Solar Array Subsystems Study
FINAL REPORT

Prepared For
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

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June 6, 1980
ECA-PWR-80-171

NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

Attention: Mr. Louis Light, Contracting Officer, MS500-306

Subject: Submission of Final Report

Reference: Contract Number NAS3-21926, Solar Array Subsystem Study

Gentlemen:

In compliance with the referenced contract, the Solar Array Subsystem Study Final Report is hereby submitted.

Should you have any questions, please contact the undersigned at (205) 883-2900.

Very truly yours,

PRC SYSTEMS SERVICES COMPANY

Peter W. Richardson

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Project Manager

PWR/bjs
Enclosures: As Stated

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NASA CR-159857

Final Report

SOLAR ARRAY SUBSYSTEMS STUDY

by

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PRC SYSTEMS SERVICES COMPANY

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-Lewis Research Center

Contract NAS3-21926

FOREWORD

This is the final report of a study entitled Solar Array Subsystems Study performed for NASA Lewis Research Center under Contract NAS3-21926. The technical effort extended from 20 March 1979 through 29 February 1980.

The LeRC Project Manager for the study was Julian F. Been. The PRC/SSc Project Manager was Peter W. Richardson. The study team for PRC consisted of Fred Q. Miller, lead engineer, Marti N. White, lead cost analyst, M. B. Badgley, research associate, and Ron Rosic, graphics. Final report coordinated by Brenda J. Speight.

TABLE OF CONTENTS

		PAGE
	LIST OF EXHIBITS	v
	GLOSSARY	viii
1.0	INTRODUCTION AND EXECUTIVE SUMMARY	1
	1.1 Objective and Purpose of Study	1
	1.2 Approach to the Study	2
	1.2.1 Task I-Determination of Characteristics of a 500 kW Solar Array Subsystem	4
	1.2.2 Task II-Determination of Total Cost for Baseline Subsystem	14
	1.2.3 Task III-Analysis of Cost-Technology Parameters	19
	1.3 Conclusions and Recommendations	22
	1.3.1 Conclusions of the Study	22
	1.3.2 Recommendations	28
2.0	BASELINE	30
	2.1 Space Services Platform System	30
	2.1.1 Solar Array Subsystem	30
	2.1.2 Energy Storage Distribution and Conditioning Subsystem	30
	2.1.3 Structural/Mechanical Subsystem	30
	2.1.4 Propulsion and Control Subsystem	33
	2.1.5 Command and Data Subsystem	33
	2.1.6 Operations and Maintenance Crew Subsystem	33
	2.1.7 Thermal Control Subsystem	33
	2.2 Mission Scenario and System Requirements	33
	2.3 Work Breakdown Structure	34
	2.4 Solar Array Design	34
	2.4.1 Electrical/Mechanical	34
	2.4.2 Structural	45
	2.5 Array Summary	54
	2.5.1 Performance Summary	54
	2.5.2 Weight Statement	54
	2.5.3 Array Table	54
3.0	FUNCTIONAL FLOWS	58
4.0	TOTAL LIFE CYCLE COST	68
	4.1 Design, Development, Test and Evaluation	68
	4.2 Total Production Phase Cost	68
	4.2.1 Total Manufacturing Cost	68

TABLE OF CONTENTS (CONTINUED)

Page

4.2.2 NASA Cost 77
4.2.3 Project Management 77
4.2.4 Systems Engineering 78
4.3 Total Operations and Maintenance Phase Cost 78
4.3.1 Total Contractor's Cost 78
4.3.2 NASA Incurred Cost 78
4.4 Summary 79
5.0 SOLAR ARRAY PERFORMANCE AND COST MODEL 81
5.1 Basic Concept 81
5.2 Description of Model 81
5.2.1 Solar Array Performance Parameters 81
5.2.2 Maintenance Requirements 104
5.2.3 Array Performance Requirements 106
5.2.4 Solar Cell Quantity 106
5.2.5 Transportation Requirements 106
5.2.6 Array Design 106
5.2.7 Array Materials 106
5.2.8 Material Costs 106
5.2.9 Array Weight 109
5.2.10 Array Maintenance 109
5.2.11 Life Cycle Cost 109
5.3 Summary 109
6.0 TECHNOLOGY VS. LIFE CYCLE COST 111
6.1 General 111
6.2 Methodology 111
6.3 Technology Areas 112
6.3.1 Cell Thickness vs. LCC 112
6.3.2 Cover Thickness vs. LCC 119
6.3.3 Blanket Temperature vs. LCC 119
6.3.4 Cell Efficiency vs. LCC 124
6.3.5 Cover Degradation vs. LCC 124
6.3.6 Cell Degradation vs. LCC 124
6.3.7 Line Voltage vs. LCC 131
6.3.8 Years Between Overhaul vs. LCC 131
6.3.9 Mean Time Between Failures vs. LCC 136

TABLE OF CONTENTS (CONTINUED)

	PAGE
6.3.10 Cell and Cover Assembly Unit Costs vs. LCC	136
6.4 Summary	136
6.5 Recommendations	142
6.5.1 Specific Technology Recommendations	142
6.5.2 Further Applications of the Model	143
7.0 REPORTING OF STUDY STATUS AND RESULTS	144
LIST OF APPENDICES	
A. Baseline 500 kW Solar Array Subsystem Requirements	A-1
B. Life Cycle Cost Data	B-1
C. Solar Array Performance and Cost Model Program	C-1
D. Average Temperature Variations	D-1
E. SACPM Program Data Printout (Ti-59)	E-1

LIST OF EXHIBITS

Number	Title	Page
1-1	Solar Array Subsystem Study	3
1-2	SAS Work Breakdown Structure	5
1-3	Space Services Platform System	7
1-4	SSPS Subsystem Interfaces and Functions	8
1-5	Baseline Solar Array Layout	11
1-6	SAS Hierarchy	12
1-7	Baseline Weight Statement	13
1-8	DDT&E Functional Flow	15
1-9	Production Functional Flow	16
1-10	O&M Functional Flow	17
1-11	Solar Array Subsystem Life Cycle Cost Model Structure	18
1-12	Solar Array Performance and Cost Model	21
1-13	Technology Parameters Versus LCC	23
1-14	Technology Parameters Versus LCC	24
1-15	Summary Results Of Study	25
2-1	Space Services Platform System	31
2-2	Space Services Platform System	32
2-3	System Requirements	35
2-4	SAS Work Breakdown Structure	36
2-5	SAS Hierarchy	37
2-6	Array Blanket	39
2-7	Array Panel	40
2-8	Module Cross Section	41
2-9	Solar Cell Interconnects Basic Pattern, 3 Cells in Parallel, 5 Cells in Series	43
2-10	Cross Section Details, Mechanical Interconnects	44
2-11	Space Services Platform System	46
2-12	Outboard End Tip Arrangement	48
2-13	Compression Plate and Tension Plate Details	49
2-14	Outboard End Tip Price Detail	50
2-15	Intermediate Stiffener Rib Collar Detail	51
2-16	Drive End Tip Piece	52

LIST OF EXHIBITS (Continued)

Number	Title	Page
2-17	SAS Structure Weight Statement	53
2-18	Baseline Solar Array — Performance	55
2-19	Baseline Weight Statement	56
2-20	Solar Array Totals	57
3-1	DDT&E Functional Flow	59
3-2	Solar Array Subsystem Flow	60
3-3	O&M Functional Flow	61
3-4	Cell/Cover Assembly Flow, Production Phase	62
3-5	Module Substrate Assembly Flow, Production Phase	63
3-6	Module Assembly Flow, Production Phase	64
3-7	Panel Assembly Flow, Production Phase	65
3-8	Blanket Assembly Flow, Production Phase	66
3-9	Space Assembly and Checkout	67
4-1	Solar Array Subsystem Life Cycle Cost Model Structure	69
4-2	Ground Rules and Assumptions	70
4-3	SAS Baseline Life Cycle Cost	72
4-4	Baseline Inputs to LCCM	73
4-5	SAS Manufacturing Process Factors and Baseline Direct Labor Costs	74
4-6	SAS Baseline Materials Cost	75
4-7	SAS Baseline Process Equipment Costs	76
5-1	Solar Array Performance and Cost Model	82
5-2	Solar Cell Performance Parameters	83
5-3	Module Cross Section	86
5-4	Physical Parameters	89
5-5	Radiation Shielding	90
5-6	Radiation Flux	91
5-7	Radiation Degradation	93
5-8	Solar Array Thermal Mass	95
5-9	Thermal Parameters	97
5-10	Temperature Derating	100
5-11	Blanket Power Distribution	103

LIST OF EXHIBITS (Continued)

Number	Title	Page
5-12	Cell Performance Factors	105
5-13	Array Design	107
5-14	Baseline Inputs to LCCM	108
5-15	SAS Baseline Life Cycle Cost	110
6-1	LCC Vs Cell Thickness (Conventional Cell)	113
6-2	LCC Vs Cell Thickness (Back Surface Field)	115
6-3	LCC Vs Cell Thickness (Back Surface Field & Thin Diffused Top Region	117
6-4	LCC Vs Composite Cell Thickness	119
6-5	LCC Vs Cover Thickness	120
6-6	LCC Vs Temperature	122
6-7	LCC Vs Cell Efficiency	125
6-8	LCC Vs Cover Degradation	127
6-9	LCC Vs Cell Degradation	129
6-10	LCC Vs Line Voltage	132
6-11	LCC Vs Years Between Overhaul	134
6-12	LCC Vs Meatime Between Failure	137
6-13	LCC Vs $/Cell & Cover Assembly	139
6-14	Summary of Results of Study	141

GLOSSARY

Acronyms

AMO	Air Mass Zero
BOL	Beginning of Life
BSF	Back Surface Field
CCA	Cell Cover Assembly
CDS	Command and Data Subsystem
DDT&E	Design, Development, Test & Evaluation
EOL	End of Life
ESDCS	Energy Storage, Distribution and Conditioning Subsystem
I.C.	Interconnect
LCC	Life Cycle Cost
LCCM	Life Cycle Cost Model
LEO	Low Earth Orbit
mh	Man-hour
MTBF	Mean Time Between Failure
O&M	Operations and Maintenance
OMCS	Operations and Maintenance Crew Subsystem
PCS	Propulsion and Control Subsystem
QA	Quality Assurance
SA&CO	Space Assembly and Checkout
SAPCM	Solar Array Performance & Cost Model
SAS	Solar Array Subsystem
SMS	Structural Mechanical Subsystem
SSPS	Space Services Platform System
TCS	Thermal Control Subsystem
WBS	Work Breakdown Structure

GLOSSARY (Continued)

Greek Symbols

α	Absorbitivity
β	Bending moment factor
ε	Emissivity
ϕ	Electron Flex (1 mev electrons/cm^2)
η_{BOL}	Cell beginning-of-life efficiency
η_{EOL}	Cell end-of-life efficiency
Γ	Angle of incidence, heat or solar energy
ρ	Density (cubic)
θ	Bending angle (of boom)
ω	Natural frequency

English Symbols

A	Cross section area of boom longeron or area of cell, cover, adhesive, etc.
A_s	Substrate area
B/L	Baseline
C_D	Conductor
C_p	Specific heat
D	Density (of cell, cover, adhesive)
EI	Bending stiffness
f	Boom cross section area factor
F_A	Assembly factor
F_C	Cover factor ($= F_G + F_\tau$)
F_G	Glassing factor
F_{leak}	High voltage leakage loss factor
F_{p_i}	Cell performance factors
F_{p_j}	Cover performance factors
F_{RAD}	Cell degradation factor

GLOSSARY (Continued)

English Symbols (Continued)

F_{tc}	Temperature cycling factor
$F_{\overline{TOP}}$	Temperature derating factor
F_{τ}	Cover degradation factor
I_b	Current
ℓ	Length of boom
M_b	Blanket mass
mCp	Thermal Mass
N_{CH}	Number of channels
P	Tension load
P_{cr}	Critical buckling load
P_D	Power density
P_{mp}	Maximum power cell
Q	Quantity
q_E	Electrical energy
r	effective boom radius
S'	Effective illumination
t	Thickness
$\bar{T}$	Average temperature
T	Thickness of cell, cover or of substrate, module or panel
Ta_2O_5	Tantalum pentoxide
V_D	Diode voltage drop
V_{IC}	Interconnect voltage drop $(=V_{SC} + V_{mm} + V_{PP} + V_{mb} + V_{sr})$
V_{mb}	Main bus conductor voltage drop
V_{mm}	Module to module interconnect drop
V_{sr}	Slip ring voltage drop
V_{SC}	Cell connection voltage drop
W	Weight
W_b	Weight of boom
W_{str}	Weight of structure

1.0 INTRODUCTION AND EXECUTIVE SUMMARY

NASA's proposed space programs for the 1980's and 1990's indicate increases in space power requirements in the multi-hundred kilowatt range. Some missions are projected to require as much as 100 to 250 kilowatts of power by the mid to late 1980's. These large space power systems requirements, within this time frame, present a technical and economic challenge to NASA. The projected costs of multi-hundred kilowatt systems based on present technology cost is considerable and becomes a constraint on a number and types of space programs NASA will be able to carry out.

Historically the solar array subsystem's costs have contributed a significant percent of total space power systems costs. This makes the solar array a logical candidate for potential cost reduction of the total space power systems. One of the most effective approaches to cost reduction in the past has been through technology advances, yet the relationships between total systems cost and the many solar array technologies have not been established.

While there is considerable commonality in the different mission requirements placed on the photovoltaic space power system there are also many unique requirements for each class of missions. This suggests that it would be productive to examine each class of missions separately. The class of missions which has the potential for providing considerable cost reduction through technology is the high-power low-earth-orbit Space Platform. This is one of several large earth orbiting satellites proposed which can yet be impacted through advanced technology. This is the type of baseline mission which is to be analyzed in this study.

1.1 Objective and Purpose of Study

It is the purpose of this study to establish the cost-technology relationships of a 500 kW (250 kW continuous to load) silicon planar solar array subsystem for a low-earth-orbit Space Platform type of mission. The study is to identify areas of new technology which if the technology were incorporated, would reduce the cost of space power systems in the LEO, large space platform mission class.

Stated another way, the study is to establish the relative sensitivity of array life cycle costs (LCC) to variation in parameters such as cell thickness, blanket temperature, and cell/cover degradation. The cost of implementing specific technology solutions is, however, not quantified. For example, the effect of blanket temperature on life cycle costs was determined to be $3.2 million per degree centigrade (in the vicinity of the baseline), however, the impact on array parameters and hence the cost of the means to achieve a particular blanket temperature was not quantified.

However, the capability exists within the model to determine these relationships, given the specific technology.

1.2 Approach to the Study

From the outset, the technique and model to be applied to the study objectives was developed with adaptability and versatility as key features. This would enable application of the solar array model to a large spectrum of mission classes and at the same time provide quantification of life cycle (LCC) costs versus technologies for the specific mission class of this study. Further, the technique was developed to accommodate any analog relationship; for example solar cell thickness versus cell efficiency or cell/cover degradation characteristics versus end-of-life array power output. The model, while used to quantify the influence of varied technology parameters versus LCC for a baseline design, can be used to optimize the baseline, and with modification, a broad spectrum of missions.

The study was performed in four phases, or tasks:

- Task I - Determination of characteristics of a 500 kW Solar Array Subsystem (a baseline design)
- Task II - Determination of Total Cost (LCC) for the Baseline Subsystem
- Task III - Analysis of Cost-Technology Parameters (LCC vs. Technology)
- Task IV - Reporting

The sequencing of these tasks is shown in Exhibit 1-1.

The approach and general results obtained within each task are summarized in the following paragraphs. Detailed discussion of results is provided in Sections 2.0 through 7.0 for each task/subtask, as specifically referenced in this section.

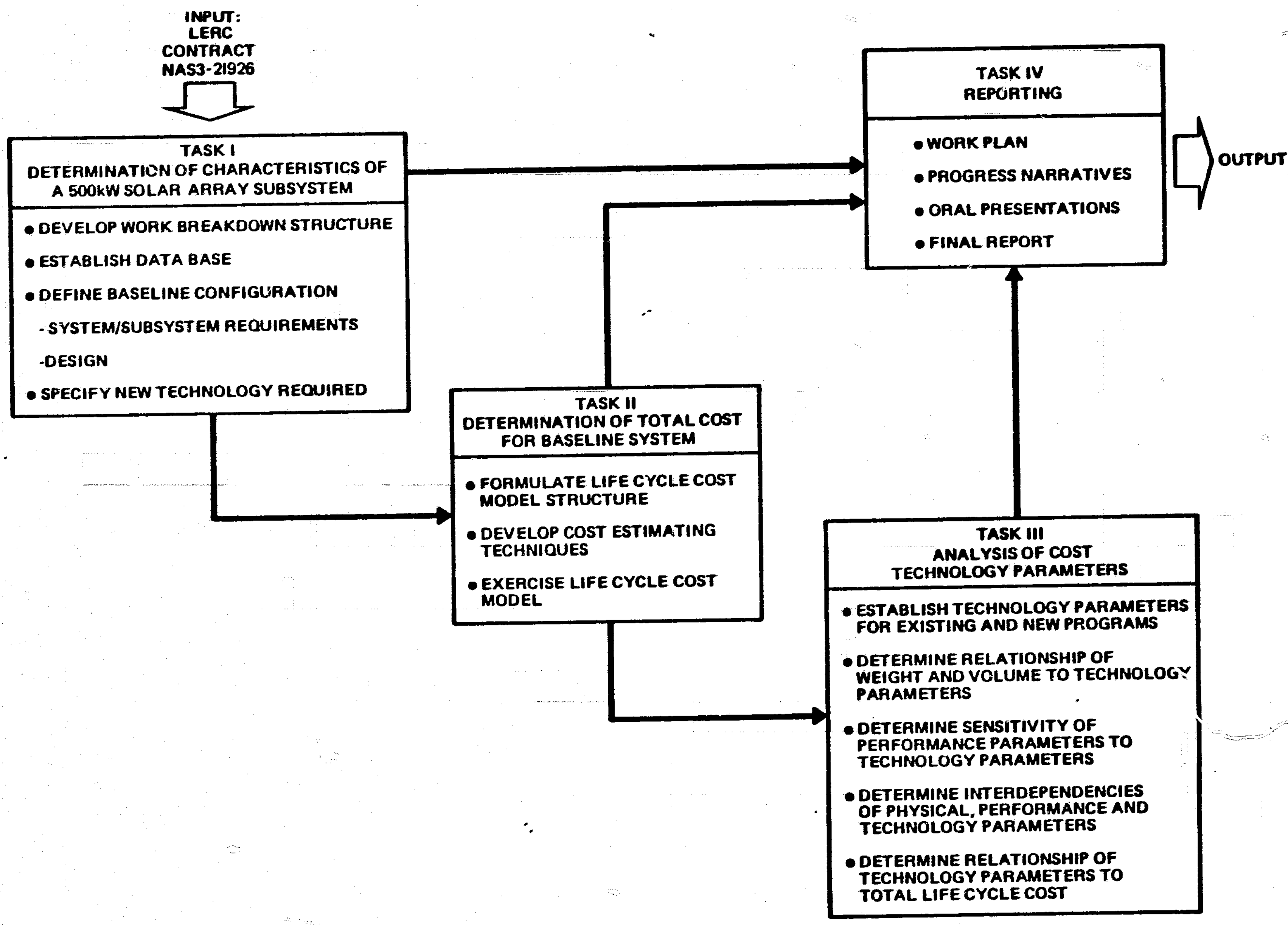


EXHIBIT 1-1. SOLAR ARRAY SUBSYSTEM STUDY

1.2.1 Task I - Determination of Characteristics of a 500 kW Solar Array Subsystem

The purpose/objective of this task was to develop a conceptual baseline solar array subsystem design. The design was developed to a level of detail considered necessary to support a variation of technology parameter values, for example, cell/cover assembly life degradation, bus voltage level, life/reliability and others. Further, the design included scenarios for manufacturing processes, space transportation, assembly and checkout, and operations and maintenance, again parametrically variable to support cost/technology analyses.

Ground rules for the design called for a silicon planar array, use of existing and proven technology, Shuttle transportation, and an operational date in the 1985-1995 time frame.

Task I consisted of four subtasks:

- Subtask I-1: Develop the Work Breakdown Structure (WBS)
- Subtask I-2: Establish the Data Base
- Subtask I-3: Define the Solar Array Baseline Configuration
- Subtask I-4: Specify (any) New Technology Required

1.2.1.1 Subtask I-1: Develop the Work Breakdown Structure (WBS)

The WBS was developed initially to accommodate any configuration and then made more specific to reflect the baseline array subsystem configuration. The resulting WBS is shown in Exhibit 1-2. The WBS served as the basis for the life cycle cost model (LCCM) developed in Task II, (Section 4.0) and for the manufacturing, space assembly and check-out, and operations and maintenance functional flows, (Section 3.0). The WBS is discussed in more detail in Section 2.3.

1.2.1.2 Subtask I-2: Establish the Data Base

A base was established to provide technical, cost and programmatic data for this study. The data base was researched and summary data sheets developed on approximately 50 historical and planned space solar arrays to provide fast access to technical and cost information as required.

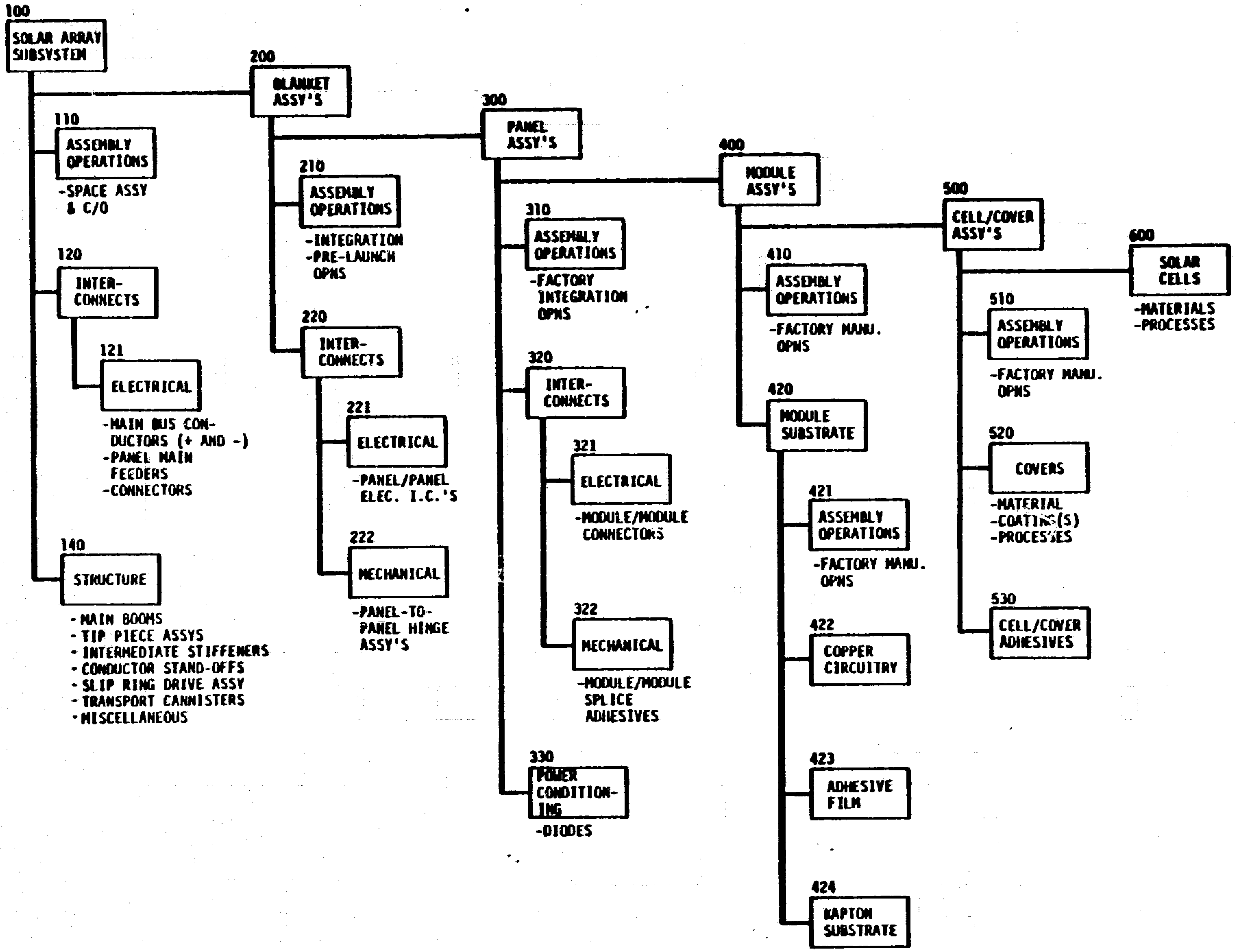


EXHIBIT 1-2. SAS WORK BREAKDOWN STRUCTURE

1.2.1.3 Subtask I-3: Define the Solar Array Baseline Configuration

The definition of a baseline array configuration was preceded by development of system/subsystem requirements. These requirements were developed for the study and documented in a "Specification of Requirements, 500 kW Solar Array Subsystem," which is provided as Appendix A . The specification is summarized in the following paragraphs.

A Space Services Platform System (SSPS) was conceptualized to create a system structure within which a Solar Array Subsystem (SAS) could be defined to provide a baseline design for the study. The purpose of the Space Services Platform System (SSPS) is to provide services to varied User Systems. The User Systems may be engaged in materials processing, manufacturing, astronomy, solar system and earth observation, life sciences, communications, testing and other operations. The User Systems may be secured to the platform or docked for servicing or short-term operations. The general configuration of the SSPS is shown in Exhibit 1-3. The subsystems of the SSPS, their functions and major interfaces are summarized in Exhibit 1-4.

The major system requirements on the SSPS, and the subsystem requirements on the SAS, are:

- System operational 1985-1995
- State-of-art (1979) design
- Silicon solar cells; planar array (no concentration)
- Transportation to LEO: Shuttle
- LEO Orbit: 444 km. Inclination 55°
- 250 kW continuous to loads, provided in 48 individual power channels to the ESDCS subsystem at the slip ring interface
- Provide this output from BOL to EOL
- Varied angle to sun to maintain 250 kW to load
- Bus voltage for users to be:
  30 VDC = small, experimental projects (20% of power)
  100-250 VDC-intermediate power projects and other SSPS subsystems (30% of power)
  1000 VDC-manufacturing, processing, large ion engine testing (50% of power)
- 10 Year Life before SAS solar blanket replacement
- Folded blankets for space transport

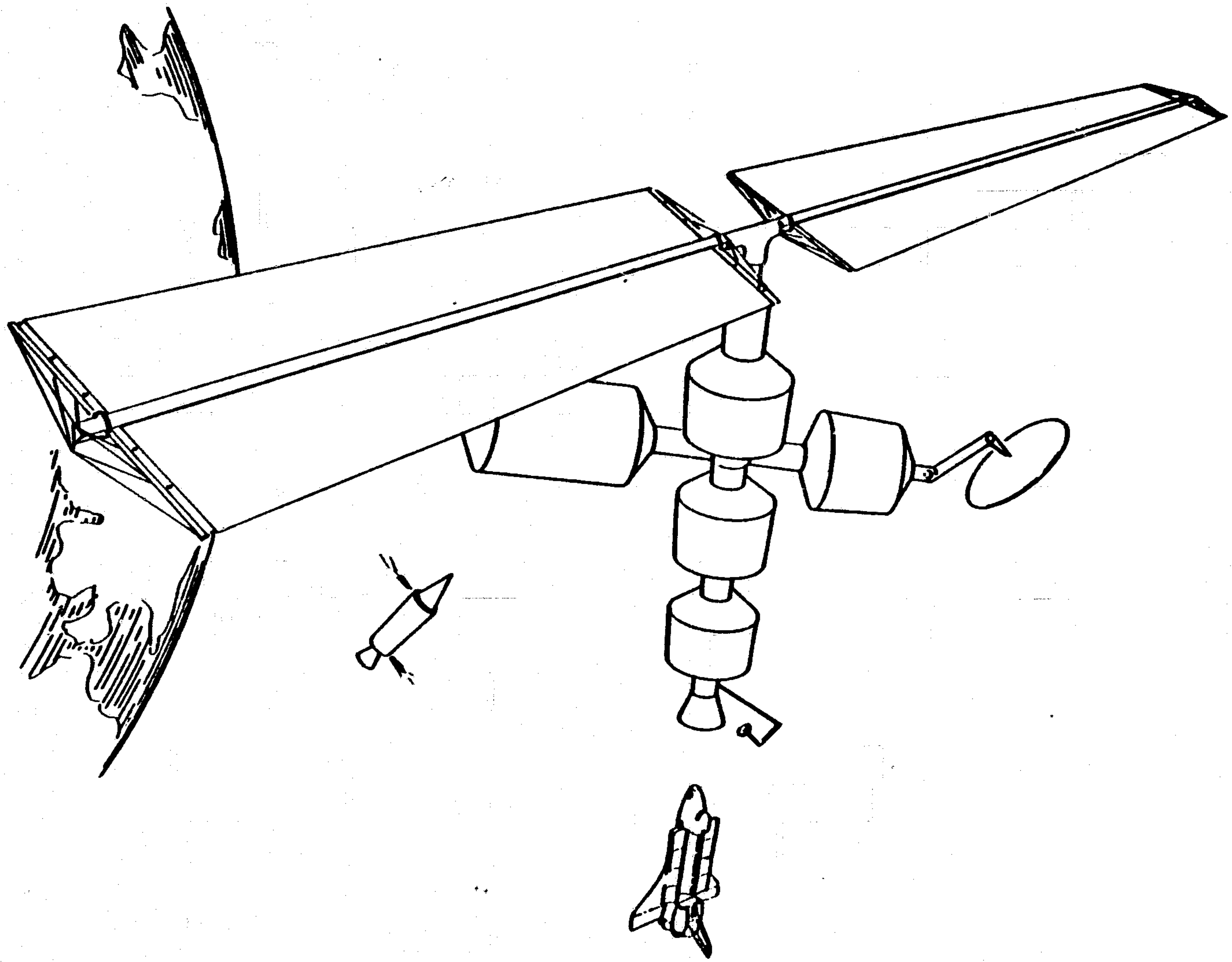
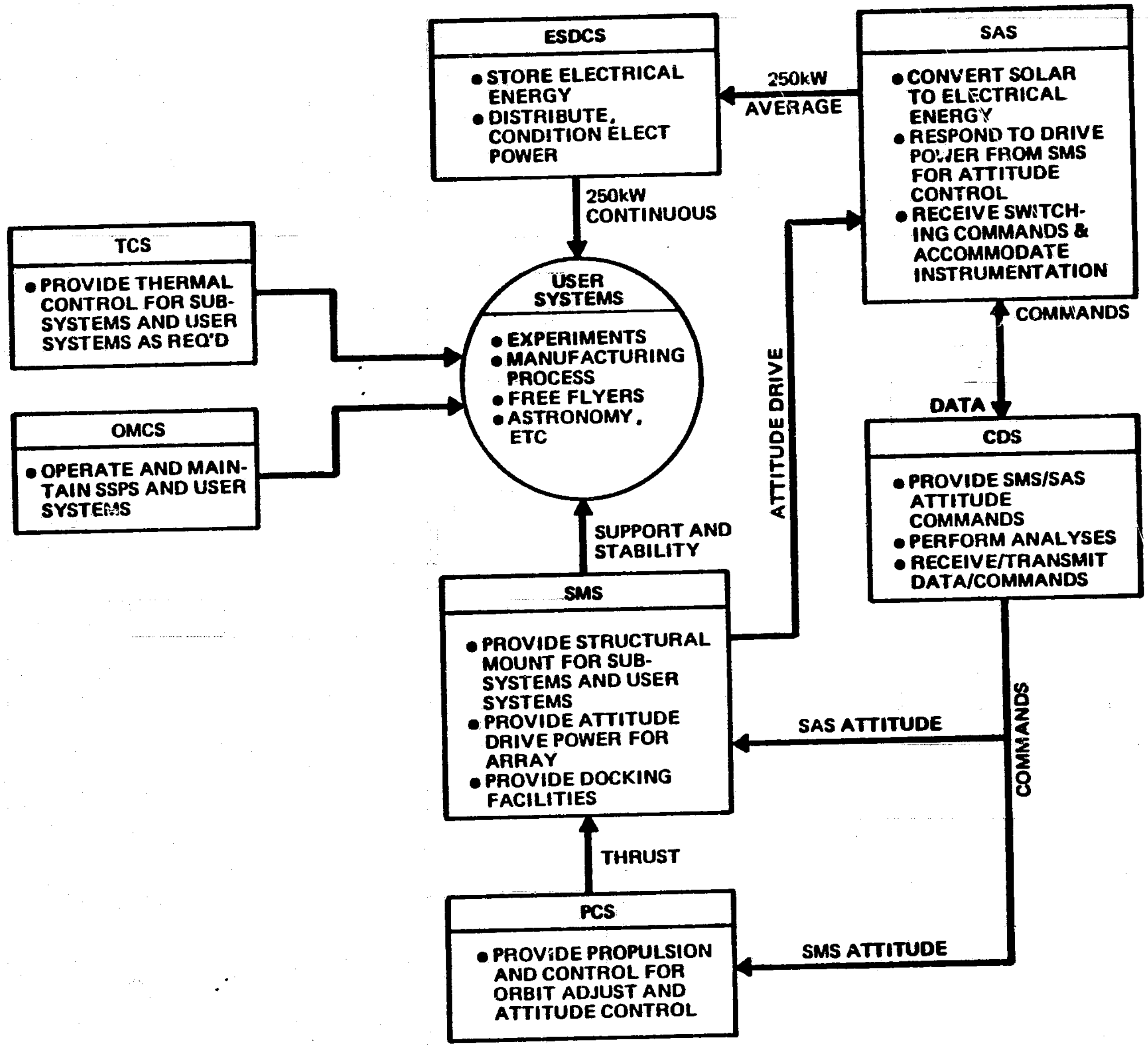


EXHIBIT 1-3. SPACE SERVICES PLATFORM SYSTEM



LEGEND:

SAS	SOLAR ARRAY SUBSYSTEMS
CDS	COMMAND AND DATA SUBSYSTEM
SMS	STRUCTURAL MECHANICAL SUBSYSTEM
PCS	PROPULSION AND CONTROL SUBSYSTEM
OMCS	OPERATIONS AND MAINTENANCE CREW SUBSYSTEM
TCS	THERMAL CONTROL SUBSYSTEM
ESDCS	ELECTRICAL STORAGE, DISTRIBUTION AND CONDITIONING SUBSYSTEM

EXHIBIT 1-4. SSPS SUBSYSTEM INTERFACES AND FUNCTIONS

- Astronaut assembly and check-out, assisted by maneuverable work platforms
- Panel level replacement by astronauts for maintenance (when power output degrades below design value)

The derived requirements on the SAS are:

- Orbit Parameters

- period	87.3 minutes
- illumination	53.7 minutes
- eclipse	33.6 minutes
- # cycles	60,239 in ten years

- Array Electrical Requirements:

	ENERGY	POWER
Total Per Orbit - Array	429.60 kW HR	480 kW
- To User	223.75 kW HR	250 kW
- To Energy Storage Subsystem (68%)	205.85 kW HR	230 kW

The conceptual design of the baseline SAS was developed to a level of detail required to support the cost/technology analyses of Task III. The design approach, generally, was to

- select the baseline cell, cover, substrate and circuitry
- determine the value of the factors which affect performance and apply to the baseline cell/cover assembly to determine EOL performance. This can be expressed as,

$$EOL\ P_{mp}(W/m^2) = \left[\left(\eta_{BOL} \times \prod_{i=1}^{11} F_{p_i}\right) \times \left(S' \times \prod_{j=1}^{2} F_{p_j}\right) \times PF \right] \times A_s$$

Where P_{mp} = cell max power

F_{p_i} = Cell performance factors

F_{p_j} = Cover performance factors

S' = effective illumination

η_{BOL} = cell BOL efficiency

PF = per-cell packing factor

A_s = per-cell array area

- determine number of cell/cover assemblies required for baseline orbit and load power/energy requirements
- determine total array area, dimensions and structural (a function of mass and dimensions) requirements
- determine array weight breakdown and totals.

The resulting baseline array conceptual design, covered in detail in Section 2.0, is summarized as follows:

The baseline SAS is a two-wing planar array, with dimensions as shown in Exhibit 1-5. A single boom structure (one for each wing) will hold the array blankets in tension using tip pieces as shown. On each wing at eleven equidistant positions along the length of each blanket will be intermediate stiffeners to aid in maintaining planarity. These extend across the boom through spreader rings. The hierarchy of the array is shown in Exhibit 1-6.

The electrical power will be bussed to the centrally located slip-ring assembly. The bus conductors will be supported by semi-circular (300°) light weight insulator segments attached to the booms. The slip ring assembly is double-gimballed to make independent the orientations and motions of the array and the SSPS platform. The EOL array output will be held constant over the array life by varying the sun-vector/array plane intersection angle.

The power generated by the array is provided at 198 VDC by 48 independent channels at the slip ring output. Each channel provides 10 kW of power. This power level is on the same order of magnitude as the Spacelab and Shuttle.

The use of 48 independent power circuits in the design, while requiring multiple slip rings, is considered compatible with a multi-user operation. Also, this configuration is closer to the space state-of-the-art for slip rings. The use of one or a few high power regulators versus the 48 relatively low power regulators suggested in this baseline design is subject to trade analyses.

The weight statement for the SAS baseline design concept is contained in Exhibit 1-7.

Definition of the baseline subsystem included the flow sequencing, timelining, manloading (numbers, manhours and skills) and the facilities and equipments required to perform DDT&E, Production, and Operations and Maintenance. This is covered in detail in Section 3.0. In summary, the SAS subsystem and system requirements (Appendix A) which drive the flows and the facility, equipment,

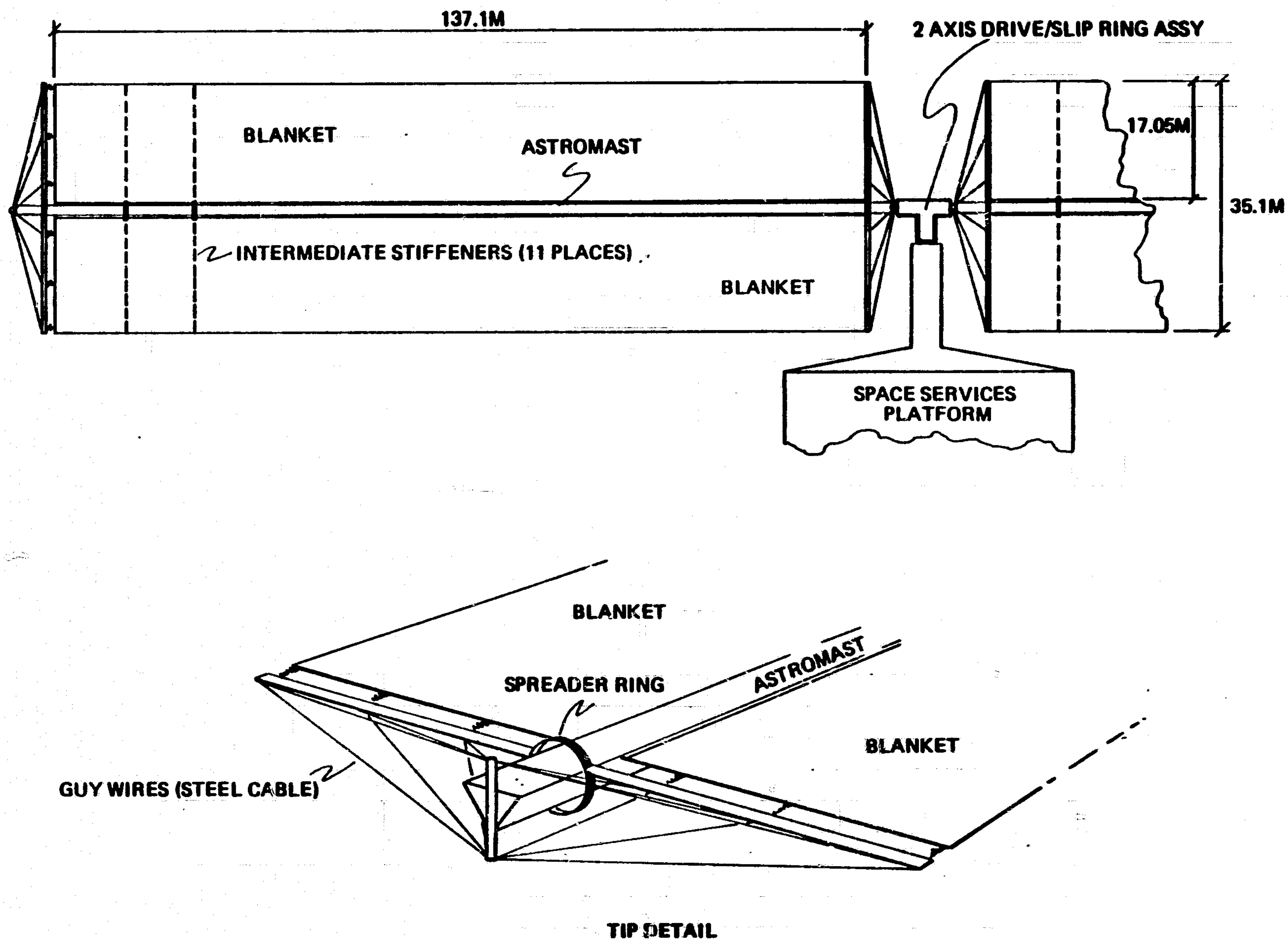


EXHIBIT 1-5. BASELINE SOLAR ARRAY LAYOUT

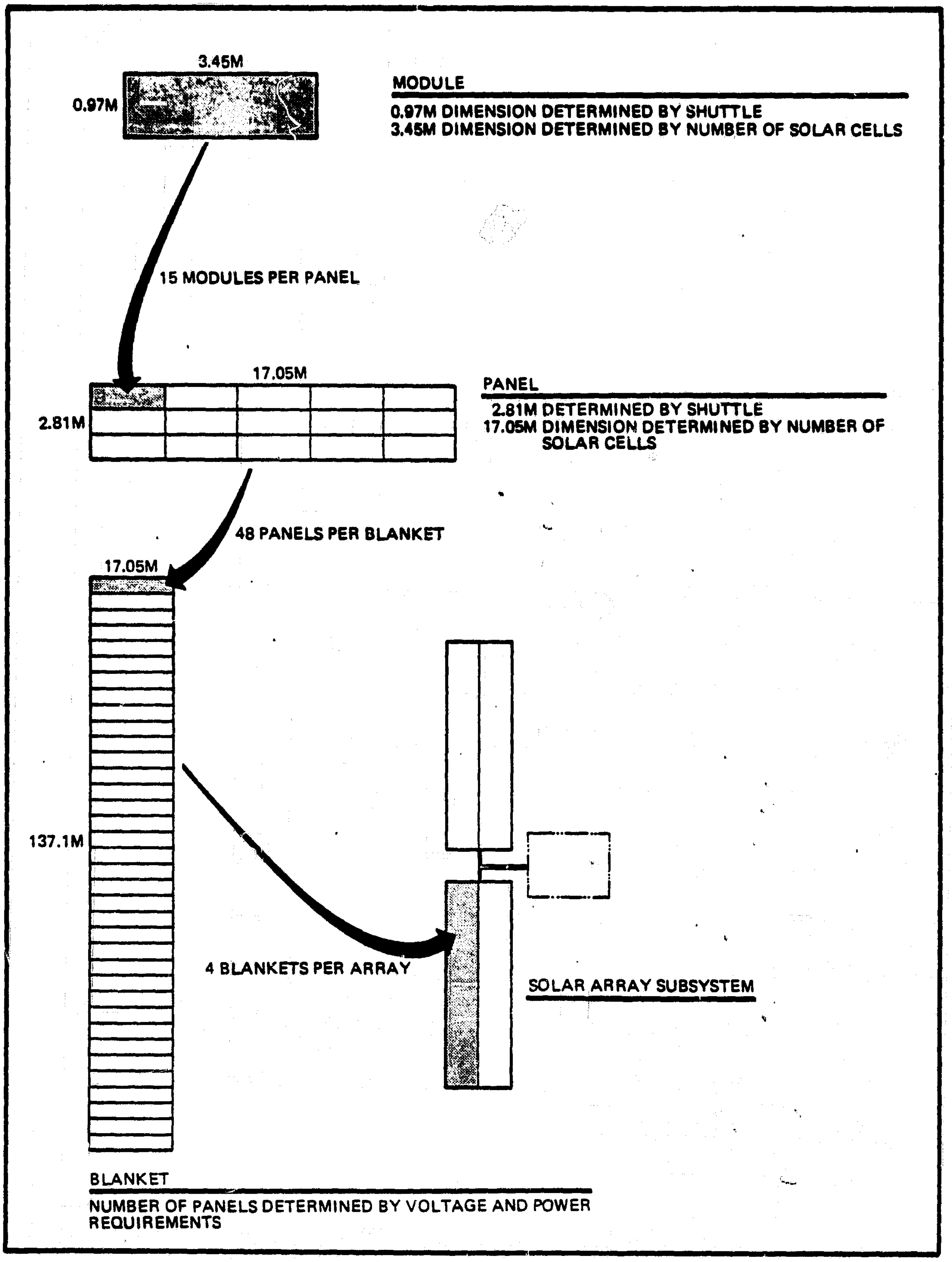


EXHIBIT 1-6. SAS HIERARCHY

ELEMENT		WEIGHT (KG)
PANEL LEVEL		
MODULES (15/PANEL)	42.48	
ELECT. INTERCONNECTS	0.75	
TOTAL EACH PANEL	43.23	
BLANKET LEVEL		
PANELS (48/BLANKET)	2075	
MECHANICAL INTERCONNECTS	751	
COMPRESSION PLATE CUSHIONS	128	
ELECT. INTERCONNECTS	31	
TOTAL EACH BLANKET	2985	
ARRAY LEVEL		
BLANKETS (4/ARRAY)		11,940
STRUCTURE (INCL. SLIP-RINGS		7778
MAIN BUS CONDUCTORS		656
TOTAL FOR ARRAY		20,374

EXHIBIT 1-7. BASELINE WEIGHT STATEMENT

manloading, scheduling, and transportation requirements are:

- System Operational 1985-1995
- State-of-art
- Transport by Shuttle
- Space assembly of SAS by equipment assisted crews
- Overhaul at 10 years
- Panel replacement at 90% Po (EOL)
- Spares availability in space
- On-station O&M crew
- Panel level replacement capability
- 24 man-hour panel replacement time
- Automated fault isolation

The top level DDT&E, Production and O&M functional flows are shown in Exhibits 1-8, 1-9, and 1-10 respectively.

1.2.2 Task II - Determination of Total Cost for Baseline Subsystem

The purpose/objective of this task was to develop a life cycle cost model (LCCM) for use in the Task III technology vs. cost analyses, and to determine the life cycle cost (LCC) of the baseline array (SAS).

Task II consisted of three subtasks:

- Subtask II-1: Formulate the LCCM Structure
- Subtask II-2: Develop Cost Estimating Techniques
- Subtask II-3: Exercise the LCCM

1.2.2.1 Subtask II-1 - Formulate the LCCM Structure

The LCCM structure was derived from the WBS (Exhibit 1-2) and the flow diagrams for the Production and O&M flow diagrams (Exhibits 1-8, 1-9). The top level LCCM structure is shown in Exhibit 1-11. The LCCM is discussed in detail in Section 4.0.

1.2.2.2 Subtask II-2 - Develop Cost Estimating Techniques

The purpose of this subtask was to develop the cost estimating relationships to be used to obtain cost estimates for each element of the LCCM. The sources and the relationships used are discussed in detail in Section 4.0.

