD will slightly more than double the loading on the thermal control system. Therefore, some modifications to that interface are anticipated.

6-32

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SUBSYSTEM PERFORMANCE AND COMPONENT CHARACTERISTICS

The 100 kW PM EPS performance requirements are assumed to be double that of the 50 kW PM. Solar array area and battery DOD are double, and new power controllers are required with higher current capability. The EPS weight for this 100 kW configuration is given below:

100 kW EPS CHARACTERISTICS AND WEIGHTS

ITEM	CONFIGURATION	
	100-1K [1]	100-1 [2]
Power — kW	100	100
Cell Type, # Ft^2	Si, 0.2	Si, 0.2
Cell Eff. (%)	16	16
Battery	Ni-H$_2$	Ni-H$_2$
DOD (%)	80	80
Voltage, DC Reg	(28)/110 Optional	(28)/110 Optional
	Weight (LB)	Weight (LB)
Solar Array	8,400	7,200
Solar Array Drives	550	300
Batteries	12,800	6,400
Electronics	3,450	2,055
Pwr. Distribution	2,025	1,145
Wire Harness	1,000	500
Subtotal	28,225	17,600
Contingency - 25%	7,056	4,400
Total	35,281	22,000

Notes

1. Vehicle is built up on orbit by addition of (50-100 kW Kit), weights shown include the assembled kit.

2. 100 kW configuration launched from ground

100 kW PM ELECTRICAL POWER SUBSYSTEM COMPONENTS CHARACTERISTICS LIST

The table provides a listing of components and their estimated size and weight.

100kW PM ELECTRICAL POWER SUBSYSTEM COMPONENTS CHARACTERISTICS LIST

ITEM NO.	COMPONENT	REQ'D	PWR (WATTS)	SIZE (L X W X H) (IN.)	UNIT WEIGHT (LB)	100-1' [1] TOTAL WEIGHT (LB)	100-1 [2] TOTAL WEIGHT (LB)
						CONFIGURATION	
1	BATTERY CONTROL ASSEMBLY	12	TBD	12 X 24 X 9	80	1,680	960
2	BATTERY MODULE (NI-H$_2$ TYPE)	12		52 X 17 X 10	533	12,800	6,400
3	BUS REGULATOR	12		18 X 24 X 12	80	1,685	960
4	SOLAR ARRAY WING	4		130 X 44	1,800	8,400	7,200
5	SOLAR ARRAY DRIVE ASSEMBLY	2		TBD	150	550	300
6	POWER TRANSFER ASSEMBLY	2		18 DI X 20 L	150	600	300
7	DRIVE ELECTRONICS	2		12 X 12 X 12	30	60	60
8	DC/DC CONVERTERS	3		12 X 12 X 9	25	150	75
9	POWER INTERFACE DISTRIBUTOR	1		40 X 17 X 10	400	800	400
10	MAIN POWER DISTRIBUTOR	1		17 X 17 X 8	65	130	65
11	SOLAR ARRAY DISTRIBUTOR	1		17 X 17 X 8	50	50	50
12	BERTHING DISTRIBUTOR	1		16 X 14 X 8	200	200	200
13	RACK DISTRIBUTORS	3		20 X 17 X 8	40	120	120
14	REMOTE POWER CONTROLLERS	30		4 X 7 X 5	<0.5 LB	10	10
15	POWER CABLES				500	1,000	500

NOTES

1. VEHICLE IS BUILT UP ON ORBIT BY ADDITION OF (50-100 kW KIT), WEIGHTS SHOWN INCLUDE THE ASSEMBLED KIT.

2. 100 kW CONFIGURATION LAUNCHED FROM GROUND

6.3.3   100 kW Thermal Control Subsystem

The 100 kW TCS design is basically identical to that of the 50 kW module with respect to radiator area, coolant flow rates, and temperature control of internal equipment. The thermal influence of the larger solar array blankets of the 100 kW configuration reduce the 50 kW radiator performance approximately 10%. Consequently, the radiators were extended and a rotational capability provided on the design to reduce the direct heat exchange from the solar arrays and to keep the panels edge-lit. The PM heat rejection system meets the anticipated maximum internal heat generation growth to 36 kW while still providing some payload cooling capability.

The remaining coolant loop components, pumps, cold plates, payload heat exchangers, and flow control approach are identical to that of the 50 kW configuration. The simultaneous operation of all pumps and the scheduled 2 1/2-year replacement interval will also remain in effect.

Payload Interface

Flow control of the payload coolant will remain identical to that of the 50 kW configuration. Although it is anticipated that payload cooling capacity will decrease as the result of increases in the Power Module's requirements, the payload heat exchanger remains unchanged. Consequently, the Power Module can handle payload heat loads equivalent to the 50 kW design under ideal thermal environments.