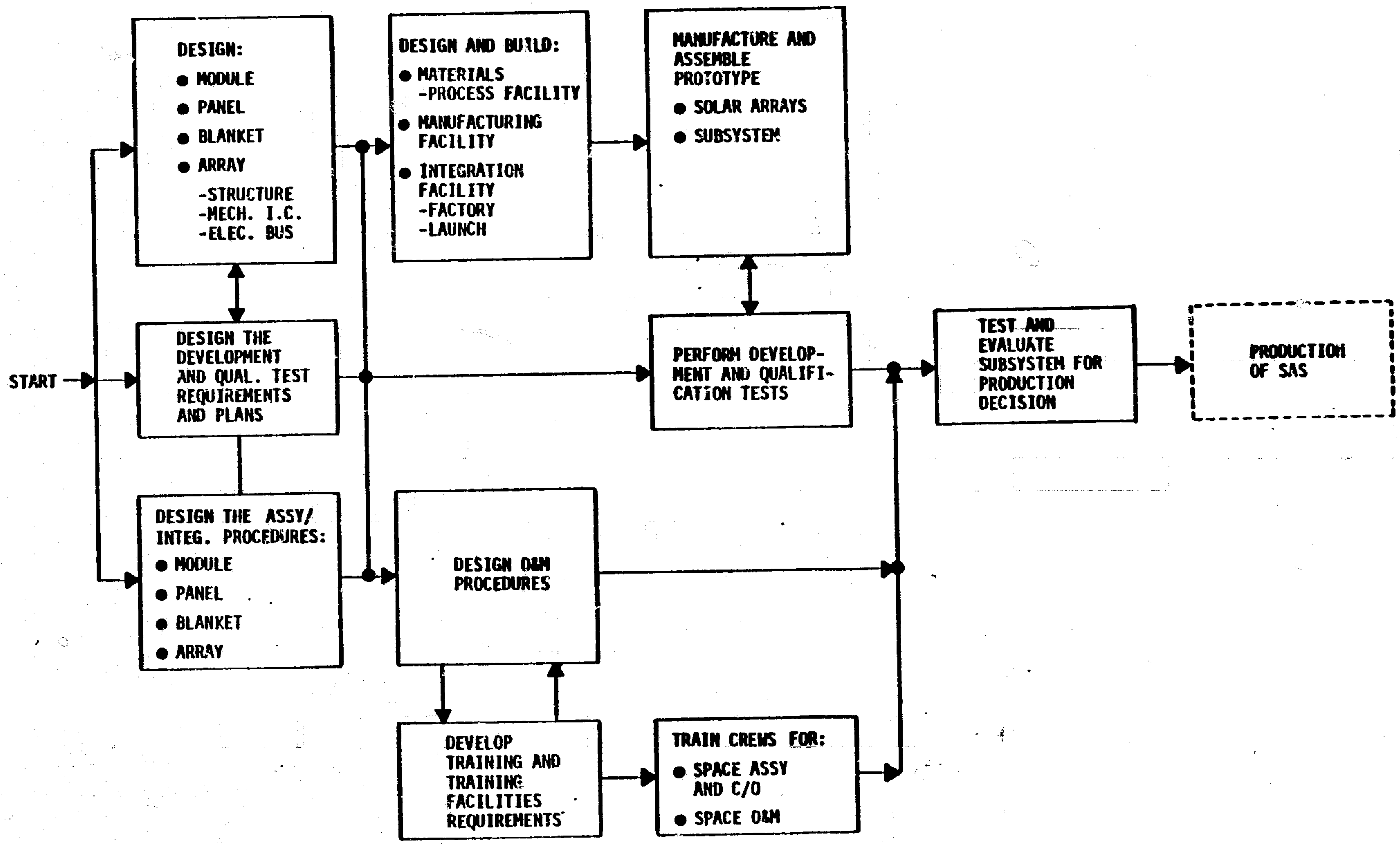


EXHIBIT 1-8. DDT&E FUNCTIONAL FLOW

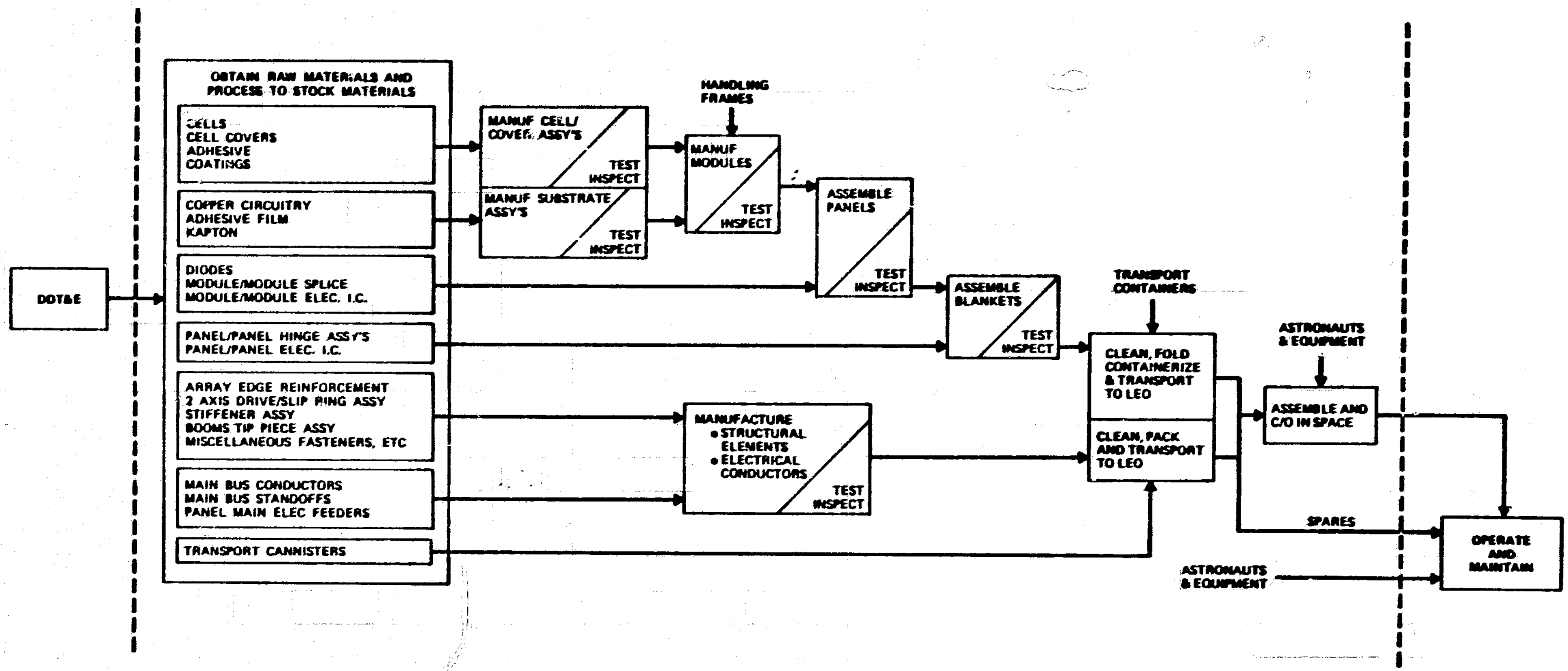


EXHIBIT 1-9. PRODUCTION FUNCTIONAL FLOW

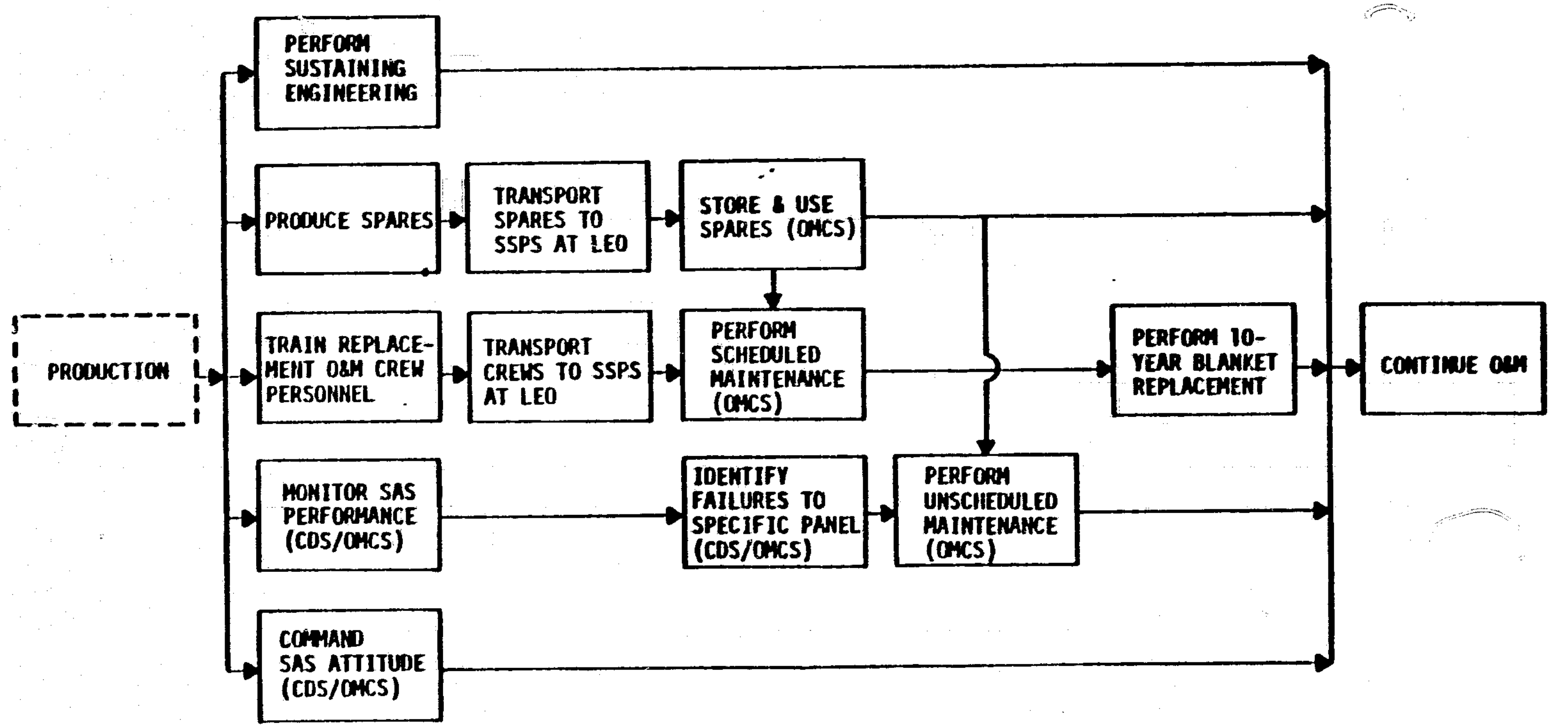


EXHIBIT 1-10. O&M FUNCTIONAL FLOW

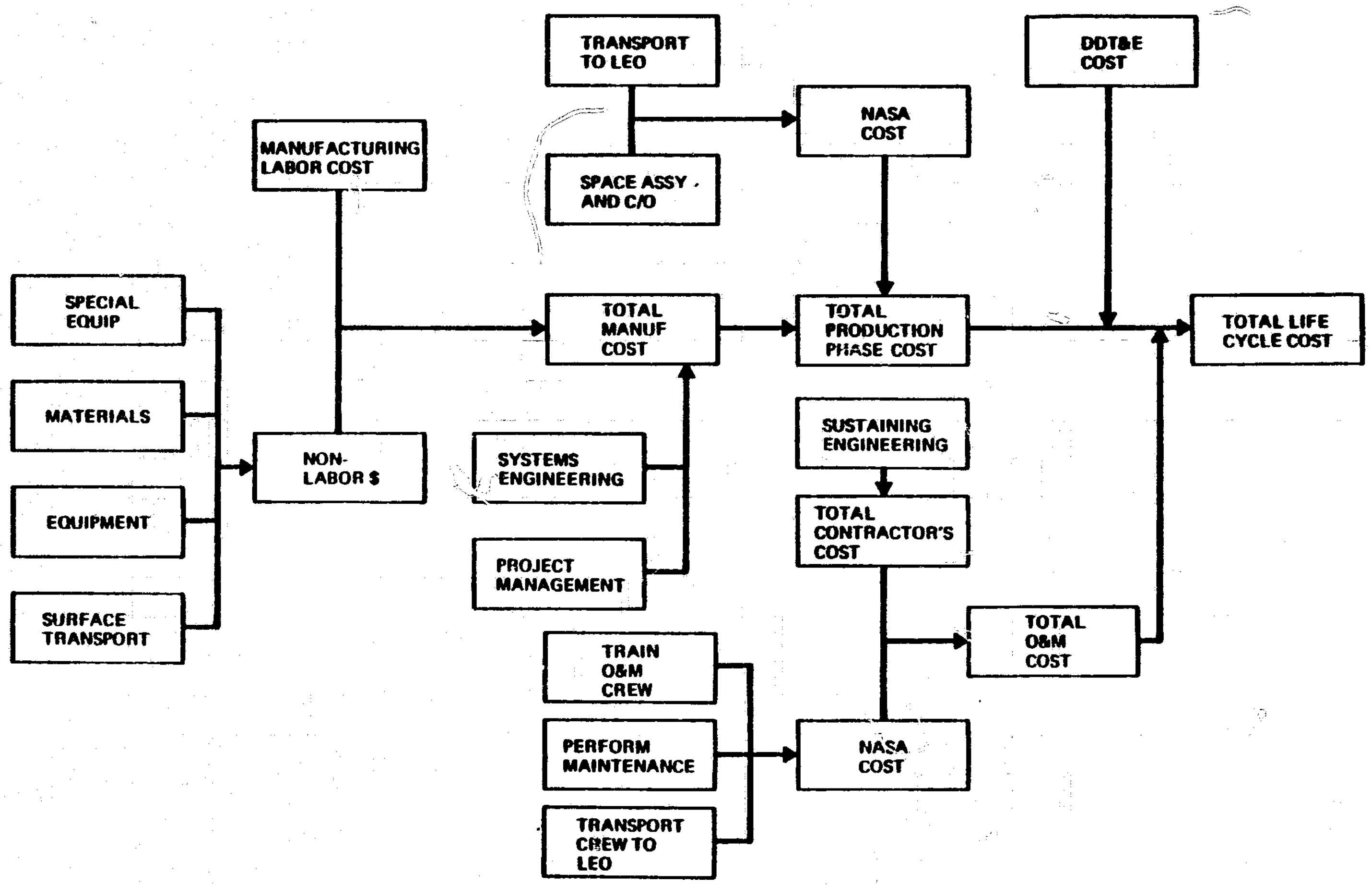


EXHIBIT 1-11. SOLAR ARRAY SUBSYSTEM LIFE CYCLE COST MODEL STRUCTURE

1.2.2.3 Subtask II-3 - Exercise the LCCM

The purpose of this task was to determine the LCC of the SAS baseline using the LCCM, and to vary the inputs to the model to assure its validity over the range of input values expected in Task III.

The LCC for the baseline SAS is discussed in detail in Section 4.0. The top level baseline LCC costs are summarized as follows:

LCC PHASE	1980 DOLLARS IN MILLIONS
DDT&E	153.9
Production Phase	439.9
O&M	160.7
TOTAL LCC	754.5

For the purpose of comparison with other space array subsystems, the cost performance values of the baseline SAS are:

		\$/WATT (1980 \$)
Total LCC	BOL	792
	EOL	1,569
Production	BOL	462
	EOL	914
Manufacturing	BOL	394 (1)
	EOL	782

(1) $303/Watt in 1977 $.

1.2.3 Task III - Analysis of Cost-Technology Parameters

The purpose/objective of this task was to determine the effect on the baseline LCC of varying technology parameters. Task III consisted of five subtasks:

- Subtask III-1: Establish Technology Parameters for Existing and New Programs
- Subtask III-2: Determine the Relationship of Weight and Volume to Technology Parameters
- Subtask III-3: Determine Sensitivity of Performance Parameters to Technology Parameters
- Subtask III-4: Determine Interdependencies of Physical, Performance and Technology Parameters

- **Subtask III-5: Determine Relationship of Technology Parameters to Total Life Cycle Cost**

While these subtasks were required to obtain the study output, they were accomplished integrally as part of the development of a subsystem performance/cost model. Accordingly, the approach for Task III is the development of the model, and the results are the model outputs.

The performance model was developed from the design procedure followed in Task I to define the baseline SAS, with, however, variable quantitative relationships inserted to replace specific design values. The relationships which were developed include radiation flux, radiation degradation, and temperature derating. The relationships were derived from telemetry and laboratory test data, design values for historical and planned programs using regression analysis and theory. The output of the performance model consists, generally, of the weights (and masses), material quantity (number of cells, substrate area), and, where required, attrition losses, or numbers of spares (affected by reliability and maintenance). These, then, are inputs to the LCCM. The LCCM provides the LCC for the particular set of input values, which represent a specific set of parameter values defining a variation in the baseline SAS design.

The performance/cost model as applied to Task III is discussed in more detail in Section 5.0. Exhibit 1-12 is a top level block diagram of the performance/cost model.

The results of Task III are the relationships of LCC versus:

- cell thickness
- blanket temperature
- cover thickness
- cell efficiency
- cell degradation
- cover degradation
- line voltage (bus)
- years between overhaul
- meantime between failure
- cell/cover unit cost

These are shown in the graphs of Exhibit 1-13 and Exhibit 1-14.

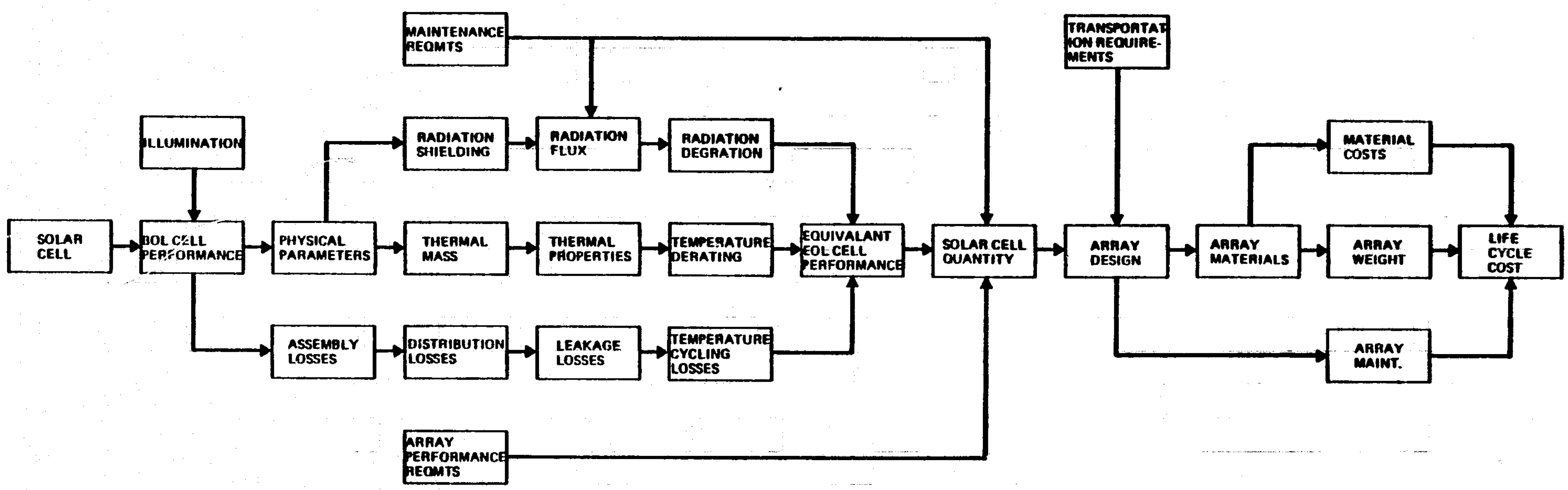


EXHIBIT 1-12. SOLAR ARRAY PERFORMANCE AND COST MODEL

1.3 Conclusions and Recommendations

This section summarizes the analyses and results of the study and presents recommendations. More detailed discussions are provided in Section 5.0 of the performance/cost model which was applied to quantify technology vs LCC, and in Section 6.0 of the quantitative results obtained for specific technology vs LCC.

1.3.1 Conclusions of the Study

Conclusions to be drawn from the study results are valid in the vicinity of the baseline under the study requirements, and the assumptions and scenarios generated in Tasks I and II. Generally these are:

- Silicon cells, planar array
- Orbit of 444 km, 56^{o} inclination
- Shuttle transportation
- Earth manufacturing scenario
- Manual assembly in space (equipment assisted)
- Space-based maintenance includes personnel for routine maintenance
- DDT&E, program management and SE&I are "wraparound" cost factors
- $31M/14,000 kg space transportation costs
- Cell/cover assembly costs are historical, but adjusted to 70%, recognizing the large quantity required.

It is important to note that the performance/cost model and/or data base can be easily changed to reflect variations in the above requirements, scenarios and assumptions, in effect to perform trade studies to optimize the subsystem.

Exhibits 1-13 and 1-14 of Section 1.2.3 show the relationships of the various technology areas to LCC. The following sections discuss each technology area result. Exhibit 1-15 gives the results in tabular form.

1.3.1.1 Cell Thickness vs LCC

The relationships shown on Exhibit 1-13 (a) are for three types of silicon cells: (1) conventional/historical, (2) back surface field and (3) back surface field plus thin diffused top region. The data for all three types of cells were derived from "Semi-Conductors and Semi-Metals" Volume II, Hovel, 1975, Academic Press.

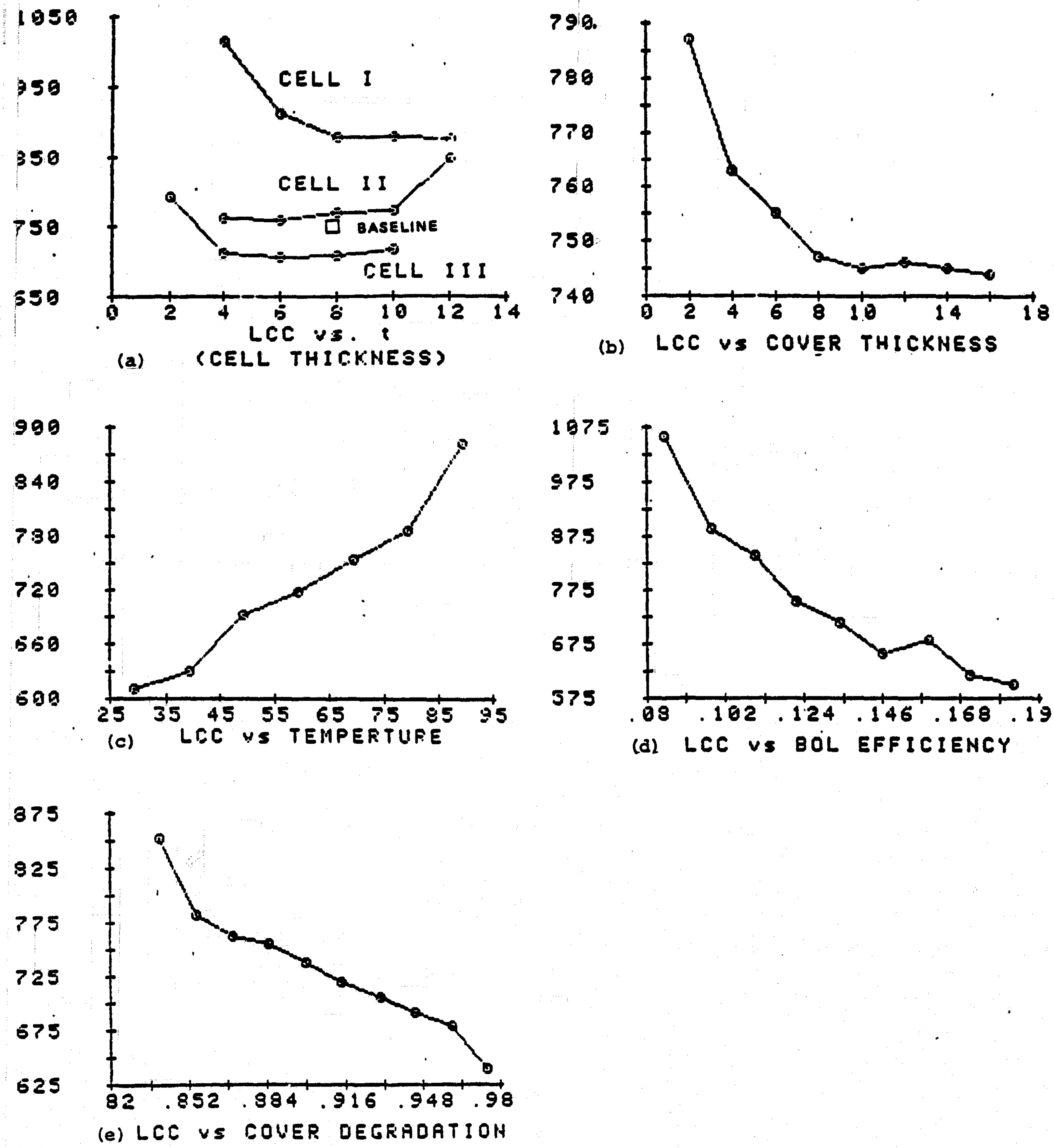


EXHIBIT 1-13. TECHNOLOGY PARAMETERS vs LCC

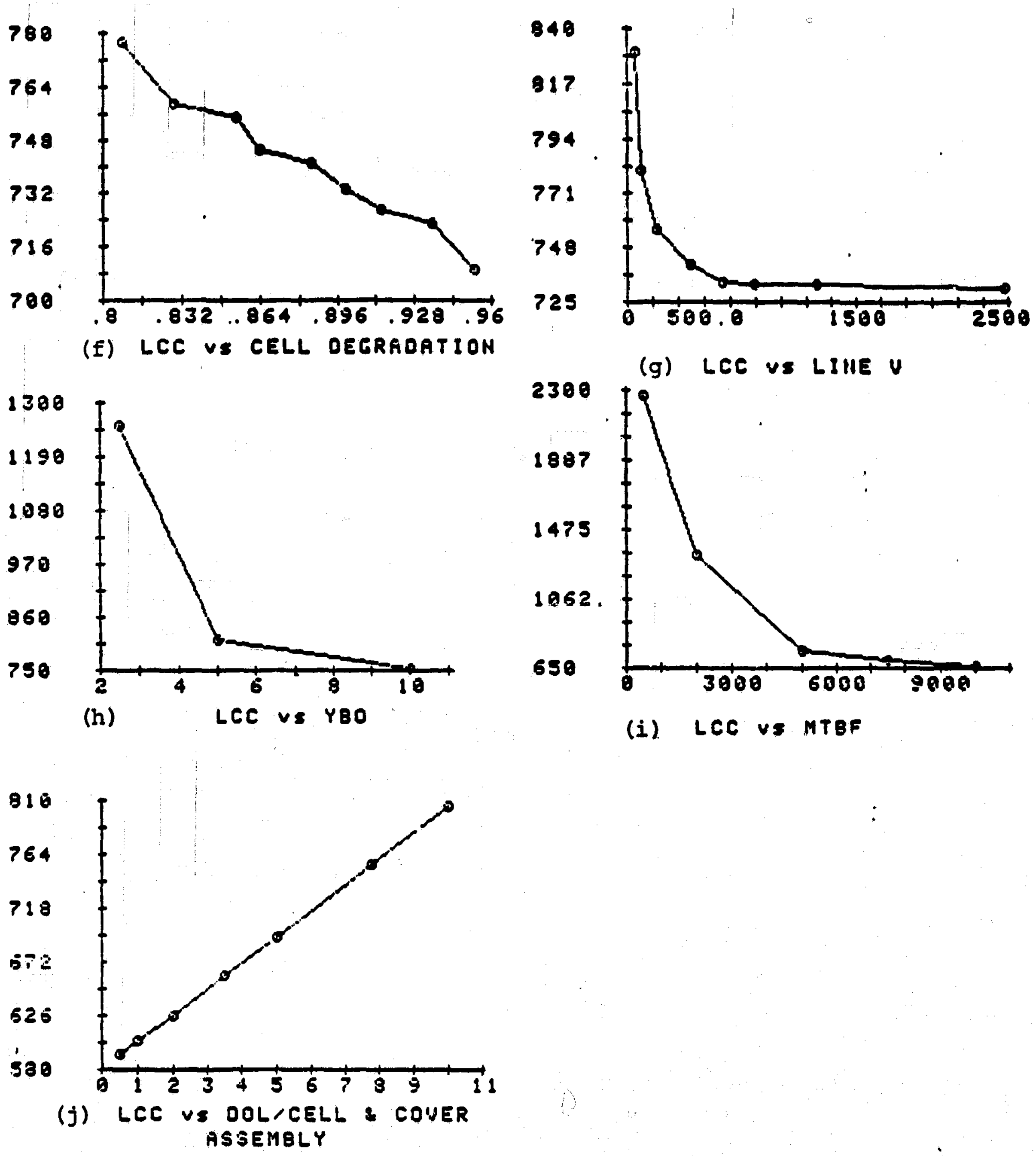


EXHIBIT 1-14. TECHNOLOGY PARAMETERS vs LCC

TECHNOLOGY AREA	INFLUENCE ON LCC
CELL THICKNESS	MEDIUM/STRONG - 6 MILS OPTIMUM*
COVER THICKNESS	MEDIUM - LITTLE GAIN ABOVE 12 MILS
BLANKET TEMPERATURE	STRONG - $3.2M/^oC
CELL EFFICIENCY	STRONG - $46M/1% CHANGE
COVER DEGRADATION	MEDIUM/STRONG - $10M/1% CHANGE
CELL DEGRADATION	MEDIUM - $5.4M/1% CHANGE
LINE VOLTAGE	WEAK - LITTLE GAIN ABOVE 400 VOLTS
YEARS BETWEEN OVERHAUL	WEAK - LONGER LIFE BETTER
MTBF	MEDIUM - KEEP MTBF UP, SPARES LOW
CELL COVER ASSEMBLY COSTS	STRONG - $22M/$ CELL COVER ASSEMBLY UNIT COST

*RESULTS ARE GIVEN FOR THREE CLASSES OF CELLS (THIS APPLIES TO BSF + THIN DIFFUSED TOP REGION CELL ONLY).

EXHIBIT 1-15. SUMMARY RESULTS OF STUDY

The cell thickness relationships of 1-13 (a) all show a strong influence on LCC, and more importantly the advantages of the back field, thin diffused top region cell. For this type of cell, a thickness of 6 mils is optimum.

The deviation of the data points from a smooth curve fit are a result of the number of panels required per power channel which in turn is a result of the Shuttle payload bay dimensional constraints. The SAS baseline is plotted as a reference point ($t = 8$ mil, $\eta_{BOL} = .122$).

1.3.1.2 Cover Thickness vs LCC

The relationship shown in Exhibit 1-13 (b) for cover thickness displays a strong influence on LCC in the vicinity of four mils, a somewhat reduced influence near the baseline (eight mils), and with little gain above at 12 mils. An increasing cover thickness has three effects on LCC: (1) increased weight of array, (2) reduction of degradation rate of cell, and (3) decrease in blanket mean temperature.

1.3.1.3 Blanket Temperature vs LCC

The relationship shown in Exhibit 1-13 (c) shows a strong influence on LCC of the mean blanket temperature. This derives basically from the change in cell efficiency with temperature ($3.2M per $1^{\circ}C$). The two curves (C1 & C2) reflect differences in the number of panels/channel due to shuttle transportation volume limitations.

1.3.1.4 Cell Efficiency vs LCC

The relationship shown in Exhibit 1-13 (d), as expected, shows a strong influence on LCC. In the vicinity of the baseline, the slope is $46M per 1% change in cell efficiency (measured at BOL). The basic effect is on baseline quantities, weights, and cell unit costs. The two separate data points reflect differences in the number of panels/channel due to shuttle transportation volume limitations.

1.3.1.5 Cover Degradation vs LCC

The relationship shown in Exhibit 1-13 (e) displays a medium/strong influence on LCC. The slope in the vicinity of the baseline optical factor (.885) is about $10M per 1% unit change of the factor. The cover unit cost variation is more than offset by the substantial reductions in weight, dimensions and number of cells in the baseline.

2.0 BASELINE

2.1 Space Services Platform System, SSPS

The SSPS has been hypothesized to create a system structure within which a Solar Array Subsystem (SAS) can be defined to provide a baseline design for cost-technology studies. The purpose of the SSPS is to provide services to varied User Systems. The User Systems may be engaged in materials processing, astronomy, solar systems and earth observation, life sciences, communications, or other operations. The User Systems may be secured to the platform or docked for servicing or short-term operations. The general configuration of the SSPS is shown in Exhibit 2-1. The subsystems of the SSPS, their functions and major interfaces are summarized in Exhibit 2-2.

2.1.1 Solar Array Subsystem, SAS

The SAS provides electrical power to the Energy Storage, Distribution and Conditioning Subsystem (ESDCS). The power is provided by a two-paddle solar array blanket assembly through a 2 axis drive/slip ring assembly. The power is fed to the ESDCS in 48 power channels at peak power levels of 10 kW and 197 volts.

2.1.2 Energy Storage Distribution and Conditioning Subsystem, ESDCS

The ESDCS, located on the Structural/Mechanical Subsystem (SMS) platform receives electrical energy from the SAS at the SAS 2-axis drive slip ring assembly output. The ESDCS provides energy storage, conditioning and distribution of power to the User Systems and to the subsystems of the SSPS.

2.1.3 Structural/Mechanical Subsystem, SMS

The SMS provides (1) the structural mounting platform for User Systems and for the SSPS subsystems, (2) drive power for the Solar Array Subsystem 2 axis/ slip ring assembly, and (3) docking facilities for free flyers. The attitude of the platform is maintained by thrusters of the Propulsion & Control Subsystem (PCS), which are commanded by the Command and Data Subsystem (CDS). There are two

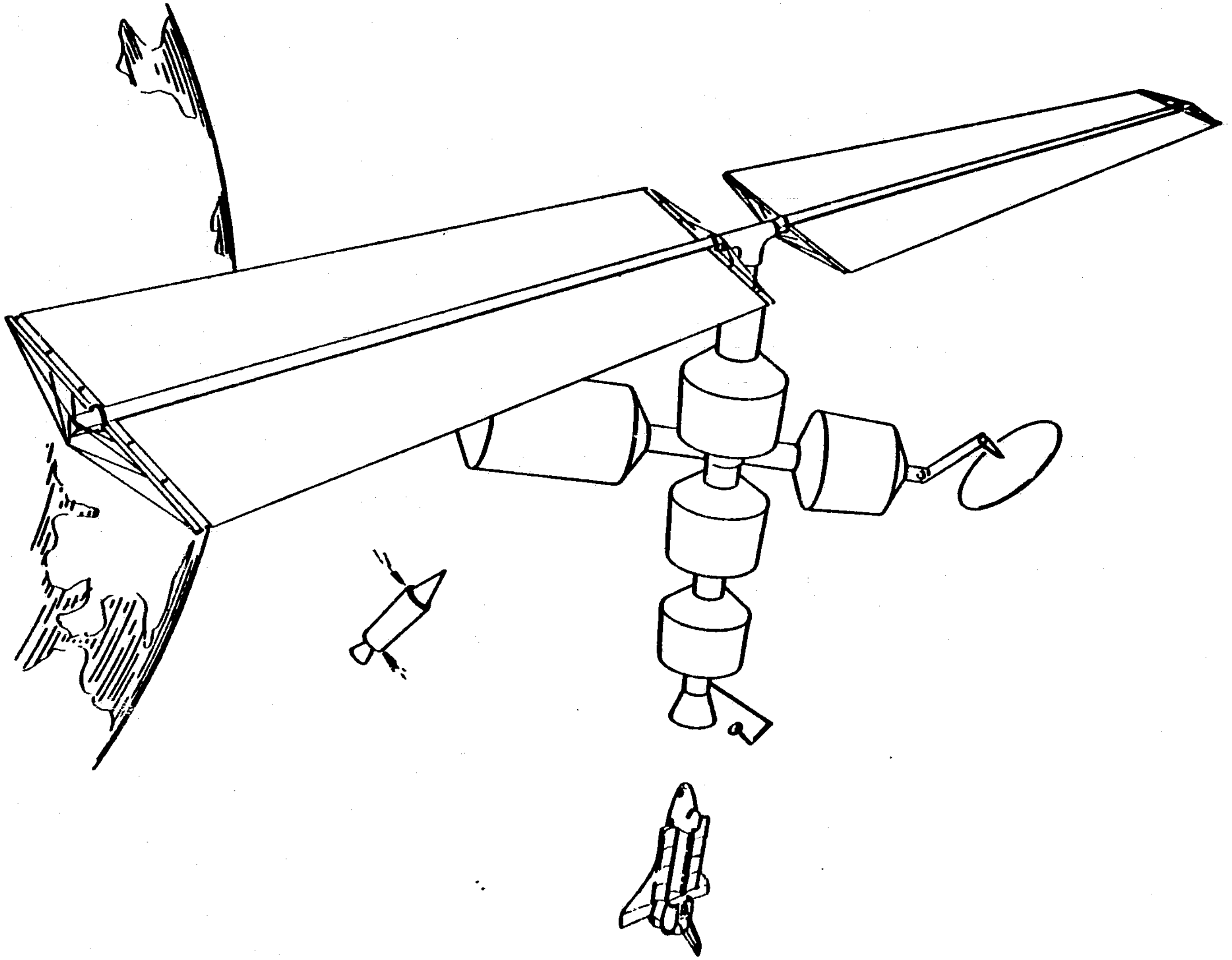
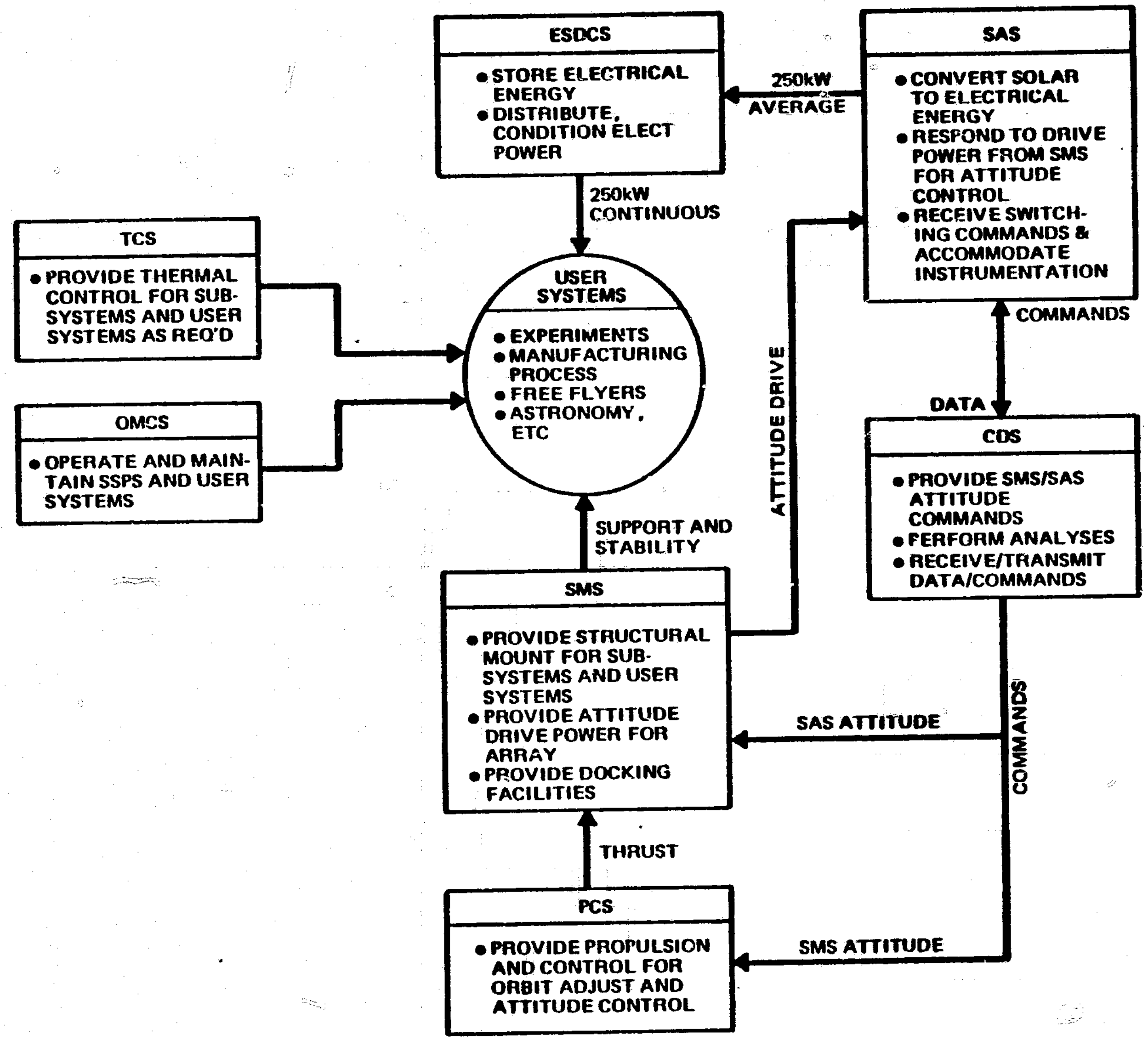


EXHIBIT 2-1. SPACE SERVICES PLATFORM SYSTEM



LEGEND:

SAS	SOLAR ARRAY SUBSYSTEMS
CDS	COMMAND AND DATA SUBSYSTEM
SMS	STRUCTURAL MECHANICAL SUBSYSTEM
PCS	PROPULSION AND CONTROL SUBSYSTEM
OMCS	OPERATIONS AND MAINTENANCE CREW SUBSYSTEM
TCS	THERMAL CONTROL SUBSYSTEM
ESDCS	ELECTRICAL STORAGE, DISTRIBUTION AND CONDITIONING SUBSYSTEM

EXHIBIT 2-2. SPACE SERVICES PLATFORM SYSTEM

interfaces of the SMS with SAS:

- structural mounting for the SAS 2 axis drive/slip ring
- mechanical drive of the SAS attitude at the input shafts of the SAS 2 axis drive/slip-ring assembly.

2.1.4 Propulsion and Control Subsystems, PCS

The PCS provides attitude control and orbit adjust thrust for the SSPS. The thrusters are mounted on the SMS platform and at the end-booms of the SAS.

2.1.5 Command and Data Subsystem, CDS

The CDS provides (1) the required attitude commands for the SMS and the SAS, (2) analyses, status reports, and corrective action based on telemetry data sensors located as required on the SSPS, SSPS subsystems and User Systems, and guidance and navigation sensors, and (3) command & data relay communications from external systems to SSPS and User Systems.

2.1.6 Operations and Maintenance Crew Subsystem, OMCS

The OMCS provides operations services and maintenance for SSPS subsystems and User Systems. The OMCS is stationed on-board the SSPS SMS platform.

2.1.7 Thermal Control Subsystem, TCS

The TCS provides thermal control capability for SSPS subsystems and User Systems as required.

2.2 Mission Scenario and System Requirements

The mission scenario and the system requirements on the SSPS and the subsystem requirements on the SAS are contained in Appendix A. The mission scenario for the SAS is summarized as follows:

- Operational 1985-1995
- LEO Orbit: 444 KM, 56° incl
- Power Output: 250 kW Continuous to Load
- Varied Angle to Sun to Maintain 250 kW to Load
- Production of Array Hardware on Earth
- Folded Blankets for Space Transport
- Space Shuttle Transport to Leo
- Astronaut Assembly and Checkout Assisted by Maneuverable Work Platforms

- Panel Level Replacement by Astronauts
- Panel Replaced When Power Output Degrades Below Design Value

The SAS system requirements are summarized in Exhibit 2-3.

2.3 Work Breakdown Structure

The baseline SAS Work Breakdown Structure (WBS) is shown in Exhibit 2-4. The WBS identifies the elements which are assembled to make up the solar array subsystem. From a project standpoint, each element represents a design package. The WBS has been developed to organize the functions and their sequencing, which include materials processing, manufacturing, integration, assembly and installation.

2.4 Solar Array Design

The baseline SAS is a two-wing planar array, with a single boom structure (one for each wing), which holds the array blankets in tension. The SAS is a fold-up array which will be shuttle transported and assembled in space.

The electrical power is bussed to the centrally located slip-ring assembly. The bus conductors are supported by a semi-circular (300°) styrofoam segment attached to the bottom of the boom. The slip ring assembly is double-gimballed to make independent the orientations and motions of the array and the user platform. The array output is held constant over the array life by varying the sun-vector/angle.

2.4.1 Electrical/Mechanical

2.4.1.1 Array Hierarchy

The array hierarchy, which is shown in Exhibit 2-5, breaks down as follows:

1 array	=	2 wings
1 wing	=	2 blankets
1 blanket	=	48 panels
1 panel	=	15 modules
1 module	=	3,150 cells (2 x 4 cm)

ORBIT PARAMETERS

• ORBIT PERIOD:	87.3 MINUTES
– ILLUMINATION	53.7 MINUTES
– ECLIPSE	33.6 MINUTES

• TOTAL CYCLES: 60,239 – TEN YEARS (INCL 2 LEAP YEARS)

ARRAY ENERGY REQUIREMENT

	ENERGY	POWER
• TOTAL PER ORBIT – ARRAY	431.25 kw HR	478.3 kw
– USER	225.4 kw HR	250 kw
– ENERGY STORAGE (0.672)	205.85 kw HR	228.3 kw

EXHIBIT 2-3. SYSTEM REQUIREMENTS

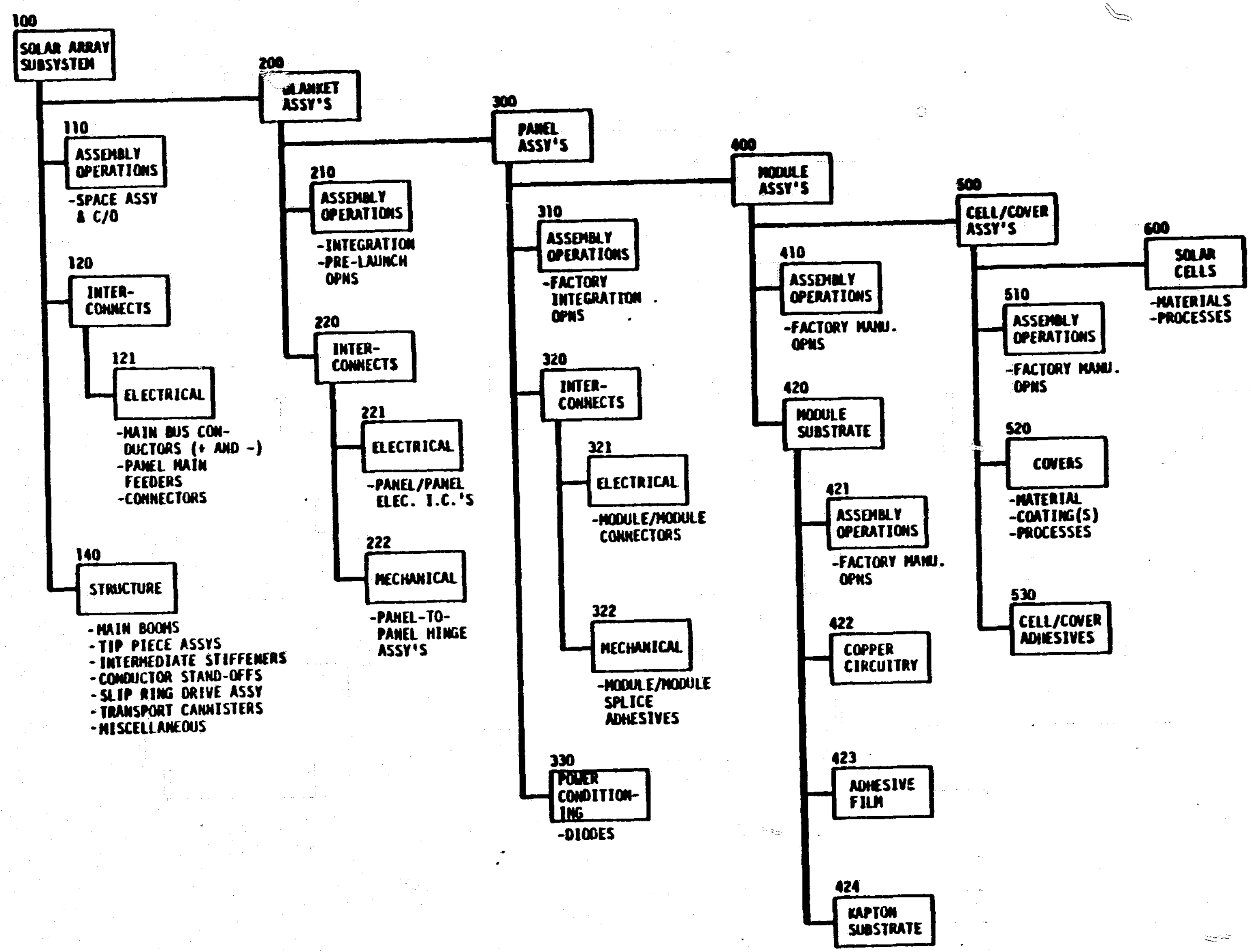


EXHIBIT 2-4. SAS WORK BREAKDOWN STRUCTURE

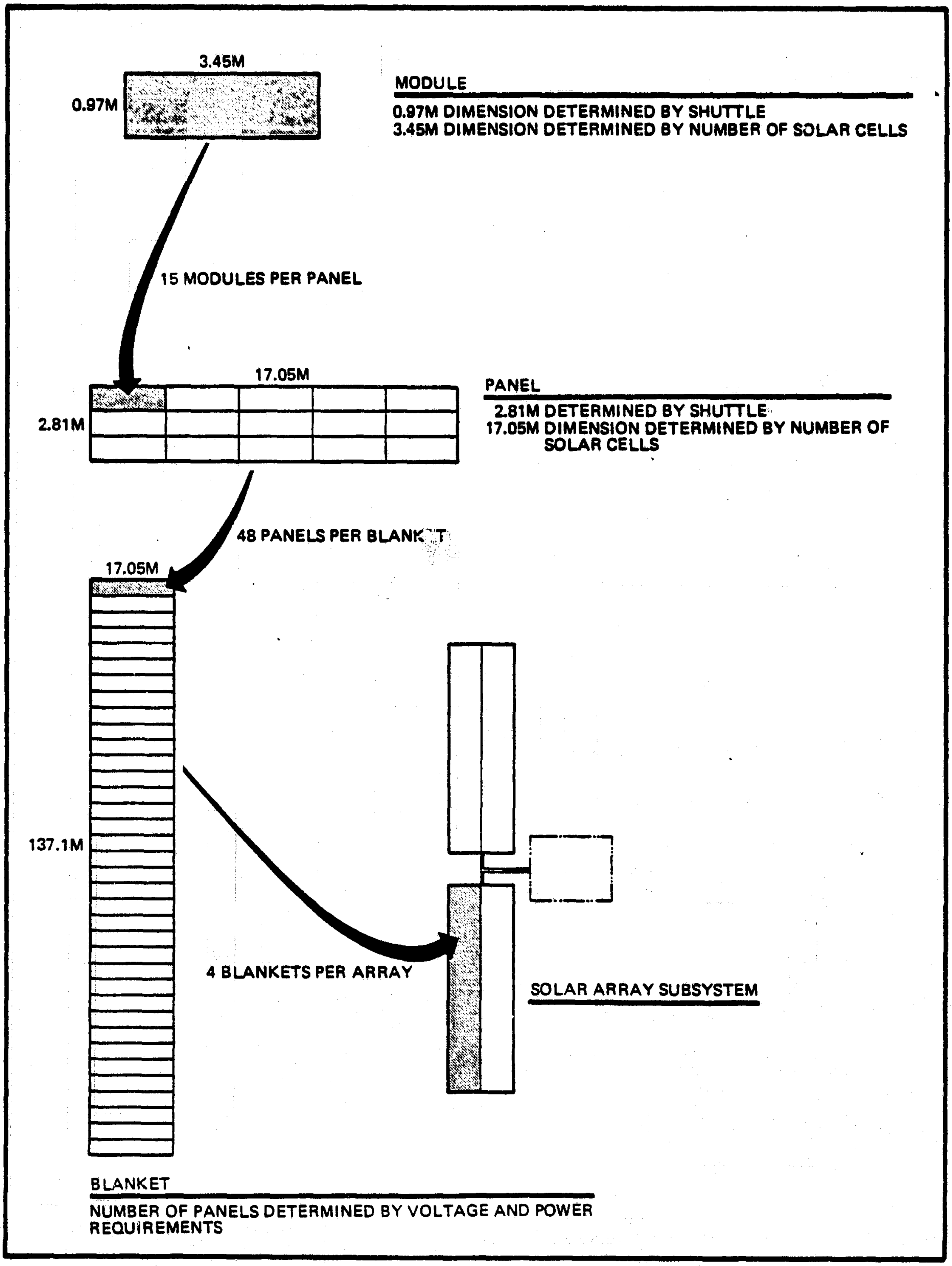


EXHIBIT 2-5. SAS HIERARCHY

2.4.1.2 Array Sizing

The sizing of the array hierarchy is summarized below.

- Wing

  Length = 152.1 m

  Width = 31.4 m

- Blanket

  Length = 137.1 m

  Width = 15.2 m

- Panel

  Length = 15.2 m

  Width = 2.81 m

- Module

  Length = 3.08 m

  Width = .97 m

Note: Panel dimensions include 5 cm overlap at module/module interfaces.

2.4.1.3 Array Blanket

The array blanket, as shown in Exhibit 2-6, consists of 12 electrical channels per blanket. Each channel provides 10 kW of power at 198.0 VDC and consists of 4 panels each providing 2.5 kW at 49.5 VDC. The main bus conductor for each blanket consists of 12 pairs of conductors (1 pair/channel) which provide the electrical distribution between the blanket and the slip-ring assembly.

2.4.1.4 Array Panel

The array panel, as shown in Exhibit 2-7, physically consists of 15 modules arranged in a 5 x 3 configuration. Electrically, the panel consists of one ½-module connected in parallel and thirty ½-modules connected in series. Each ½ module consists of 5 cells in series and 315 cells in parallel and provides 83.5W at 1.65 VDC. The total module consists of 3150 cells, with a minimum of three cells in parallel providing the basic electrical building block.

2.4.1.5 Module Assembly Cross Section and Layout

The module assembly cross section, defined in Exhibit 2-8, consists of the following:

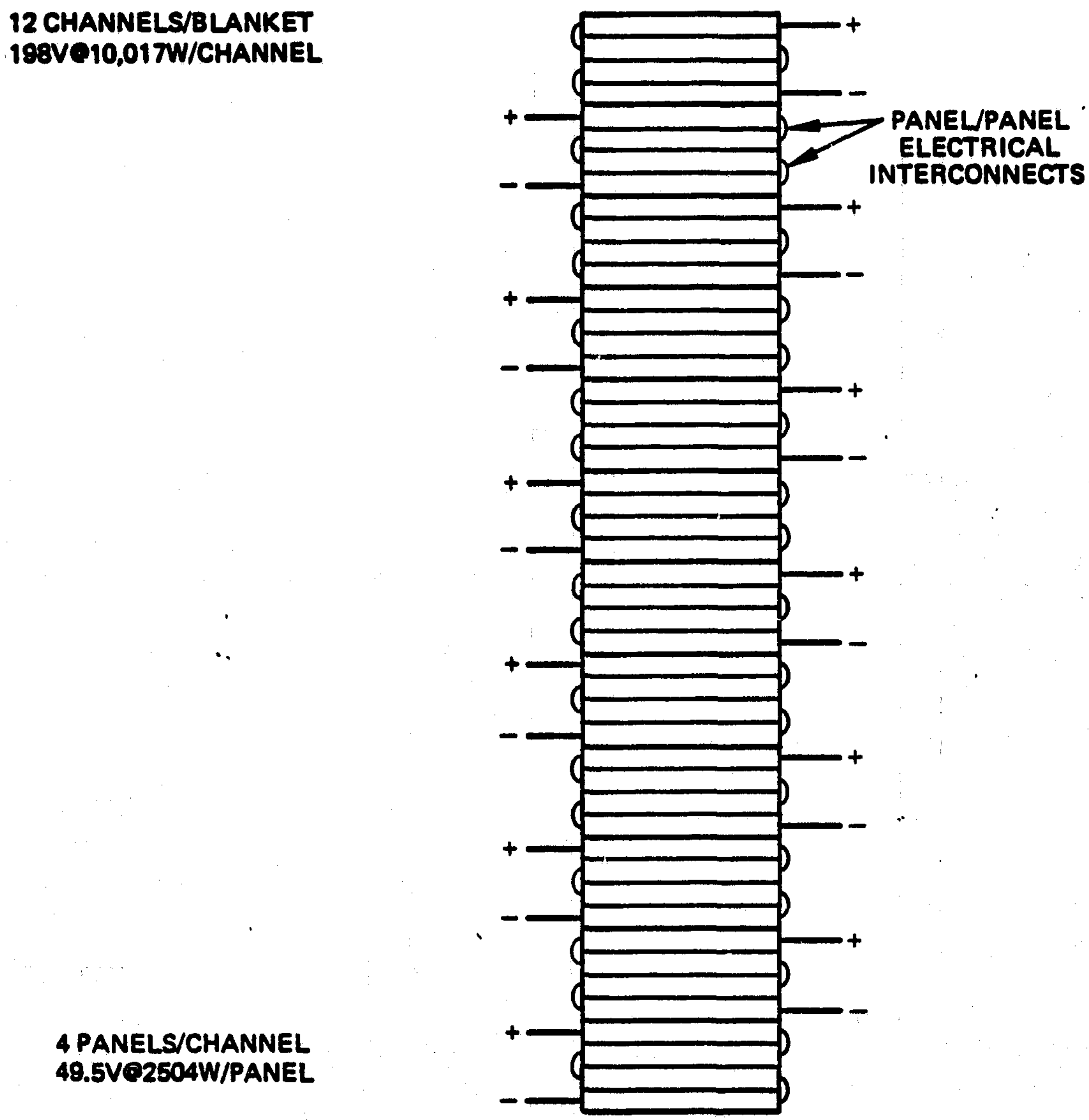


EXHIBIT 2-6. ARRAY BLANKET

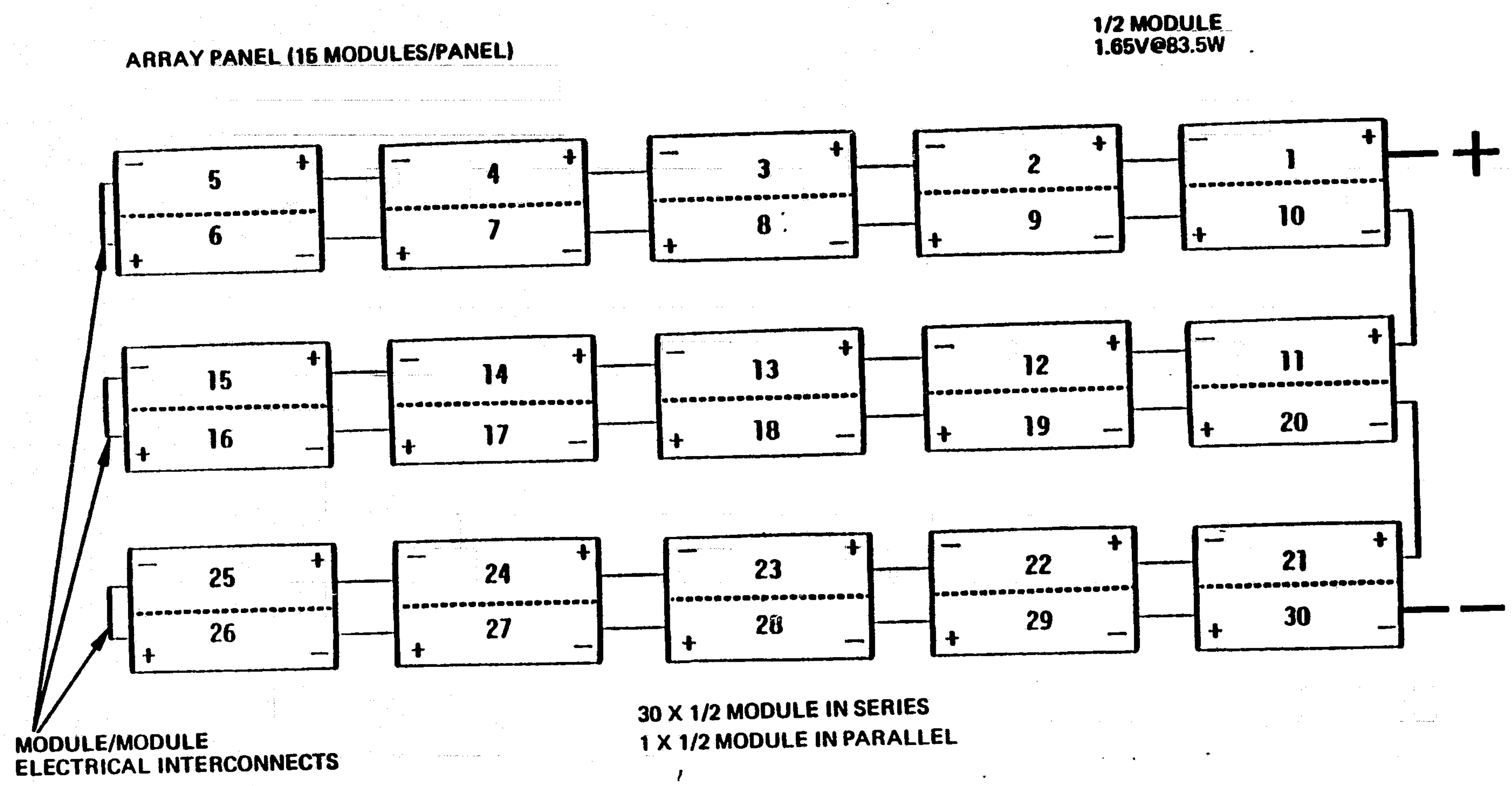


EXHIBIT 2-7. ARRAY PANEL

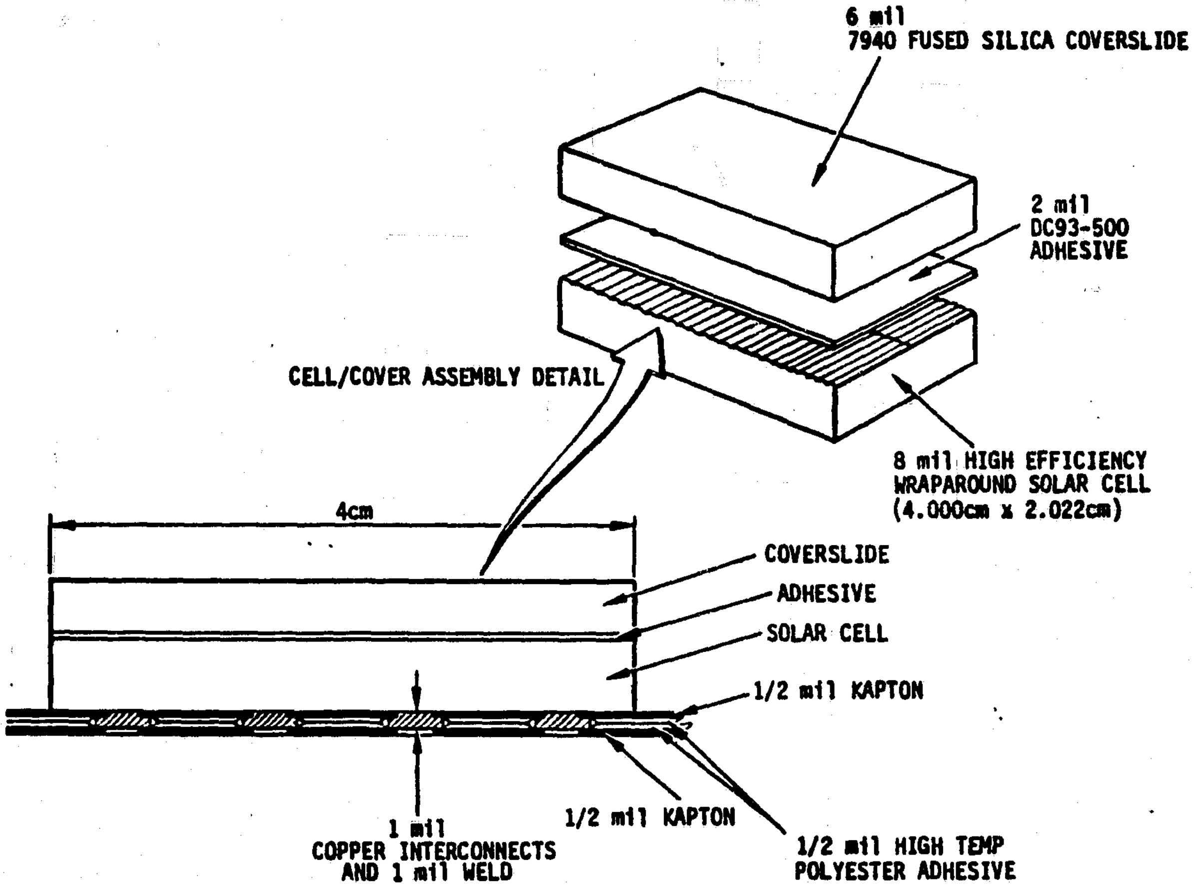


EXHIBIT 2-8. MODULE CROSS SECTION

- Solar Cell

  2.022 x 4.000 cm, wraparound contact, 8 mil silicon, 2 ohm-cm AMO base resistivity, 12.2% glassed efficiency, 28°C ambient, TA_2O_5 anti-reflective coating

- Cell Cover

  2.022 x 4.000 cm, 6 mil fused silicon, uv filter, 300 μm filter cut-on

- Cover Adhesive

  2 mil DC-93-500

- Substrate

  Laminated printed circuit, 33% area, 1 mil copper rolled annealed interconnect. Insulation is two sheets of 0.5 mil kapton/0.5 mil high-temperature polyester adhesive.

The cells are welded to the copper interconnect circuitry through the top layer of kapton, which together with the lower layer, form a kapton-copper-kapton sandwich. Exhibit 2-9 shows the copper interconnect network with one cell overlayed in dashed lines to give position relative to the copper circuitry. The per-cell module packing factor is 0.91 based on a space of 0.13 cm between cells.

As stated in 2.4.1.4, each panel consists of 15 modules. The module consists of 3,150 cells arranged in a 40 x 81 pattern, with 90 blank cell spaces. The long dimension of the cell corresponds to the long direction of the module.

2.4.1.6 Electrical Interconnects

The basic pattern for the solar cell interconnects within the substrate is shown in Exhibit 2-9. The substrate pattern consists of 5 series connected groups of 3 cells connected in parallel. The electrical connection patterns for module/module and panel/panel interconnects as shown in Exhibits 2-7 and 2-6 respectively.

2.4.1.7 Mechanical Interconnects

The interconnects, module-to-module (which form the panels), panel-to-panel (which form the blankets), and blanket-to-tip piece assembly (to form the array), are shown in cross-section detail in Exhibit 2-10. The tip-piece assembly is part of the array structure and is discussed in Section 2.4.2.

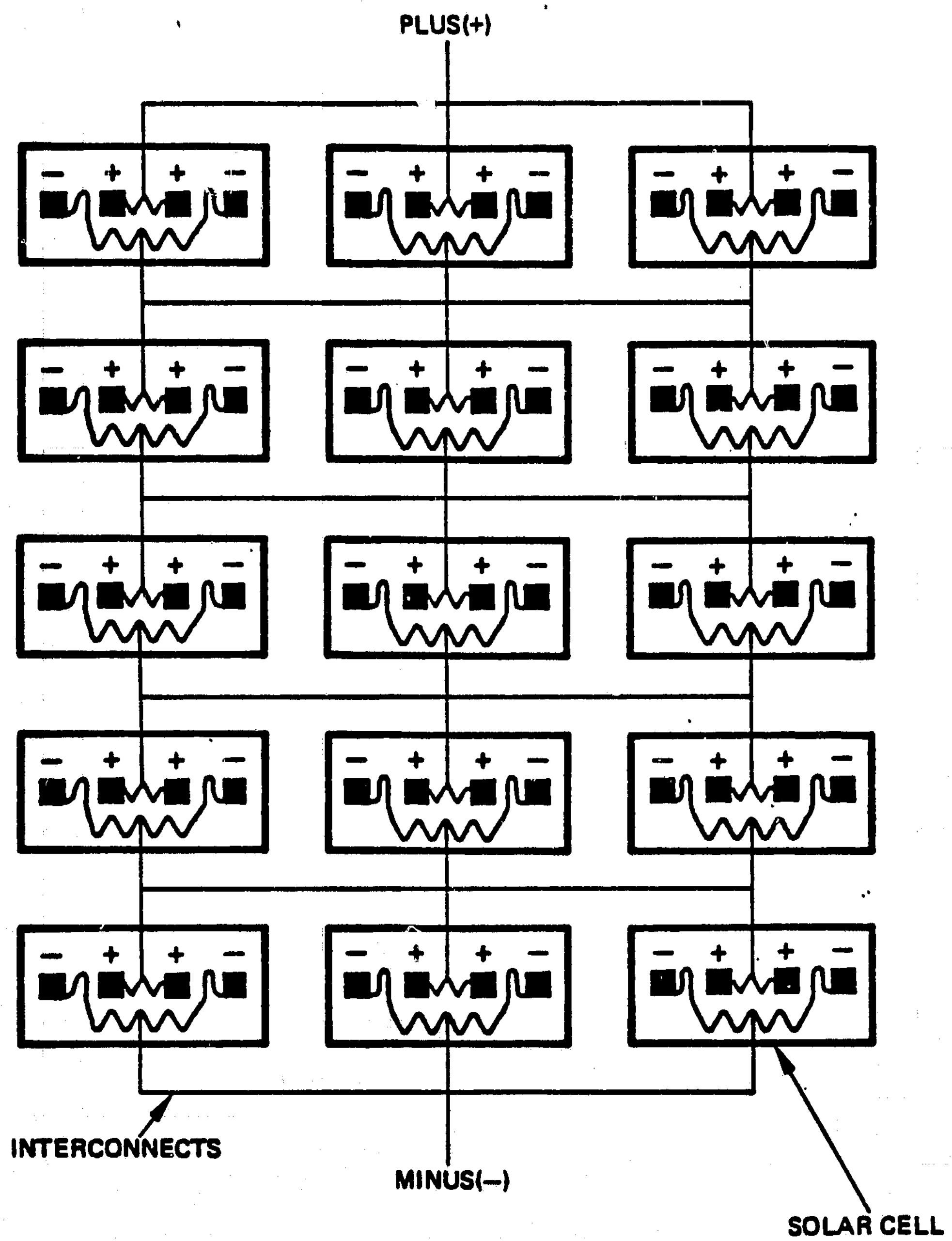
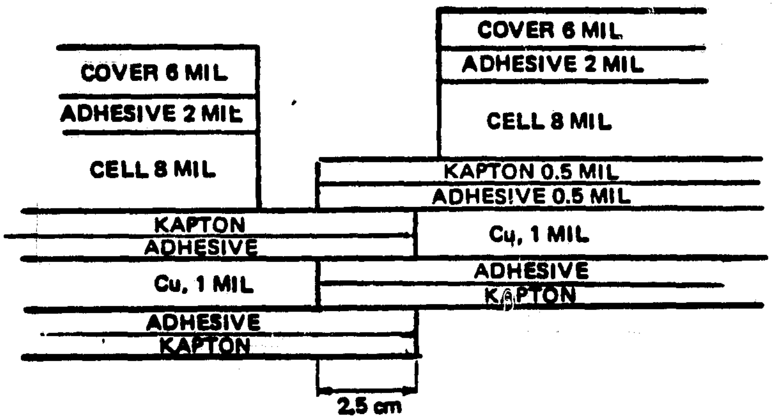
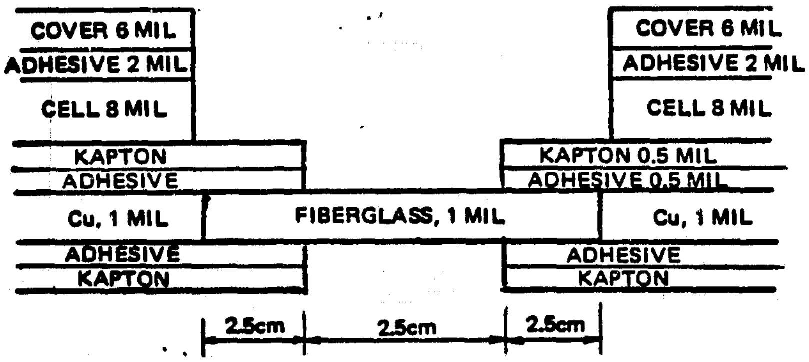


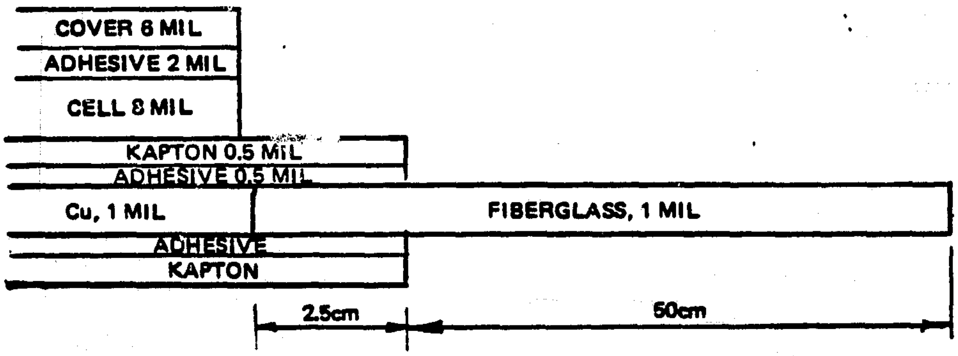
EXHIBIT 2-9. SOLAR CELL INTERCONNECTS BASIC PATTERN, 3 CELLS IN PARALLEL, 5 CELLS IN SERIES



Module/Module Interconnect



Panel/Panel Hinge Interconnect



Blanket/Tip Piece Interconnect

(NOT TO SCALE)

EXHIBIT 2-10. CROSS SECTION DETAILS, MECHANICAL INTERCONNECTS

2.4.2 Structural

The structural design assumes an astromast boom and with tip-piece assemblies for tension, and a two-axis (pitch and roll) slip-ring/drive assembly. The general layout is shown in Exhibit 2-11.

2.4.2.1 Requirements and Assumptions

The requirements and assumptions which apply to the structure are:

- 2-axis drive
- maximum angular acceleration (in pitch and roll), $\dot{\alpha} = 1.8 \times 10^{-5}$ radians/s^2
- maximum bend angle, $\theta = 10^{\circ}$ under 0.01G force applied at outboard tip
- first natural frequency, $\omega_1 = 0.04$ radians/s
- ratio of compressive preload to critical buckling load, P/Pcr = 0.3 (NAS TN D-8376)
- ratio of blanket mass to boom mass, $\bar{M} = 6$
- aluminum booms, r = 51 cm
- mass of tip piece << mass of boom $M_{tp} \ll M_b$
- length of each boom, for baseline,

  ℓ_b = blanket length + 7 meters

  = 144 m

2.4.2.2 Design

Using the relationship for bending stiffness in NAS TN D-8376

$$EI = \frac{M_b \ell^3 \omega^2}{\bar{\beta}^4} = 2.43 \text{ kg/cm}^2$$

The critical buckling load,

$$P_{cr} = \frac{\Pi^2 E\ I}{\ell^2} = 197.32 \text{ kg}$$

Therefore, for a $P/P_{cr} = 0.3$,

$P = 65.8$ kg

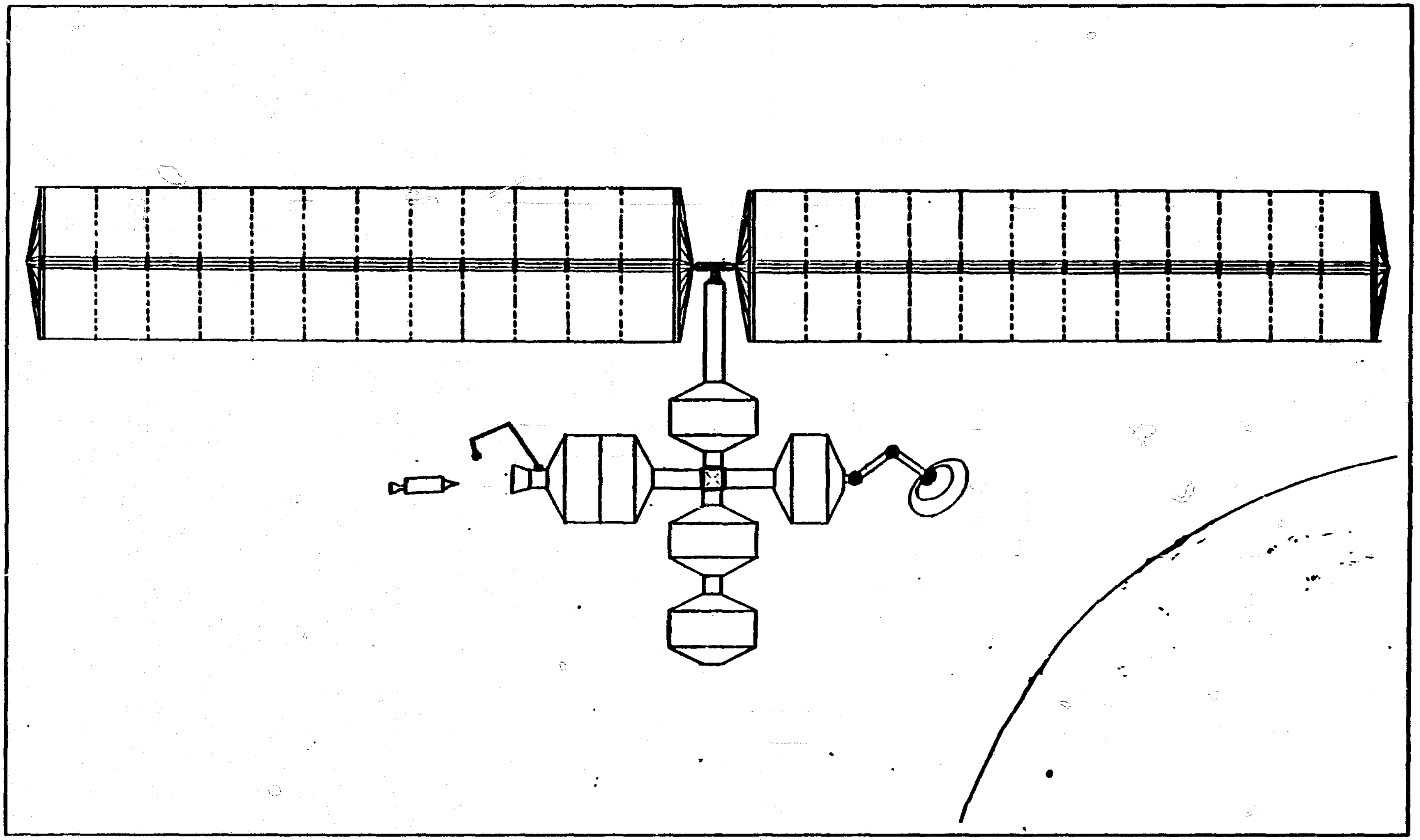


EXHIBIT 2-11. SPACE SERVICES PLATFORM SYSTEM

For F = 0.01G load at the tip of the boom, the bend angle,

$$\theta = \frac{F\ell^2}{2EI} + \frac{M_b(0.01)^2}{6EI} = 0.2^\circ,$$

which is well within the 10° constraint.

Using an Astro Research Corporation document*, the boom longerons (aluminum, solid cross-section) will have a cross-section area,

$$A = \frac{EI}{1.5Er^2} = 0.90 \text{ cm}^2.$$

The weight of each boom,

$$W_b = 3f \rho A\ell = 535 \text{ kg}.$$

The remaining structural components of the SAS were developed to the point of achieving a reasonable design concept. The structural details are shown in Exhibits 2-12 through 2-16.

To provide for varying the baseline array dimentions and weights, an analog relationship for the structure weight was derived:

$$W_{str} = \frac{W_b}{W_b(B/L)} \times 9465 \left(\frac{1}{150}\right)^3 + 154 \frac{N_{CH}}{48}$$

Where

W_{str} = structure weight, total

W_b = weight of boom

W_b (B/L) = weight of baseline boom

ℓ = length of boom

N_{CH} = number of power channels.

The detailed weight statement for the structure is shown in Exhibit 2-17.

*"Strength and Efficiency of Deployable Booms for Space Applications," R. F. Crawford, April, 1971.

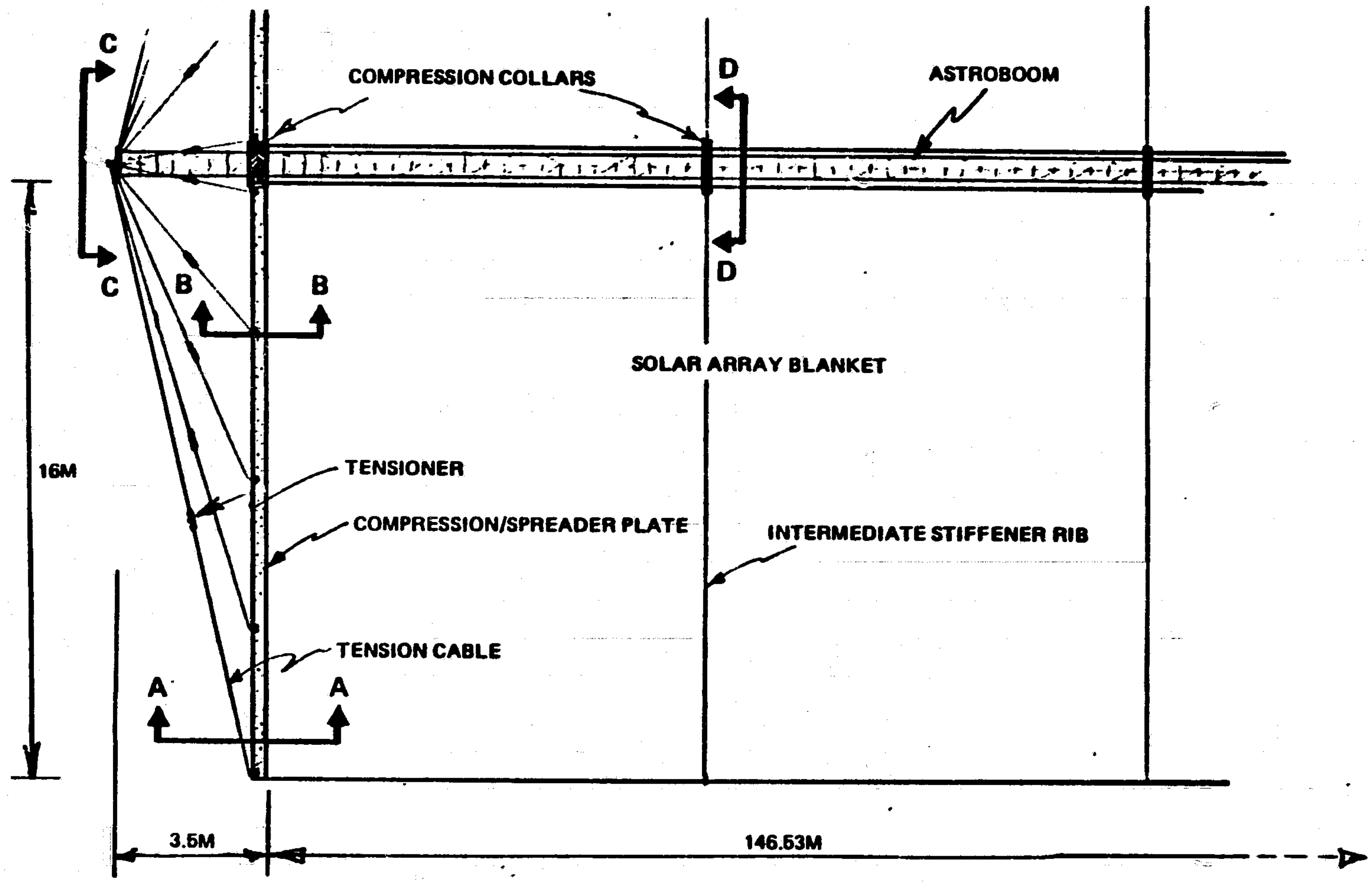
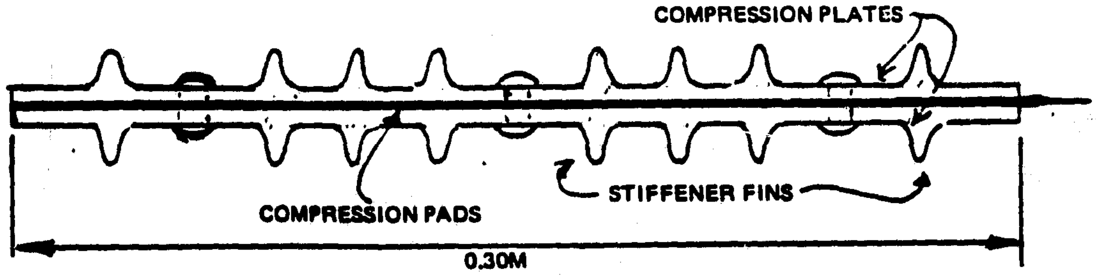
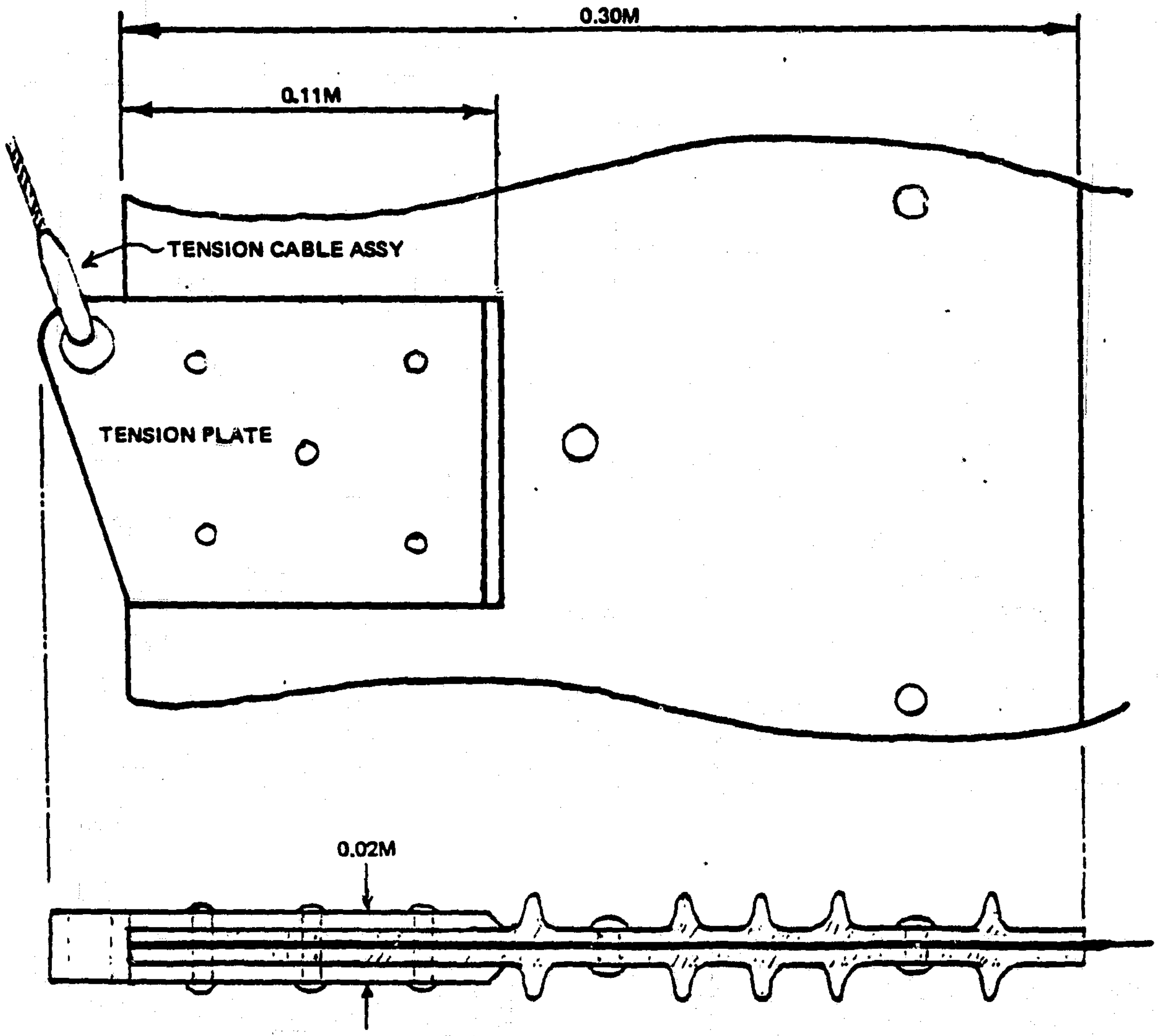


EXHIBIT 2-12. OUTBOARD END TIP ARRANGEMENT



VIEW A–A



VIEW B–B

EXHIBIT 2-13. COMPRESSION PLATE AND TENSION PLATE DETAILS

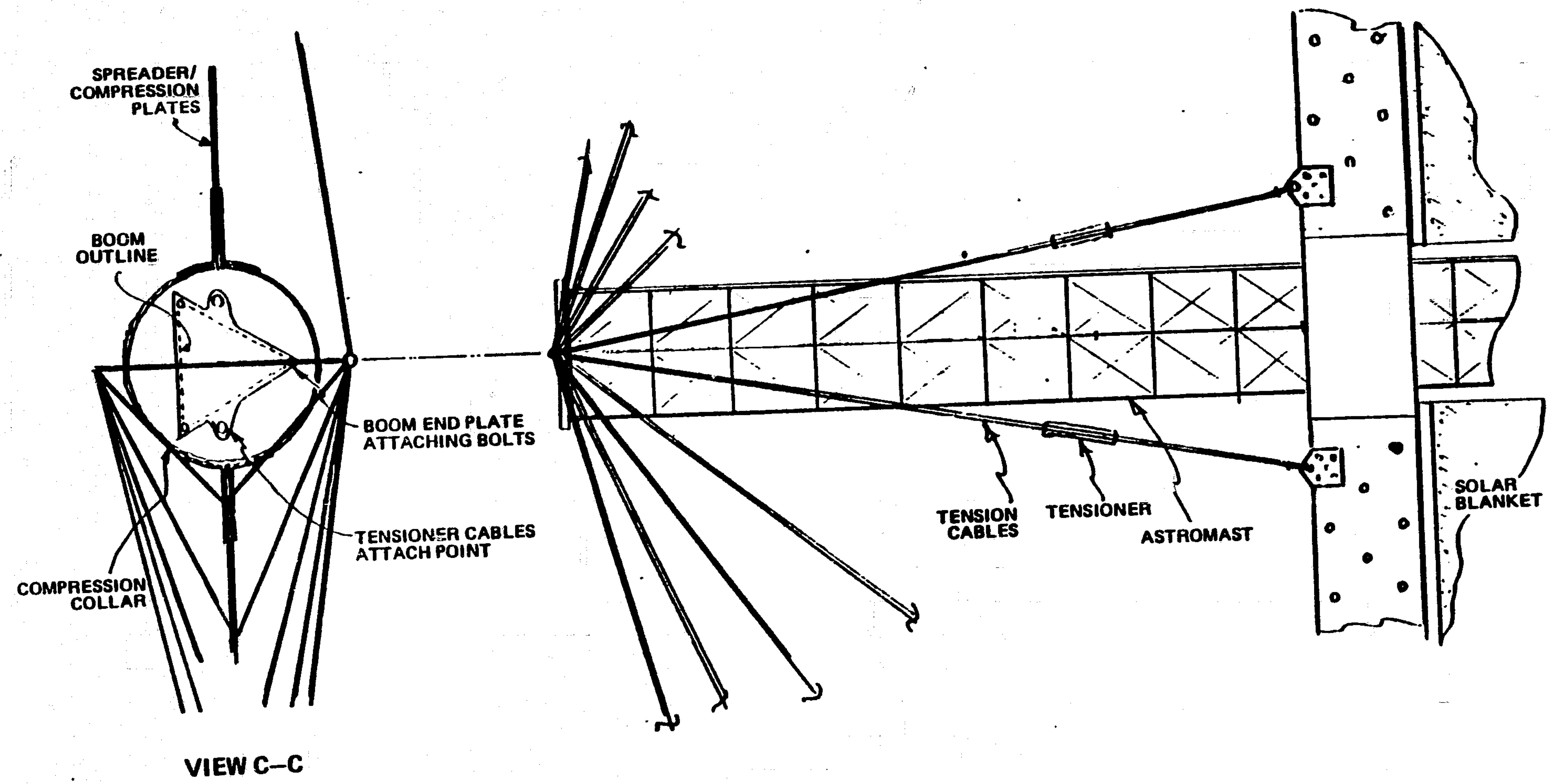


EXHIBIT 2-14. OUTBOARD END TIP PIECE DETAIL

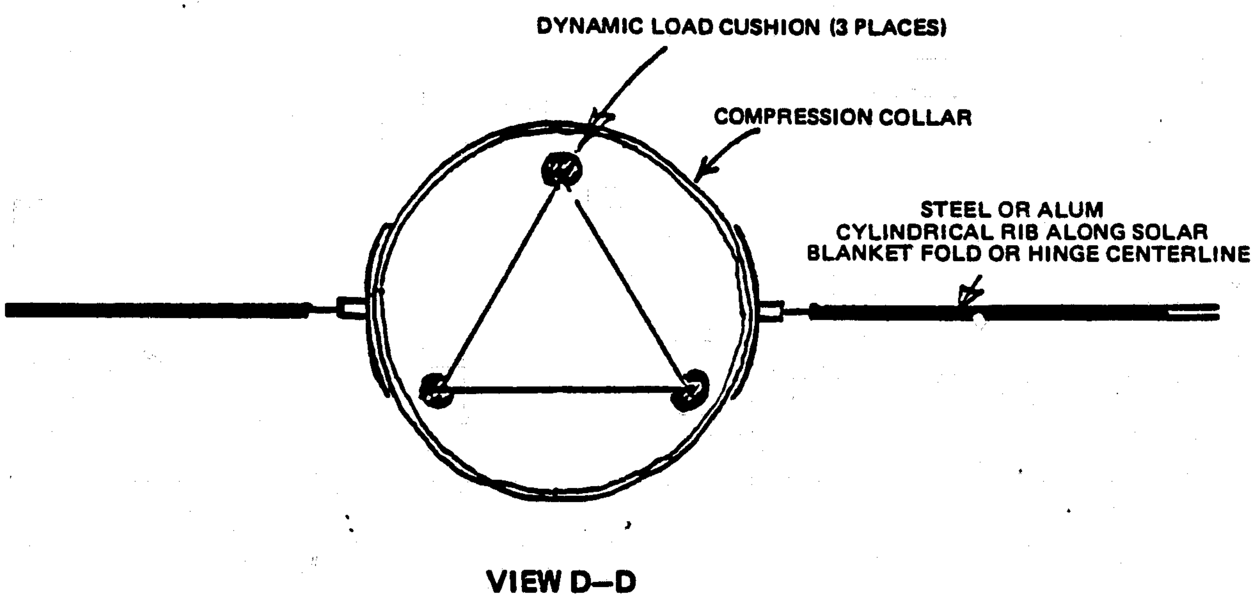


EXHIBIT 2-15. INTERMEDIATE STIFFENER RIB COLLAR DETAIL

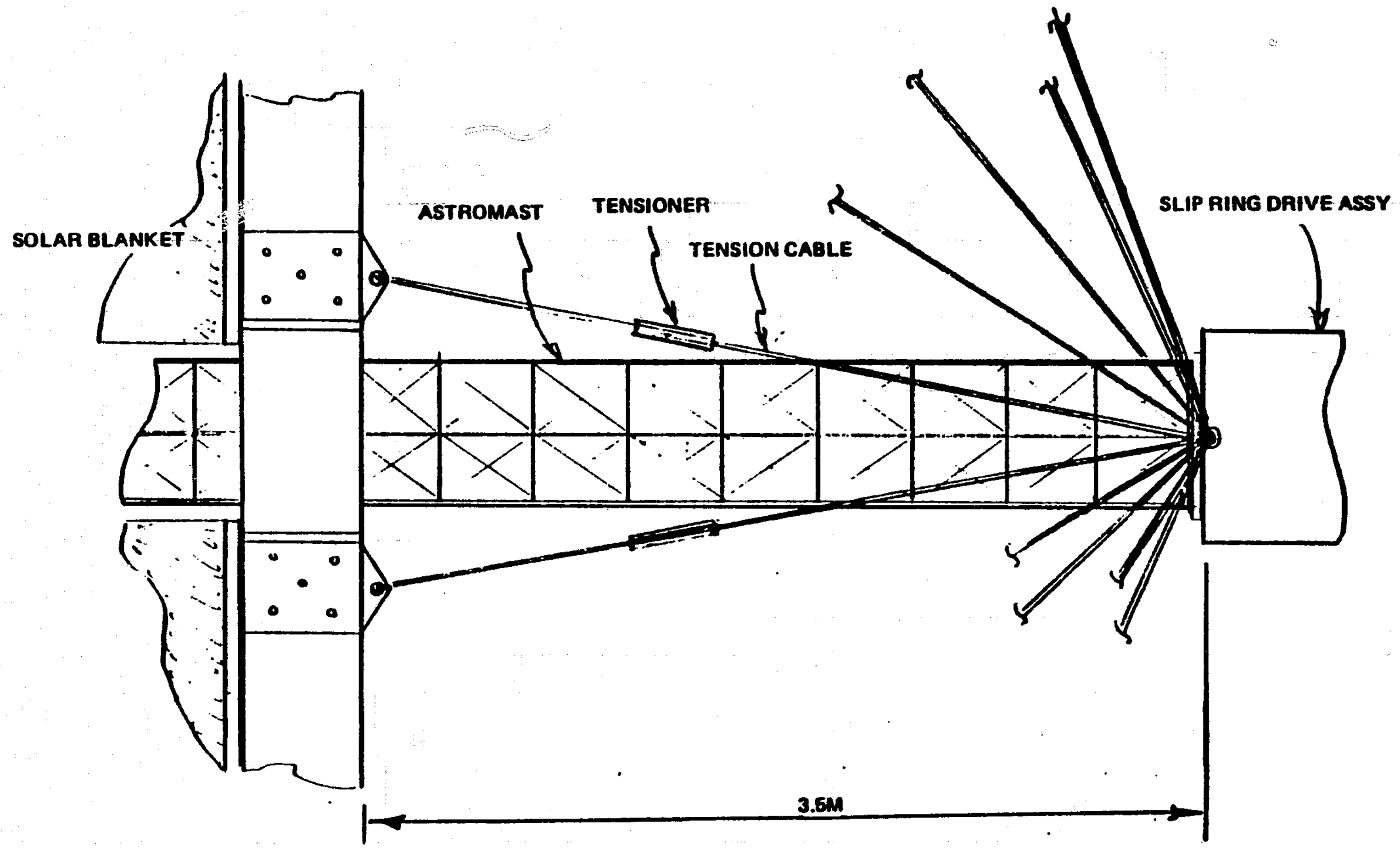


EXHIBIT 2-16. DRIVE END TIP PIECE

STRUCTURAL ASSEMBLY ITEM	DESCRIPTION (BASELINE)	WEIGHT (BASELINE) kg
• Main Booms, Astromasts (2)	Alumin Longerons, 50.8 cm. Dia. (Circum Circle), 144 m. Long	1,070.00
• Main Boom Transport Cannisters (2)	Shuttle Compatible (assume 10% of boom weight)	107.00
• Slip Ring Drive Assembly (1)	Not Specified	7,046.00
• Boom End Plates (4)	Alumin., Triangular shape, $(1x46x40 \div 2)\ cm^3$; $2685\ KG/m^3$	9.89
• End Plate Tension Posts (4)	Steel, 1 m. long, 1.9 cm. Dia.; $7972\ KG/m^3$	9.08
• Compression Plates (16)	Alumin. $(0.5x15x1600)\ cm^3$	515.52
• Tension Plates (40)	Alumin. $(1.0x11x10)\ cm^3$	11.81
• Tension Cables W/Eyes and Tensioners (80)	Steel Piano Wire	20.00
• Tip Piece Compression Collar Assemblies (4)	Alumin. 1.0 cm x 75cm Dia. x 50 cm long.	130.44
• Intermediate Stiffener Ribs (44)	Steel Rods, 0.5 cm Dia. 16 M. Long	110.06
• Dynamic Load Cushions (78)	Plastic (Styrene), Nylon Straps	7.80
• Main Bus Conductor Stand-Offs (48)	Plastic (Styrene), Nylon Straps	20.00
• Main Bus Conductors	--	525.00
• Miscellaneous Hardware	--	20.00
TOTAL		9,602.60

EXHIBIT 2-17. SAS STRUCTURE WEIGHT STATEMENT

2.5 Array Summary

2.5.1 Performance Summary

The performance of the baseline solar array is summarized in Exhibit 2-18. It should be noted that the array has been sized based upon a worst-case analysis of minimum power and voltage, which occur at minimum illumination, and maximum illumination respectively. For this reason, the minimum array current is not included in the summary.