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The dissipation of waste heat from the 100 kW batteries and equipment is expected to increase to a maximum value of 36 kW. This assumption is conservative in that no power conversion efficiency improvement has been incorporated in the heat rejection performance analysis. The total Power Module heat rejection capability was calculated to range from 42 to 54 kW. This provides a payload (or manned habitat plus payload) cooling capacity of 10 to 14 kW. The payload cooling capacity could conceivably increase to 30 kW at 100% sun orbits with negligible PM battery charge/discharge activity. The heat rejection levels are 36 kW (maximum) for the PM and 18 kW (maximum) for the payloads. Coolant loop temperature is 64°F with a range of 40/104°F. Heat rejection performance is shown below.

POWER MODULE HEAT REJECTION PERFORMANCE

Configuration	Freon-21 Mass Flow Rate (Lb/Hr)	Heat Rejection (kW)			Freon Temp (°F)	Radiator Area (Ft^2)	No. of Panels/ Configuration
		PM	P/L[1]	Total[2]			
100-1 kW	10,000	36	12.4	48.4 6	64 40/104	1,350	20 Extension + Rotation

Notes: (1) Heat rejection available to payload may be used for manned habitat control. 10 kW estimated for 3-man occupancy.
(2) Total heat rejection includes effects of beta angle, sun incident up to 30°, and earthshine.

TCS weight for the 100 kW system is given below:

100 kW TCS Weight Summary

Item	Weight (Lb)
Radiator, Structure, Motors	1,900
Cold Plates, Lines	565
Pumps, Controls	177
Heat Exchanger	137
Insulation, Paint	100
Subtotal	2,879
Contingency — 25%	720
Total	3,599

100 kW Power Module Thermal Control Subsystem Components List

TCS component characteristics are shown in this table.

100kW POWER MODULE THERMAL CONTROL SUBSYSTEM COMPONENTS

ITEM NO.	COMPONENT	NO. REQ'D	PWR (W)	SIZE (L X W X H) (IN)	UNIT WT (LB)	TOTAL WT (LB)
1	RADIATOR	20		162.0 X 60.0 X 0.925	81.0	1,620
2	COLD PLATES	24			21.7	520
3	PUMP, ACCUMULATOR, CHECK VALVE, INVERTER	2	500 (AC)	7.9 X 3.5 X 3.5* 13.1 (D) X 27.2**	58	116
4	PRESSURE TRANSDUCERS	2			5	10
5	FLOW CONTROL ASSEMBLY (MIXER VALUE)	2	57.5	24 X 20 X 9	25.5	51
6	INTERFACE H_X	1			120	120
7	GSE H_X	1			17	17
8	LINES FASTENERS, CONNECTORS, FILTERS, SOLENOID VALVES	TBD			45	45
9	INSULATION	TBD			100	100
10	HEATERS	1	TBD		TBD	
11	MOTOR AND MECHANISM TO DEPLOY THE RADIATORS	40	TBD		2.0 (EST)	80
12	FREON 21	TBD			TBD	TBD
13	RADIATOR SUPPORT STRUCTURE	1			200 (EST)	200

*INVERTER
**ACCUMULATOR, PUMP, AND CHECK VALVE

6.3.4 Attitude Control Subsystem

The attitude control sybsystem for the 100 kW Power Module is identical to that provided for the 25 kW Power Module, as described in paragraph 4.3.4 of this Volume 1, Part III Final Report except that four CMGs will be used to accommodate larger payloads.

ACS weights for the 100 kW System are given below:

100 kW ACS WEIGHT SUMMARY[1]

	Weight (LBS)
CMGs and Inverters	1,888
Rate Gyros	104
Signal Conditioner and Interface Units	90
Horizon Sensors/Electrical	54
Magnetic Torquers/Electrical	456
Miscellaneous	18
Subtotal	2,610
Contingency — 25%	653
TOTAL	3,263

Note: (1) Weights are identical for 100-1′ and 100-1 configurations.

CMG REQUIREMENTS FOR THE 100 kW POWER MODULE

The CMG requirements for the 100 kW configuration in Scenario I shown in paragraph 2.1, page 2-13 of this volume are given in the chart. The analysis is based on computing the momentum required to control the cyclic torques on the vehicle when it is in an inertial, perpendicular-to-the-orbit plane orientation, and providing two additional CMGs for maneuvering, external torques, and redundancy. The analysis was made with the Orbiter docked to the Power Module. It can be seen that vehicle A-4, because of its size, cannot be flown inertially with the Orbiter attached. Further analysis showed that ZPOP was attainable in the free-flying mode. Vehicle A-5 can be flown in either XPOP or ZPOP orientations with six CMGs. Both vehicles can be held with any principal axis along the local vertical.