2.5.2 Weight Statement

The baseline weight statement is shown in Exhibit 2-19. The panel level electrical interconnects consist of series interconnects between the ½ modules. The weight of the mechanical interconnects between modules (e.g., module overlap) is negligible. At the blanket level, the mechanical interconnects consist of the folding material between the panels. There are two compression plate cushions, one at each end of the blanket. The main bus at the array level consists of 12 pairs of conductors per blanket. The total structure weight includes the weight of the slip ring.

2.5.3 Array Table

The baseline array totals are summarized in Exhibit 2-20. All totals are for EOL performance. For BOL performance, (952.6kW and 210.6 VDC) the power density is 114.3 W/M^2 and the power/weight ratio is 52.3 W/Kg.

BASELINE SOLAR ARRAY
PERFORMANCE

	VOLTAGE (MIN)	POWER (MIN)
SOLAR CELL	.33 V	.053 W
1/2 MODULE	1.65 V	83.5 W
PANEL	49.5 V	2,504 W
CHANNEL	198.0 V	10,017 W
BLANKET	198.0 V/CHANNEL	120.2 kW
WING	198.0 V/CHANNEL	240.4 kW
ARRAY	198.0 V/CHANNEL	480.8 kW
ARRAY REQUIREMENTS	180 V/CHANNEL (MIN)	480.0 kW

EXHIBIT 2-18

ELEMENT		WEIGHT (KG)
PANEL LEVEL		
MODULES (15/PANEL)	42.48	
ELECT. INTERCONNECTS	0.75	
TOTAL EACH PANEL	43.23	
BLANKET LEVEL		
PANELS (48/BLANKET)	2075	
MECHANICAL INTERCONNECTS	751	
COMPRESSION PLATE CUSHIONS	128	
ELECT. INTERCONNECTS	31	
TOTAL EACH BLANKET	2985	
ARRAY LEVEL		
BLANKETS (4/ARRAY)		11,940
STRUCTURE (INCL. SLIP-RINGS		7778
MAIN BUS CONDUCTORS		656
TOTAL FOR ARRAY		20,374

EXHIBIT 2-19. BASELINE WEIGHT STATEMENT

SOLAR ARRAY TOTALS

TOTAL CELLS	=	9.0720×10^6
POWER	=	480.8 kW
AREA	=	9350 M^2
POWER DENSITY	=	51.42 W/M^2
WEIGHT	=	20,374 KG
POWER/WEIGHT RATIO	=	23.60 W/KG

EXHIBIT 2-20. SOLAR ARRAY TOTALS

3.0 FUNCTIONAL FLOWS

The top flow diagrams for DDT&E, Production, and Operations and Maintenance are shown in Exhibits 3-1, 3-2 and 3-3. Although the DDT&E cost estimate was based on 35% of the production costs (derived from historical program costs), a breakdown of DDT&E functions is provided for completeness and for possible future analysis; for example, the achievement of various array reliabilities would affect the design and testing costs.

It should be noted that the production phase includes transportation to space and assembly and check-out in space. The rationale here was that "buy-off" as operationally ready of the SAS as a subsystem would not occur until a final check-out of the complete and functioning assembly was accomplished. However, as discussed in Section 4.0, the space transportation and assembly and check-out are assumed to be NASA incurred costs. More detailed functional flows in the production phase are provided in exhibits as follows:

FUNCTION	EXHIBIT
Cell/Cover Assembly	3-4
Module Substrate Assembly	3-5
Module Assembly	3-6
Panel Assembly	3-7
Blanket Assembly	3-8
Space Assembly and Checkout	3-9

In the O&M flow (Exhibit 3-3) for the baseline, the "produce spares" block is null since the required number of spares (panels) are assumed to be manufactured during production. However, this could be subject to trades analysis and therefore the function has been included for completeness.

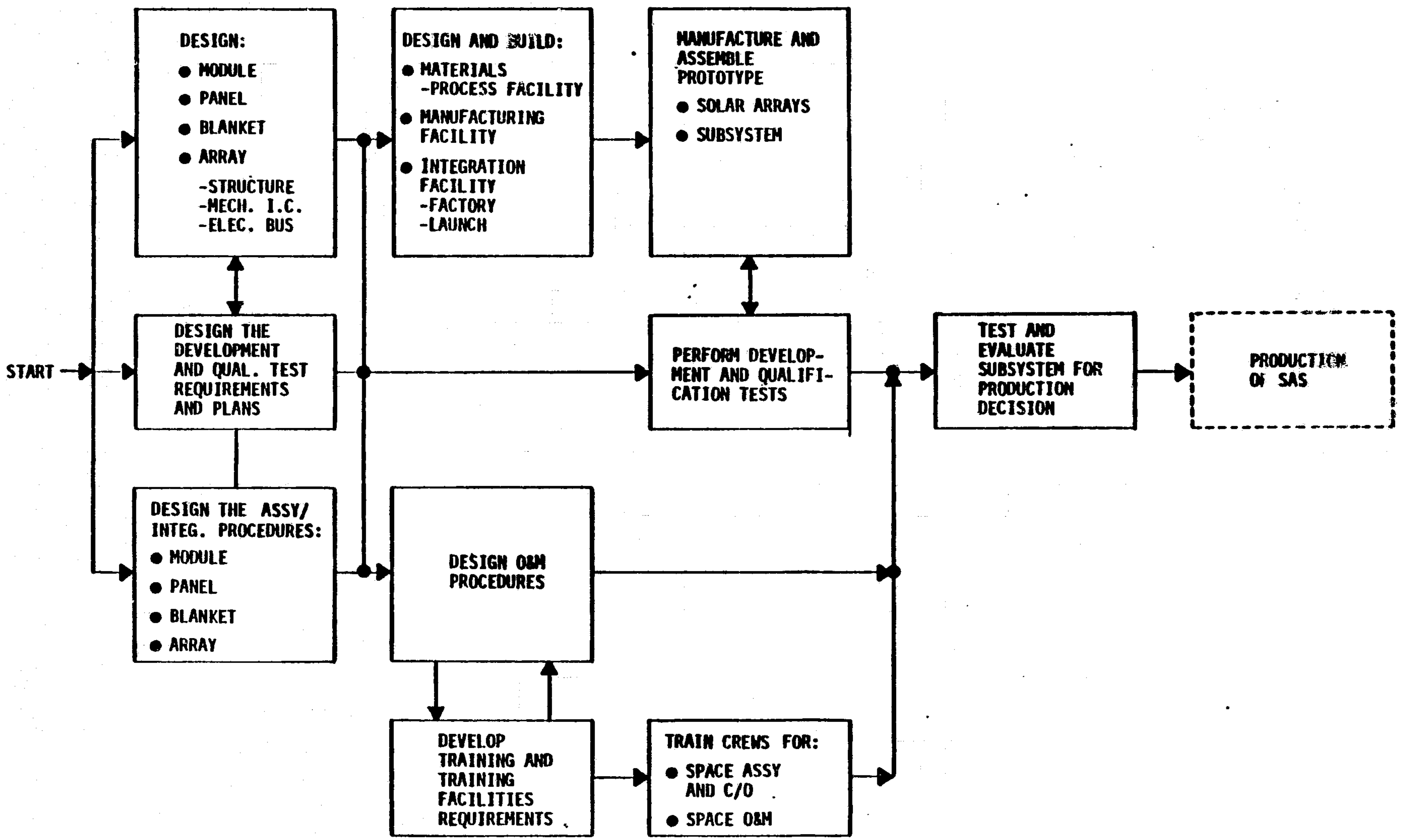


EXHIBIT 3-1. DDT&E FUNCTIONAL FLOW

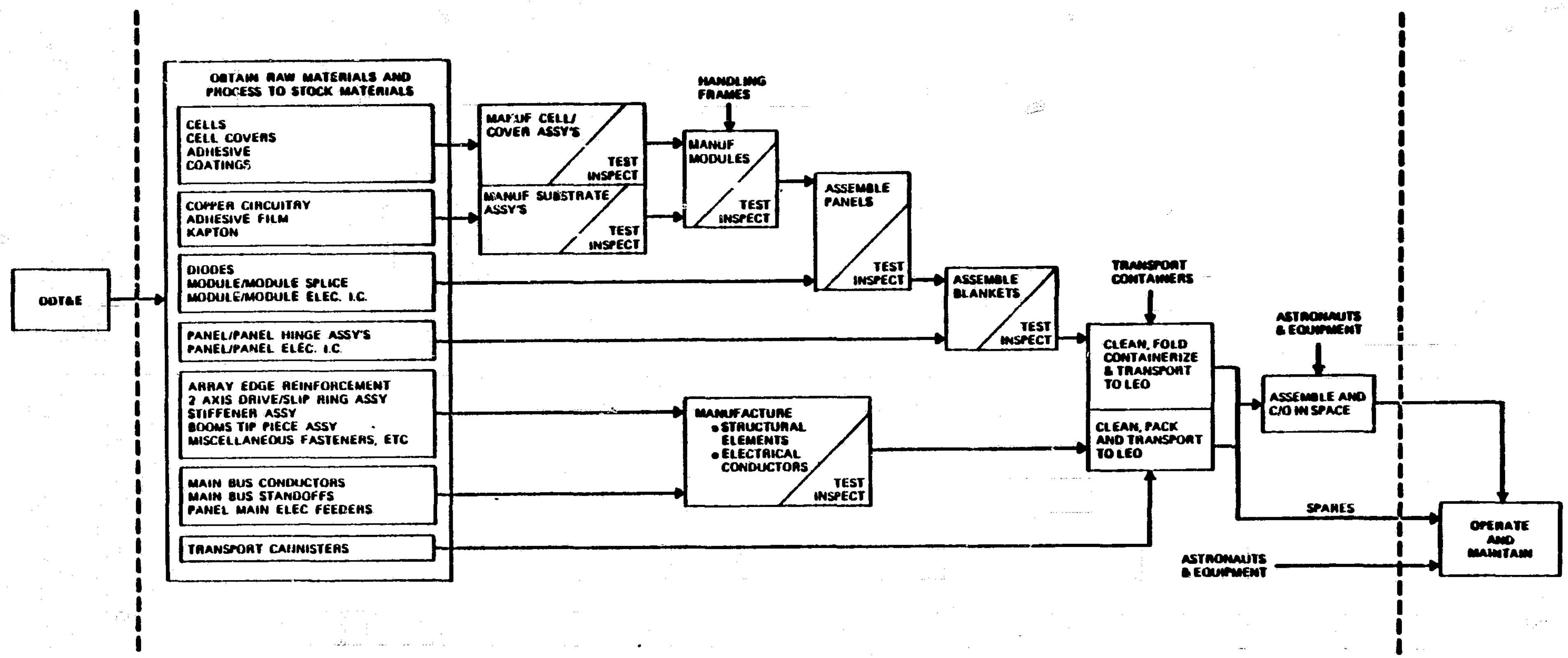


EXHIBIT 3-2. SOLAR ARRAY SUBSYSTEM FLOW.

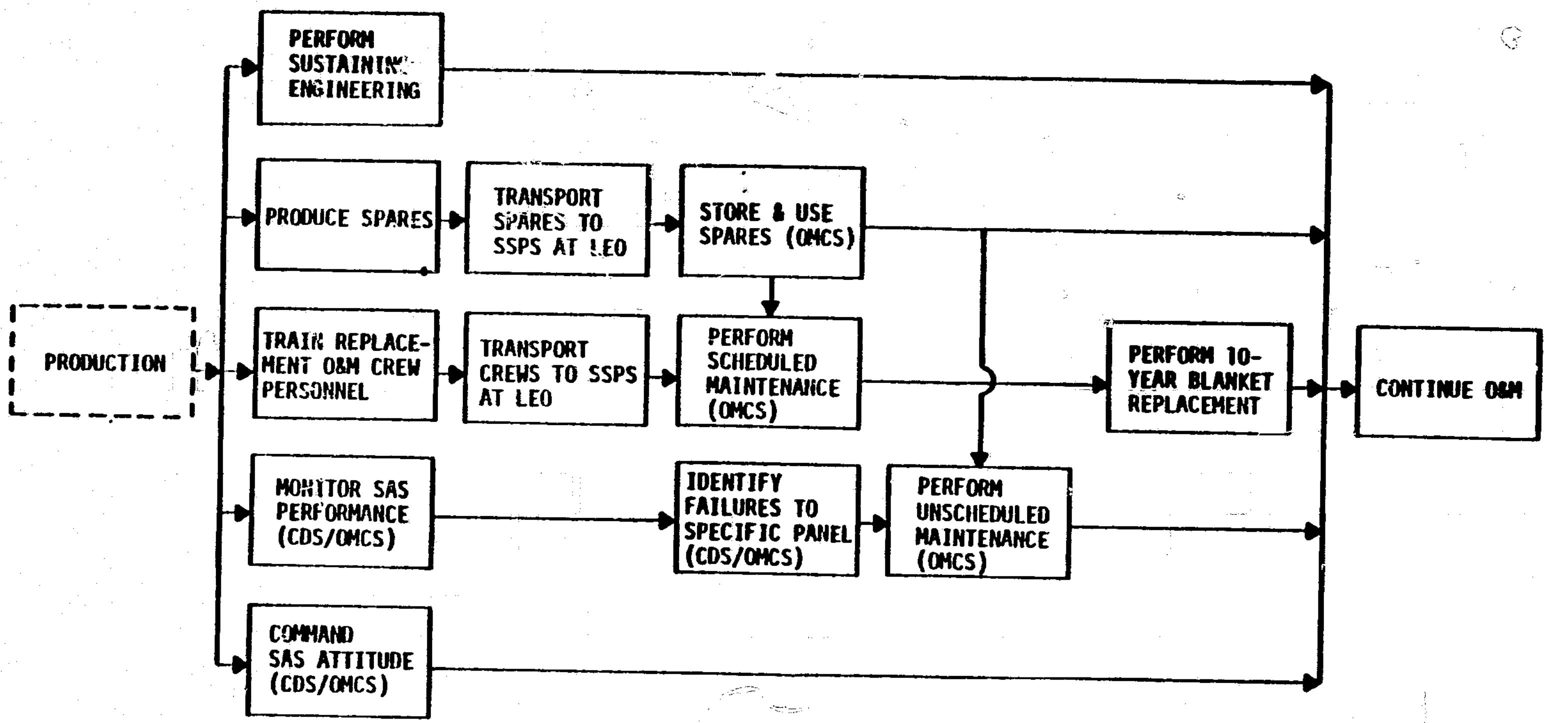


EXHIBIT 3-3. O&M FUNCTIONAL FLOW

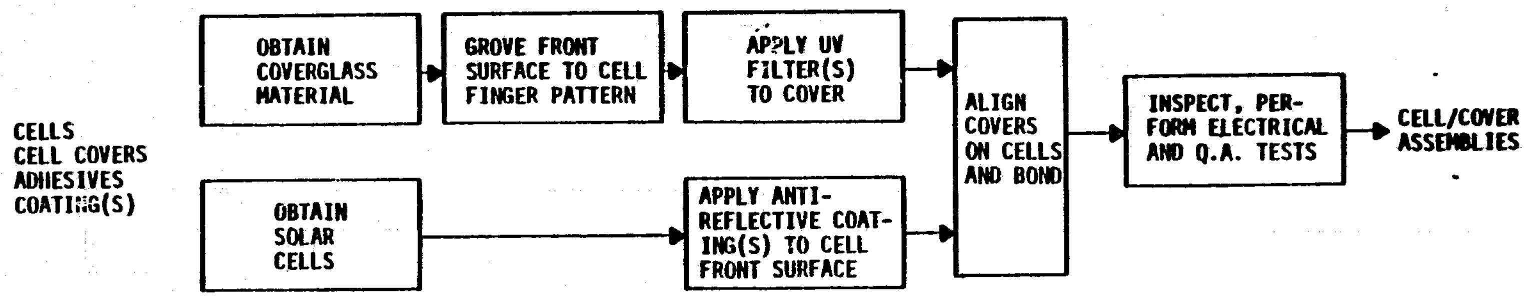


EXHIBIT 3-4. CELL/COVER ASSEMBLY FLOW, PRODUCTION PHASE

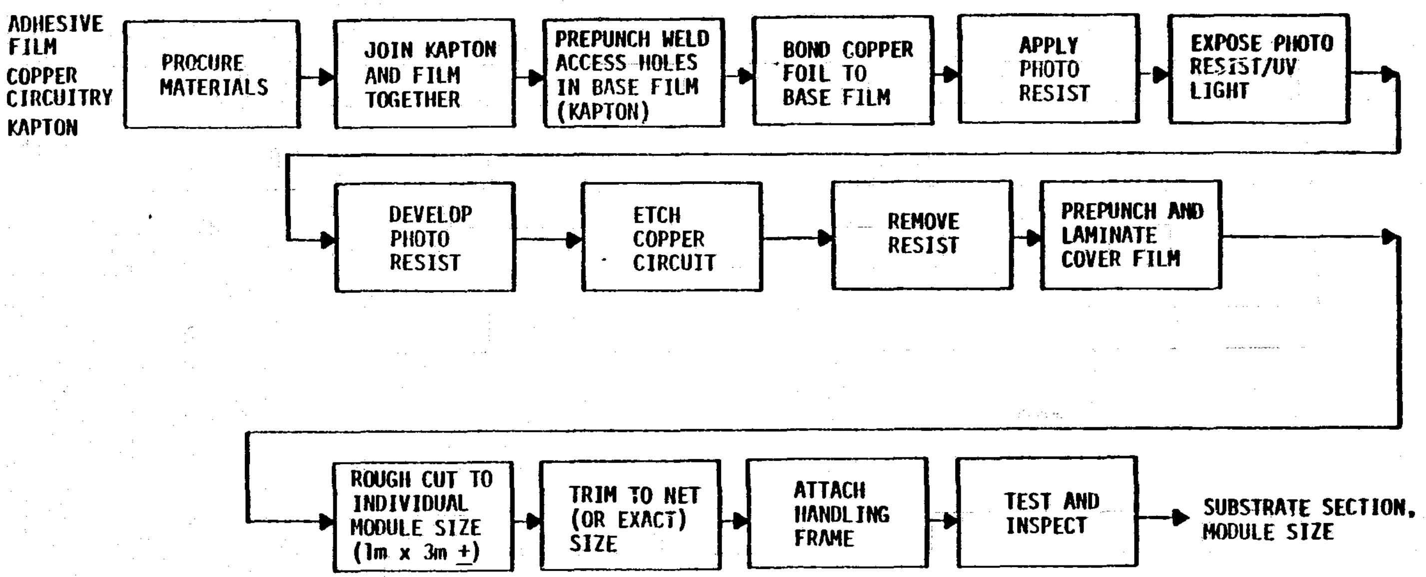


EXHIBIT 3-5. MODULE SUBSTRATE ASSEMBLY FLOW, PRODUCTION PHASE

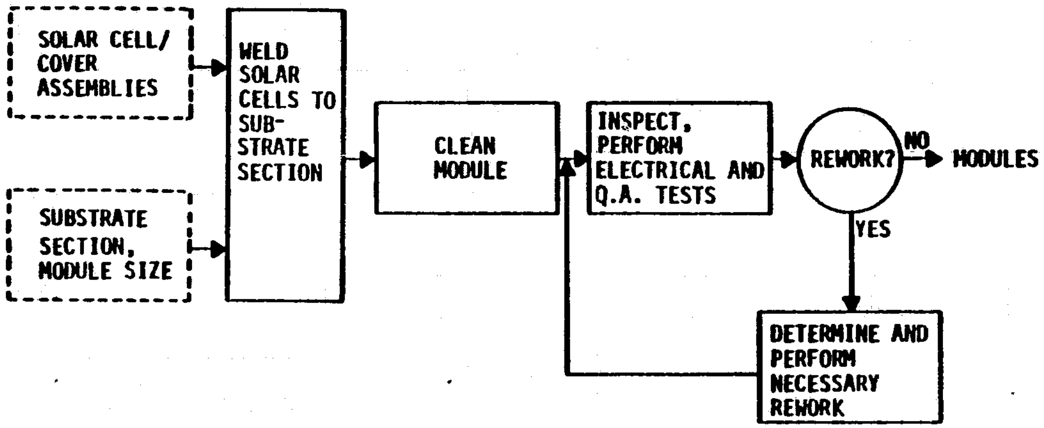


EXHIBIT 3-6. MODULE ASSEMBLY FLOW, PRODUCTION PHASE

MODULE/MODULE FRAME
MODULE/MODULE ELECTRICAL I.C.
PANEL INTERNAL ELEC. I.C.
DIODES

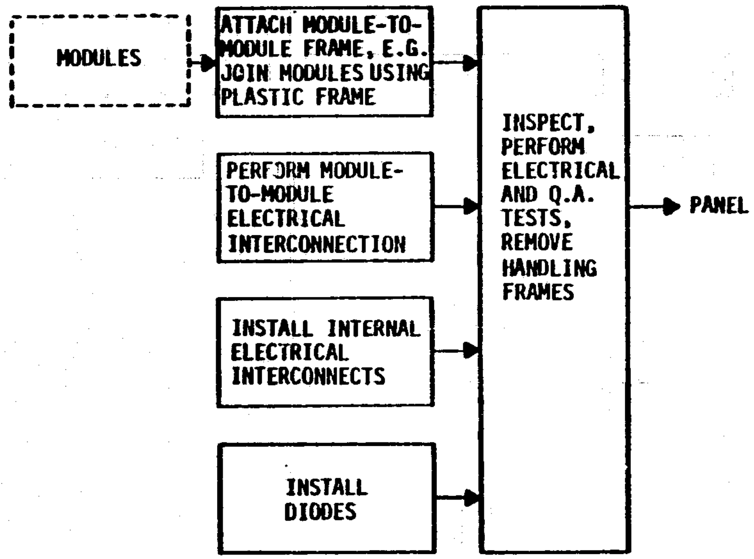


EXHIBIT 3-7. PANEL ASSEMBLY FLOW, PRODUCTION PHASE

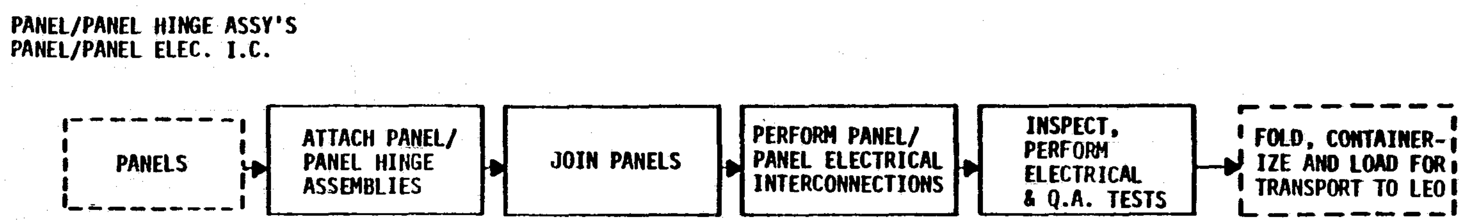


EXHIBIT 3-8. BLANKET ASSEMBLY FLOW, PRODUCTION PHASE

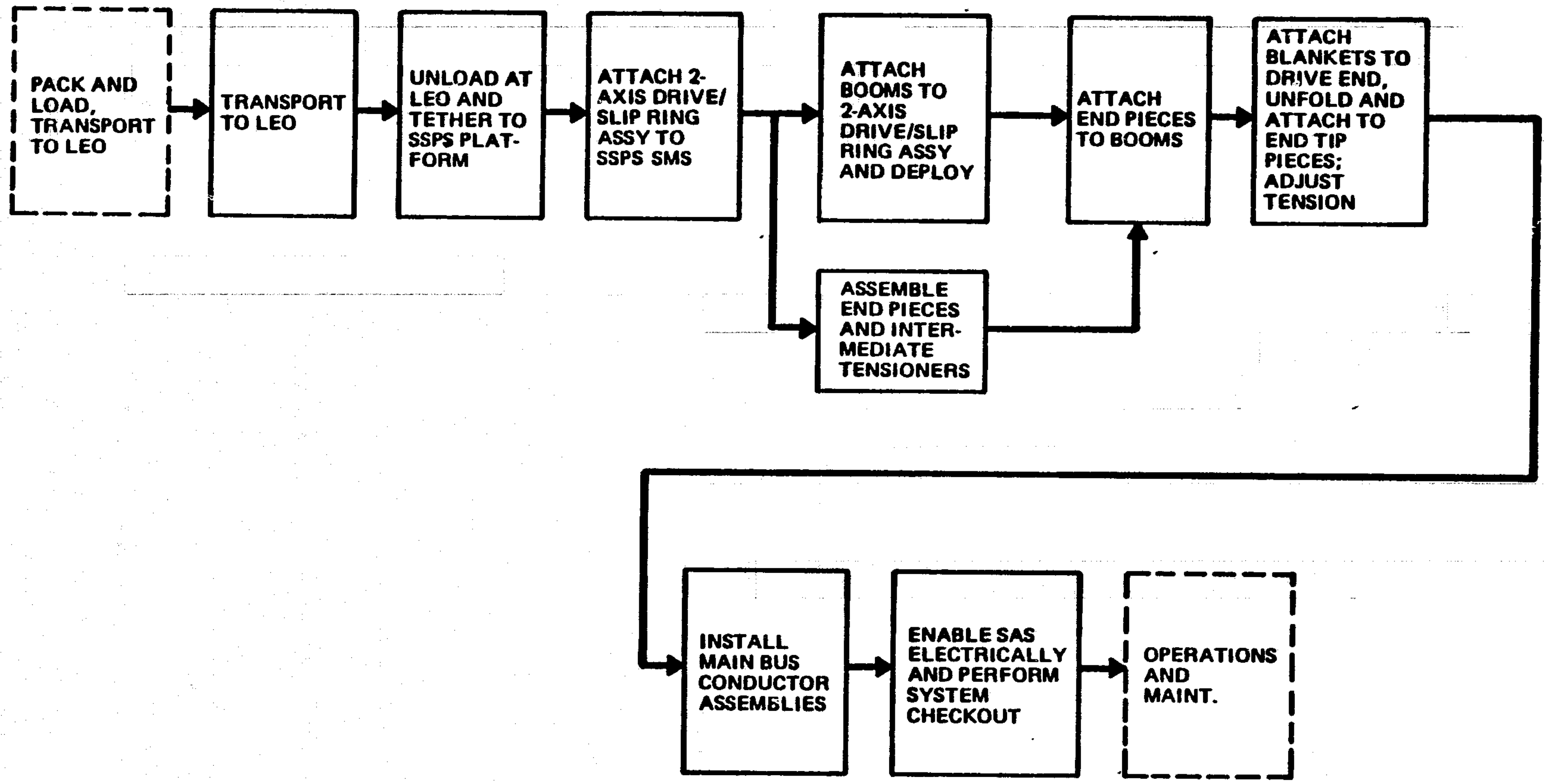


EXHIBIT 3-9. SPACE ASSEMBLY AND CHECKOUT

4.0 TOTAL LIFE CYCLE COST

The purpose of the Solar Array Subsystem Life Cycle Cost Model is to estimate the LCC of the baseline SAS and the different LCC's resulting from variations in the configuration of the SAS.

The basis for the LCCM structure (Exhibit 4-1) is the WBS (Exhibit 1-2) and the functional flow diagrams (Exhibits 3-1, 3-2, and 3-3). The LCCM structure and the functional flows which illustrate in detail the three phases of LCC are compatible with the WBS. The sources for the top level cost relationships (Page B-3) used in the LCCM consist of historical data from the SAS data base and cost and technical data from various vendors.

The Solar Array Subsystem Life Cycle Cost Model consists of three phases: (1) Design, Development, Test and Evaluation; (2) Production and (3) Operations and Maintenance. The direct costs of the baseline are listed in Exhibit 4-3. Refer to Page B-2 for a detailed breakout of cost including direct and indirect costs. The indirect expenses are discussed in Page B-6.

4.1 Design, Development, Test and Evaluation

The cost of the DDT&E phase of life cycle cost is estimated to be 35% of the production phase cost. The DDT&E phase includes the following functions: (1) designing the array and the manufacturing facility and manufacturing the prototype solar array subsystem; (2) designing the development and qualification test requirements and plans and performing development and qualification tests; (3) designing the assembly/integration procedures, designing operations and maintenance procedures, develop training requirements and (4) test and evaluate the solar array subsystem for production decision.

4.2 Total Production Phase Cost

The cost of the production phase is divided into two categories: (1) the manufacturing cost and (2) the cost incurred by NASA to transport the solar array subsystem and astronauts to LEO and the cost of space assembly and check-out.

4.2.1 Total Manufacturing Cost

It is assumed that a prime contractor will manufacture the solar array subsystem using raw stock and off-the-shelf hardware that is presently obtainable.

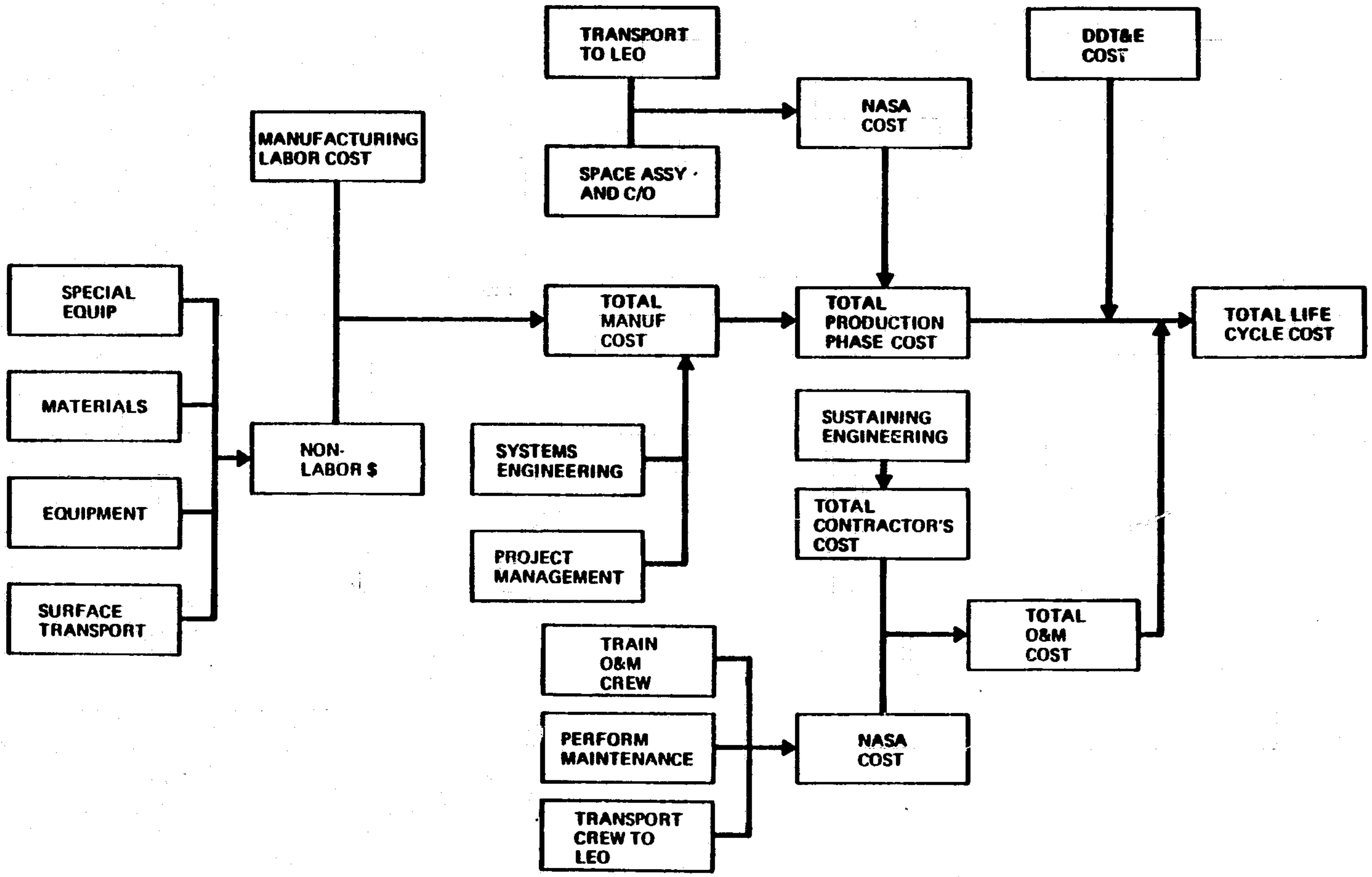


EXHIBIT 4-1. SOLAR ARRAY SUBSYSTEM LIFE CYCLE COST MODEL STRUCTURE

- ALL COSTS IN 1980$ IN MILLIONS
- STOCK MATERIALS AND COMPONENTS REQUIRED FOR MANUFACTURE OF ARRAY
- DEDICATED FACTORY FACILITY REQUIRED FOR MANUFACTURE OF ARRAY
- COST OF TRANSPORTING SAS BLANKETS AND STRUCTURE TO LEO IS INCLUDED IN PRODUCTION PHASE OF LIFE CYCLE COST
- SHUTTLE FLIGHTS ASSUMED TO BE DEDICATED TO SPACE SERVICES PLATFORM SYSTEM
- OPERATIONS AND MAINTENANCE PHASE OF BASELINE LIFE CYCLE COST COVERS 10 YEAR LIFE OF SAS

EXHIBIT 4-2. GROUNDRULES AND ASSUMPTIONS

The total manufacturers cost consists of labor cost, non-labor cost, Project Management and Systems Engineering. The labor and non-labor costs for each WBS item were estimated. These estimates are dependent on the configuration of the SAS and require the inputs described in Exhibit 4-4.

4.2.1.1 Manufacturing Labor Cost

The total manufacturing labor cost consists of the labor cost associated with each manufacturing process.

This cost was estimated based on the number of components required. The number of components determined the number of labor hours. Refer to Exhibit 4-5 for the factors used to determine the labor hours required and the resulting direct labor cost for each manufacturing process.

The labor rate used was $20/hr. The indirect rates, fringes, overhead and other direct charges, were applied to the direct labor base to obtain the total manufacturing labor cost.

4.2.1.2 Non-Labor Manufacturing Cost

The non-labor manufacturing cost consists of materials, equipment, special equipment and surface transportation. These costs are also dependent on the configuration of the array and require the inputs in Exhibit 4-4.

4.2.1.2.1 Materials

The cost of materials required for each manufacturing process was estimated based on the unit cost and amount required for the process. The unit cost is based on vendor quotes and the amounts required are dependent on the configuration of the SAS. A manufacturing burden to cover the expense of procuring and warehousing materials is applied to the total materials cost. The baseline materials cost for each manufacturing process is listed in Exhibit 4-6.

4.2.1.2.2 Process Equipment

The equipment costs for each manufacturing process for the baseline were estimated based on the production rates required to manufacture the number of components needed for the baseline SAS. Refer to Exhibit 4-7 for a list of the baseline equipment costs.

SAS BASELINE LIFE CYCLE COST

(1980 $ In Millions)

4.0	TOTAL LIFE CYCLE COST	754.5
4.1	DDT&E	153.9
4.2	TOTAL PRODUCTION PHASE COST:	439.9
4.2.1	Total Manufacturing Cost	376.1
4.2.1.1	Manufacturing Labor Cost	34.0
4.2.1.2	Manufacturing Non-Labor Cost	261.7
4.2.2	NASA Cost:	63.9
4.2.2.1	Shuttle Transportation	63.1
4.2.2.2	Space Assembly and Check-Out	.8
4.3	TOTAL O & M COST:	160.7
4.3.1	Total Contractor's Cost	.9
4.3.2	NASA Cost:	159.8
4.3.2.1	Train O & M Crew	2.5
4.3.2.2	Perform Maintenance	11.0
4.3.2.3	Transport Crew to LEO	146.3

EXHIBIT 4-3

BASELINE INPUTS TO LCCM
(1980 $)

• Cost of Labor	
ON EARTH	$ 20/manhour
IN SPACE	250/manhour
• Cost of Materials	
Cell/Cover Assembly	7.75
Module Substrate	142.29/M^2
Module Assembly (welding materials)	740,000
Mechanical and Electrical Interconnects	10,260/panel
Mechanical and Electrical Interconnects	47,000/blanket
• No. of Cell/Cover Assemblies	9,072,000
• No. of modules	2,880
• No. of panels	192
• No. of blankets	4
• Blanket Weight (4)	11,940 kg.
• Structures Weight	7,778 kg.

EXHIBIT 4-4

SAS MANUFACTURING PROCESS FACTORS
AND
BASELINE DIRECT LABOR COSTS
(1980 $ In Millions)

MANUFACTURING PROCESS	FACTORS	BASELINE LABOR COSTS
Cell/Cover Assembly	4,250 assemblies/hour	2.77
Module Substrate (flexible circuit)	9 m^2/hour	.41
Module Assembly	2.75 modules/hour	3.70
Panel Assembly	.15 panels/hour	4.31
Blanket Assembly	.003 blankets/hour	1.47
Blanket Transport (Fold & containerize)	.003 blankets/hour	.06
Structure Transport (Fold & containerize)	Weight of structure x 1.25 (weight of container) x $ 2.56	.03
Total Baseline Direct Labor Cost		12.75

EXHIBIT 4-5

SAS BASELINE MATERIALS COST

(1980 $ In Millions)

PROCESS	COST
Cell/Cover Assemblies	91.40
Module Substrate	1.78
Module Assembly (Welding Materials)	.74
Panel Assembly (Interconnects)	1.97
Blanket Assembly (Interconnects)	.31
Structures	3.07
TOTAL	99.27

EXHIBIT 4-6

SAS BASELINE PROCESS EQUIPMENT COSTS

(1980 $ In Millions)

PROCESS	COST
Cell/Cover Assembly	6.17
Module Substrate (flexible circuit)	9.83
Module Assembly	60.51
Panel Assembly	37.12
Blanket Assembly	25.71
Blanket Transport (Fold & containerize)	1.76
Structure Transport (Fold & containerize)	.44
TOTAL	141.54

EXHIBIT 4-7

4.2.1.2.3 Special Equipment

The special equipment consists of containers for packaging the SAS blankets and structures for shipment to the launch site and to LEO aboard the Space Shuttle.

4.2.1.2.4 Surface Transportation

Surface transportation costs consist of the cost of transporting the SAS blankets and structures to the launch site from the manufacturing facility. It was assumed the manufacturing facility would be located on the West Coast and the launch site would be Kennedy Space Center. The cost is dependent on the combined weight of the structure, blankets and the containers in which they are packaged.

4.2.2 NASA Cost

The NASA incurred cost portion of the total production phase cost consists of: (1) the cost of transporting the SAS blankets, structures and the SA & CO astronaut crew to LEO aboard the Space Shuttle and (2) the cost of the assembly and check-out in space.

4.2.2.1 Transportation to LEO

It is assumed that the SAS will be transported to LEO on Space Shuttle flights dedicated to the SSPS. Therefore, the transportation costs for the SAS are dependent on the weight of the SAS. The cost of transporting the astronauts and the equipment used for assembly and check-out is estimated to be 1/7 or 14% of the cost of one dedicated flight because the SAS is one of seven subsystems of the SSPS.

4.2.2.2 Space Assembly and Checkout

Space assembly and check-out includes the cost of the astronaut crew's labor to assemble and check-out the SAS in space and the cost of the equipment used. The labor cost is a function of the weight of the SAS.

4.2.3 Project Management

The cost of Project Management is estimated to be 5.8% of the sum of the manufacturing labor and non-labor costs. Project Management includes planning, organizing, directing, coordinating and controlling the project to ensure that overall project objectives are accomplished.

4.2.4 Systems Engineering

The cost of the System Engineering is estimated to be 4.8% of the sum of the manufacturing labor and non-labor costs. This function includes the application of scientific engineering efforts to: (1) transform an operational need into a description of system performance parameters and a system configuration; (2) integrate related technical parameters and assure compatibility of all physical, functional and project interfaces in a manner which optimizes total system definition and design; and (3) integrate the efforts of all engineering disciplines and specialties into the total engineering effort.

4.3 Total Operations and Maintenance Phase Cost

The Operations and Maintenance Phase of the life cycle covers the ten year life span of the SAS. There are two categories of cost in this phase: (1) a contractor's cost for the sustaining engineering's function and (2) a cost incurred by NASA to train the operations and maintenance crew, transport the crew to LEO and perform maintenance on the SAS over a ten-year period.

4.3.1 Total Contractor's Cost

It is assumed that a contractor housed at the launch site will provide sustaining engineering for the SAS over a ten-year period. It is assumed that one engineer working 2,040 hours a year at $20 an hour for ten years would constitute the labor cost. The total contractor cost for sustaining engineering is obtained by applying the fringes, overhead and other direct cost rates to the direct labor base. A general and administrative rate is also included in the total contractor's cost.

4.3.2 NASA Incurred Cost

The cost incurred by NASA in the O&M phase is the sum of the cost of training the crew, transporting them to the SSPS in LEO and performing the maintenance over a ten-year period.

4.3.2.1 Train O & M Crew

It is estimated that it will be necessary to train one astronaut crewman per year for ten years. The cost for this training is estimated to be $250,000 per year per crewman.

4.3.2.2 Perform Maintenance

The crew that performs the maintenance on the array is divided into two groups. One crew remains on the SSPS to perform scheduled maintenance. The crew works for three month periods on the space platform and is sent back to earth to be replaced by another crew. The unscheduled maintenance is performed by an earth based crew that makes a number of unscheduled trips to the SSPS per year.

4.3.2.3 Transport Crew to LEO

Four trips a year for ten years are required for the crew that is housed on the SSPS. The cost is $250K per trip. The unscheduled maintenance crew requires 1.75 trips per year @ $100K per unscheduled maintenance.

4.4 Summary

The LCCM provides a means of estimating the LCC of a SAS. LCC can be determined as various technology parameters of the baseline are varied during Task III. Specific technology parameters versus LCC were quantified based on the Mission scenario described in paragraph 2.1.

These were:

- Solar cell thickness/LCC
- Cover thickness/LCC
- Cell efficiency/LCC
- Cell degradation/LCC
- Cover degradation/LCC
- Cell and cover assembly costs/LCC
- Temperature (blanket assembly)/LCC
- Voltage (line)/LCC

In addition to the technology parameters listed above, two maintenance-related parameters versus LCC were quanitified.

These were:

- Years between overhaul/LCC
- Mean time between failure/LCC

The O&M portion of the baseline mission scenario was altered in each case to accommodate the change in maintenance-related parameters. The specific changes in configuration and the resulting LCC's will be discussed in detail in Section 5.0.

5.0 SOLAR ARRAY PERFORMANCE AND COST MODEL

5.1 Basic Concept

The Solar Array Performance and Cost Model (SAPCM) was developed to a level of detail required to support the cost/technology analyses of Task III. The modeling approach, generally, was to

- define the solar cell, cover, substrate and cell interconnect circuitry (module cross section)
- determine the value of the solar array factors which affect performance and apply to the BOL cell/cover assembly to determine the EOL per cell array performance.
- determine number of cell/cover assemblies required for baseline orbit and load power/energy requirements
- determine total array area, dimensions and structural requirements (Array Configuration)
- determine array weight breakdown and totals
- determine life cycle cost.

5.2 Description of Model

A block diagram of the SAPCM is shown in Exhibit 5-1. A discussion of the various blocks or functions is contained in the following paragraphs. To facilitate discussion of the block diagram, the baseline SAS is used as an example of exercising the model.

5.2.1 Solar Array Performance Parameters

The heart of the SAPCM consists of various solar cell performance parameters which are used to determine the equivalent End-of-Life (EOL) per cell performance. The individual factors which are depicted in Exhibit 5-2 are as follows:

- Cover Factors ($F_C = F_G + F_T$)
  1. Glassing, F_G
  2. Cover Degradation, F_T

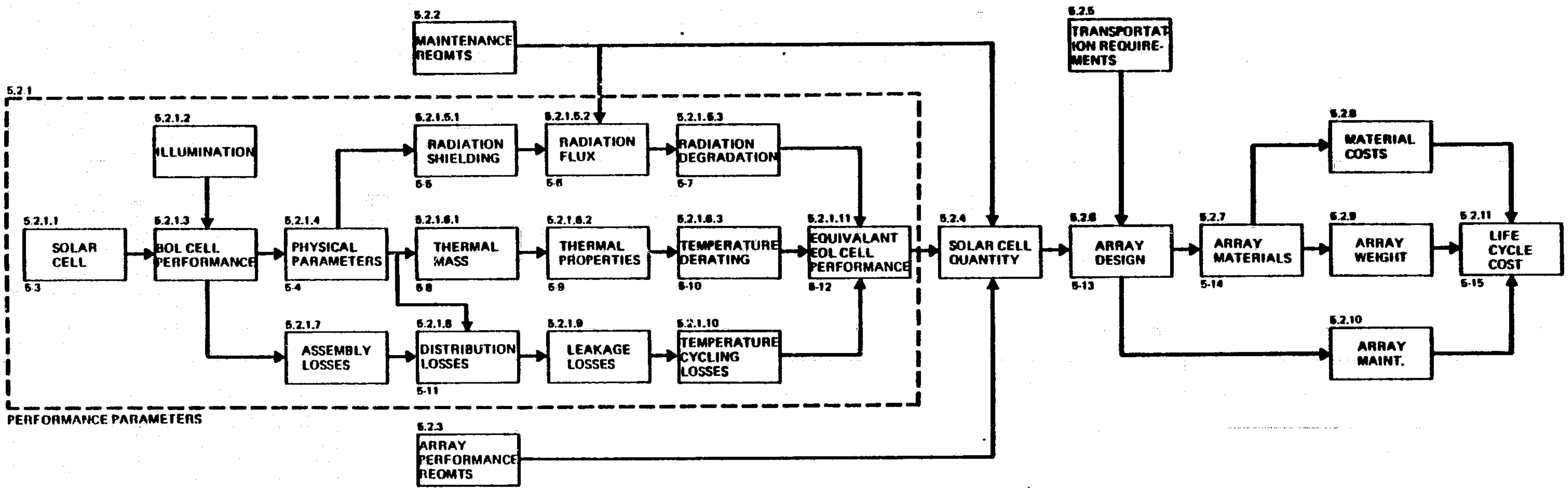


EXHIBIT 5-1. SOLAR ARRAY PERFORMANCE AND COST MODEL

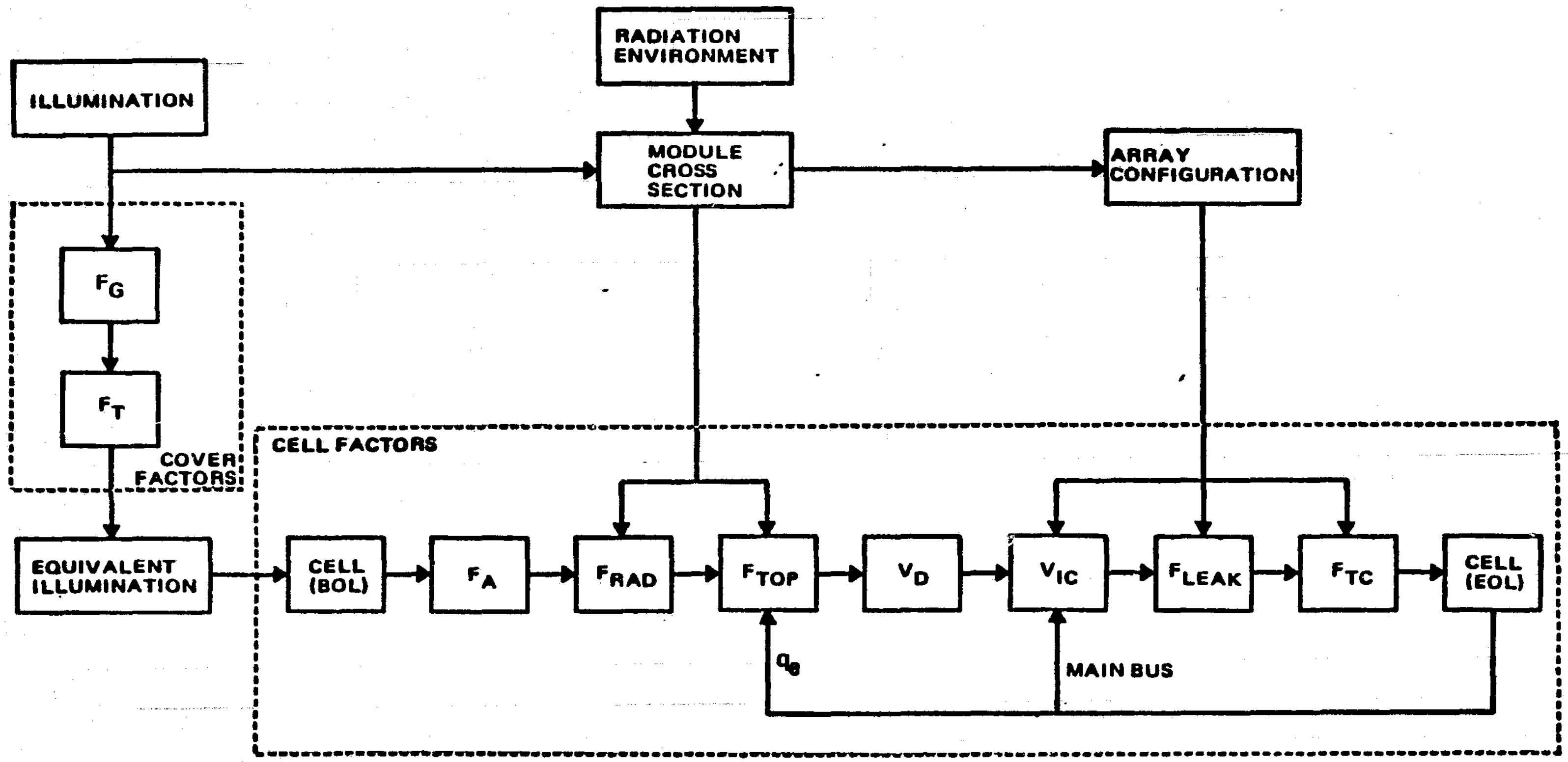


EXHIBIT 5-2. ARRAY PERFORMANCE PARAMETERS

- Cell Factors
  1. Assembly, F_A
  2. Cell Degradation, F_{RAD}
  3. Temperature Derating, $F_{\overline{TOP}}$
  4. Diode, V_D
  5. Solar Cell IC, V_{sc}
  6. Module/Module IC, V_{mm}
  7. Panel/Panel IC, V_{pp}
  8. Main Bus Conductors, V_{mb}
  9. Slip Ring Conductors, V_{sr}
  10. High Voltage Leakage Loss, F_{leak}
  11. Temperature Cycling, F_{tc}

(Items 5–8 are bracketed together as V_{IC}.)

The basic interrelationship of the various parameters can be expressed as follows:

$$\text{EOL } P_{mp}(W/m^2) = \left[(\eta_{BOL} \times \prod_{i=1}^{11} F_{p_i}) \times (S' \times \prod_{j=1}^{2} F_{p_j}) \times PF\right] \times A_s$$

Where P_{mp} = per cell max power

F_{p_i} = cell performance factors

F_{p_j} = cover performance factors

S' = effective illumination

η_{BOL} = cell BOL efficiency

PF = per cell packing factor

A_s = per cell array area

As can be seen in Exhibit 5-2, feedback loops which affect the array average temperature and the main bus configuration lead to iterations in order to arrive at the final result. The above relationship is used to determine the average minimum power of the array at EOL for a unit area of 1 m^2, which is further scaled down on a per-cell module cross-section basis. The equivalent EOL per-cell power is then used to size the array and thus determine the array configuration. The per cell voltage is similarly calculated and used for sizing.

The individual factors are discussed in subsequent paragraphs; however, for comparison with Exhibit 5-1, cell factors are further categorized as follows:

- Radiation Degradation
- Temperature Derating
- Array Loss Factors
  - Assembly
  - Distribution (Diode, V_{IC})
  - Leakage
  - Temperature Cycling

5.2.1.1 <u>Module Assembly Cross Section</u>

The module assembly is the solar array building block. For the SAS baseline, the module assembly cross section (Exhibit 5-3) consists of the following:

- <u>Solar Cell</u>

  0.022 x 4.000 cm, wraparound contact, 8 mil silicon, 2 ohm-cm AMO base resistivity, 12.2% unglassed efficiency, 28°C ambient, Ta_2O_5 anti-reflective coating

- <u>Cell Cover</u>

  2.022 x 4.000 cm, 6 mil fused silica, uv filter, 300 μm filter cut-on

- <u>Cover Adhesive</u>

  2 mil DC-93-500

- <u>Substrate</u>

  Laminated printed circuit, 33% area, 1 mil copper rolled annealed interconnect. Insulation is two sheets of 0.5 mil kapton/0.5 mil high-temperature polyester adhesive.

5.2.1.2 <u>Array Illumination</u>

An illumination summary for the SAS baseline is shown below. The orbit maximums and minimums call for minimum and maximum distances from the sun

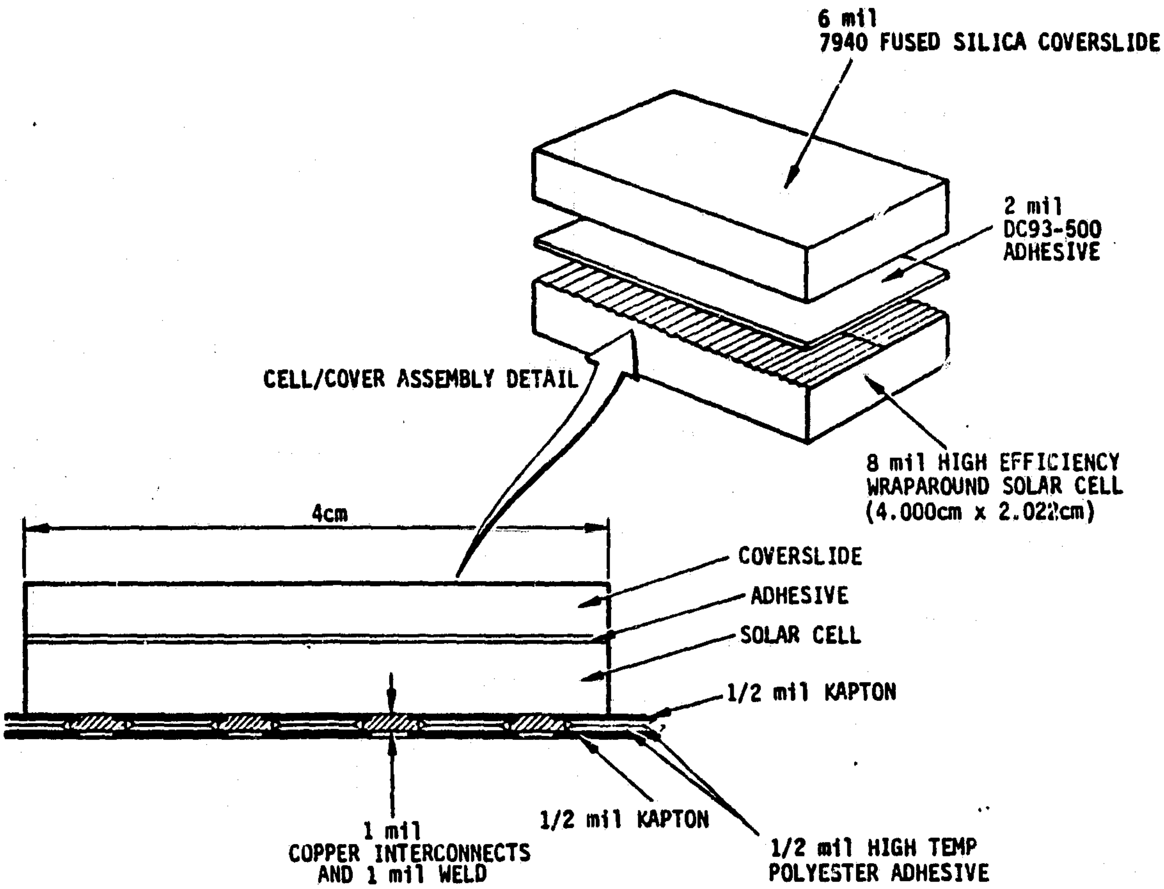


EXHIBIT 5-3. MODULE CROSS SECTION

respectively. The maximum albedo contribution is 36% of the solar illumination. The values for total orbit averages were obtained by averaging the calculated values of solar illumination plus albedo for each minute of illumination in orbit. The baseline total effective averages include the effects of cover glassing and cover degradation.

ILLUMINATION	MAX	AVG	MIN
Solar	1399	1353	1309
Albedo (36%)	504	487	471
Total Orbit Avg.	1478	1430	1383
Cover Glassing Factor	1.017	1.017	1.017
Cover Degradation Factor	.870	.870	.870
Baseline Total Effective Avg.	1308	1265	1224

5.2.1.2.1 Cover Glassing

The cover glassing factor is a measure of the optical impedance matching between the cell cover and the solar cell. Not only does the cover glass material and cover adhesive determine this factor, but also the antireflective coating applied to the solar cell itself. For the SAS baseline, the cover glassing factor is 1.017.

5.2.1.2.2 Cover Degradation

The cover degradation factor is a measure of how the transmissibility of the cover (and cover adhesive) degrades over the lifetime of the array. This effect is caused by a cumulation of the following effects:

- ultraviolet radiation dose
- particulate radiation dose
- micrometeorites

For the SAS baseline, the cover degradation factor is .870.

5.2.1.3 BOL Cell Performance

The assumed BOL Cell Performance for the SAS Baseline is 12.2% unglassed efficiency and V_{mp} = .479V. (S' = 1353 w/m^2 @ 28^oC).

5.2.1.4 Physical Parameters

This function consists of calculating the parameters indicated in Exhibit 5-4. These parameters are also used as inputs to radiation shielding, thermal mass, main bus calculations as described in subsequent paragraphs. The SAS baseline parameters are summarized in Exhibit 5-4.

5.2.1.5 Radiation Environment

The radiation degradation factor is a measure of the degradation in solar cell output due to high-energy charged particles, e.g., electrons and protons in the orbital environment. The degradation involved is a cumulative effect measured over the lifetime of the array in orbit. The amount of degradation is determined by the number of particles which have sufficient energy to penetrate the solar cell and cause permanent damage. Hence, the primary function of the solar cell cover is to reduce the quantity of particles which penetrate the solar cell. The substrate materials also assist in reducing radiation degradation. The methodology for determining this factor is summarized in the next three paragraphs.

5.2.1.5.1 Radiation Shielding

First, the effective radiation shielding provided by the various solar array module materials is determined. The results of this analysis for the baseline module are summarized in Exhibit 5-5. The analysis was accomplished by converting all materials to equivalent fused silica density shielding.

5.2.1.5.2 Radiation Flux

Next, the protection provided by the radiation shielding is determined. To accomplish this, Exhibit 5-6 was used to determine the equivalent fluence summary for 444 KM, 56^o inclination. This table is based upon historical data for different thickness of fused silica in a radiation environment similar to that anticipated for the baseline solar array described herein. The output of this table is the cumulative fluence of charged particles which will have sufficient energy to cause degradation of the solar cell over the array lifetime. For the SAS baseline,

C - 2

Cell Area = L x W = Ac = 4.000 cm x 2.022 cm = 8.088 cm^2

Substrate Area = $(L + d_L) \times (W + d_W)$ = As = 4.000 cm + 0.130 cm x 2.022 cm x 0.130 cm = 8.888 cm^2
(per cell)

Packing Factor = Ac ÷ As = PF = 8.088 cm^2 ÷ 8.888 cm^2 = .910

Cell/Cover Assembly	T (mil)	D (kg/m^3)	M (kg/m^2)	A (cm^2)	W (g)
Cover	6	2200	.3353	8.088	.2712
Adhesive	2	1080	.0549	8.088	.0444
Cell	8	2600	.5283	8.088	.4273
TOTALS	16	2260	.9185	8.088	.7429

Substrate Assembly	T (mil)	D (kg/m^3)	M (kg/m^2)	A (cm^2)	W (g)
Kapton	.5	1400	.0178	8.888	.0158
Adhesive	.5	1420	.0180	8.888	.0160
Copper	1	8890 + 3	.0753	8.888	.0669
Adhesive	.5	1420	.0180	8.888	.0160
Kapton	.5	1400	.0178	8.888	.0158
TOTALS	3	1927	.1468	8.888	.1305

Module Assembly	T (mil)	D (kg/m^3)	M (kg/m^2)	A (cm^2)	W (g)
Cell/Cover Assembly	16	2057	(1) .8358	(1) 8.888	.7429
Substrate Assembly	3	1927	.1468	8.888	.1305
TOTALS	19	(1) 2036	(1) .9827	8.888	.8734

(1) Includes packing factor (PF)

EXHIBIT 5-4. PHYSICAL PARAMETERS

FRONT

MATERIAL	MATERIAL THICKNESS (mil)	MATERIAL DENSITY (Kg/m^3)	EQUIVALENT THICKNESS (mil)
Cover	6	2200	6.00
Adhesive	2	1080	.98
TOTALS	8	1920	6.98

BACK

MATERIAL	MATERIAL THICKNESS (mil)	MATERIAL DENSITY (Kg/m^3)	EQUIVALENT THICKNESS (mil)
Cell	8	2600 x .375	3.55
Kapton	.5	1400	.32
Adhesive	.5	1420	.32
Copper	1	8890 ÷ 3	1.35
Adhesive	.5	1420	.32
Kapton	.5	1400	.32
TOTALS	11	1236	6.18

EXHIBIT 5-5. RADIATION SHIELDING

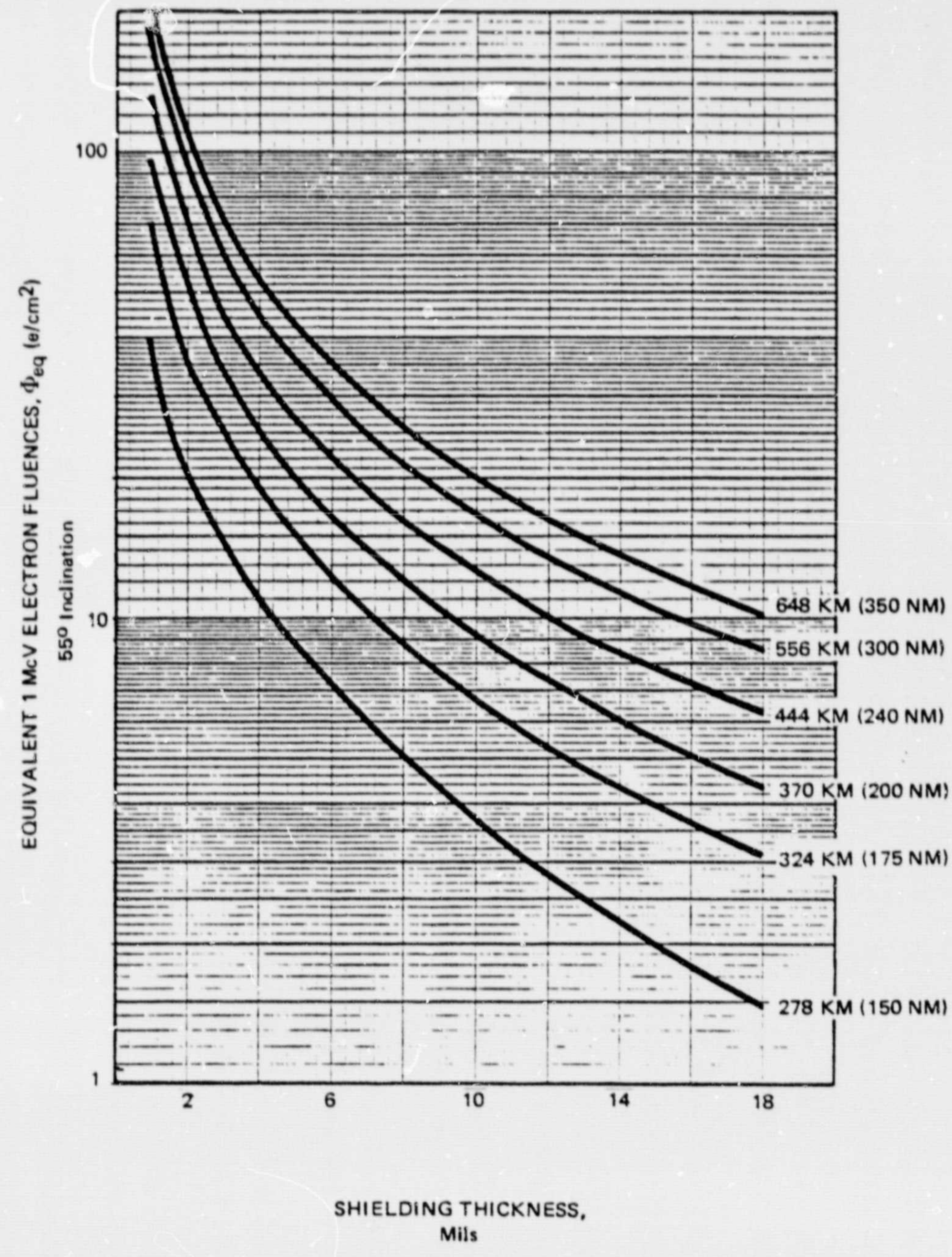


EXHIBIT 5-6. RADIATION FLUX

the total flux for a 10-year period, was 40.89×10^{13}. This consisted of 19.01×10^{13} for the front shielding and 21.88×10^{13} for the back shielding respectively.

5.2.1.5.3 Radiation Degradation

Finally, the predicted solar cell degradation caused by particles with sufficient energy to penetrate the radiation shielding and cause solar cell damage is determined. To accomplish this, the data in Exhibit 5-7 is used. Based upon the equivalent fluence, a predicted degradation is determined. For the SAS baseline, the power degradation factor is .854 for an array life of 10 years, while the voltage factor is .968.

5.2.1.6 Array Temperature

The temperature derating factor is a measure of the effect of the operating temperature upon cell performance. The methodology for determing this factor is summarized in the next three paragraphs.

5.2.1.6.1 Thermal Mass

This function consists of calculating the parameters indicated in Exhibit 5-8. Thermal mass is in turn used as a parameter in the temperature calculations described in paragraph 5.2.1.6.3. The thermal mass for the SAS baseline is also plotted as a function of temperature in Exhibit 5-8.

5.2.1.6.2 Thermal Properties

This function consists of calculating the parameters indicated in Exhibit 5-9. These properties are in turn used in the temperature calculations described in the subsequent paragraph. The thermal properties for the SAS baseline are summarized in Exhibit 5-9.

5.2.1.6.3 Temperature Derating

The most complex function of the SAPCM is determining the cell temperature derating factor. Using the array thermal mass profile and the thermal properties discussed in the preceding paragraphs, this factor is calculated using the following procedure:

- Determine array temperature vs time profile during period of minimum solar illumination (including effects of albedo, earth radiation, and heat from the space platform).

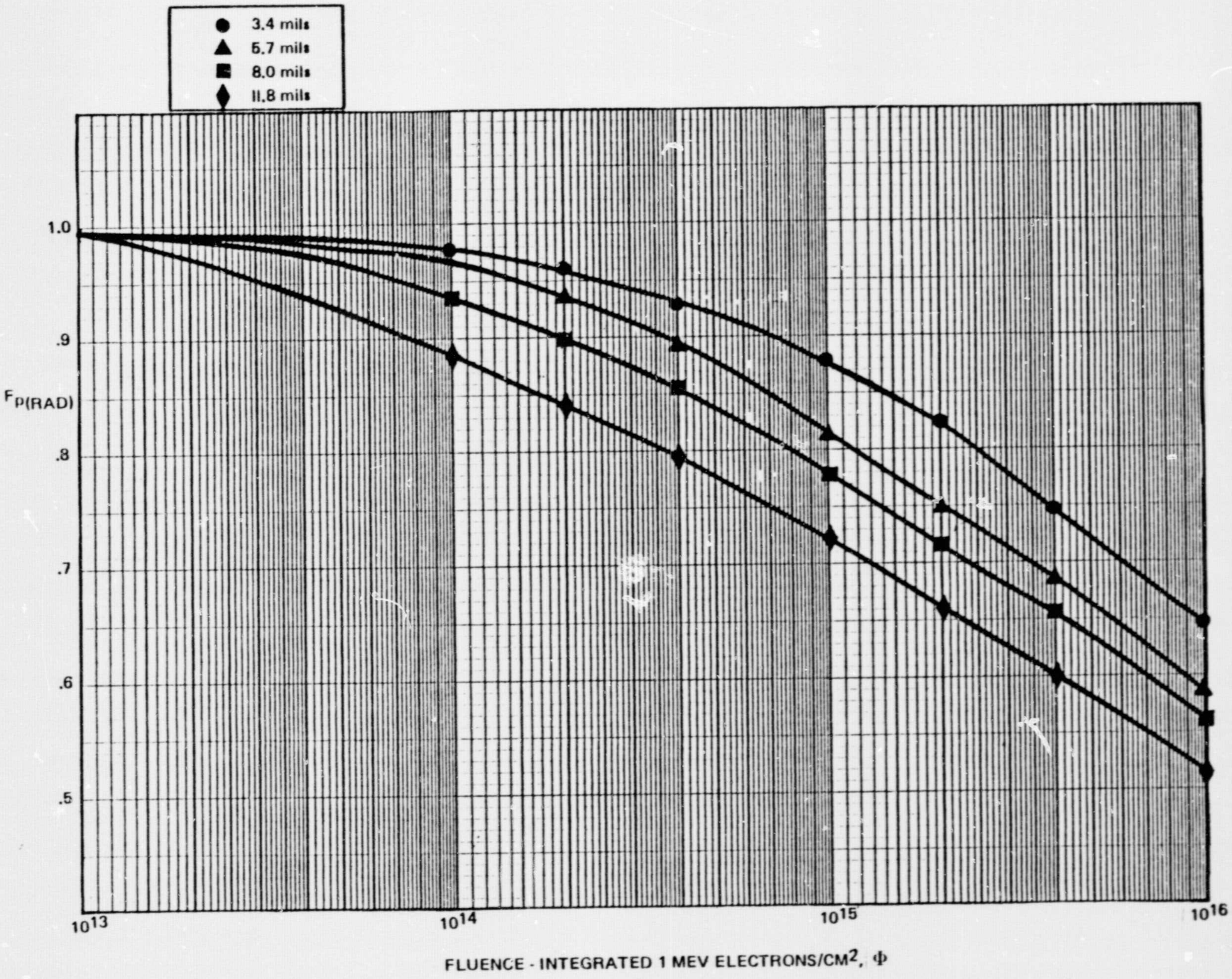


EXHIBIT 5-7. RADIATION DEGRADATION (POWER)

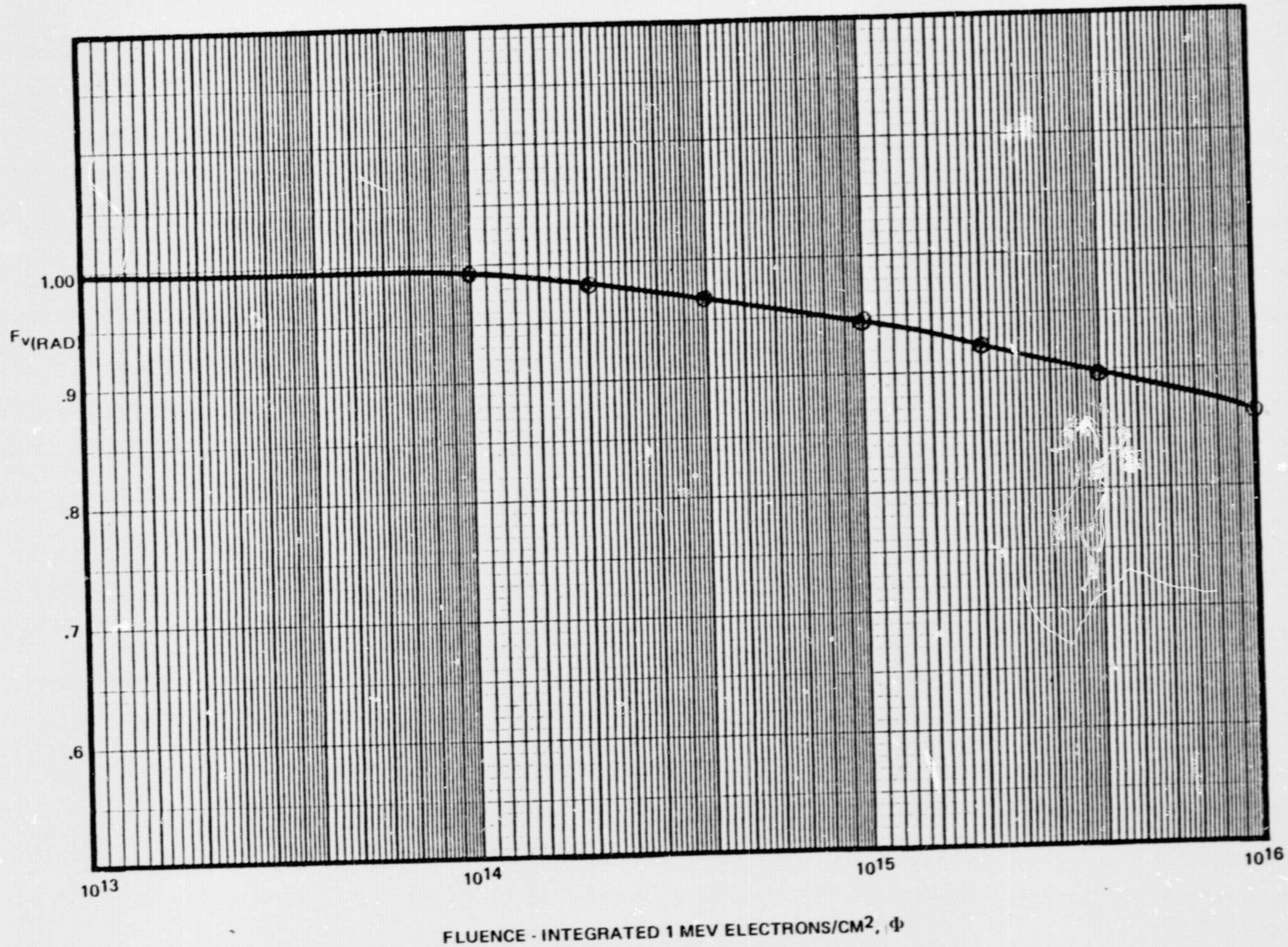


EXHIBIT 5-7. RADIATION DEGRADATION (VOLTAGE) (Continued)

SOLAR ARRAY

THERMAL MASS

BASELINE	ARRAY	-100°C		-75°C		-50°C		-25°C		-0°C		25°C		50°C		75°C		100°C	
MATERIAL	MASS	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp	Cp	mCp
Cover	[1].3051	475	145	510	156	575	175	625	191	675	206	720	220	765	233	800	244	850	259
Adhesive	[1].0500	660	33	725	36	795	40	865	43	910	46	945	47	985	49	1000	50	1015	51
Cell	[1].4808	500	240	560	269	615	296	650	313	700	337	720	346	725	349	735	353	750	361
Kapton	.0178	725	13	800	14	875	16	950	17	1000	18	1040	19	1085	19	1100	20	1115	20
Adhesive	.0180	725	13	800	14	875	16	950	17	1000	18	1040	19	1085	20	1100	20	1115	20
Copper	.0753	315	24	320	24	330	25	335	25	350	26	380	29	415	31	440	33	495	37
Adhesive	.0180	725	13	800	14	875	16	950	17	1000	18	1040	19	1085	20	1100	20	1115	20
Kapton	.0178	725	13	800	14	875	16	950	17	1000	18	1040	19	1085	19	1100	20	1115	20
TOTALS			494		541		600		640		687		718		740		760		788

[1] Includes PF = .91

EXHIBIT 5-8

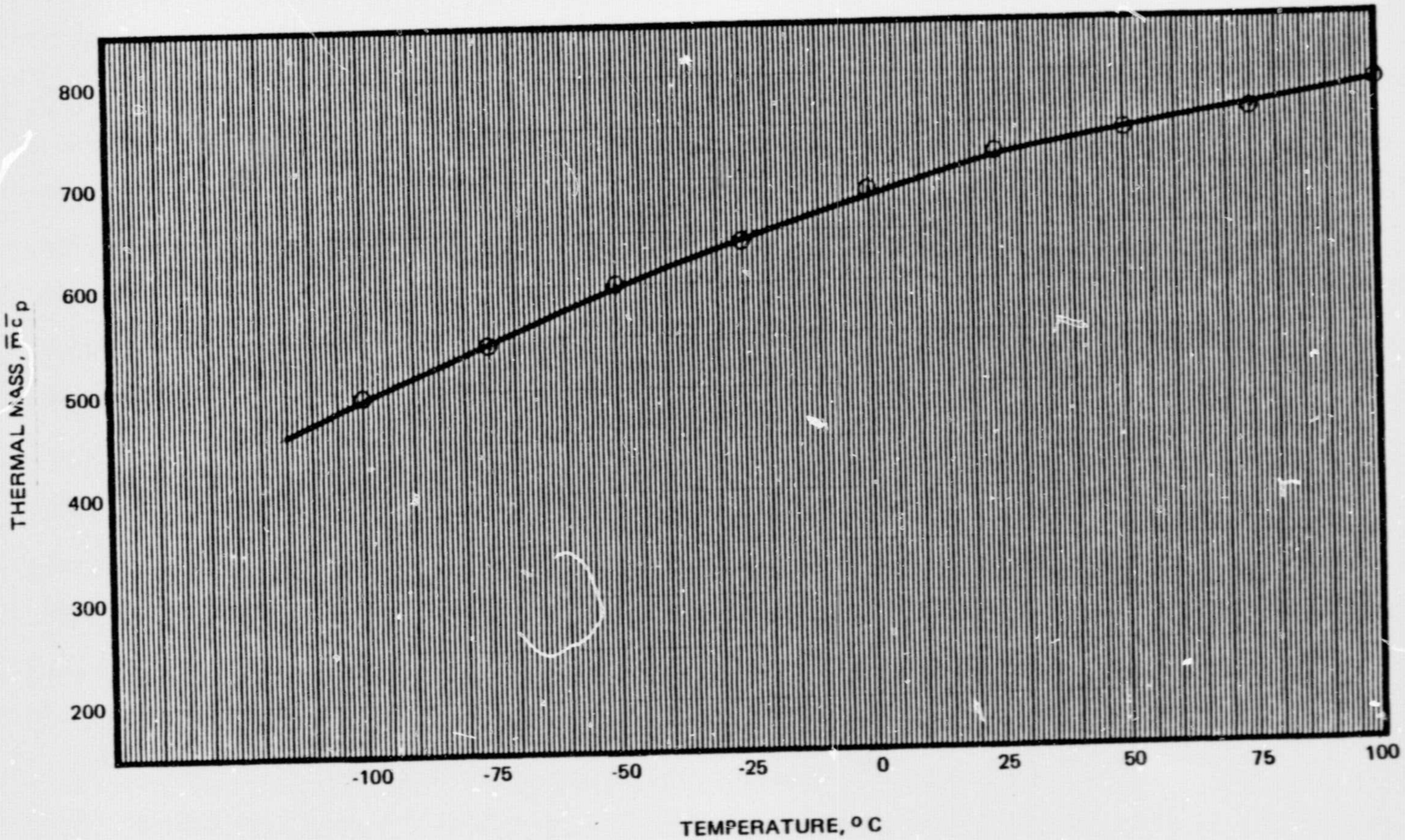


EXHIBIT 5-8. SOLAR ARRAY THERMAL MASS (Continued)

$\bar{\alpha}_F = \alpha_{cover} \times PF + \alpha_{substrate} \times (1-PF) = .780 \times .910 + .450 \times .090 = .750$

$q_E = F_P \times EOL \text{ loss factor} \times \eta_{BOL} = .910 \times .45 \times .122 = .050$

$\alpha_B = .450 \quad \bar{\alpha}_{SF} = \bar{\alpha}_F - q_E = .750 - .050 = .700$

$\bar{\epsilon}_F = \epsilon_{cover} \times F_P + \epsilon_{substrate} \times 1-F_P = .820 \times .910 + .800 \times .090 = .818$

$\epsilon_B = \epsilon_{substrate} \times \text{adj factor} = \epsilon_B \quad .800 \times .75 = .600$

EXHIBIT 5-9. THERMAL PROPERTIES

$$q_{AL}(F) = \bar{\alpha}_{SF} \times .36 \times S' \times \cos \Gamma_2 \qquad \text{(Albedo)}$$

$$q_{AL}(B) = \alpha_B \times .36 \times S' \times \cos \Gamma_2 = .450 \times .36 \times S^1 \times \cos \Gamma_2$$

$$q_{ER}(F) = \bar{\alpha}_F \times 208.2 \times \cos \Gamma_3 = .750 \times 208.2 \times \cos \Gamma_3 = 156.2 \times \cos \Gamma_3$$

$$q_{ER}(B) = \alpha_B \times 208.2 \times \cos \Gamma_3 = .450 \times 208.2 \times \cos \Gamma_3 = 93.7 \times \cos \Gamma_3$$

$$q_{SP} = \varepsilon_B \times (\;_{SP} \times \cos \Gamma_4 \times \cos \Gamma_4) \times (\sigma) \times (^{\circ}4) = .600 \times (.050 \times .7071 \times .7071) \times (5.6697 \times 10^{-8}) \times (50 \_ 273)^4 = 9.3$$

$$\varepsilon_\sigma = (\varepsilon_F + \varepsilon_B) \times (1 + \alpha_{SP} \times \cos \Gamma_4 \times \cos \Gamma_4) \times (\sigma) = (.818 + .600) \times (1 + .050 \times .7071 \times .7071) \times (5.6697 \times 10^{-8}) = 8.24 \times 10^{-8}$$

EXHIBIT 5-9. THERMAL PROPERTIES (CONTINUED)

- Determine average array temperature during same period.
- Determine array illumination vs time profile during period of minimum solar illumination (including albedo = 36%).
- Determine average illumination during same period.
- Determine effect of cell cover glassing and degradation factors upon effective illumination "seen" by solar cell.
- Determine power derating factor by extrapolating the data summarized in Exhibit 5-10, using the average temperature and effective illumination determined above.
- Repeat same procedure for voltage derating factor for period of maximum solar illumination, using average temperature only.

(See Appendix C for the effect of various parameters upon average temperature during a period of average solar illumination).

5.2.1.7 Assembly Factor

The assembly factor is a measure of the reduction in solar cell output due to design and assembly processes. Based on a manufacturing estimate for the SAS baseline, this factor is assumed to be .965 for power and 1.000 for voltage.

5.2.1.8 Distribution Loss Factors

Distribution losses include voltage drops and power losses due to blocking diodes, various electrical interconnects on the array, the main bus conductor, and the slip ring assembly. These factors are discussed in the following paragraphs.

5.2.1.8.1 Blocking Diodes

This factor is a measure of the voltage drop and power loss due to blocking diodes (3 in parallel for each array panel). For the SAS baseline, this factor is assumed to be .993 for both power and voltage.

5.2.1.8.2 Solar Cell Interconnects

This factor is a measure of the voltage drop and power loss due to solar cell interconnects. For the SAS baseline, this factor is assumed to be .999 for both power and voltage.

5.2.1.8.3 Module-To-Module Interconnects

This factor is a measure of the voltage drop and power loss due to module-to-

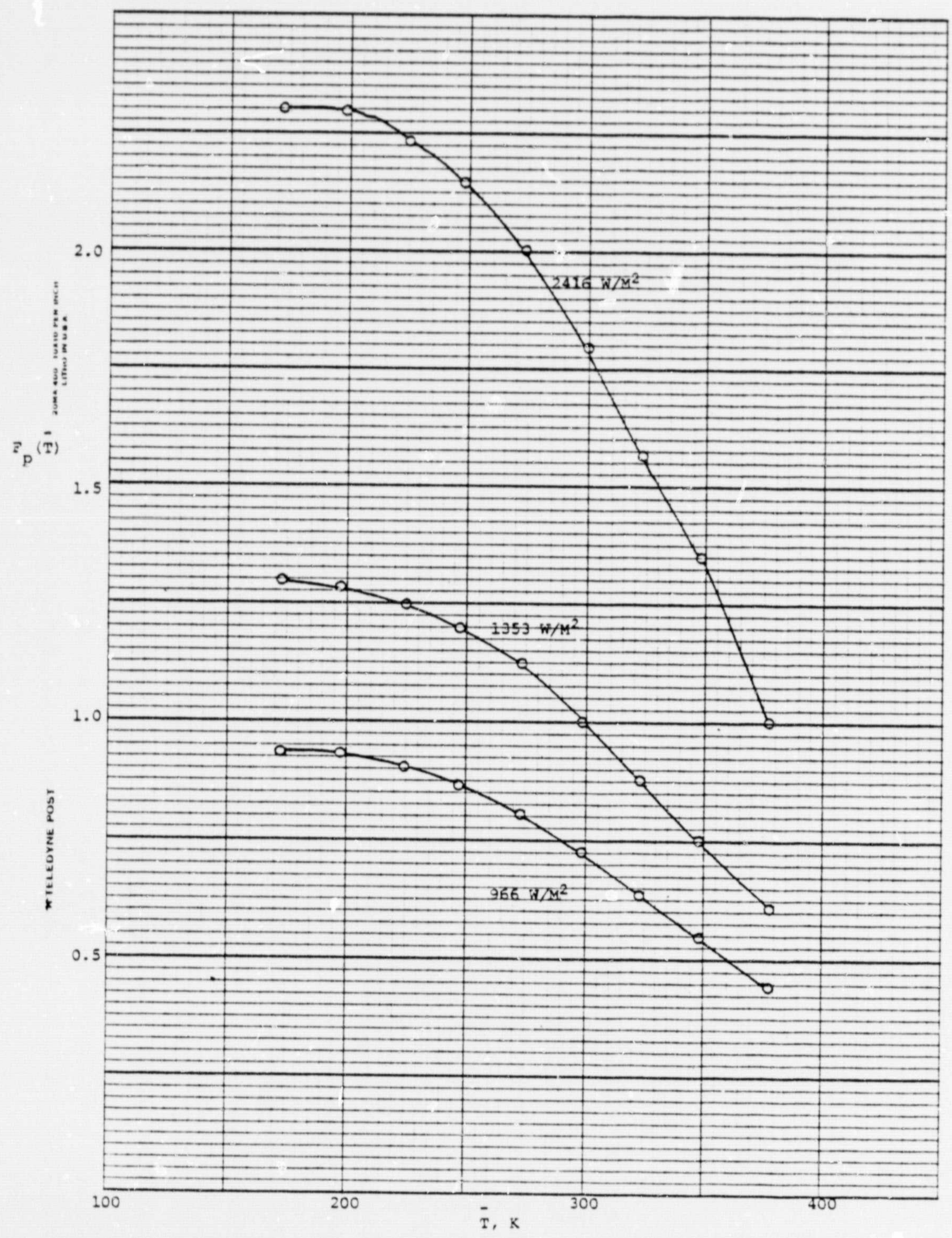


EXHIBIT 5-10. TEMPERATURE DERATING

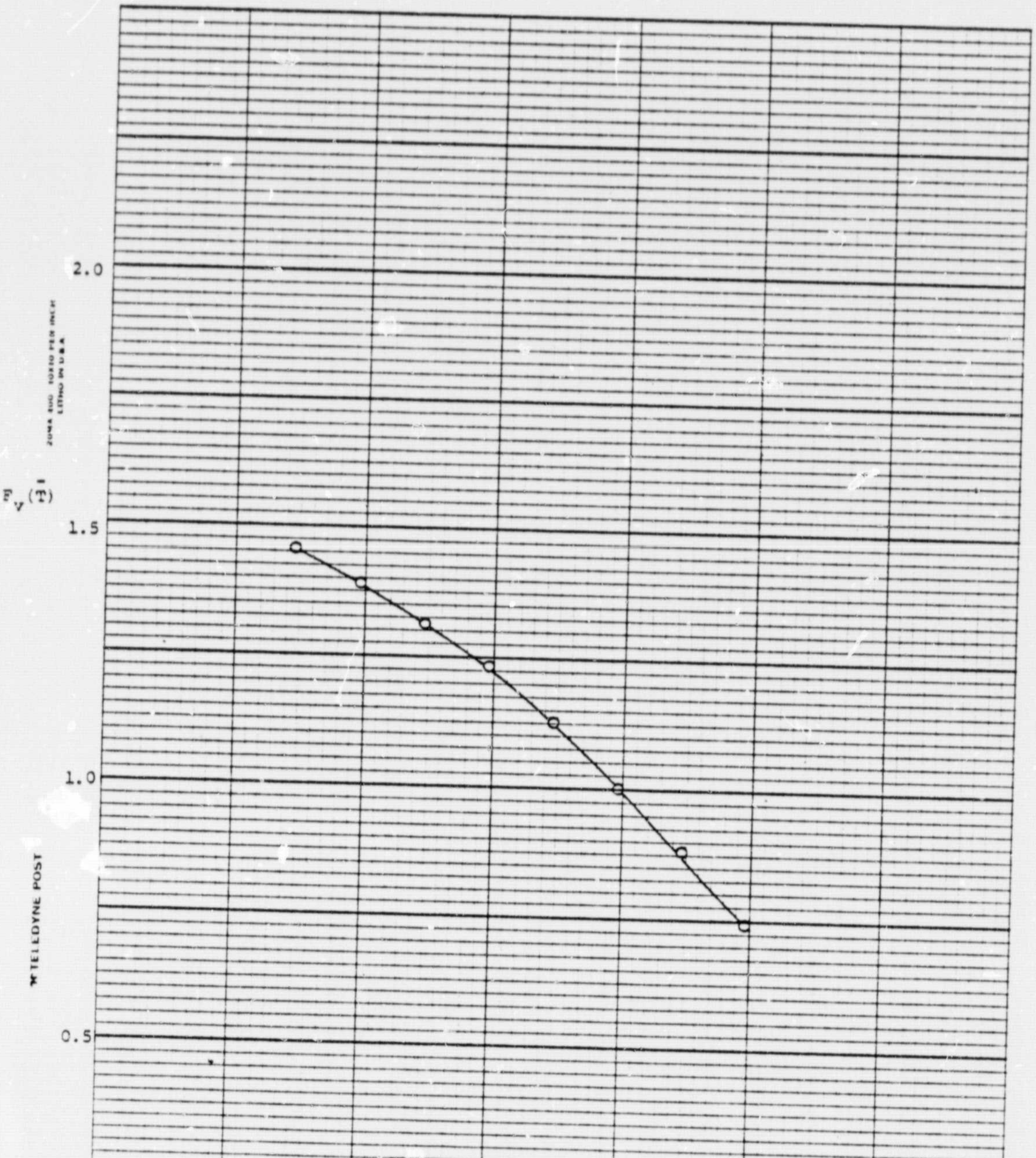


EXHIBIT 5-10. TEMPERATURE DERATING (CONTINUED)

module electrical interconnects. For the SAS baseline, this factor is assumed to be .999 for both power and voltage.