CMG REQUIREMENTS FOR 100 kW POWER MODULES

CONFIGURATION	ORIENTATION	CMGs REQUIRED TO CONTROL CYCLE TORQUES	CMGs REQUIRED FOR MANEUVERING AND REDUNDANCY	TOTAL CMGs REQUIRED	DESIRABLE ORIENTATION
	XPOP	26	2	28	
A-4	YPOP	16	2	18	NONE
	ZPOP	10	2	12	
	XPOP	1	2	3	✓
A-5	YPOP	5	2	7	
	ZPOP	4	2	6	✓

NOTE 1   CONFIGURATION DESIGNATORS REFER TO CONFIGURATIONS SHOWN ON PAGE 3-62 OF THIS VOLUME 1, OF PART III FINAL REPORT

6.3.5   Communication and Data Handling Subsystem

The Communication and Data Handling Subsystem for the 100 kW Power Module is identical to the design for the 25 kW PM. Refer to paragraph 4.3.5 of this Volume 1, Part III Final Report, for this description.

A weight breakdown of the C&DH subsystem for the 100 kW Power Module is given below.

C & DH SUBSYSTEM WEIGHT SUMMARY

Item	Weight (Lb)	
Configuration	100-1′	100-1
Transponders	31	31
Computer	130	130
Central and Remote Units	140	120
Antennas/Drives	116	116
Steering Electronics	48	48
Switches and Cables	29	27
SUBTOTAL	494	472
Contingency — 25%	124	118
TOTAL	618	590

The baseline C & DH subsystem can be readily expanded to accommodate any additional requirements by adding remote command and telemetry units to the central unit data bus. This is illustrated in the C & DH Block Diagram in paragraph 4.3.5 of this Volume.
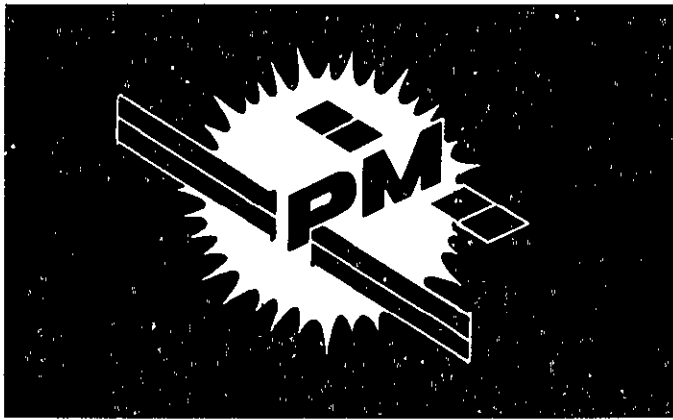
SECTION 7
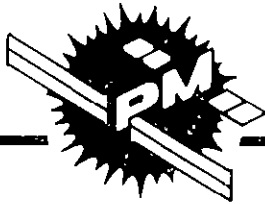# LARGE POWER MODULE
CONSIDERATIONS

200/250 kW POWER MODULE EVOLUTION

Background

The Evolutionary scenario that was selected as a recommended NASA Program Plan represents a best mix from balancing payload discipline mission requirements and Power Module evolutionary growth and use. Scenario I shown in paragraph 2.1, page 2-13 of this Volume I, Part III Final Report indicates that the PM is only required to grow to 100 kW by 1990. This nominal growth requirement is achieved by the use of multiple 100 kW PM's in low earth, low inclination orbits, one PM oriented to Material Processing missions, and the other PM oriented to Space Science-Construction Base missions. A Power Module larger than 100 kW, which would serve the MP, SS-CB payloads, was not recommended since the low "g" environmental requirements of the MP missions are basically incompatible with the SS-CB missions where manned habitation is required.

In the initial phase of the study, one task team collected mission discipline desires and derived Power Module requirements, while the preliminary designers were conceptualizing feasible Evolutionary Growth designs of the Power Module. The results of the early preliminary design work showing 200/250 kW Power Module concepts are documented in this section. This design was not developed further under the Part III study because PMs larger than 100 kW were not part of the recommended scenario. These designs represent a logical growth of the PM system beyond 1990. They extend the use of the solar array configuration concept identical to that used in the 50 and 100 kW PM, and they provide packaging concepts to maximize the use of the Orbiter Payload Space using these solar arrays. The designs include the results of technology forecasting permitting higher efficiencies and high packaging densities that will significantly reduce the transportation costs to place a large Power Module into an operational mode. Further study and analysis of this size Power Module is recommended as a next program step, to prepare realistic planning into the mid-1990's.

Task considerations for these large Power Module studies are shown here.

LARGE POWER MODULE CONSIDERATIONS
FOR FURTHER STUDY

- ON-ORBIT CONSTRUCTION/ASSEMBLY

- STS LAUNCHES/LIMITATIONS

- ELECTRIC POWER GENERATION/TRANSMISSION

- SEP ARRAY VS SPS ARRAY

- ENERGY STORAGE TECHNIQUES

- BATTERIES

- ATTITUDE CONTROL/STRUCTURE/SOLAR ARRAY INTERACTION

- PROPULSION/DRAG MAKE-UP

- THERMAL CONTROL TECHNIQUES

- ON – ORBIT MAINTENANCE

- EQUIPMENT LIFE

- SYSTEM GROWTH

- COMMONALITY

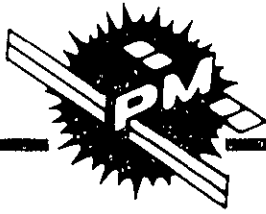- TECHNOLOGY

- INVESTMENT COST/PAYBACK

200/250 kW Power Module

The following three charts portray a conceptual design of a 200-250 kW Power Module in its launch configuration, on-orbit preparation for deployment, and in its deployed configuration. In this conceptual design, the solar array wings are attached to and folded against support beams that are fastened by hinges to each end of a center beam. The solar array support beams and center beam are shown as of truss design and can be structurally separated along the longitudinal center line.

Segments of a deployment boom, V band clamps and a gimballing unit are stowed within the solar array support booms. At the outer ends of the solar array support booms are stowed the folded panels of the thermal radiator system.

LAUNCH CONFIGURATION

For installation in the Orbiter payload compartment, the solar array support beams and the center beam are structurally joined at their separation planes and the outer beams are folded and locked against the sides of the center beam. The center beam is attached to the payload compartment structure by the conventional sill trunnion and keel fitting system — the sill trunnions extending by outriggers from the center beam through the truss structure of the outer beams.

200/250 kW POWER MODULE
LAUNCH CONFIGURATION

1990 TECHNOLOGY
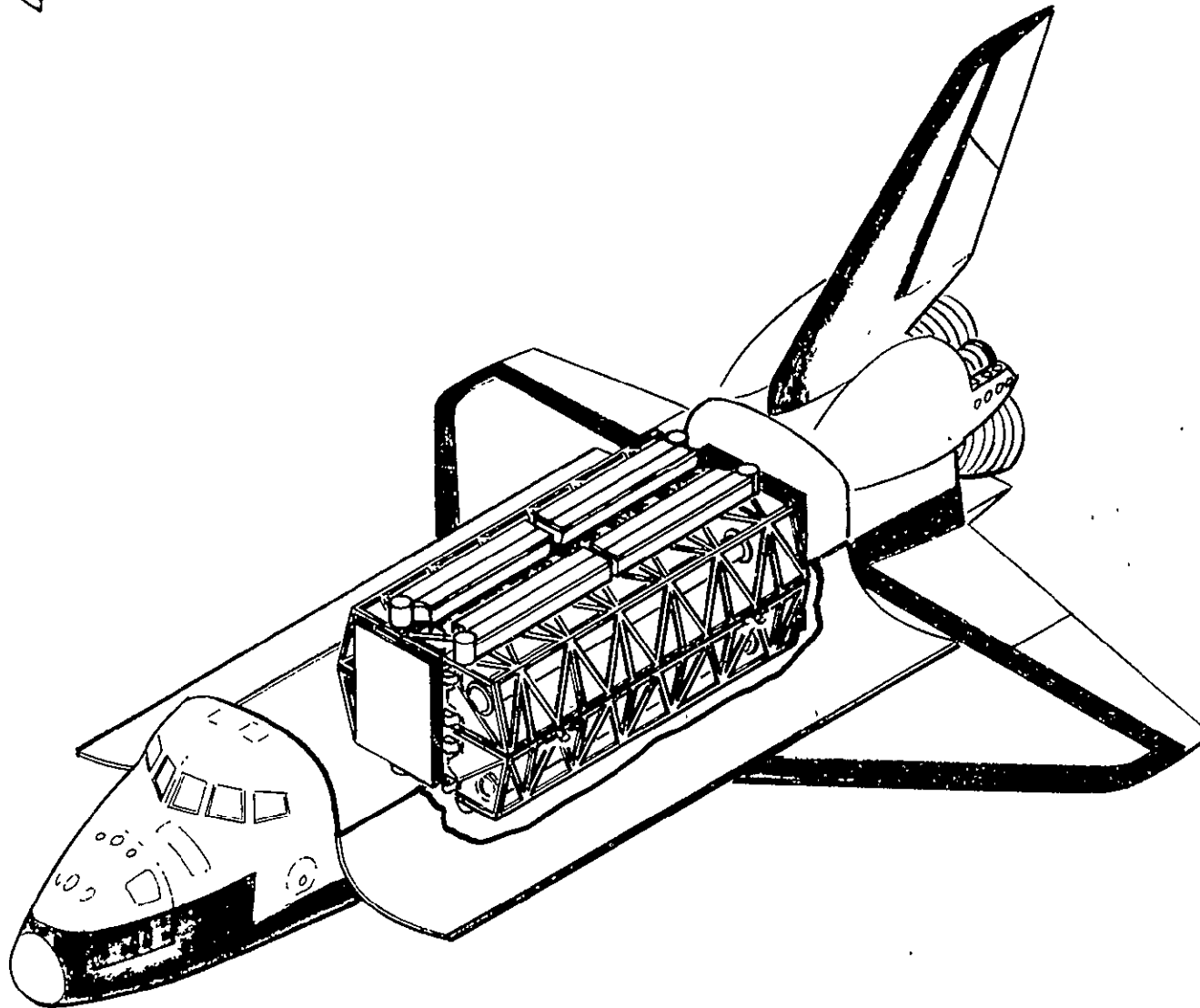
200/250 kW POWER MODULE SYSTEM
ON-ORBIT PREPARATION FOR DEPLOYMENT