5.2.1.8.4 Panel-To-Panel Interconnects

This factor is a measure of the voltage drop and power loss due to panel-to-panel electrical interconnects. For the SAS baseline, this factor is assumed to be .999 for both power and voltage.

5.2.1.8.5 Main Bus Conductor

This factor is a measure of the voltage drop and power loss due to the main bus conductor. The methodology for determing this factor is as follows:

- Determine sizes of conductors (optimized weight and volume).
- Determine conductor resistance @ $55^{\circ}C$ (L/A = constant).
- Determine voltage drop and power loss.
- Determine percentage of total output.

For the SAS baseline, the electrical distribution system for each blanket is as shown in Exhibit 5-11. For an electrical configuration of 12 channels/blanket, there will be a total of 12 pairs of conductors/blanket. The conductor material is 37/36 aluminum/copper alloy.

The Length/Area ratios for the bus conductors are the same throughout the array and have been optimized for each blanket using the following parametric relationship (LSMC-D384250):

$$\frac{L}{A} = \sqrt{\frac{P_D \times C_D \times \Sigma L^2}{N \times I^2 \times \rho}}$$

where P_D = power density of module cross section

C_D = conductor density

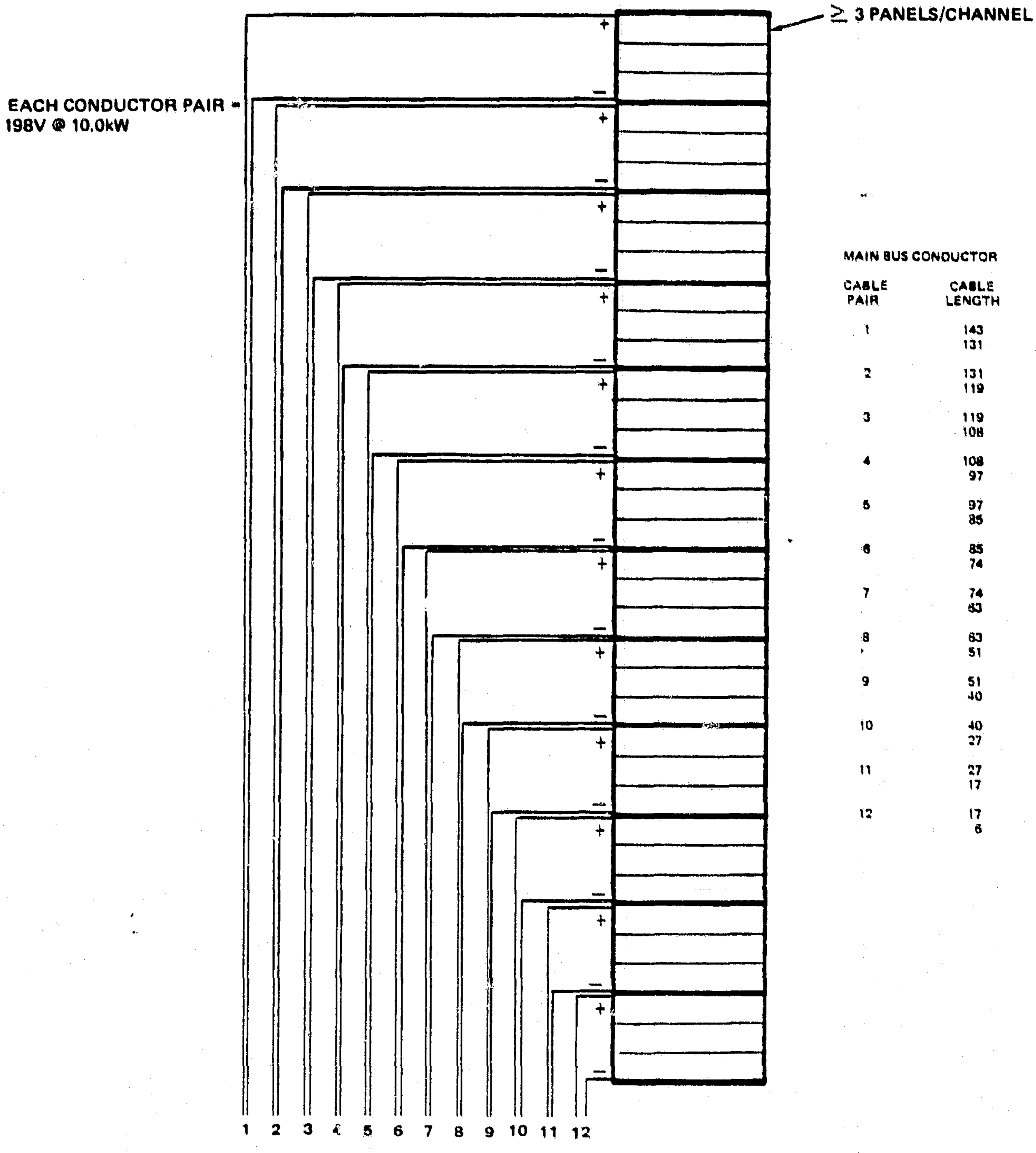
ΣL^2 = sum of conductor lengths

N = number of conductors

I = current

ρ = conductor resitivity

From the resultant L/A ratio, each conductor was sized using a constant cable thickness of .060 in = .15 cm. For insulation, 1 mil kapton + 1 mil high temperature polyester adhesive was used. The total weight of the insulation and adhesive is



MAIN BUS CONDUCTOR

CABLE PAIR	CABLE LENGTH
1	143 131
2	131 119
3	119 108
4	108 97
5	97 85
6	85 74
7	74 63
8	63 51
9	51 40
10	40 27
11	27 17
12	17 6

EXHIBIT 5-11. BLANKET POWER DISTRIBUTION

assumed to be 2.5% of the total conductor weight. For the SAS baseline, the main bus factor is calculated to be .961 for power and .957 for voltage.

5.2.1.8.6 Slip Ring Assembly

This factor is a measure of the voltage drop and power loss due to the slip ring assembly. For the SAS baseline, this factor is assumed to be .988 for both power and voltage.

5.2.1.9 High Voltage Leakage

This factor is a measure of the voltage drop and power loss due to High Voltage leakage currents in a plasma radiation environment. For the SAS baseline, this factor is assumed to be 1.000 for both power and voltage.

5.2.1.10 Temperature Cycling

This factor is a measure of the voltage drop and power loss due to temperature cycling failures. For the SAS baseline, this factor is assumed to be .800 for power and 1.000 for voltage.

5.2.1.11 Equivalent EOL Per-Cell Performance

The equivalent EOL per-cell performance is determined by applying the solar array performance factors to the BOL cell/cover assembly. For the SAS baseline, the cell performance factors are summarized in Exhibit 5-12. This results in an equivalent EOL per-cell performance of .053 watts and .33 volts.

5.2.2 Maintenance Requirements

The maintenance requirements include the array life and also the paralleling of various electrical components to assure design reliability. For the SAS baseline, this results in the following:

- 10-year array life (greater cell and cover degradation factors and temperature cycling losses)
- minimum of 3 cells in parallel
- two sets of interconnects/solar cell
- minimum of 3 blocking diodes in parallel/panel.

CELL PERFORMANCE FACTORS

i	FACTOR	Fv	Fp
1	ASSEMBLY, F_a	1.000	.965
2	RADIATION, F_{rad}	.968	.854
3	TEMPERATURE, F_{top}	.759	.717
4	DIODE, V_d	.993	.993
5	SOLAR CELL IC, V_{sc}	.999	.999
6	MODULE/MODULE IC, V_{mm}	.999	.999
7	PANEL/PANEL IC, V_{pp}	.999	.999
8	MAIN BUS CONDUCTORS, V_{mb}	.957	.961
9	SLIP RING CONDUCTORS, V_{sr}	.988	.988
10	HIGH VOLTAGE LEAKAGE, F_{leak}	1.000	1.000
11	TEMPERATURE CYCLING, F_{tc}	1.000	.800
	TOTALS($\prod_{i=1}^{11}$)	.688	.444

EXHIBIT 5-12

5.2.3 Array Performance Requirements

The array performance requirements determine the number of solar cells required, which in turn determine the size and panel/channel configuration of the array. For the SAS baseline, these requirements are:

- 480 kW Total EOL Power
- 10 kW/channel (48 channels)
- 180 V minimum/channel.

5.2.4 Solar Cell Quantity

The quantity of solar cells is determined by the interaction of the solar array performance requirements and the EOL equivalent per-cell performance. For the SAS baseline, 9,072,000 cells are required to meet the 480 kW array total power requirements EOL.

5.2.5 Transportation Requirements

The transportation requirements influence the array design in two ways:

- Fold-Up Array to fit in Shuttle (fold between panels)
- Size of Panel limited by size of shuttle bay.

For the SAS baseline, this resulted in a panel size of 2.81 m x 17.05 m.

5.2.6 Array Design

The basic array design is a fold-up blanket which fits in the shuttle bay. The resultant building block concept is depicted in Exhibit 5-13. The sizes and quantities of modules, panels, and blankets for the SAS baseline are also summarized in Exhibit 5-13.

5.2.7 Array Materials

Variations in the quantities of the various array materials very significantly affect the life cycle cost for a solar array, particularly one as large as 480 kW EOL (953 kW BOL). The array inputs to the life cycle cost model are summarized in Exhibit 5-14. The SAS baseline input values are also summarized in Exhibit 5-14.

5.2.8 Material Costs

Variations in the per unit material costs also significantly effect the array LCC. The costs of materials for the SAS baseline are also summarized in Exhibit 5-14.

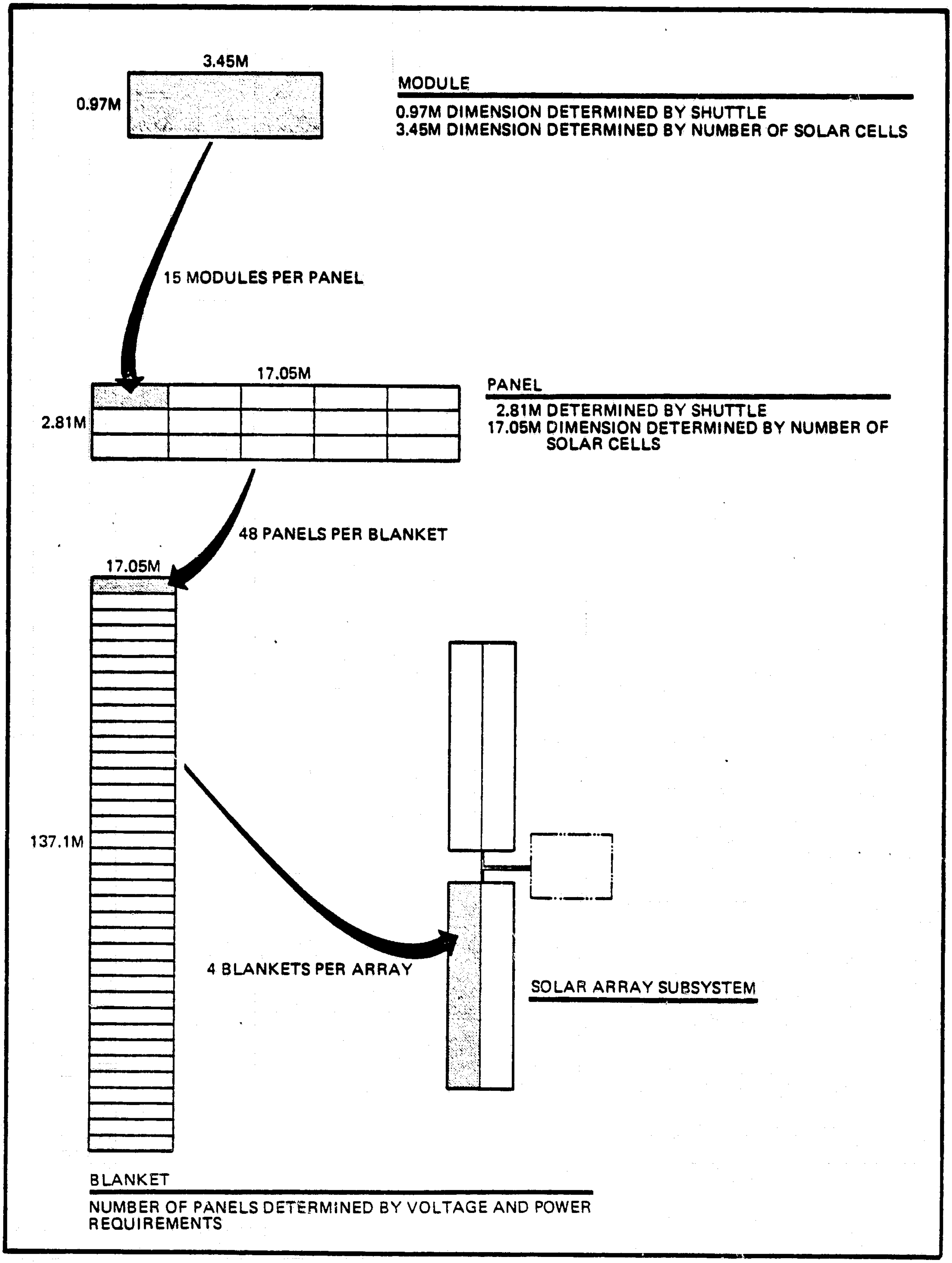


EXHIBIT 5-13. ARRAY DESIGN

BASELINE INPUTS TO LCCM

(1980 $ In Millions)

• Cost of Labor	
ON EARTH	$ 20/manhour
IN SPACE	250/manhour
• Cost of Materials	
Cell/Cover Assembly	7.75
Module Substrate	$142.29/M^2$
Module Assembly (welding materials)	740,000
Mechanical and Electrical Interconnects	10,260/panel
Mechanical and Electrical Interconnects	47,000/blanket
• No. of Cell/Cover Assemblies	9,072,000
• No. of modules	2,880
• No. of panels	192
• No. of blankets	4
• Blanket Weight (4)	11,940 kg.
• Structures Weight	7,778 kg.
• Main Bus Conductors (4)	656 kg.

EXHIBIT 5-14

5.2.9 Array Weight

The array weight determines the space transportation and space assembly/ checkout costs. For the SAS baseline, the total blanket weight is 11,940 Kg while the structure's weight is 7,778 Kg, and the weight of the main bus conductors is 656 kg

5.2.10 Array Maintenance

The array maintenance scenario affects the cost of the operations and maintenance phase of LCC, as well as the production phase costs. The primary cost contributions are number of spares required and number of maintenance trips and activities required. For the SAS baseline, 23 sparepanels (12% of total area) is required, and an average of 1.75 maintenance trips/year during the array life of 10 years.

5.2.11 Life Cycle Cost

The life cycle cost consists of three phases:

- DDT&E
- Production
- O&M

The total manufacturing cost during the production phase is basically a quantity related cost, while the NASA cost during the production phase is a weight driven cost. The Life Cycle Costs for the SAS baseline are summarized in Exhibit 5-15.

5.3 Summary

The SAPCM is a very versatile tool which can be used to derive various technology vs LCC relationships. Using assumed relationships, a basic model has been developed. In Section 6.0, the results of varying various parameters are discussed. It should also be noted, that the data bases indicated for radiation flux and radiation degradation, and for temperature derating can be changed, to analyze the effect of newly acquired data in these areas. In addition, the model can be further expanded to address other pertinent factors such as reliability, and other manufacturing and/or maintenance scenarios.

SAS BASELINE LIFE CYCLE COST

(1980 $ In Millions)

4.0	TOTAL LIFE CYCLE COST	754.5
4.1	DDT&E	153.9
4.2	TOTAL PRODUCTION PHASE COST:	439.9
4.2.1	Total Manufacturing Cost	376.1
4.2.1.1	Manufacturing Labor Cost	34.0
4.2.1.2	Manufacturing Non-Labor Cost	261.7
4.2.2	NASA Cost:	63.9
4.2.2.1	Shuttle Transportation	63.1
4.2.2.2	Space Assembly and Check-Out	.8
4.3	TOTAL O & M COST:	160.7
4.3.1	Total Contractor's Cost	.9
4.3.2	NASA Cost:	159.8
4.3.2.1	Train O & M Crew	2.5
4.3.2.2	Perform Maintenance	11.0
4.3.2.3	Transport Crew to LEO	146.3

EXHIBIT 5-15

6.0 TECHNOLOGY VS. LIFE CYCLE COST

6.1 General

This section summarizes the analysis and results of using the Solar Array Performance and Cost Model (SAPCM) described in Section 5.0 to quantify technology vs. LCC. Conclusions to be drawn from the study results are valid in the vicinity of the baseline under the assumptions, requirements and scenarios of the study and/or as generated previously in this report. Generally, these are:

- Silicon cells, planar array
- Orbit of 444 km, 56° inclination
- Shuttle transportation
- Earth manufacturing scenario
- Manual assembly in space (equipment assisted)
- Space-based maintenance includes personnel for routine maintenance
- DDT&E, program management and SE&I are "wraparound" cost factors
- $31M/14,000 kg space transportation costs
- Cell/cover assembly costs are historical, but adjusted to 70%, recognizing the large quantity required.

6.2 Methodology

The study results were achieved by addressing each technology area separately and varying key independent parameters in the SACPM to determine resultant variations in life cycle cost. The variations in various intermediate parameters were also observed. The basic methodology consisted of the following:

- Selection and variation of one independent parameter as primary input to the SACPM (e.g., cell thickness, temperature, MTBF, etc.).
- Application of resultant variations in other key parameters as secondary inputs to SACPM (e.g., effects on efficiency, cell degradation, unit material costs, etc.).
- Determination of variations in key intermediate SACPM parameters (e.g., EOL Pmp, quantity of cells, # of panels, etc.)
- Determination of variations in LCC
- Determination of the characteristic equation which quantifies the relationship between the key independent technology parameter and LCC.

It is also important to note that the performance/cost model and/or data base can be easily changed to reflect variations in the array requirements, scenarios and/or assumptions, in effect to perform optimization trade studies.

6.3 Technology Areas

During the course of the study, ten technology areas were addressed using the general methodology discussed above and are discussed in the following paragraphs. These technology areas are listed below.

- Cell Thickness (6.3.1)
- Cover Thickness (6.3.2)
- Average Blanket Temperature (6.3.3)
- Cell Efficiency (6.3.4)
- Cover Degradation (6.3.5)
- Cell Degradation (6.3.6)
- Line Voltage (6.3.7)
- Years Between Overhaul (6.3.8)
- MTBF (6.3.9)
- Cell Cover Assembly Costs (6.3.9)

6.3.1 Cell Thickness vs LCC

The relationships shown in Exhibits 6-1 through 6-3 are for three types of silicon cells: (1) conventional/historical, (2) back surface field and (3) back surface field plus thin diffused top region. The data for all three types of cells were derived from "Semi-Conductors and Semi-Metals" Volume II, Hovel, 1975, Academic Press. The relationships to determine the variations in cell efficiency vs cell thickness and unit cell cost vs. cell thickness and efficiency are indicated for each type of cell. It should be noted that the conventional cells resulted in 5 or more panels/channel, which made a significant contribution to LCC due to the resultant increase in structures weight (e.g., longer booms required). In contrast, the other two categories resulted in only 4 panels/channel except for the 12 mil-12% efficiency cell in category II. One other factor which strongly affects the results is the wide variations in radiation degradation due to variations in cell thickness. Given smaller variations, the effect on life cycle cost would be less pronounced. A composite graph of all three types of cells is shown in Exhibit 6-4.

t	n_{BOL}	F_p(Rad)	$\bar{T}$ max	$\bar{T}$ min	$F_p(\bar{T})$	P_{mp}	Ω	$/Cell	Ω $	W	W $	LCC
12	.110	.800	345.5	340.2	.717	.046	10.4544	3.51	419.728	36.989	110.370	876.282
10	.105	.828	346.0	340.6	.715	.045	10.6848	3.46	426.041	34.924	104.384	876.725
8	.099	.854	346.4	341.1	.713	.044	10.9152	3.40	432.398	33.206	99.369	878.535
6	.092	.878	347.0	341.7	.710	.041	11.7216	3.33	458.576	32.684	97.778	911.728
4	.083	.905	347.7	342.3	.708	.038	12.64896	3.24	502.403	44.380	129.732	1014.032

Cell Thickness = I

$$n_{BOL} = .0582\ t^{.256}, \quad 4 \leq t \leq 12$$

$$\$/Cell = 210.09\ n_{BOL}^{1.502}\ t^{-.313}$$

TABLE 6-1. LCC vs CELLTHICKNESS (CONVENTIONAL CELL)

ACTUAL

EQUATION	CORRELATION
$LCC = 999.305t^{-0.056}$	0.861
	STANDARD ERROR
	0.009

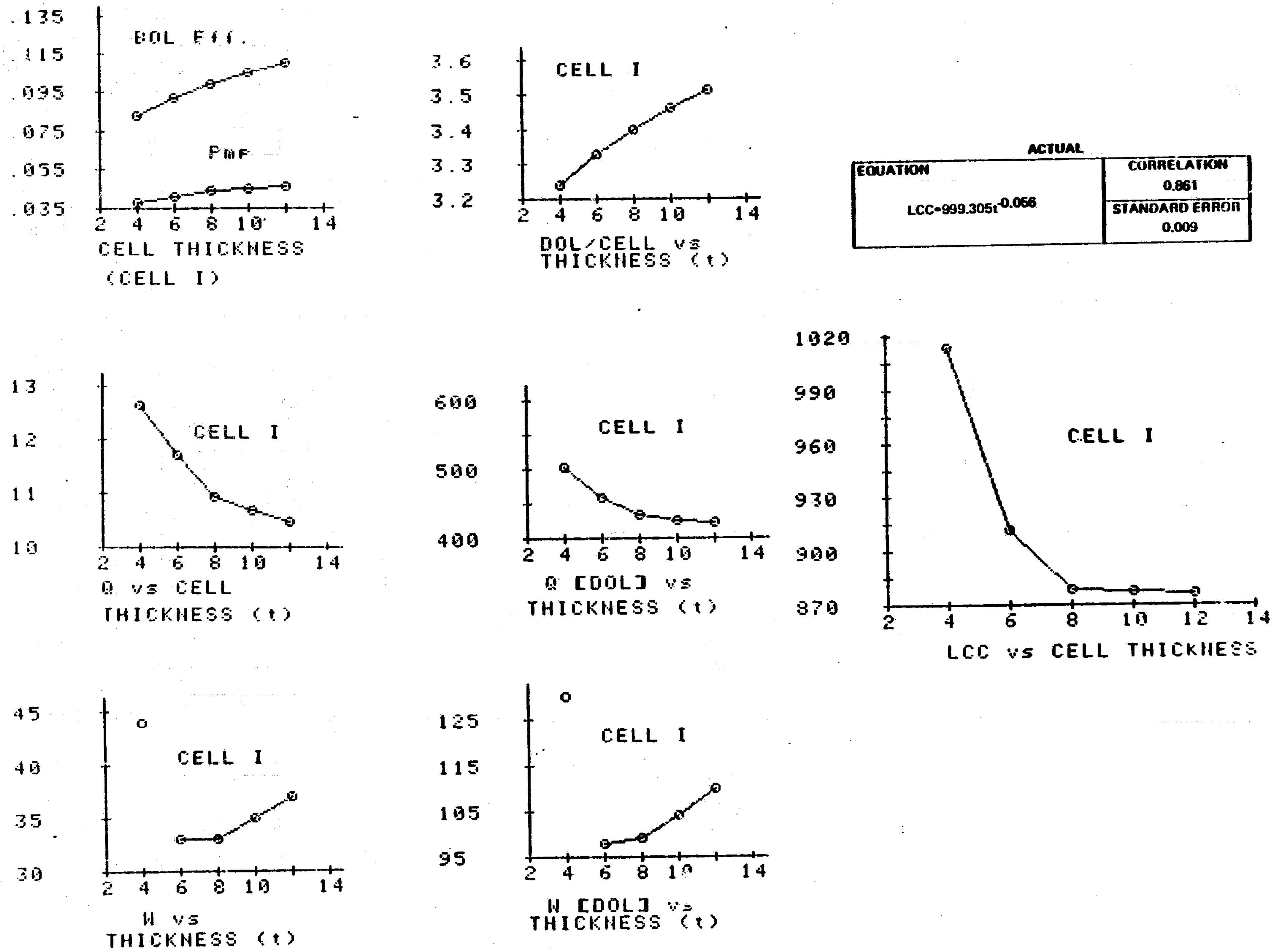


EXHIBIT 6-1. LCC vs CELL THICKNESS

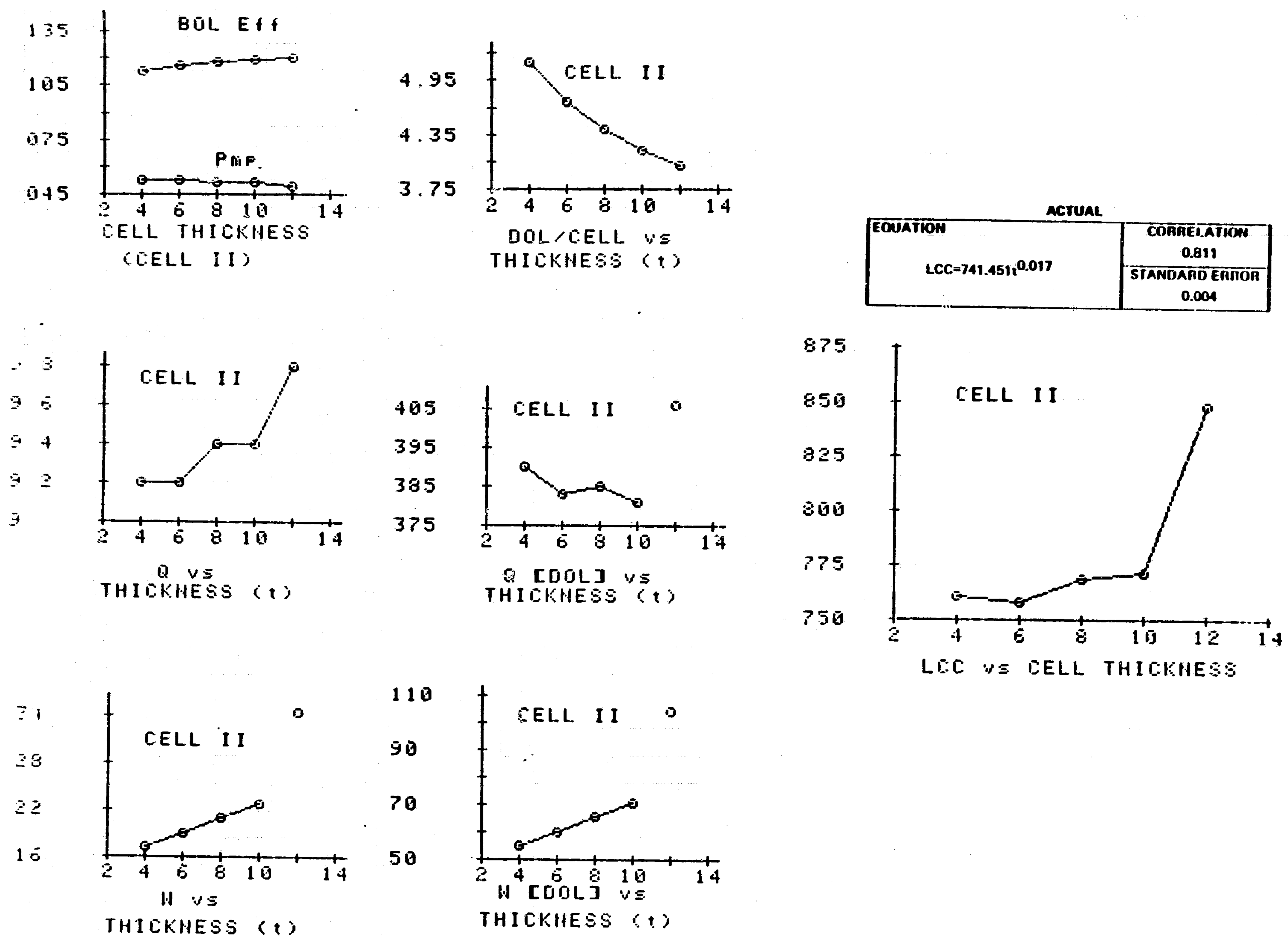
t	n_{BOL}	F_p(Rad)	$\overline{T}$ max	$\overline{T}$ min	$F_p(\overline{T})$	P_{mp}	Q	$/Cell	Q $	W	W $	LCC
12	.120	.800	345.2	339.8	.719	.049	9.8208	4.00	405.703	34.645	103.660	848.290
10	.119	.828	345.4	340.0	.718	.051	9.4176	4.18	381.272	22.758	70.870	771.042
8	.118	.854	345.6	340.4	.716	.051	9.4176	4.42	385.010	21.080	65.872	769.341
6	.116	.878	346.0	340.7	.715	.052	9.2448	4.72	383.244	18.947	59.556	758.430
4	.113	.905	346.4	341.1	.713	.052	9.2448	5.15	390.108	17.302	54.656	761.081

Cell Thickness - II

$$n_{BOL} = .105\ t^{.0547}, \quad 4 \leq t \leq 12$$

$$\$\ Cell = 210.09\ n_{BOL}^{1.502}\ t^{-.313}$$

TABLE 6-2. LCC vs CELL THICKNESS (BACK SURFACE FIELD)



ACTUAL

EQUATION	CORRELATION	STANDARD ERROR
$LCC = 741.451t^{0.017}$	0.811	0.004

EXHIBIT 6-2. LCC vs CELL THICKNESS

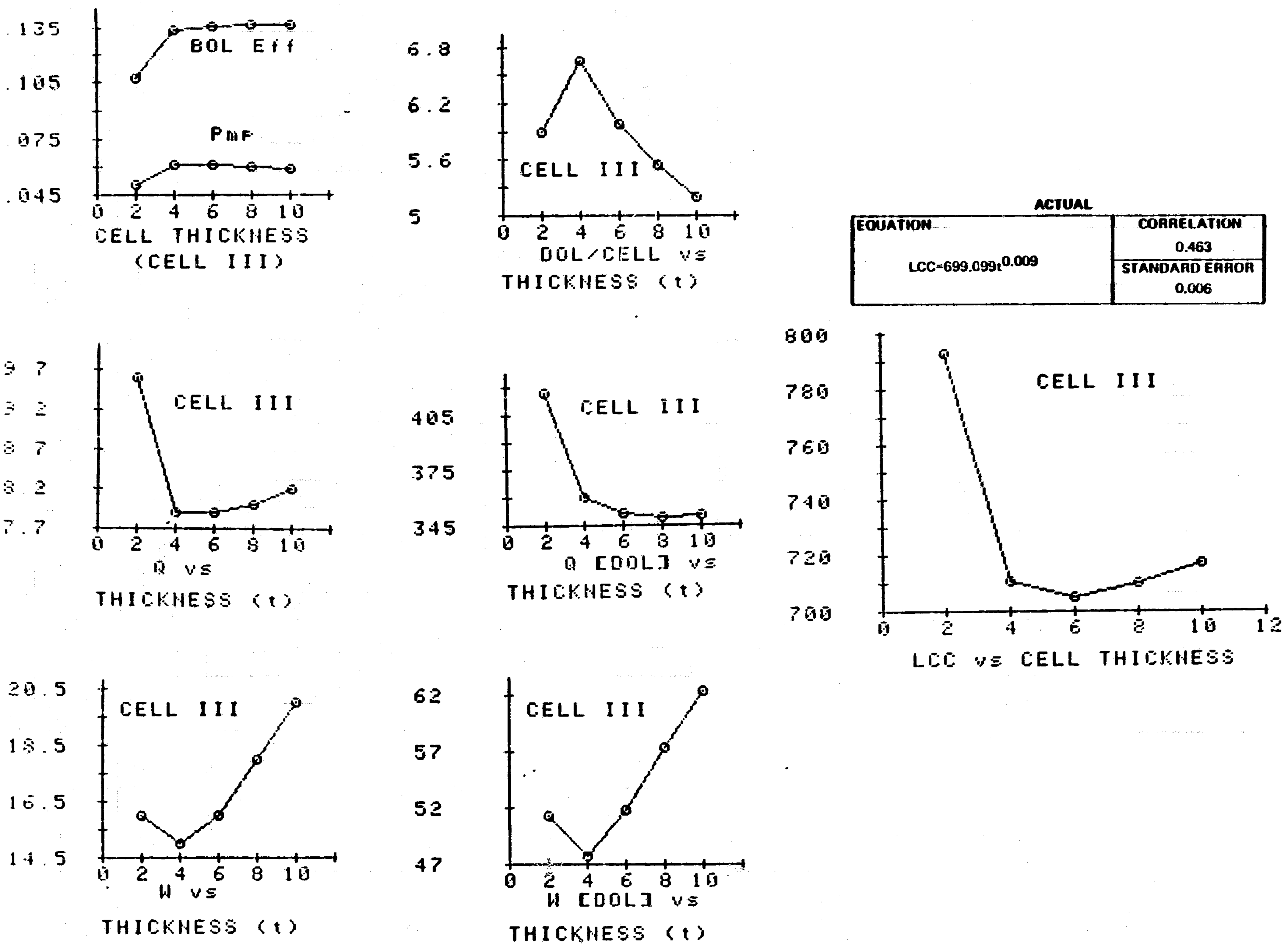
t	n_{BOL}	F_p(Rad)	$\overline{T}$ max	$\overline{T}$ min	$F_p(\overline{T})$	P_{mp}	Q	$/Cell	Q $	W	W $	LCC
10	.1375	.828	344.7	339.3	.721	.059	8.1504	5.19	350.049	19.822	62.285	717.301
8	.137	.854	344.9	339.6	.720	.060	8.0064	5.53	349.256	18.183	57.404	709.641
6	.136	.878	345.1	339.9	.718	.061	7.8912	5.99	350.927	16.332	51.933	704.511
4	.134	.905	345.5	340.3	.717	.061	7.8912	6.65	360.081	14.911	47.703	711.158
2	.107	.937	347.0	341.6	.711	.050	9.6192	5.89	416.888	16.197	51.324	792.763

Cell Thickness - III

$$n_{BOL} = .1289\ t^{.0281},\quad 4 \leq t \leq 10$$

$$\$/\text{Cell} = 210.09\ n_{BOL}^{1.502}\ t^{-.313}$$

TABLE 6-3. LCC vs CELL THICKNESS (BACK SURFACE FIELD & THIN DIFFUSED TOP REGION)



ACTUAL

EQUATION	CORRELATION
$LCC = 699.099t^{0.009}$	0.463
	STANDARD ERROR
	0.006

EXHIBIT 6-3. LCC vs CELL THICKNESS

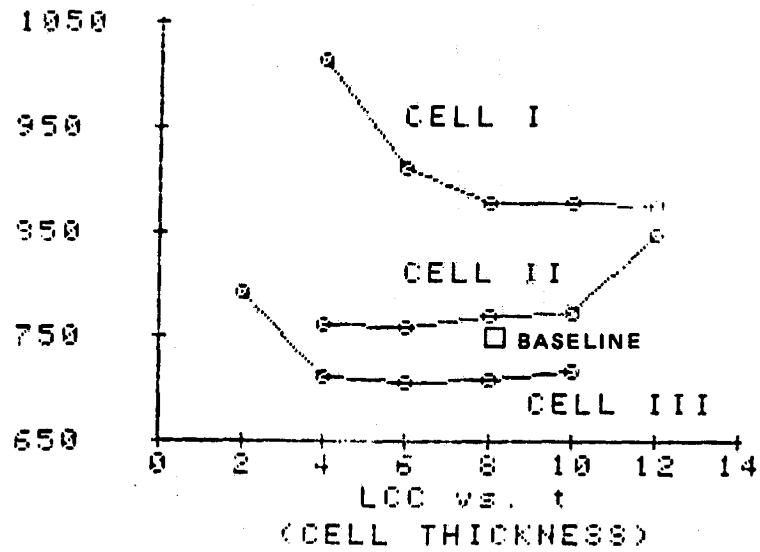


EXHIBIT 6-4. COMPOSITE CELL THICKNESS vs LCC

As seen in the composite, the cell thickness relationships all show a strong influence on LCC, and more importantly the advantages of the back field, thin diffused top region cell. For this type of cell, thickness of 6 mils is optimum.

The deviation of the data points from a smooth curve fit are a result of the number of panels required per power channel which in turn is a result of the Shuttle payload bay dimensional constraints. The SAS baseline is plotted as a reference point (t=8 mil, η_{BOL} = .122).

6.3.2 Cover Thickness vs LCC

The relationship shown in Exhibit 6-5 for cover thickness, displays a strong influence on LCC in the vicinity of four mils, a somewhat reduced influence near the baseline (eight mils), and with little gain above 12 mils. An increase in cover thickness has three effects on LCC: (1) increased weight of array, (2) reduction of degradation rate of cell, and (3) decrease in blanket mean temperature. The variations in radiation degradation are less pronounced due to cover thickness variations than for cell thickness variations. The relationship of unit cover cost versus cover thickness is as indicated. All configurations are based on 4 panels/channel which result in reasonably smooth curves for all parameters indicated.

6.3.3 Blanket Temperature vs LCC

The relationship shown in Exhibit 6-6 shows a strong influence on LCC due to changes in the mean blanket temperature. This derives basically from the change

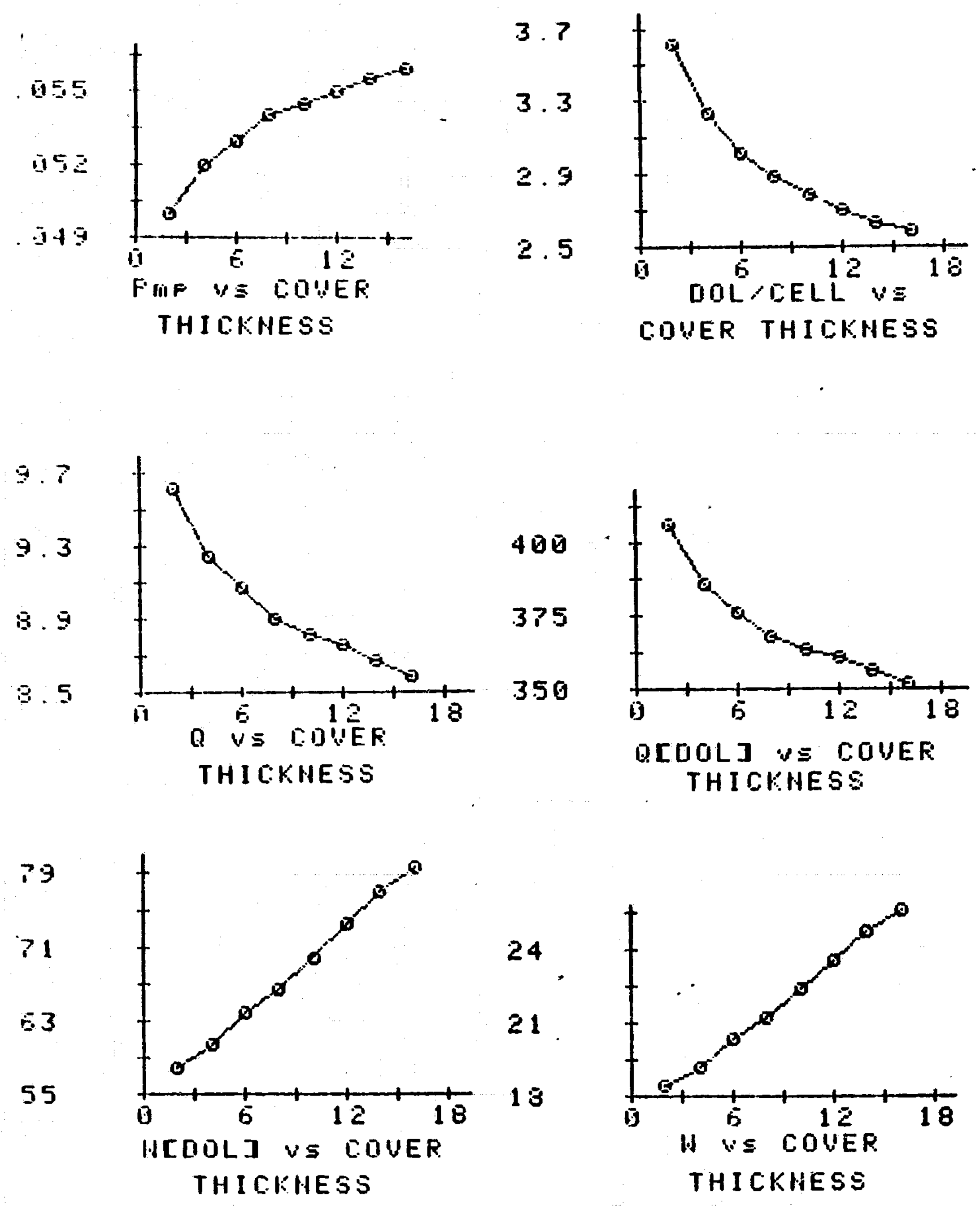
t	F_p (Rad)	$\overline{T}$ max	$\overline{T}$ min	$F_p(\overline{T})$	P_{mp}	Q	$/Cover	Q $	W	W $	LCC
16	.877	343.8	338.3	.726	.056	8.5824	2.58	352.288	25.619	79.520	743.591
14	.875	344.1	338.8	.723	.0555	8.6688	2.63	356.121	24.789	77.005	745.370
12	.872	344.5	339.1	.722	.055	8.7552	2.70	360.060	23.639	73.578	746.061
10	.868	344.7	339.75	.719	.0545	8.8128	2.78	363.139	22.418	69.939	745.305
8	.862	345.1	339.8	.719	.054	8.8992	2.88	367.599	21.223	66.376	746.516
6	.854	345.4	340.2	.717	.053	9.0720	3.02	376.100	20.374	63.808	754.526
4	.839	346.0	340.6	.715	.052	9.2448	3.23	385.657	19.212	60.344	762.751
2	.812	346.5	341.0	.713	.050	9.6192	3.61	406.022	18.446	58.021	787.108

$$\$/\text{Cover} = 4.04\ t^{-.162}$$

$$cc = .945$$

$$se = .036$$

TABLE 6-5. LCC vs COVER THICKNESS



ACTUAL

EQUATION	CORRELATION
$LCC = 794.780t^{-0.026}$	0.948
	STANDARD ERROR
	0.006

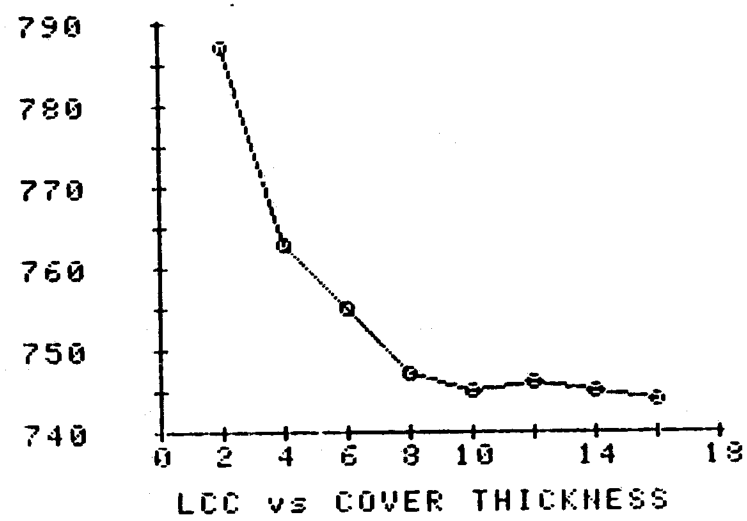
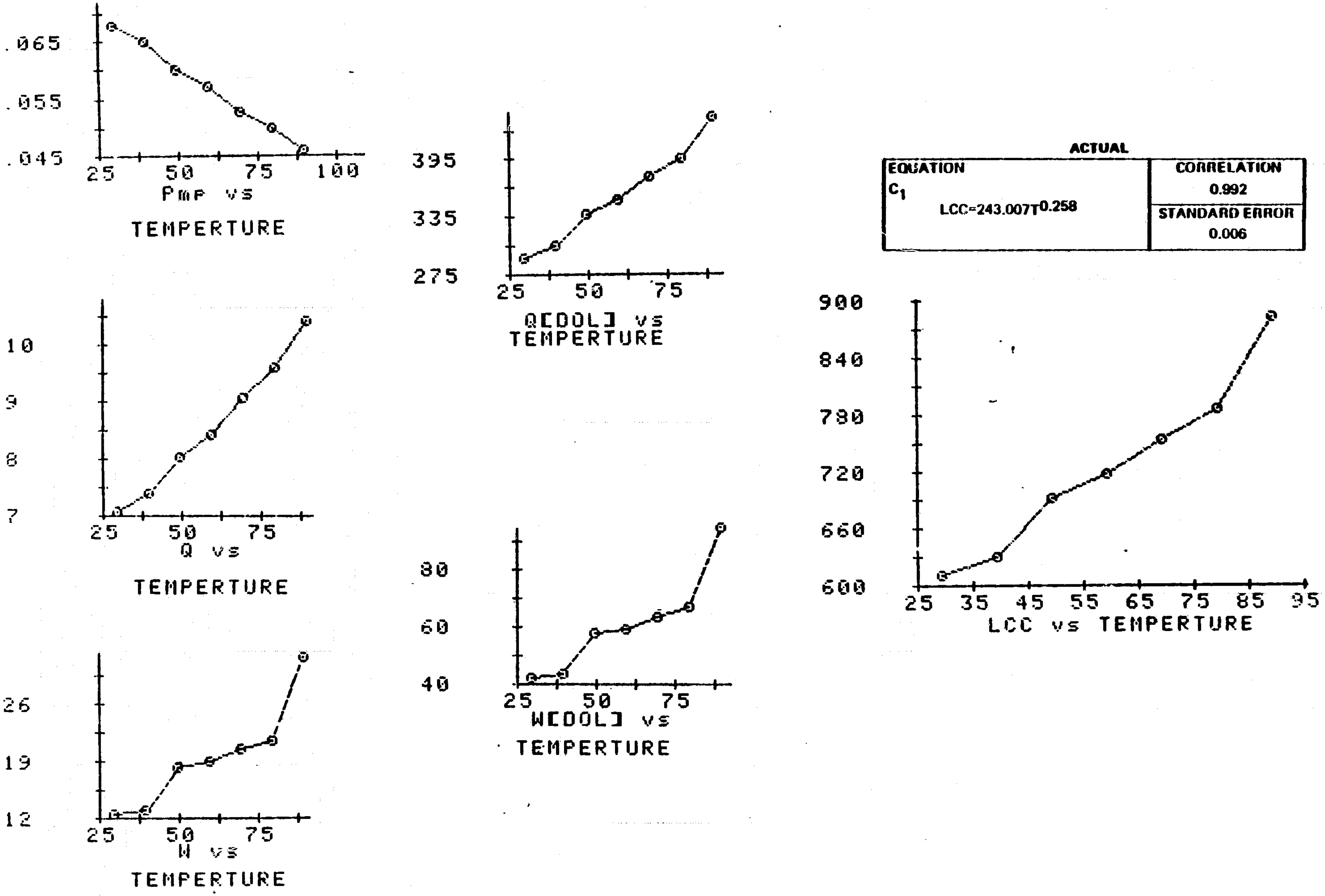


EXHIBIT 6-5. LCC vs COVER THICKNESS

$T^{o}C$	P_{mp}	Q	W	Q $	W $	LCC
89.2	.046	10.4400	31.766	439.275	95.256	882.267
79.2	.050	9.6192	21.411	396.393	66.841	785.994
69.2	.053	9.0720	20.374	376.100	63.808	754.526
59.2	.057	8.4384	18.933	352.427	59.612	716.903
49.2	.060	8.01792	18.287	336.911	57.697	693.371
39.2	.065	7.3872	13.074	303.583	43.746	629.544
29.2	.068	7.0632	12.518	291.593	42.076	611.103

TABLE 6-6. LCC vs TEMPERATURE



ACTUAL

EQUATION	CORRELATION
C_1 LCC=243.007$T^{0.258}$	0.992
	STANDARD ERROR
	0.006

EXHIBIT 6-6. LCC vs TEMPERATURE

in cell efficiency with temperature ($3.2M per 1°C). Of the technology areas addressed, temperature proved to have one of the greatest effects on LCC. As can be seen in the exhibit, the C_1 curve is for arrays with 4 panels/channel. The C_2 curve is for 3 panels/channel. The 89.2° point results in 5 panels/channel. It should be noted that the cost to achieve any reduction in temperature is not included in the LCC. Only the resultant effect of the reduction is included.