The folded Power Module is removed from the payload compartment and the solar array support booms are unfolded and locked open. The upper and lower halves of the support booms and the center beam are separated and the gimballing unit is installed between them. The segments of the deployment boom are unstowed and joined together by V Band Clamps to make one boom which is then connected to the gimballing unit. The solar arrays and thermal radiator panels are extended and the system is ready for connection to a payload and operation.

200/250 kW POWER MODULE SYSTEM

OUTER BEAM
FULLY EXTENDED
AND LOCKED

BEAM
HINGE

GIMBAL UNIT

SOLAR ARRAYS
PRIOR TO
EXTENSION

THERMAL RADIATORS
PRIOR TO EXTENSION

THERMAL
RADIATORS
FULLY EXTENDED

V BAND
CLAMPS

BOOMS REMOVED FROM
OUTER BEAMS AND
ASSEMBLED BY V BAND
CLAMPS INTO ONE BOOM (EVA)

BEAM STRUCTURES
UNBOLTED AT SEPARATION
JOINT AND MOVED APART
FOR INSTALLATION OF
GIMBAL UNIT BETWEEN
CENTER BEAMS (EVA)
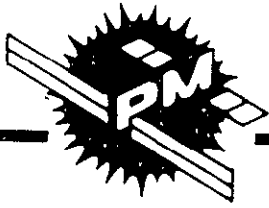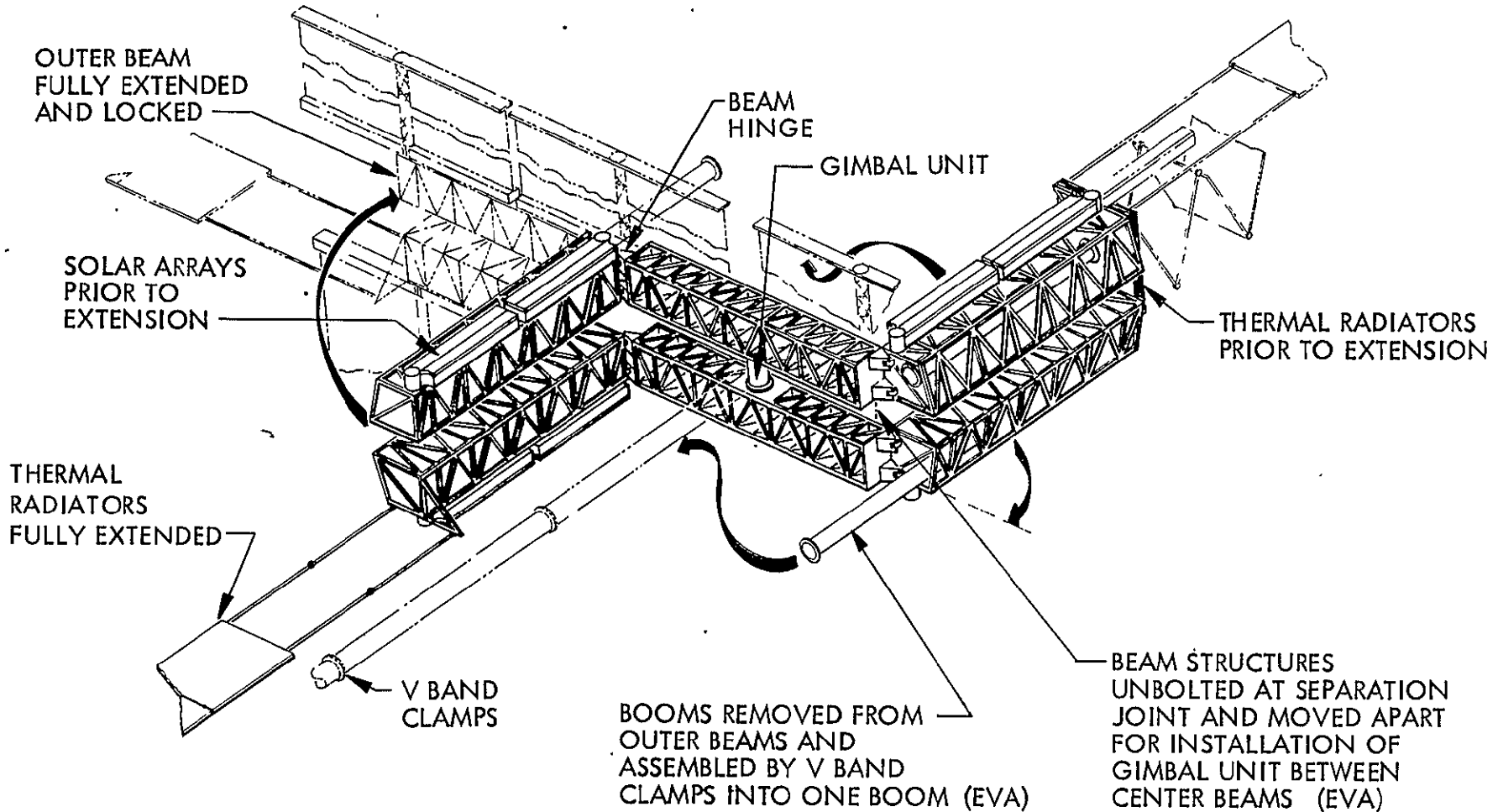
200/250 kW POWER MODULE DEPLOYED

The chart shows the Power Module fully unfolded and with the solar arrays
and thermal radiators extended. A typical payload is attached by V Band
Clamp to the free end of the deployment boom and the system is ready for
operation.

200/250 kW POWER MODULE (DEPLOYED)

SPACE VACUUM RESEARCH FACILITY
(SVRF)

PAYLOAD DOCKING ADAPTER

MEM I 8 PLCS

~ 90° ROTATIONAL
CAPABILITY

THERMAL
RADIATORS

56.0M
(180.0
FT)

150.0M
(490.0
FT)

112.6M
(365.0
FT)

76.5M
(250.0
FT)

~ 360° ROTATIONAL
CAPABILITY
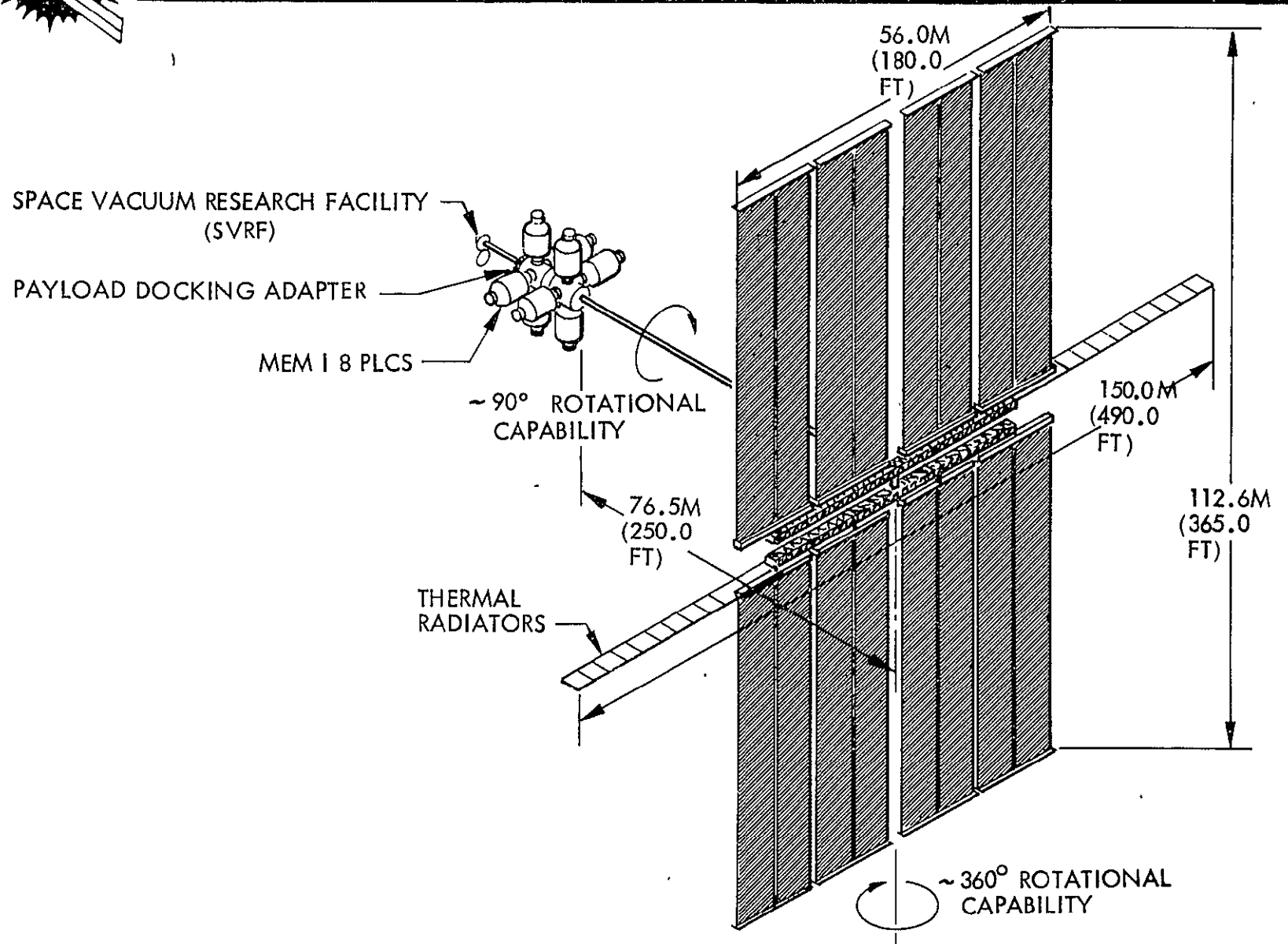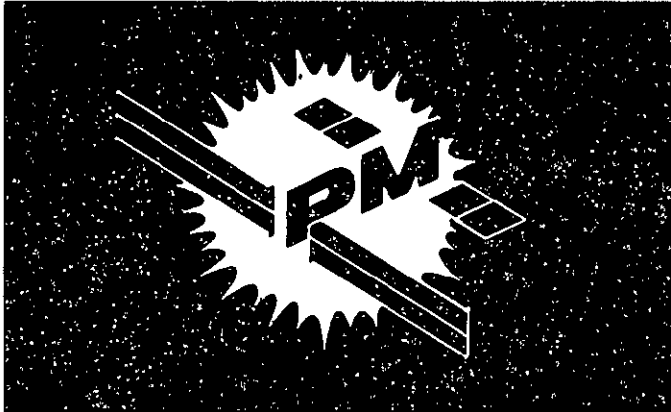
SECTION 8
REFERENCES