6.3.4 Cell Efficiency vs LCC

The relationship shown in Exhibit 6-7, as expected, shows a strong influence on LCC. In the vicinity of the baseline, the slope is $46M per 1% change in cell efficiency (measured at BOL). The basic effect is on baseline quantities, weights, and cell unit costs. The relationship of unit cell cost vs. cell efficiency is as indicated. The study results also indicated the following relationship between EOL Pmp and the number of panels/channel.

EOL Pmp (w)	#Panels/Channel
.064 - .093	3
.050 - .063	4
.040 - .049	5
.034 - .039	6

6.3.5 Cover Degradation vs LCC

The relationship shown in Exhibit 6-8 displays a medium/strong influence on LCC. The slope in the vicinity of the baseline optical factor (.885) is about $10M per 1% change of the factor. The cover unit cost variation as indicated is more than offset by the substantial reductions in weight, dimensions and number of cells in the baseline. The effect of cover degradation is two-fold: (1) the illumination reaching the solar cell is effected; (2) the illumination effect in turn effects the temperature derating. Hence, the effect of cover degradation on LCC is greater than the effect of cell degradation, which is discussed in paragraph 6.3.6. All array configurations have 4 panels/channel except the two extremes (.974 & .840), which have 4 and 5 respectively.

6.3.6 Cell Degradation vs LCC

The relationship shown in Exhibit 6-9 displays a medium influence on LCC. The slope is nearly constant at $5.4M per one percent change for all values of the

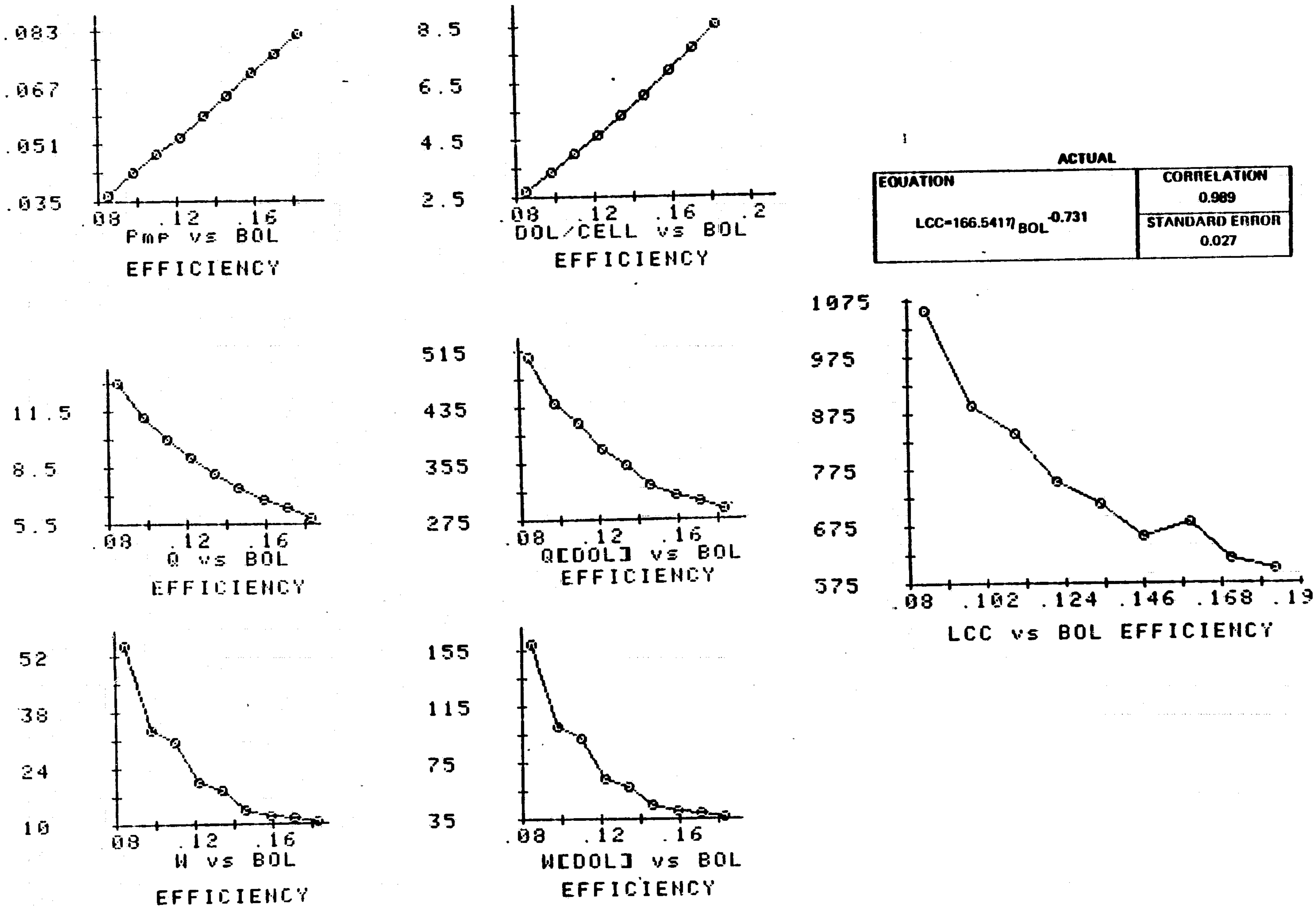
η_{BOL}	P_{mp}	# Panels/ Channel	Q	W	$/Cell	Q $	W $	LCC
.183	.082	3	5.85792	10.687	8.55	288.665	36.506	599.631
.171	.076	3	6.32448	11.520	7.72	299.741	39.010	617.964
.159	.071	3	6.76512	12.139	6.92	308.573	40.892	682.428
.146	.065	3	7.3872	13.308	6.09	323.117	44.400	656.798
.134	.059	4	8.1504	18.369	5.35	352.100	57.958	714.228
.122	.053	4	9.0720	20.374	4.65	376.100	63.808	754.526
.110	.048	5	10.0224	30.740	3.98	411.437	92.307	840.704
.098	.043	5	11.1744	33.668	3.35	440.365	100.706	891.096
.085	.037	6	12.99456	54.558	2.70	505.251	158.695	1056.977

$$\$/\text{Cell} = 109.6\ \eta_{BOL}^{1.502}$$

CC = .9998

SE = .004

TABLE 6-7. LCC vs CELL EFFICIENCY



ACTUAL

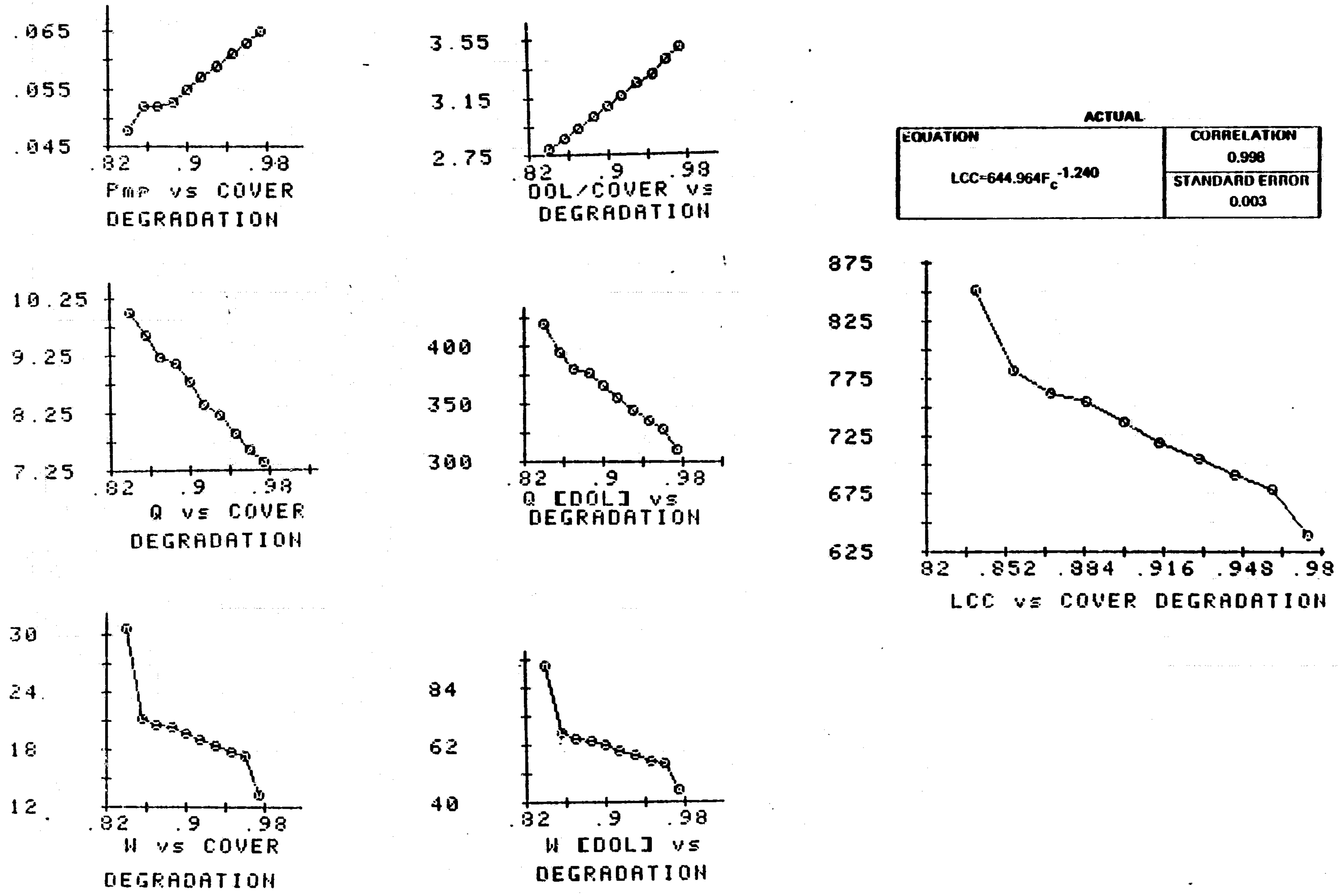
EQUATION	CORRELATION
$LCC = 166.5417\eta_{BOL}^{-0.731}$	0.989
	STANDARD ERROR
	0.027

EXHIBIT 6-7. LCC vs BOL EFFICIENCY

F_c	P_{mp}	Q	W	$/Cover	Q $	W $	LCC
.974	.065	7.3872	13.308	3.49	310.085	44.400	639.205
.960	.063	7.6320	17.412	3.41	327.925	55.152	677.804
.945	.061	7.8912	17.733	3.33	336.457	56.107	690.611
.930	.059	8.1504	18.369	3.25	345.133	57.958	704.823
.914	.057	8.4384	18.998	3.17	354.763	59.793	720.301
.900	.055	8.7552	19.693	3.10	365.561	61.820	737.614
.885	.053	9.0720	20.374	3.02	376.100	63.808	754.526
.870	.052	9.2448	20.599	2.94	381.088	64.477	762.163
.855	.052	9.6192	21.332	2.87	393.712	66.621	782.100
.840	.048	10.0224	30.740	2.79	419.456	92.307	851.530

$$\$/\text{Cover} = 3.628\ F_c^{1.502}$$

TABLE 6-8. LCC vs COVER DEGRADATION



ACTUAL

EQUATION	CORRELATION
$LCC = 644.964 F_c^{-1.240}$	0.998
	STANDARD ERROR
	0.003

EXHIBIT 6-8. LCC vs COVER DEGRADATION

F_p (Rad)	P_{mp}	Q	W	$/Cell	Q $	W $	LCC
.953	.060	8.0064	18.157	5.48	348.516	57.332	708.545
.935	.058	8.2944	18.806	5.33	357.437	59.223	723.141
.914	.057	8.4384	18.986	5.15	360.128	59.758	727.496
.899	.056	8.5824	19.165	5.02	363.505	60.293	732.777
.885	.055	8.7552	19.687	4.91	368.424	61.803	741.456
.864	.054	8.8992	19.873	4.73	370.857	62.356	745.488
.854	.053	9.0720	20.374	4.65	376.100	63.808	754.526
.829	.052	9.2448	20.605	4.45	379.073	64.494	759.465
.808	.050	9.6192	21.352	4.28	389.872	66.677	776.991

$$\$/\text{Cell} = 5.894 \; F_p\,(\text{Rad})^{1.502}$$

TABLE 6-9. LCC vs CELL DEGRADATION

ACTUAL	
EQUATION	CORRELATION 0.989
$LCC = 694.923 F_p(Rad)^{-0.506}$	STANDARD ERROR 0.004

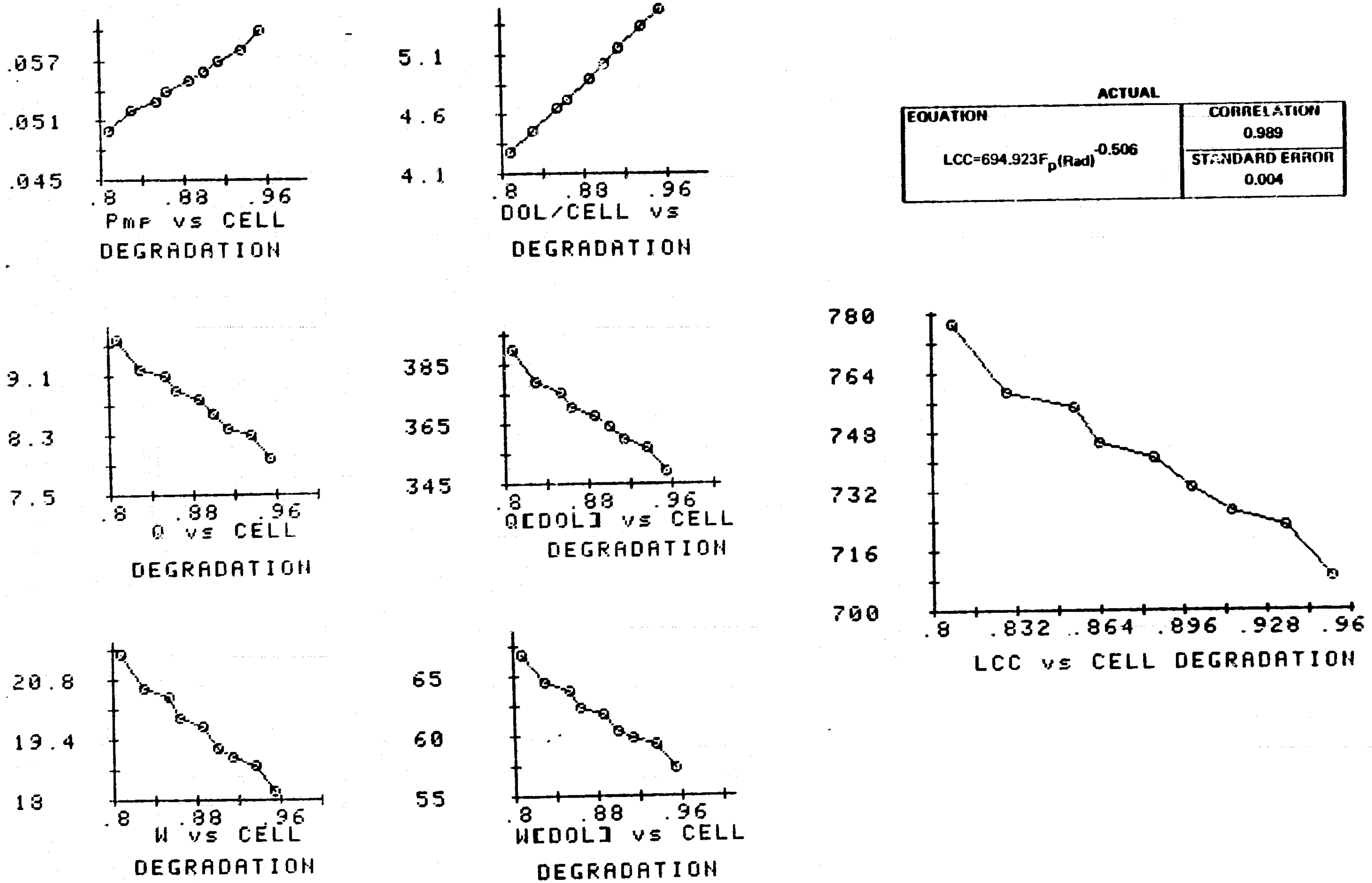


EXHIBIT 6-9. LCC vs CELL DEGRADATION

degradation factor. The basic effects, as the factor increases, are due to quantity, weight and dimensional reductions. The unit cell cost increases with degradation resistance but does not substantially offset the other basic effects. All array configurations have 4 panels/channel.

It should be noted that the basic methodology used to achieve the results indicated could be applied to any solar cell performance parameter with similar results. In addition, the results obtained here can be used in conjunction with the cell thickness results to determine the effect of a smaller variation cell degradation vs cell thickness over the array lifetime.

6.3.7 Line Voltage vs LCC

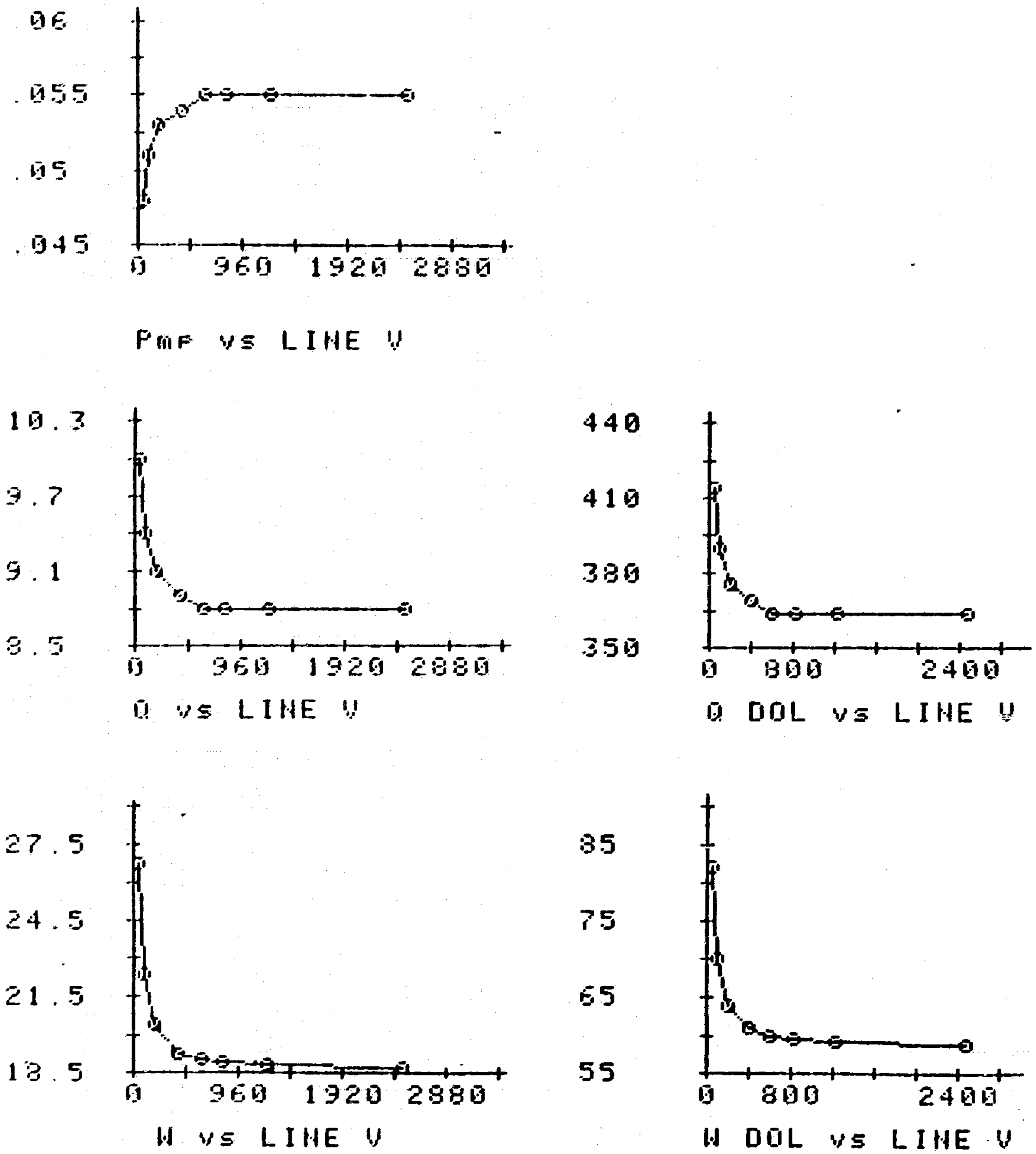
The relationship shown in Exhibit 6-10 displays a moderate influence on LCC in the low (40 to 100 volts) range, and very weak influence above 400 volts. For each data point, an array weight and size was calculated for an optimum selection of I^2R losses versus blanket area. The variations in line voltage were achieved by simply increasing the number of panels/channel (e.g., connected in series) while decreasing the total number of channels. This means that the total array size and the total current through the main bus conductors does not significantly change. It should be noted that these curves do not include the effect of high voltage leakage which could prove to have a quite drastic effect on the results.

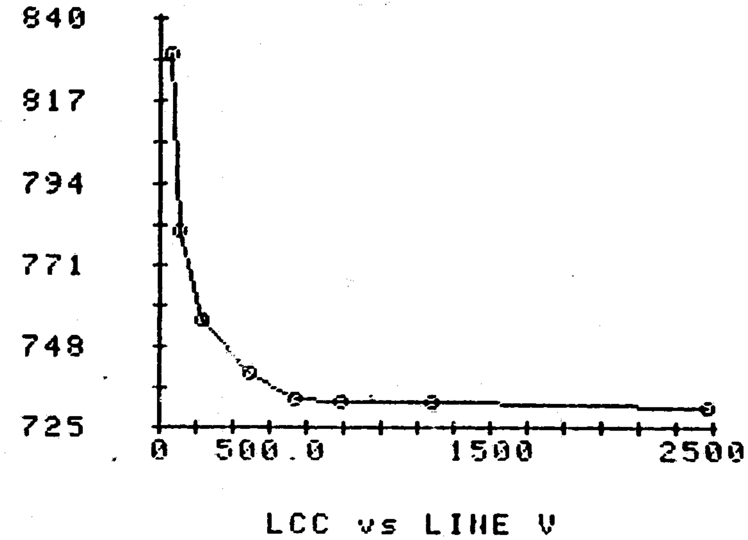
6.3.8 Years Between Overhaul vs LCC

The relationship shown in Exhibit 6-11 displays an optimum life (or time between blanket changeout) near the baseline 10 years. The transportation costs of earlier overhauls dominate the reduced blanket area required for the baseline design. The cost of achieving the longer life design was not quantified (effect on DDT&E and material costs, for example). It should be noted that although the array quantities and weights would be smaller for a shorter array lifetime, the totals required to be manufactured and sent into space would increase drastically as the lifetime decreases. (e.g., four times as much is required for 2.5 years between overhaul.) This leads to the conclusion that the array should be designed for a minimum of overhaul during its projected period of operation.

Line V	P_{mp}	Q	W	Q $	W $	LCC
51.8	.048	10.0224	26.742	413.884	81.778	829.794
93.9	.051	9.4176	22.386	389.654	69.501	780.509
198.0	.053	9.0720	20.374	376.100	63.808	754.526
404.4	.054	8.8992	19.329	369.267	60.844	741.300
612.0	.055	8.7552	18.971	363.892	59.813	732.652
818.4	.055	8.7552	18.880	363.842	59.560	732.243
1231.2	.055	8.7552	18.794	363.798	59.321	731.861
2469.6	.055	8.7552	18.703	363.752	59.069	731.458

TABLE 6-10. LCC vs LINE VOLTAGE





ACTUAL

EQUATION	CORRELATION / STANDARD ERROR
$LCC=904.918^{-0.031}$	CORRELATION 0.893
	STANDARD ERROR 0.022

EXHIBIT 6-10. LCC vs LINE V

Yrs	Array Ω	Array W	Total Ω	Total W	Ω $	W $	O&M $	LCC
2.5	5.93568	10.774	23.74272	43.096	614.838	115.764	265.483	1251.796
5	6.76512	12.150	13.53024	24.300	483.334	67.716	160.650	813.151
10	9.0720	20.374	9.0720	20.374	376.100	63.808	160.650	754.526

TABLE 6-II. LCC vs YEARS BETWEEN OVERHAUL

ACTUAL

EQUATION	CORRELATION
$LCC = 1648.321^{-0.365}$	0.926
	STANDARD ERROR
	0.146

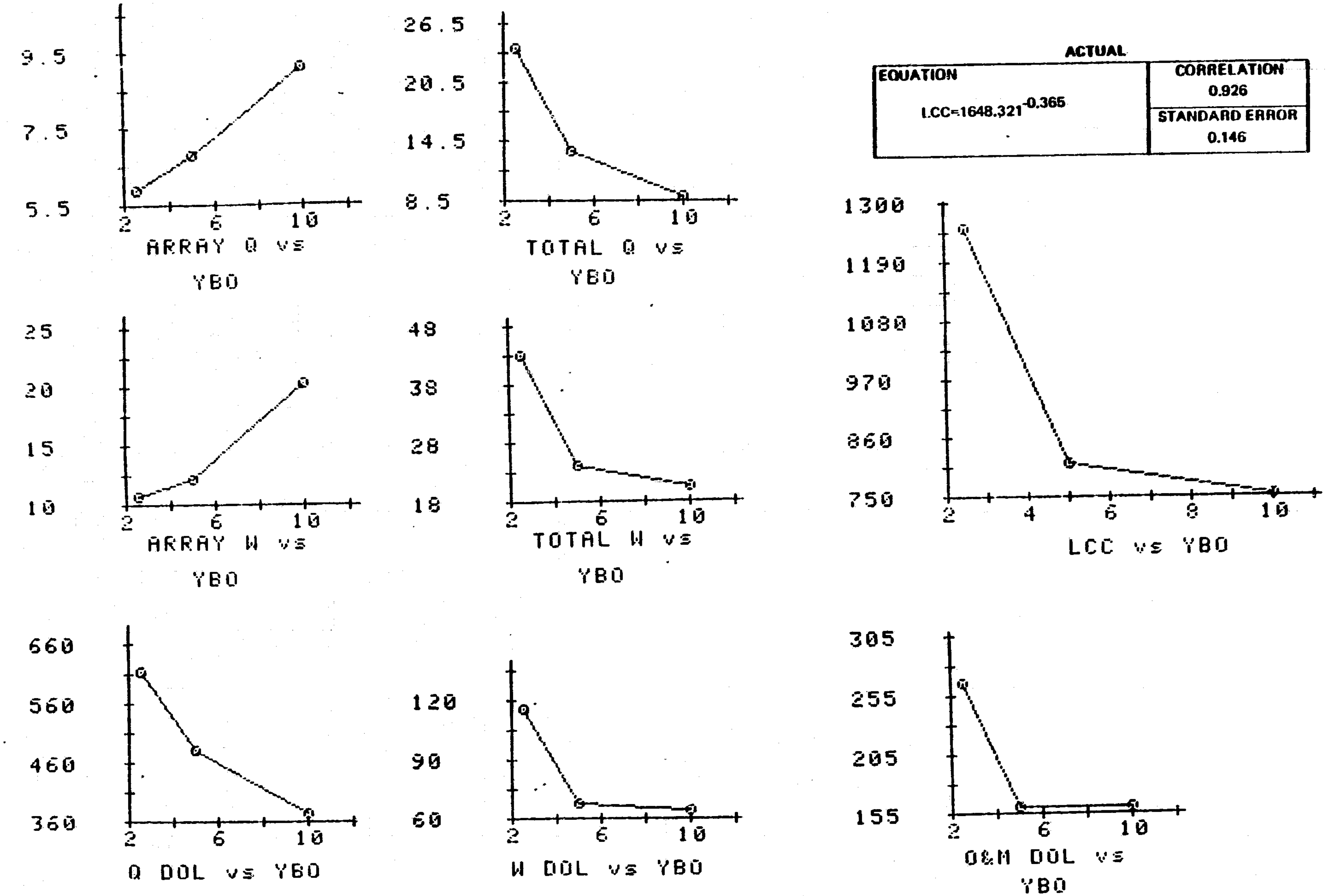


EXHIBIT 6-11. LCC vs YBO

6.3.9 Mean Time Between Failures vs LCC

The relationship shown in Exhibit 6-12 displays a moderate influence on LCC near the baseline. For the baseline design, 23 panel failures over the 10 year life (MTBF = 5,000 Hrs.) were assumed for the purpose of determining spare panel quantities. A higher failure rate means more spares and increased space transportation costs. The primary result indicates a need to look at this area further by including a more rigorous study of the relationship between the MTBF and number of spares, and particularly the effect on DDT&E phase costs.

6.3.10 Cell and Cover Assembly Unit Costs vs LCC

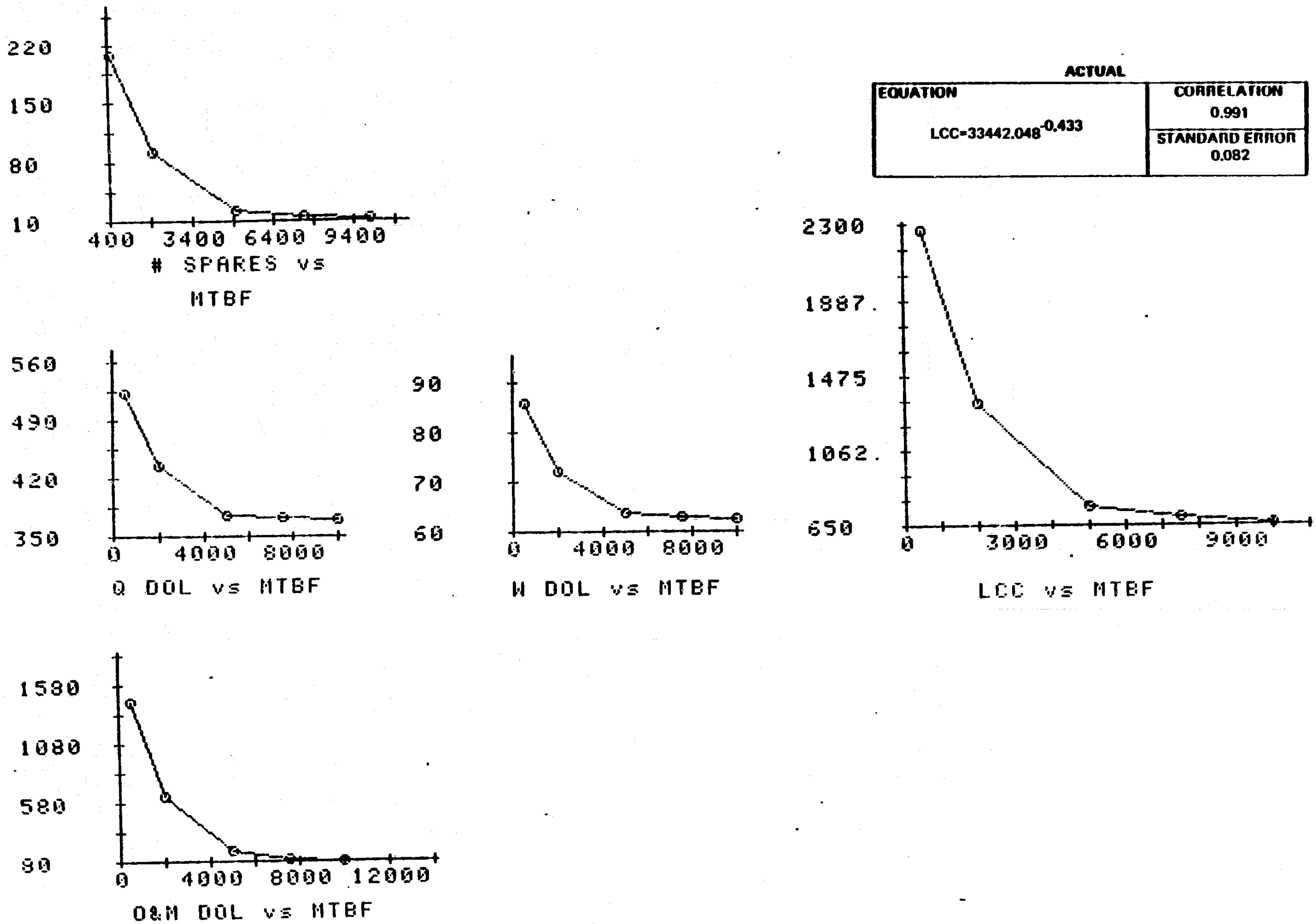
The relationship shown in Exhibit 6-13 gives a slope of $22M savings in LCC for each dollar reduction in cell and cover assembly unit costs. The results in this technology area indicate what benefits could be realized in LCC reduction, simply by reducing the unit cost of the cell and/or cover. In addition, the relationship between unit cost and LCC indicated here can be used to adjust the results of exercising the corresponding LCC relationship in any or all of the other technology areas.

6.4 Summary

The results of the various technology areas vs LCC are summarized in Exhibit 6-14. It should be emphasized that the slopes (e.g., $/% change) apply only within the immediate region of the baseline SAS. It should also be noted that while the individual results were obtained by varying only one independent parameter at a time, it is possible to use the various relationships in various combinations. For example, given a solar cell which does not exactly fit one of the cell thickness vs LCC curves, it is possible to adjust the effect of a different efficiency, cell degradation, and/or unit cell cost on the LCC by applying the appropriate relationships in conjunction with one another. However, it should also be emphasized that this method will give only approximate results, and should be used in only relatively simple combinations. To obtain a better composite result, the Solar Array Performance

Hrs	# Spares	Q $	W $	O&M	LCC
10,000	12	369.213	62.486	84.247	667.041
7,500	15	371.952	62.847	105.084	692.063
5,000	23	376.100	63.808	160.650	754.526
2,000	92	434.660	72.098	639.900	1324.023
500	207	522.630	85.915	1438.650	2260.186

TABLE 6-12. LCC vs MEAN TIME BETWEEN FAILURES



ACTUAL

EQUATION	CORRELATION
$LCC = 33442.048^{-0.433}$	0.991
	STANDARD ERROR 0.082

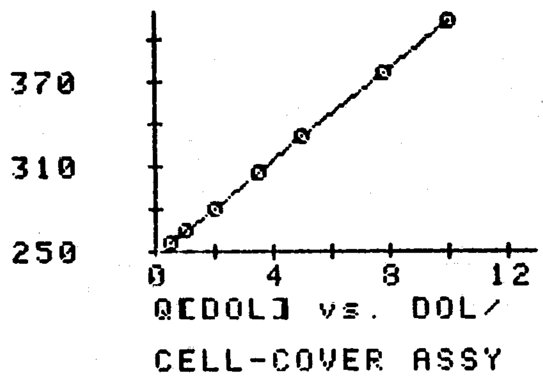
EXHIBIT 6-12. LCC vs MTBF

$/CCA	Q $	LCC
10.00	413.225	804.645
7.75	376.100	754.526
5.00	330.725	693.270
3.50	305.975	659.857
2.00	281.226	626.446
1.00	264.726	604.171
.50	256.476	593.033

TABLE 6-13. LCC vs $/CELL & COVER ASSEMBLY

ACTUAL

EQUATION	CORRELATION
$LCC = 607.593\$/CCA^{0.099}$	0.942
	STANDARD ERROR
	0.036



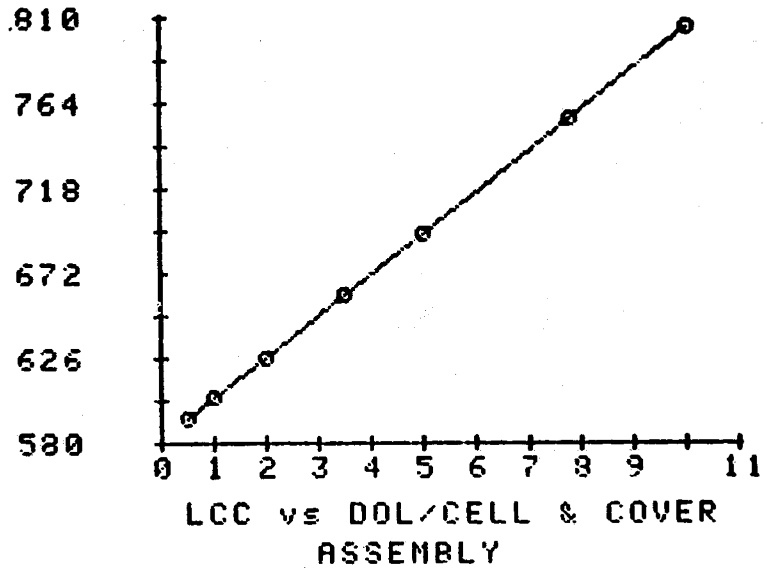


EXHIBIT 6-13. LCC vs DOL/CELL & COVER ASSEMBLY

TECHNOLOGY AREA	INFLUENCE ON LCC
CELL THICKNESS	MEDIUM/STRONG - 6 MILS OPTIMUM*
COVER THICKNESS	MEDIUM - LITTLE GAIN ABOVE 12 MILS
BLANKET TEMPERATURE	STRONG - \$3.2M/^{o}C
CELL EFFICIENCY	STRONG - \$46M/1% CHANGE
COVER DEGRADATION	MEDIUM/STRONG - \$10M/1% CHANGE
CELL DEGRADATION	MEDIUM - \$5.4M/1% CHANGE
LINE VOLTAGE	WEAK - LITTLE GAIN ABOVE 400 VOLTS
YEARS BETWEEN OVERHAUL	WEAK - LONGER LIFE BETTER
MTBF	MEDIUM - KEEP MTBF UP, SPARES LOW
CELL COVER ASSEMBLY COSTS	STRONG - \$22M/\$ CELL COVER ASSEMBLY UNIT COST

*RESULTS ARE GIVEN FOR THREE CLASSES OF CELLS (THIS APPLIES TO BSF + THIN DIFFUSED TOP REGION CELL ONLY).

EXHIBIT 6-14. SUMMARY OF RESULTS OF STUDY and Cost Model should be adjusted and/or exercised accordingly.

6.5 Recommendations

The recommendations to be made are in two categories: (1) those based on each technology area/LCC quantified (Section 6.5.1) and (2) general recommendations for further applications of the model and techniques developed for the study (Section 6.5.2).

6.5.1 Specific Technology Recommendations

Cell Thickness - Determine an optimum cell thickness and type of cell (back field, thin diffused top region, etc.) for various array designs, missions and manufacturing and maintenance scenarios.

Cover Thickness - Same as for cell thickness.

Blanket Temperature - Explore the feasibility of various thermal control methods/materials to optimize LCC ($3.2M/^{o}C).

Cell Efficiency - Perform an in-depth study to model the optimum relationship of cell cost vs. cell efficiency involving various manufacturing scenarios ($46M/1% change in Efficiency).

Cover Degradation - Explore methods to increase cell degradation resistance ($10M/1% change in F_c).

Cell Degradation - Explore methods to increase cell degradation resistance ($5.4M/1% change in F_p(rad)).

Line Voltage - Perform a LCC trade study on the benefits of higher line voltages versus high voltage losses.

Years Between Overhaul - Explore the benefits of an add-on concept to offset degradation.

Mean Time Between Failures - Perform an in-depth study of the effects of reliability and maintenance on LCC.

Cell Costs - Perform an indepth study to model the relationship of cell cost versus cell efficiency, involving various manufacturing/maintenance scenarios. ($22M/$ of Cell Unit Cost).

6.5.2 Further Applications of the Model

The performance/cost model and techniques developed for this study can be modified, without complication, to support not only the specific technology studies recommended in 6.5.1, but a number of other areas:

A. To determine an optimized combination of solar array parameters;

B. To compare various solar array technologies (different cell and cover materials, cell/cover/coating combinations, etc.);

C. To study various manufacturing scenarios;

D. To study various missions: differing power requirements, orbits (all, LEO through GEO) and interplanetary;

E. To study various reliabilities and maintenance scenarios;

F. With more modification, the model can be expanded to determine technology vs. LCC for a total system such as the SSPS or any other space station concept. Thus, the total effect of subsystem technology may be quantified to include interfacing subsystems and other system elements such as DDT&E, Production, O&M, tracking, command and control, transportation, safety, and so forth.

7.0 REPORTING OF STUDY STATUS AND RESULTS

The following output has been provided over the course of the study:

- Monthly Progress Narratives (April, 1979 through March, 1980)
- Oral Presentations at:
  - Lewis Research Center, October 19, 1979
  - Lewis Research Center, February 20, 1980
  - NASA Headquarters, March 4, 1980
- Document: "Specification of Requirements, 500 kW Solar Array Subsystem", PRC, July 30, 1979 (Appendix A)
- Document: "Baseline 500 kW Solar Array Subsystem Definition", PRC July 30, 1979
- Document: "Solar Array Subsystem Study Final Report", PRC, Preliminary, March 20, 1980.

APPENDIX A

BASELINE 500 kW SOLAR ARRAY SUBSYSTEMS REQUIREMENTS
(SPECIFICATION)

SPECIFICATION

BASELINE 500kW SOLAR ARRAY SUBSYSTEMS REQUIREMENTS

Prepared For
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

MARCH 20, 1980

CONTRACT NAS3-21926

prc

PRC/SSC Solar Array Subsystems Project Office

7911 CHARLOTTE DRIVE · HUNTSVILLE, ALABAMA 35802

SPECIFICATION

BASELINE 500 kW
SOLAR ARRAY SUBSYSTEMS
REQUIREMENTS

CONTRACT NAS3-21926

JULY, 1979

MARCH, 1980 - UPDATE

TABLE OF CONTENTS

Page

1.0 INTRODUCTION AND SCOPE 1.0

2.0 APPLICABLE DOCUMENTS 2.0

3.0 REQUIREMENTS 3.0

3.1 System Level Requirements 3.0

3.1.1 System Level Description 3.0

3.1.2 Mission Requirements 3.3

3.2 Subsystem Performance and Interface Requirements and Constraints 3.3

3.2.1 Electrical Performance and Interface Requirements 3.4

3.2.2 Structural/Mechanical/Thermal Performance and Interface Requirements and Constraints 3.5

3.2.3 Transportation/Transportability 3.7

3.2.4 Life and Reliability 3.8

3.2.5 Safety 3.8

3.2.6 Maintenance/Maintainability 3.9

3.2.7 Environment 3.10

3.3 Design & Construction 3.11

3.3.1 Materials Properties 3.11

3.4 Verification Requirements 3.12

3.5 Personnel & Training Requirements 3.12

1.0 INTRODUCTION AND SCOPE

Under contract to NASA LeRC, a baseline Solar Array Subsystem (SAS) conceptual design is being developed for the purpose of determining the influence of varied technology on the life cycle costs of the subsystem and its interfacing elements.

This specification defines the requirements on the 500 kW (250 kW average) Solar Array Subsystem (SAS), a subsystem of the Space Support Platform System (SSPS). This is a top level subsystem specification. The relationship of this specification to the SSPS hierarchy of specifications is contained in Section 2.0.

2.0 APPLICABLE DOCUMENTS

2.1 The SSPS System specification tree is shown in Exhibit 2-1.

2.2 JSC 07700 Volume XIV, Space Shuttle Payload Accommodations, September 22, 1978

2.3 The applicability of other specifications, standards and other documents is TBD.

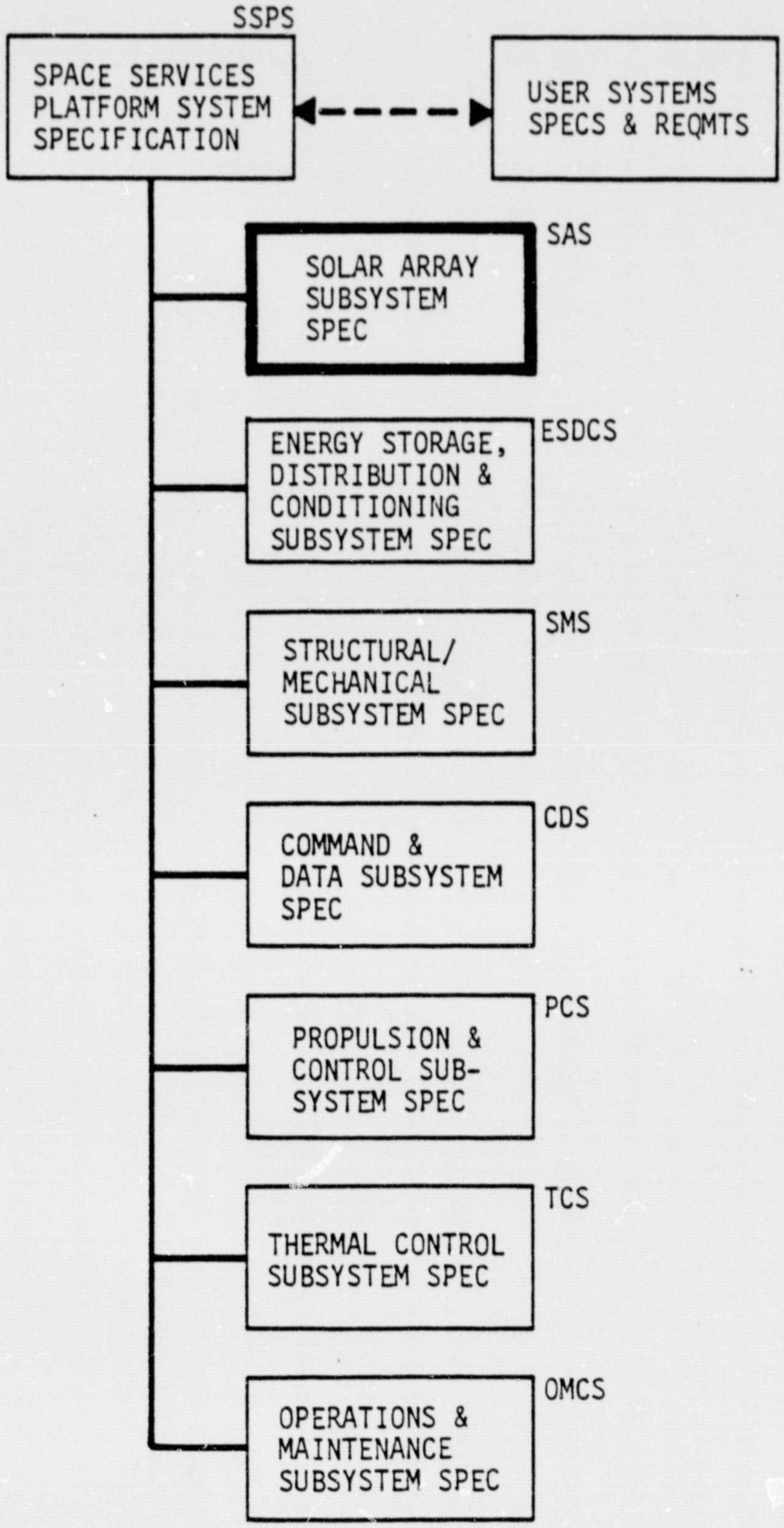


EXHIBIT 2-1 SSPS SPECIFICATION TREE

3.0 REQUIREMENTS

3.1 System Level Requirements

These requirements apply to the system level (the Space Service Platform System, SSPS) directly. The requirements on the Solar Array Subsystem derive from the system level requirements and are specified in Sections 3.2 through 3.5.