8.1   BIBLIOGRAPHY FOR PART III

8.2   REFERENCES

8.3   25 kW POWER MODULE STUDY DOCUMENTS

8.1 BIBLIOGRAPHY FOR PART III

The following lists the primary published document references utilized in conjunction with Part III of the study.

No.	Document No.	Title	Author/Source/Contact	Date
1	STAR 15	Shuttle Turnaround Analysis Report	KSC	9 Dec 1977
2	JSC 07700 Vol XIV	Space Shuttle System--Payload Accommodations (Revision F, Change 27)	NASA (JSC)	11 Nov 1978
3	NASA/Langley Memo 78668	An Introduction to Shuttle/LDEF Retrieval Operations: The R-Bar Approach Option	NASA	1 Feb 1978
4		25 kW Power Module Preliminary Definition	MSFC	Sep 1977
5		Power Module Data Management System (OMS) Study (IBM-FSD Huntsville)	IBM	9 June 1978
6		Teleoperator Retrieval System	Hethcoat (MSFC)	16 Mar 1978
7		Orientation Briefing for Power Module Evolution Study, Skylab	Rutland (MSFC)	16 Mar 1978
8		Space Shuttle External Tank Briefing	MSFC	16 Mar 1978
9	MSFC-SPEC-582A	Power Module System Design Requirements Document	NASA/MSFC	1 May 1978
10		System Capabilities	Beasley (MSFC)	17 Mar 1978

No.	Document No.	Title	Author/Source/Contact	Date
11		25 kW Attitude Control System Trade Studies	MSFC	Feb 1978
12		Power Module CMG Status	MSFC	Mar 1978
13		Solar Electric Propulsion	MSFC (Austin)	May 1978
14		25 kW Power Module Mass Properties (Concept IV)	MSFC (Collins)	1 Feb 1978
15	K-STSM-09 Vol VI	Launch Site Accommodations Handbook for STS Payloads	NASA (KSC)	14 Mar 1978
16	SAI No. SAI-79-602-HU	Space Industrialization		15 Apr 1978
17		Study of the Use of Spacelab Derived Elements	ERNO	Jan 1978
18	ICD 2-19001 CH 1	Shuttle Orbiter/Cargo Standard Interfaces	NASA (JSC)	24 Apr 1978
19	TMX-64972	A Miniaturized Pointing Mount for Spacelab Missions	C. G. Fritz, J. T. Howell, P. D. Nicaise, J. R. Parker	11 Nov 1975
20	LMSC-D569577	Contamination Control of Long-Life Shuttle Payload	M. C. Fong, C. K. Liu	10 Dec 1976
21	Combustion and Flames, Vol 14, No. 13, pp 397-404	Simultaneous Mass Spectrometric Differential Thermal Analyses of Nitrate Salts of MMII and Methylamine	P. Breisacher, H. H. Takimoto, G. C. Denault, W. A. Hicks	Jun 1970

No.	Document No.	Title	Author/Source/Contact	Date
22	MCR-75-13, Martin Marietta Aerospace, Denver	Payload/Orbiter Contamination Control Assessment Support	R.O. Rantanen, E.B. Ross	27 Jun 1975
23	NASA TM X-68212	Exhaust Plume and Contamination Characteristics of a Bipropellant (MMH/N_2O_4) RCS Thruster	E.W. Spisz, R.L. Bowman, J.R. Jack	1973
24	Special Report 332	Special Report	L.J. Jacchia, Smithsonian Observatory	5 May 1971
25	ES 84	Solar Activity Indices and Predictions	NASA/MSFC	5 Jan 1978
26	Viewgraph Briefing	1978 Predicted Solar Flux	W.D. McFadden/ MSFC	23 Oct 1978
27	LMSC-A374573	A High Speed Computer Program for Predicting the Decay of Earth Satellites	H.W. Small, R.C. Johnson/LMSC	13 May 1963
28	IBM K42-78-001	Power Module Data Management System (DMS) Study--Final Report	IBM, Federal Systems Div., Huntsville	30 Nov 1978
29	STAR 15	Shuttle Turnaround Analysis Report	Rockwell International	5 June 1978
30	SLP 2104, Issue No. 1	Spacelab Payload Accommodation Handbook	NASA/MSFC	30 June 1977
31	LMSC-D614928A	25 kW Power Module Evolution Study: Part II Payload Support System Evolution	LMSC/J.W.Overall	30 Sep 1978

No.	Document No.	Title	Author/Source/Contact	Date
32	LMSC-665411	25 kW Power Module Solar Array Preliminary Design	LMSC/J. F. Milton	29 Nov 1978
33	NASA Fact Sheet No. 78-49	Teleoperator Retrieval System	NASA	31 Mar 1978

8.2 REFERENCES

The following documents are referenced in Volume 1.

No.	Document No.	Title	Author/Source/Contact	Date
1	JSC 07700 Vol I	Space Shuttle System — Program Description and Requirements Baseline (Rev A – Change 17)	NASA (JSC)	8 Dec 1978
2	JSC 07700 Vol VIII	Space Shuttle System — Flight Operations (Change 6)	NASA (JSC)	18 Aug 1978
3	JSC 07700 Vol IX	Space Shuttle System — Ground Operations (Change 7)	NASA (JSC)	15 Aug 1978
4	JSC 07700 Vol X	Space Shuttle System — Flight and Ground System Specification (Rev C/Ch 50)	NASA (JSC)	30 Oct 1978
5	JSC 07700 Vol XII	Space Shuttle System — Integrated Logistics	NASA (JSC)	21 Apr 1977
6	JSC Vol XIV	Space Shuttle System — Payload Accommodations (Revision F, through Change 27)	NASA (JSC)	11 Nov 1978
7	ICD 2-19001 Change 1	Shuttle Orbiter/Cargo Standard Interfaces	NASA (JSC)	24 Apr 1978
8	K-STSM-09	Launch Site Accommodations Handbook for STS Payloads	NASA (KSC)	14 Mar 1978

No.	Document No.	Title	Author/Source/Contact	Date
9	LMSC-D665412	25 kW Power Module Solar Array Preliminary Design Final Review Presentation to Marshall Space Flight Center	LMSC	29 Nov 1978
10	LMSC-D614928A	25 kW Power Module Evolution Study: Part II Payload Support System Evolution	LMSC/J.W. Overall	30 Sep 1978

8.3   25 kW POWER MODULE STUDY DOCUMENTS

The following study documents were prepared in conjunction with Part II of the study.

No.	Document No.	Title	Author/Source/Contact	Date
1	LMSC-D614940	25 kW Power Module Evolution Study, Presentation Material for Mission Accommodations Analysis	LMSC	14 Nov 1978
2	LMSC-D614945	25 kW Power Module Evolution Study Final Review Presentation	LMSC	28 Nov 1978
3	EM C-1.2.2-102	Engineering Memorandum – Preliminary Weight Comparison Summary	LMSC/B. G. Wong	5 Apr 1978
4	EM C-1.2.2-103	Engineering Memorandum – (1) Interface-Space Shuttle/Strawman 1; (2) RMS Deployment-Strawman 1/Shuttle	LMSC/B. G. Wong	7 Apr 1978
5	EM C-1.2.2-104	Engineering Memorandum – Update of the Equipment Arrangement for the 25 kW Power Module	LMSC/B. G. Wong	14 Apr 1978
6		Space Construction Base Control System Final Report	Bendix	27 Oct 1978

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Bendix

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