3.1.1 System Level Description

The purpose of the Space Services Platform System (SSPS) is to provide services to varied User Systems. The User Systems may be engaged in materials processing, astronomy, solar system and earth observation, life sciences, communications, or other operations. The User Systems may be secured to the platform or docked for servicing or short term operations.

The general configuration of the SSPS is shown in Exhibit 3-1. The subsystems of the SSPS, their functions and major interfaces are identified in Exhibit 3-2. The User Systems will interface with the SSPS subsystems as follows:

- Electrical power - ESDCS
- Thermal control - TCS
- Structure - SMS
- Mechanical - SMS
- Instrumentation - CDS
- Operations/Maint. - [illegible]CS
- Gross Pointing Stability - CDS (GUIDANCE)
  PCS (SSPS ATTITUDE)

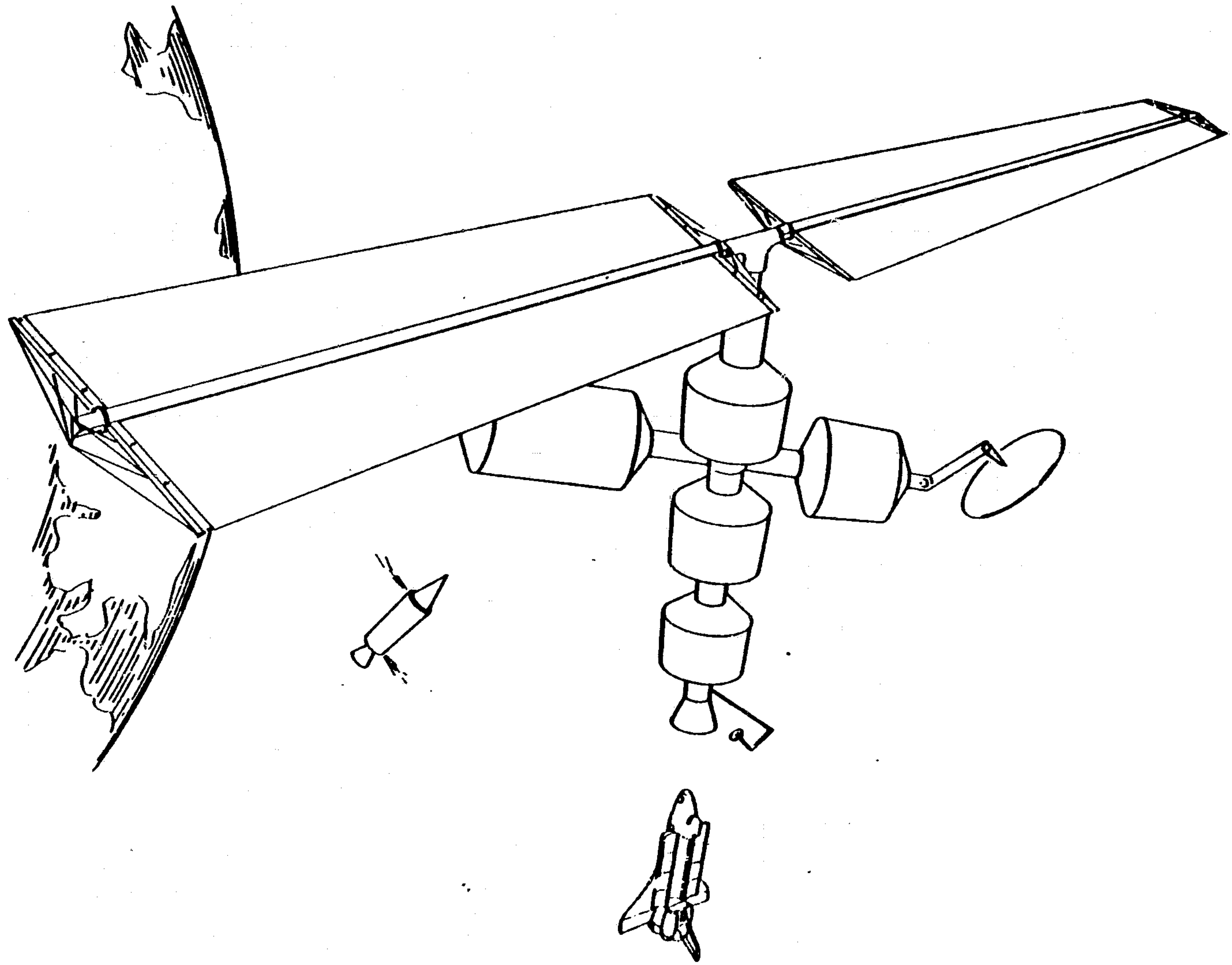


EXHIBIT 3-1 SSPS GENERAL CONFIGURATION

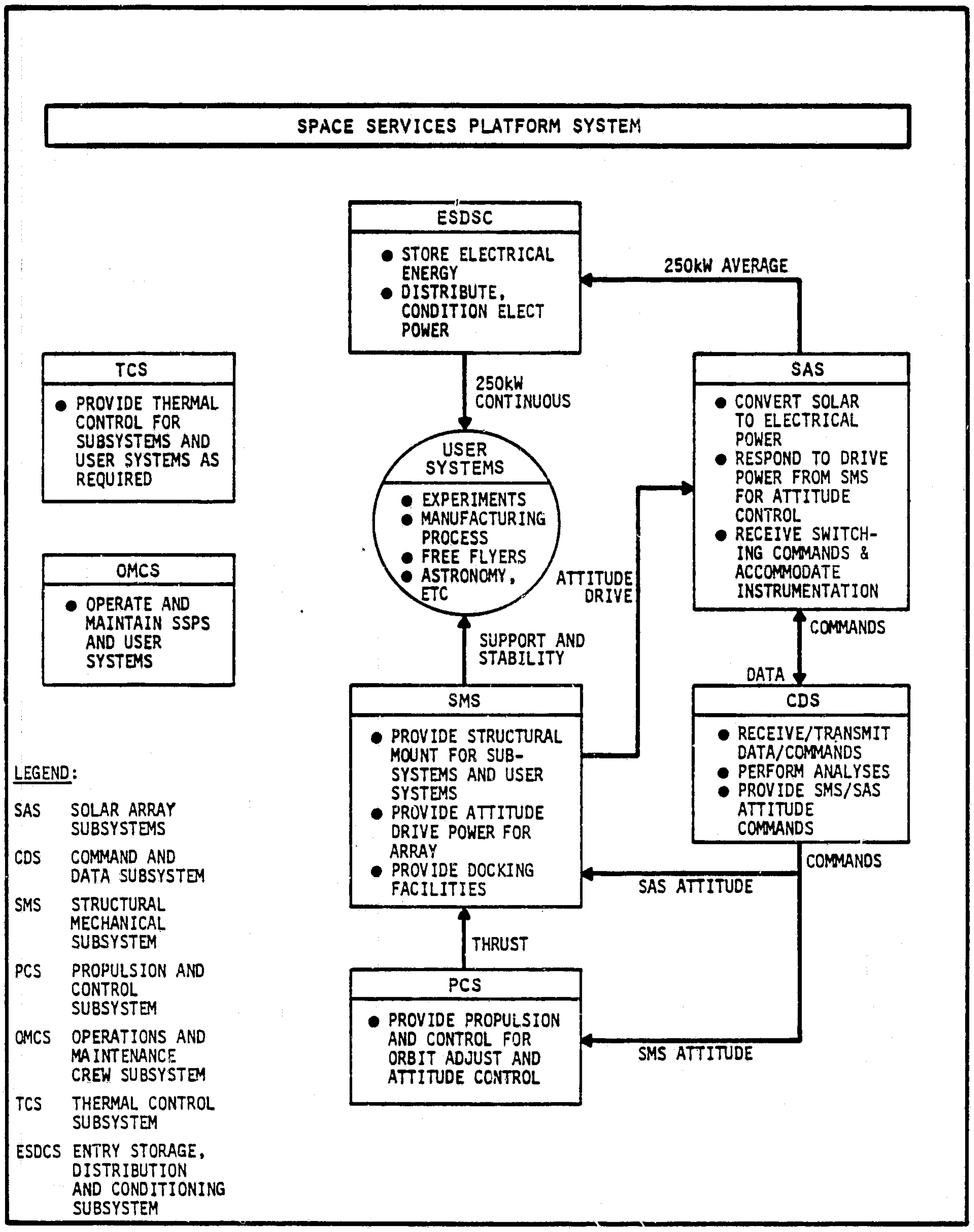


EXHIBIT 3-2 SSPS SUBSYSTEM FUNCTIONS AND INTERFACES

3.1.2 Mission Requirements

The following characteristics shall be used in the system and subsystem design.

3.1.2.1 General

- System operational 1985-1995
- State-of-art (1979) design
- Silicon solar cells; planar array (no concentration)
- Transportation to LEO: Shuttle

3.1.2.2 Orbit and Mission Parameters

- LEO circular, 444 km. Inclination 56°.
  - Orbital period: 87.3 minutes
  - Time in sun: 53.7 minutes, minimum
  - Time in eclipse: 33.6 minutes, maximum
  - Number of eclipses: 60,239–Ten Years

3.1.2.3 Electrical

- 250 kW continuous to loads, provided in 48, 24 or 16 individual power channels to the ESDCS subsystem at the slip ring interface (See Section 3.2.2.1)
- Provide this output from BOL to EOL
- Bus voltage for Users Systems to be:

  30VDC - small, experimental projects (20% of power)

  100-250 VDC-intermediate power projects and other SSPS subsystems (30% of power)

  1000 VDC - manufacturing, processes, large engine testing (50% of power)

3.2 Subsystem Performance and Interface Requirements and Constraints

These requirements apply to the Solar Array Subsystem (SAS) of the Space Services Platform System (SSPS); and have been derived from the system level requirements of Section 3.1.

3.2.1 Electrical Performance and Interface Requirements

3.2.1.1 SAS/ESDCS Electrical Interface

- The SAS shall provide electrical power to the ESDCS for energy storage, distribution and conditioning. The ESDCS will provide the electrical power/energy to the User Systems and other subsystems of the SSPS: SAS, CDS, SMS, TCS, PCS, and OMCS.

- The SAS shall provide electrical power to the ESDCS at the 2 axis drive/slip ring assembly output in accordance with the following table of options:

NUMBER OF POWER CHANNELS	MINIMUM POWER KW PER CHANNEL	MINIMUM VOLTAGE AT SLIP RING OUTPUT
48	10.0	180

- Total power output to the ESDCS shall be 480 kW peak EOL.

3.2.1.2 SAS Power Losses

The total power losses of the array shall not exceed 10%. These losses include:

- assembly factor
- diode drop
- wiring (cell, module panel interconnections and main buses
- slip rings.

3.2.1.3 Degradation Compensation

The SAS shall be designed to achieve a constant electrical power output by varying the angle of incidence of the sun vector on the plane of the array over the 10 year period between overhauls.

3.2.1.4 Environmental Degradation

The SAS shall not exceed 50% degradation of BOL maximum power output (at slip-ring output) under the environment specified in Section 3.2.7.

3.2.2 Structural/Mechanical/Thermal Performance and Interface Requirements and Constraints

3.2.2.1 SAS Structural/Mechanical Performance

- The SAS shall be capable of withstanding orbit changes of altitude and inclination.
- Loads:
  - Perpendicular to plane of array: 0.01 G
  - Parallel to plane of array: 0.01 G
- The SAS array shall be held within ± 10 degrees of planar except during orbit maintenance thrusting.

3.2.2.2 SAS/SMS Interface

The SAS interfaces with the SMS shall be:

- Structural Attachment: The SMS shall provide the mounting assembly which secures the SAS to the SMS structure, at the SAS two axis drive/slip ring assembly.
- Attitude Control Drive Interface: The SMS shall provide the drive power required to implement SAS attitude commands received from the CDS. The interface shall be the two-axis drive assembly shaft at the SMS drive power source. Maximum angular velocity and acceleration required of the SMS drive power source shall be $\omega = 1\ ^{o}/sec$, and $\dot{\omega} = 1^{o}/sec^{2}$ about the axes of pitch and roll, where pitch is motion about the SAS boom axis.

3.2.2.3 SAS/ESDCS Interface

- This mechanical interface shall be the electrical interconnects between the 2 axis drive/slip ring assembly output and the ESDCS.

3.2.2.4 SAS/PCS Interface

- Thruster induced loads shall be consistent with structural/mechanical requirements of Section 3.2.3.1
- Contaminant and charged particle constraints and tolerances shall be TBD.
- Thrusters will be located near the end-boom on the spar axis. These thrusters will be used for orbit maintenance thrusting.

3.2.2.5 SAS/TCS Interface

The SAS thermal control requirements and mechanical interfaces shall be: TBD

3.2.2.6 SAS/CDS Interface

- The SAS shall provide mechanical accommodations for command and data instruments which shall be components of the CDS. The CDS shall provide electrical power for command and data channels which interface with the SAS.
- The command and data channel list for SAS shall be: TBD.
- Communication requirements for space assembly, check-out, operations and maintenance activities will be (TBD).

3.2.2.7 SAS/OMCS Interface

- This interface is covered in Section 3.2.7

3.2.3 Transportation/Transportability

3.2.3.1 The SAS components shall be transportable to space by the Space Shuttle.

3.2.3.2 The SAS shall incorporate fold-up panels for space transportation.

3.2.3.3 The SAS design, as stowed for transportation shall meet the transportation environment specified in Section 3.2.7.

3.2.3.4 The maximum dimensions and total weight including containers, of a single-flight set of SAS components (blankets, structural components, electrical and mechanical interconnects, electrical buses, 2 axis drive/slip ring assembly) shall not exceed: 3.6 meters in diameter, 18 meters in cylindrical length, and 27,000 kg in weight. The CG limits shall be as specified in JSC 07700 Volume XIV.

3.2.4 Life and Reliability

3.2.4.1 The SAS shall be designed for a ten year operational period between blanket change-out with on-orbit scheduled and unscheduled maintenance performed by the OMCS. Over the ten year period, the electrical output shall not degrade due to the natural environment greater than 50% of BOL electrical power output.

3.2.4.2 The design shall be such that failures will be non-proliferating.

3.2.4.3 Reliability specifications shall be subject to life cycle cost trade analyses.

3.2.4.4 The design shall provide that the number of panels whose output is $\leq$ 92% P_o (EOL) shall not exceed 5% of the array area at any one time over the 10 year blanket life.

3.2.4.5 The number of panels changed out for failure shall not exceed 12% of the array area over the 10 year blanket life.

3.2.4.6 Storage life is TBD.

3.2.5 Safety

The SAS design and procedures for all phases of production, earth and space integration, transportation and O&M, shall assure the chance of serious injury or death over a 10 year period is less than one in 10^7 man-hours.

3.2.6 Maintenance/Maintainability

3.2.6.1 Logistics and Spares

The normal supply mode shall be a set of on-hand (in space) spares and materials sufficient for ten year's operation. The spares set shall be delivered by the Space Shuttle.

The OMCS personnel crew shall be changed out every three months. Transport mode shall be Space Shuttle.

3.2.6.2 Overhaul

The SAS shall be designed for array blanket change-out every 10 years.

3.2.6.3 Maintenance

- The SAS blanket shall be modularized for panel removal and replacement with a serviceable spare.
- In place (on-array) repair shall be limited to the panel level or higher.
- In-space, shop repair of panels at panel level or lower shall be: TBD
- Panels shall be considered failed at 90% of P_o(EOL), and shall be changed out.
- The SAS design shall enable repair/replacement (and checkout) time of 24 manhours per modular panel.
- The SAS design shall permit automatic fault isolation to the failed panel(s).
- The Solar Array Subsystem (SAS) shall be capable of assembly and checkout in space. Assembly will include hook-up and attachment to the (SMS) and other subsystems of the SSPS system.

3.2.7 Environment

3.2.7.1 Natural Environment

The design shall meet the requirements of this specification within the natural environment (worst case 20 year prognosis) of the earth orbit range of: 300 to 1900 km, all inclinations. This environment shall include effects due to U.V. radiation, solar flares, trapped radiation and micrometeorites.

3.2.7.2 Transportation Induced

- Earth surface/air transport:
  TBD
- Launch and ascent to LEO
  - Axial acceleration of 5g
  - Lateral acceleration of 0.5g
  - Decaying sinusoidally of 7g at 16 Hz
  - Sinusoidal vibration (three mutually perpendicular directions) ±1 g peak from 2 to 40 Hz
  - Random vibration (gaussian amplitude distribution) 0.1 g^2/Hz from 10 to 60 Hz, 0.4 g^2/Hz from 60 to 2,000 Hz
  - Acoustic noise (decibels re 0.0002 microbar) up to 150 db (3 minutes duration) 45 to 11,200 Hz
- Ascent Venting Profile - TBD

3.2.7.3 Operational Induced

- The induced operational environments shall be as specified in Section 3.2 interface requirements.
- Contaminants - TBD

3.3 Design & Construction

3.3.1 Materials Properties

3.3.1.1 Materials Compatibility

TBD

3.3.1.2 Outgassing

TBD

3.3.1.3 Insulation Resistance

TBD

3.3.1.4 Voltage Breakdown

TBD

3.3.1.5 Contaminants Sources

TBD

3.4 Verification Requirements

The requirements of this specification shall be as specified in Section 4.0, verification. (Section 4.0 is TBD)

3.5 Personnel & Training Requirements

TBD

APPENDIX B

LIFE CYCLE COST DATA

INDIRECT EXPENSES

PRODUCTION PHASE

- Fringe Rate = 32% and includes all fringe benefits.
- Overhead Rate = 125% and includes:
  - Utilities and telephones
  - Depreciation of facilities and capital equipment
  - Maintenance and operations of facilities and equipment
  - Indirect Labor - supervisors, foremen, clerks, typists, secretaries
  - Indirect Labor Fringe Benefits
- Other Direct Charges = 10% and includes computer supplies and expense, travel expense and direct rental equipment expense.
- General and Administrative Rate = 15% and includes: Finance, contracts, personnel, legal services, public relations, and a manager and their associated costs of doing business, taxes and insurance.

OPERATIONS AND MAINTENANCE PHASE

- Fringe Rate = 32% and includes all fringe benefits.
- Overhead Rate = 50% and includes program management, secretarial support and supervision, and use of a test facility as required.
- Other Direct Charges = 10% and includes computer supplies and expense, travel expense and direct rental equipment expense.
- General and Administrative Rate = 15% and includes finance, procurement, contract, legal services, public relations, and a general manager and their associated costs of doing business, taxes and insurance.

LIFE CYCLE COST - DDT&E PHASE
(1980 DOLLARS IN MILLIONS)

$C_{DDT\&E} = .35\ C_{PROD} = 153.9$

LIFE CYCLE COST - PRODUCTION PHASE
(1980 DOLLARS IN MILLIONS)

SAS MANUFACTURING COST

LABOR		NON-LABOR	
DIRECT LABOR	12.8	MATERIALS	99.3
FRINGES	4.0	MATERIALS BURDEN	9.9
OVERHEAD	16.0	EQUIPMENT	141.5
ODC	1.2	EQUIPMENT MAINTENANCE	9.9
SUBTOTAL	34.0	SPECIAL EQUIPMENT	1.0
		SURFACE TRANSPORTATION	0.1
		SUBTOTAL	261.7

TOTAL MANUFACTURING COST

LABOR	34.0
NON-LABOR	261.7
SUBTOTAL	295.7
PROJECT MANAGEMENT	17.2
SE	14.2
SUBTOTAL	327.1
G&A	49.0
TOTAL $	376.1

NASA COST

SHUTTLE TRANSPORTATION	63.0
SPACE ASSEMBLY & CHECKOUT	.8
TOTAL	63.8

TOTAL PRODUCTION PHASE COST

MANUFACTURING	376.1
NASA	68.8
TOTAL	439.9

LIFE CYCLE COST - O&M PHASE
(1980 DOLLARS IN MILLIONS)

CONTRACTOR COST	
DIRECT LABOR $	.4
FRINGES	.1
OVERHEAD	.2
ODC	.1
SUBTOTAL	.8
G&A	.1
TOTAL CONTRACTOR'S COST	.9
NASA INCURRED COST	
TRAIN O&M CREW	2.5
TRANSPORT CREW	146.3
PERFORM MAINTENANCE	11.0
TOTAL NASA INCURRED COST	159.8
TOTAL COST OF O&M PHASE	
CONTRACTOR'S COST	.9
NASA COST	159.8
	160.7

TOTAL LIFE CYCLE COST SUMMARY
(1980 DOLLARS IN MILLIONS)

DDT&E	153.9
PRODUCTION	439.9
O&M	160.7
TOTAL LIFE CYCLE COST	754.5

TOP LEVEL COST RELATIONSHIP SOURCES

- AEROSPACE CORPORATION ADVANCED SPACE POWER REQUIREMENTS & TECHNIQUES
  - HISTORICAL AND PROJECTED DATA
- MSFC COMMON SOLAR ARRAY COST ESTIMATE SUMMARY:
  - CELL, CELL/COVER ASSEMBLY, MODULE ASSEMBLY
- PRC COST ESTIMATING TECHNIQUES FOR MISSION SYSTEM INTEGRATION AND TEST ELEMENTS OF FUTURE SPACE MISSIONS
  - PROJECT MANAGEMENT AND SE
- NASA REPORT TO THE SPECIAL PANEL FOR SPACE EVALUATION:
  - $300/WATT
  - DDT&E = 0.35 PRODUCTION COST
- JSC STS REIMBURSEMENT GUIDE:
  - $31 M/DEDICATED FLIGHT TO 444 km 56° INCLINATION.
- MSFC/JSC TELECONS
  - ASTRONAUT LABOR OF $250 PER MAN-HOUR INCLUDES:
    OVERHEAD, TRAINING, LIFE SUPPORT, DIRECT LABOR
  - SPACE MANEUVERING PLATFORM COST
- LABOR, MATERIALS, PROCESS AND EQUIPMENT SOURCES:
  - BOEING
  - LOCKHEED
  - HUGHES
  - TRW
  - BALL BROTHERS
  - SPECTROLAB
  - OCLI
  - ASTRO RESEARCH
  - HEWLETT-PACKARD
  - 3M
  - REYNOLDS
  - UAL
  - OTHER

APPENDIX C

SOLAR ARRAY PERFORMANCE & COST MODEL PROGRAM

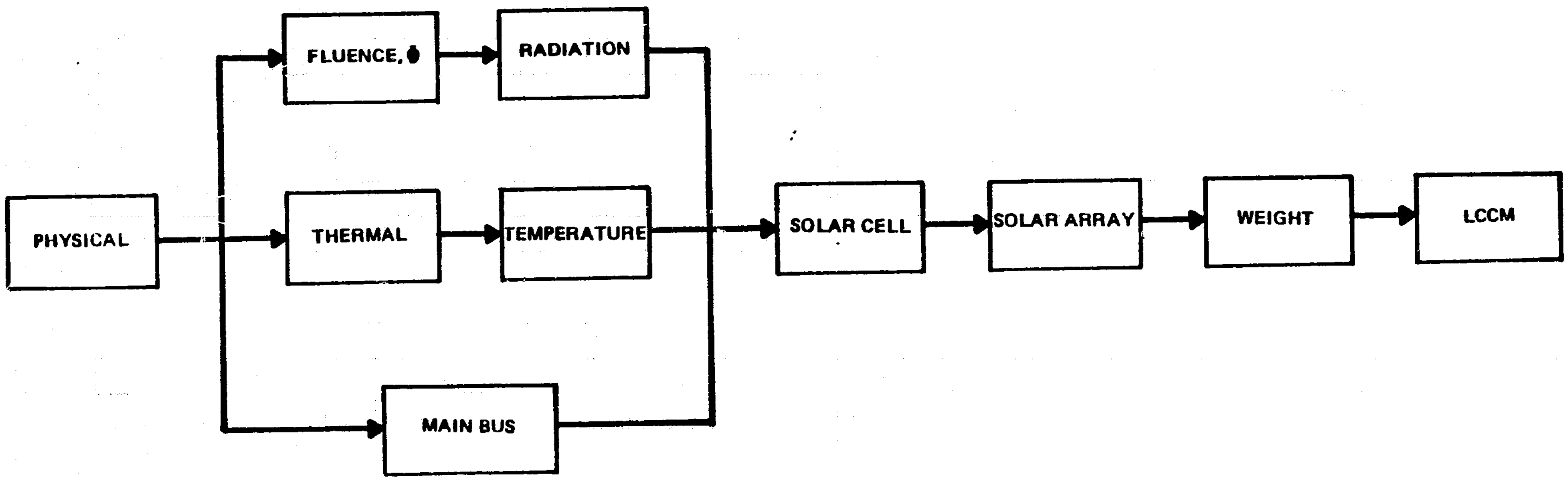


EXHIBIT C-1 BASIC INTERRELATIONSHIP OF SACPM PROGRAM SECTIONS

1.0 INTRODUCTION

The program for the Solar Array Performance and Cost Model (SACPM) is written for the TI-59 programmable calculator with a Master Library module. The total program consists of 4649 steps which are divided into 10 subroutines as indicated in the table below:

PROGRAM SUBROUTINE	PROGRAM STEPS	DATA BASE REGISTERS	PROGRAM BANKS	DATA BASE BANKS	TOTAL BANKS	TOTAL # CARDS
1. Physical	716		3		3	2
2. Fluence, Φ	421	15	2	1	3	2
3. Radiation	344	21	2	1	3	2
4. Thermal	478		2		2	1
5. Temperature	636		3		3	2
6. Main Bus	267		2		2	1
7. Solar Cell	470	30	2	1	3	2
8. Solar Array	478	16	2	1	3	2
9. Weight	461		2		2	1
10. LCCM	378	26	2	1	3	2
	4649	108	22	5	27	17

1.1 Program Description

The SACPM program models the cost-technology relationships of a silicon planar 500 kW (250 kW continuous) space solar array for a LEO Space Platform mission. The modeling approach, generally, is to

- define the solar cell, cover, substrate and cell interconnect circuitry (module cross section)
- determine the value of the solar array factors which affect performance and apply to the BOL cell/cover assembly to determine the EOL per cell array performance.
- determine number of cell/cover assemblies required for baseline orbit and load power/energy requirements

- determine total array area, dimensions and structural requirements (array configuration)
- determine array weight breakdown and totals
- determine life cycle cost.

Exhibit C-1 is a block diagram which shows the basic interrelationship of the SACPM program subroutines. The following paragraphs contain a description of the program subroutines.

1.1.1 Physical

Given the inputs listed below, the physical subroutine of the SACPM program provides the outputs indicated. The exhibit numbers refer to exhibits in the main body of this report which contain the information described.

INPUTS	OUTPUT(S)	EXHIBIT(S)
All Length Cell Width L Distance Between Cells W Distance Between Cells	Cell Area Substrate Area Packing Factor	5.4
Material Thickness Material Density Material Area	Mass/Weight Shielding Thickness	5.4 5.5
Material Mass Material Heat Capacity	Thermal Mass	5.8

1.1.2 Fluence, Φ

The fluence subroutine of the SACPM program computes the equivalent radiation fluence that the solar cell "sees". The total back and front shielding thickness previously computed in the physical subroutine section (Exhibit 5.5) and the orbit altitude provide the inputs for this subroutine section. The fluence environment model is graphically depicted in Exhibit 5-6 of the main body of this report. The front and back fluences are summed to determine the total equivalent fluence.

1.1.3 Radiation

Given the fluence subroutine output described above and the solar cell thickness as inputs to the radiation subroutine, the solar cell radiation performance factors are calculated for power and voltage. The radiation factor modeling for power and voltage is graphically depicted in Exhibit 5-7 of the main body of this report.

1.1.4 Thermal

The thermal subroutine performs the calculations shown in Exhibit 5-9 of the main body of the report. The outputs of this subroutine are inputs to the temperature subroutine.

1.1.5 Temperature

The temperature subroutine uses as inputs the thermal mass profile in Exhibit 5.8 and the thermal calculations in Exhibit 5-9 of the main body of this report. The temperature subroutine calculates temperature profiles of array temperature versus time in orbit, and array average illumination and average temperature during the illuminated portion of the array orbit. Examples of these calculations are contained in Appendix D of this report.

1.1.6 Main Bus

The main bus subroutine provides the input parameters for the following equation:

$$\frac{L}{A} = \sqrt{\frac{P_D \times C_D \times \Sigma L^2}{N \times I^2 \times p}}$$

The equation and its parameters, together with its use in determining the performance factors for the main bus conductor, are described in paragraph 5.2.1.8.5 of the body of this main report.

1.1.7 Solar Cell

The solar cell subroutine performs four functions in conjunction with the solar array parameters as described in paragraph 5.2.1 of the main body of this report. The first function is computation of the EOL maximum power per cell using the basic equation:

$$\text{EOL } P_{mp}\ (W/m^2) = [\ (\eta_{BOL} \times \prod_{i=1}^{11} F_{p_i}) \times (S' \times \prod_{j=1}^{2} F_{p_j}) \times PF] \times A_s$$

The equation and its parameters are discussed in the main body of this report (paragraph 5.2.1).

The second function is calculation of the temperature derating factor using the temperature curves in Exhibit 5-10 of the report's main body. It should be noted that because of the influence of the average illumination, the calculation for the temperature derating power factor is a "two-dimensional" process.

The third function is calculation of the main bus conductor performance factor. This is accomplished as described in paragraph 5.2.1.8.5 of the main body of this report.

The fourth function is calculation of the EOL maximum power and maximum voltage per cell, which are used for array sizing in the solar array subroutine.

1.1.8 Solar Array

The solar array subroutine uses the EOL maximum power and maximum voltage per cell to determine the array configuration and performance. The outputs are the information depicted in Exhibits 2-5, 2-6, 2-7 and 2-18 of the main body of this report.

1.1.9 Weight

The weight subroutine provides the information shown in Exhibits 2-19 and 2-20 of this report, with the exception of array area, which is calculated in the solar array subroutine above.

1.1.10 Life Cycle Cost Model (LCCM)

The block diagram of the LCCM subroutine is shown in Exhibit 4-1 of the main body of this report. The inputs and factors used are summarized in Exhibits 4-4 and 4-5. The output data is summarized in Exhibits 4-3, 4-5, 4-6, and 4-7. A discussion of the LCCM is included in Section 4 and Appendix B of this report.

1.2 Use of SACPM Program

The procedure for using the SACPM program subroutines is given in the following paragraphs. A sample output tape is described in Appendix E. (NOTE: Once the initial partition -- 729.19 -- is set, the program will automatically set the partition for the remaining subroutines if all ten subroutines are used in the sequence listed on the following pages.)

1.2.1 Physical Subroutine (729.19)

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
1. Enter cell length	L	A'	L		
2. Enter distance between cells in L direction	ΔL	B'	ΔL		
3. Enter cell width	W	C'	W		
4. Enter distance between cells in W direction	ΔW	D'	ΔW		
5. Calculate/print area parameters	-	A	-	L	L = Cell length
				ΔL	ΔL = Distance in L direction
				W	W = Cell width
				ΔW	ΔW = Distance in W direction
				A_c	A_c = Cell area
				A_s	A_s = Per-cell substrate area
				PF	PF = Packing factor
6. Enter material thickness	T	C	T		
7. Enter material density	D	D	D		
8. Enter material ID # and calculate physical parameters	ID#	E/E'	-	T	T = Material thickness
(NOTE: Press E to insert				D	D = Material density
material; E' to delete material				M	M = Material Mass
from data base - card bank #4)				A	A = Material Area
				W	W = Material Weight

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
				T	T = Material thickness
				D	D = Material density
				T'	T' = Shielding thickness
				M'	M' = Per cell mass (includes packing factor)
9. Enter material heat capacity profile and calculate thermal mass (NOTE: Repeat step 9 for 9 values of C_p - See Exhibit 5-8)	C_p	R/S	-	C_p MCP ↓ C_p MCP	C_p = Material heat capacity MCP = Thermal mass

Steps 6-9 are repeated for each material. The material ID #'s to be used are as follows:

0 - Cover
0.1 - Cell/cover adhesive
0.X - Cover coating (if applicable)
1 - Cell
1.X - Cell coating (if applicable)
2 - Cell laydown adhesive (if applicable)
3.X - Substrate materials

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
10. Print summation of array parameters	-	B	-	Σ+	
(NOTE: The array component ID #'s are as follows:				L	Per cell area parameters
				ΔL	
1 - Cell/Cover assembly				W	
2 - Cell/Substrate adhesive (if applicable)				ΔW	
				AC	
3 - Substrate				AS	
5 - Module assembly (includes packing factor)				PF	
				ID#	Parameters for array components e.g., cell/cover assembly, substrate, module
				T	
				D	
(NOTE: The radiation shielding ID #'s are as follows:				M	
				A	
7 - Front shielding				W	
8 - Back shielding				ID#	Parameters for radiation shielding e.g., front and back
				T	
				D	
				T'	
				R_{21} ↓ R_{29}	R_{21} - R_{29} are parameters for thermal mass profile

1.2.2 Use of Fluence Subroutine (719.29)

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
1. Enter orbit altitude (NOTE: Enter KM at A; NM at A')	Alt	A/A'	KM		
Step 1 changes partition from 719.29 to 479.59					
2. Enter lifetime of array (2.5, 5 years) (NOTE: This step is not required if array lifetime = baseline array lifetime = 10 years.)	Yrs	B	Yrs		
3. Calculate/print total fluence	-	C	-	KM	KM = Altitude in KM
(NOTE: This step uses the front and back shielding thicknesses calculated (and stored) during the physical subroutine.)				YRS	YRS = Array lifetime
				T'	T' = Shielding thickness
				F	F = Fluence
				T'	(Prints fluence for both front
				F	and back shielding thickness)
				ΣF	ΣF = Total fluence

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
3a. Calculate/print fluence for manually entered shielding thickness parameter (NOTE: This function calculates fluence for any input value of shielding thickness (1 mil = T' $\leq$ 18 mils). It is not intended for use in conjunction with outputs from the subroutine.)	T'	D/D'	-	KM YRS T' F	D' input does not print KM, YRS (KM, YRS entered in steps 1 and 2 respectively)
3b. Calculate/print fluence profile (T' = 1, 2, 3...18 mils) (NOTE: This function provides a fluence profile for values of T' from 1 mil to 18 mils in steps of 1 mil)	-	E	-	KM YRS T' F	Entered in step 1 Entered in step 2 Repeats for T' = 1, 2, 3 ...18

1.2.3 Use of Radiation Subroutine (479.59)

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
1. Enter cell thickness (NOTE: This step is not required if cell thickness = baseline cell thickness = 8 mil.)	t	B	t		

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
2. Calculate/print solar cell performance factors	-	C	-	"RAD"	
				CT	CT = Cell thickness
				ΣF	ΣF = Total fluence
				FP	FP = Power performance factor
				FV	FV = Voltage performance factor
2a. Enter fluence and calculate/print solar cell performance factors	ΣF	D/D'	-	"RAD"	D input does not print "RAD" and CT (CT entered in step 1)
(NOTE: This function calculates the solar cell power and voltage performance factors for any input value of fluence ($1 \leq \Sigma F \leq 1000$) - see Exhibit 5-7. The function is not intended use in conjunction with outputs from the fluence subroutine.)				CT	
				ΣF	
				FP	
				FV	
2b. Calculate/print radiation performance factor profiles (ΣF = 1, 10, 20, 40, 100, 200, 400, 1000)	-	E	-	"RAD"	
				CT	Entered in step 1

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
(NOTE: This function provides a fluence profile for values of fluence from 1 to 1000 (10^3 to 10^{16}) in the steps indicated above.)				ΣF FP FV	Repeats for ΣF = 1, 10, 20, 40, 100, 200, 400, 1000
1.2.4 Use of Thermal Subroutine (479.59)					
(NOTE: To perform entire subroutine operation using only baseline numbers, press SBR SUM.)					
1. Calculate/print orbit parameters	-	A	-	"O" KM Θ a b	O = ID # KM = Orbit altitude Θ = Reference angle (used in calculations) a = Total orbit period b = Period of illumination
(NOTE: To enter orbit altitude if not entered previously during fluence subroutine, enter alt. in NM and press SBR INV or in KM and press SBR X/T.)					
2. Enter α cover	α_1	B	α_1		
3. Enter α substrate	α_2	C	α_2		

C-12

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
4. Calculate/print $\overline{\alpha}_F$ array front	-	A'	-	"1"	1 = ID #
(NOTE: To enter packing factor if not entered previously during physical subroutine, enter PF and press SBR lnx.)				α_1	α_1 = α cover
				PF	PF = Packing factor
				α_2	α_2 = α substrate
				(1-PF)	
				$\overline{\alpha}_F$	$\overline{\alpha}_F$ = Composite absorptivity for front of array
5. Enter estimated EOL solar cell power loss factor	$\overline{F}_p$	B	$\overline{F}_p$		
6. Enter solar cell BOL efficiency	η_{BOL}	C	η_{BOL}		
7. Calculate/print array electrical power density	-	B'	-	"2"	2 = ID #
				PF	PF = Packing factor
				$\overline{F}_p$	$\overline{F}_p$ = EOL loss factor
				η_{BOL}	η_{BOL} = BOL efficiency
				q_E	q_E = Array electrical power density (W/m^2)

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
8. Enter α back and calculate/print $\bar{\alpha}_{SF} = \bar{\alpha} - q_E$	α_B	C'	-	"3"	3 = ID #
				α_B	$\alpha_B = \alpha$ back
				$\bar{\alpha}_{SF}$	$\bar{\alpha}_{SF}$ = effective $\bar{\alpha}$ front
9. Enter ε cover	ε_1	B	ε_1		
10. Enter ε substrate	ε_2	C	ε_2		
11. Calculate/print $\bar{\varepsilon}_F$ array front	-	D'	-	"4"	4 = ID #
(NOTE: To perform steps 12 thru 17 using <u>only</u> <u>baseline numbers</u>, enter $\varepsilon_B = .8$ and press SBR RCL.)				ε_1	$\varepsilon_1 = \varepsilon$ cover
				PF	PF = Packing factor
				ε_2	$\varepsilon_2 = \varepsilon$ substrate
				(1-PF)	$\bar{\varepsilon}_F$ = Composite emissivity for front of array
				$\bar{\varepsilon}_F$	
12. Enter α space platform	α_{SP}	SBR lnx	α_{SP}		
13. Enter cos Γ_4 (Γ_4 = "look angle" from array to space platform)	cos Γ_4	B	cos Γ_4		
14. Enter cos Γ_5 (Γ_5 = "look angle" from space platform to array)	cos Γ_5	C	cos Γ_5		

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
15. Enter space platform temperature	^oC	D	^oC		
16. Enter back emissivity adjustment factor (if $\neq .75$) (NOTE: The adjustment factor estimates the effect of solar cell interconnects on array back emissivity.)	f	SBR CE	f		
17. Enter ε array back material and calculate/print thermal parameters	ε_B	E	-	"5"	"5" = ID #
				ε_B	ε_B = ε array back material
				f	f = Back emissivity adjustment factor
				$\bar{\varepsilon}_B$	$\bar{\varepsilon}_B$ = Composite emissivity for back of array
				α_{SP}	α_{SP} = Absorptivity of thermal energy from space platform
				$\cos \Gamma_4$	Γ_4 = "look angle" from array to space platform
				$\cos \Gamma_5$	Γ_5 = "look angle" from space platform to array

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
				q_{SP}	q_{SP} = Thermal energy absorbed from space platform
				^oC	^oC = Space platform temperature
				R8 ↓ R29	R_8 thru R_{29} - Various parameters used for calculation of array temperature profile using temperature subroutine.
17a. Enter ε array back material and calculate/print thermal parameters	ε_B	E'	-		(Same as step 17 except α_{SP}, cos Γ_4 and cos Γ_5 are omitted)
(NOTE: Step 17a is an alternate to steps 12 thru 17 for q_{SP} = .025 and ^oC = 50. If the adjustment factor f ≠ .75, step 16 must be performed prior to performing step 17a.					

1.2.5 Use of Temperature Subroutine (639.39)

See Appendix D

(NOTE: Use of thermal subroutine prior to use of this subroutine will properly set partition for this subroutine.

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
(NOTE: To start temperature profile at beginning of orbit eclipse period, enter period of illumination b at A before performing the following steps.)	(b)	(A)	(b)		
1. Enter average illumination	$\overline{S}$	B	$\overline{S}$		(NOTE: t, S', T are printed respectively for orbit period of illumination. t, T only are printed respectively for orbit period of eclipse.)
2. Enter temperature (NOTE: Enter ^oK at C; ^oC at C'.)	T	C/C'	T		
3. Calculate/print temperature profile	-	E/E'	-	t S' T	t = time in Orbit period S' = effective illumination (includes albedo effect) at time t in orbit T = Array temperature at time t in orbit
(NOTE: Pressing E starts profile at the beginning of the orbit illumination period. Pressing E' starts profile at the end of the orbit illumination period (beginning of orbit eclipse period.)				$\overline{S'}$	$\overline{S'}$ = Average effective illumination for total orbit period of illumination
				$\overline{T}$	$\overline{T}$ = Average array temperature for total orbit period of illumination
				t T	

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
4. Print data base	-	D	-	R_8 ↓ R_{29}	R_8 thru R_9 is data base for temperature subroutine.
1.2.6 Use of Main Bus Subroutine (639.39)					
(NOTE: To perform entire subroutine operation using only baseline numbers, press SBR SUM. This also stores baselines values for solar cell efficiency and maximum voltage.))					
1. Change partition	-	A	0		Changes partition to 479.59
(NOTE: Use step 2 if main bus subroutine is used in conjunction with parameters calculated by physical subroutine. To enter new new numbers, use steps 2a and 26.)					
2. Compute/store per-cell module area and weight	-	B	-		Uses as inputs, area and weight parameters calculated by physical subroutine.
2a. Store per-cell module area	A_s	A'	A_s		A_s = per-cell module area

	PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
2b.	Store per-cell module weight	W_S	B'	W_S		W_S = per-cell module weight
3.	Store density of main bus conductor	C_D	C'	C_D		C_D = conductor density
4.	Store resitivity of main bus conductor	p	C	p		p = conductor resitivity
	(NOTE: Use step 5 if main bus subroutine is used in conjunction with parameters calculated by solar array subroutine. To enter new numbers, use steps 5a - 5c.)					
5.	Compute/print ΣL^2	-	D^1	-	L_1 $(L_1)^2$ ↓ L_N $(L_N)^2$ ΣL^2	L = Length of one bus conductor N = Number of conductor pairs/blanket ΣL^2 = Sum of squares of all bus conductor lengths
5a.	Enter number of channels for total array	n_c	SBR CE	n_c		n_c = # channels/array

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
5b. Enter number of panels/ channel	n_p	SBR lnx	n_p		n_p = # of panels/channel
5c. Enter length folded blanket and compute/ store ΣL^2 (NOTE: Use only step 6 if main bus subroutine is used in conjunction with parameters calculated by solar array subroutine. To enter new number, use step 5a before step 6.)	w_p	D	ΣL^2	(Same as for step 5)	w_p = width of panel
6. Compute/store number of conductor pairs/blanket (NOTE: Use only step 7 if main bus subroutine is used in conjunction with parameters calculated by solar array subroutine. To enter new number, use steps 5b and 7a before step 7.)	-	E	N		N = Number of conductor pairs/ blanket

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
7. Enter number of cells in series per ½-module and compute/store total number of cells in series per channel	S_M	E'	S_C		S_M = Number of cells in series/ ½-module S_C = Number of cells in series/ channel
7a. Enter number of ½ modules/panel	N_M	SBR INV	N_M		N_M = # of panels/channel
8. Print stored parameters	-	SBR RCL	-	R_8 ↓ R_{29}	R_8 - R_{29} contain parameters for use as inputs to solar cell subroutine.

1.2.7 Use of Solar Cell Subroutine (479.59)

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
1. Store solar cell BOL efficiency	η_{BOL}	D'	η_{BOL}		η_{BOL} = BOL solar cell efficiency
2. Store solar cell BOL maximum voltage	$V_{mp(BOL)}$	E'	$V_{mp(BOL)}$		Vmp(BOL)= BOL solar cell maximum voltage

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
3. Store average illumination during orbit period from temperature subroutines	$\overline{S'}$	A	$\overline{S'}$		$\overline{S'}$ = average illumination during orbit period from temperature subroutine
4. Store average temperature during orbit period from temperature subroutine	$\overline{T}$	B			$\overline{T}$ = average temperature during orbit period from temperature subroutine
(NOTE: Step 5 must be performed twice. Once for EOL cell efficiency at minimum average illumination/temperature and once for EOL maximum voltage at maximum average illumination/temperature.)					
5. Compute/print solar cell EOL efficiency/maximum voltage	–	C	Fp(Vmb)*	η_{EOL}	η_{EOL} = EOL solar cell efficiency
	Fp(V)	↓		$\overline{S'}$	$\overline{S'}$ = average temperature during orbit period from temperature subroutine
(NOTE: To initiate computation press C. Then compare displayed $Fp(V_{mb})$* with printed $Fp(V_{mb})$*. If ≠, recompute by pressing E or by entering the Fp(Vmb)* value and pressing D.)		D or E		F_G	F_G = glassing factor
				F_τ	F_τ = cell cover degradation factor
				$\overline{S'}$	$\overline{S'}_{EOL}$ = EOL effective illumination
				$\overline{T}$	
				$\overline{T}_{op}$	

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
					$\overline{T}$ = average temperature during orbit period from temperature subroutine
				Fp($\overline{T}op$)	
				Fp(A)	
				Fp(V_D)	$\overline{T}_{op}$ = EOL average operating temperature
				Fp(V_{SC})	
				Fp(V_{MM})	Fp( ) = solar cell power performance factors (see below for specific factor)
				Fp(V_{PP})	
				Fp(V_{mb})*	
				Fp(V_{sr})	Fv( ) = solar cell voltage performance factors (see below for specific factor)
				Fp(Leak)	
				Fp(tc)	
				Fp(Rad)	A = assembly factor
				Fp(Π)	V_D = blocking diode voltage factor
				Fv($\overline{T}_{op}$)	V_{SC} = solar cell electrical interconnect voltage factor
				Fv(A)	
				Fv(V_D)	V_{MM} = module/module electrical interconnect voltage factor
				Fv(V_{SC})	
				Fv(V_{MM})	V_{PP} = panel/panel electrical interconnect voltage factor
				Fv(V_{PP})	
				Fv(V_{mb})	V_{mb} = main bus conductor voltage factor
				Fv(V_{sr})	
				Fv(Leak)	V_{sr} = slip ring conductor voltage factor
				Fv(tc)	
					Leak = High voltage leakage factor

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
				$Fv(Rad)$	tc = temperature cycling factor
				$Fv(\Pi)$	Rad = radiation degradation factor
				P_{mp} EOL	Π = product of all individual factors
(NOTE: To change stored factors, use steps 6-8.)				V_{mp} EOL	$P_{mp\ EOL}$ = EOL solar cell maximum power
					$V_{mp\ EOL}$ = EOL solar cell maximum voltage
6. Enter Fp( ) or glassing factor	Fp( ) F_G	A'	Fp( ) F_G		Fp( ) = solar cell power performance factor F_G = glassing factor
7. Enter F_V( ) or cover degradation factor	F_V( ) F_τ	B'	F_V( ) F_τ		F_V( ) = solar cell voltage performance factor
8. Enter ID # and store factors	#	C'	-		

(NOTE: ID #'s for the various factors are as follows:)

ID #	FACTOR
0	F_G/F_τ
1	$\overline{T}_{op}$
2	A
3	V_D

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
4 V_{SC}					
5 V_{MM}					
6 V_{PP}					
7 V_{mb}					
8 V_{sr}					
9 Leak					
10 tc					
-21 Rad					

1.2.8 Use of Solar Array Subroutine (479.59)

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
1. Store EOL solar cell maximum power	$P_{mp(EOL)}$	A	$P_{mp(EOL)}$		
2. Store EOL solar cell maximum voltage	$V_{mp(EOL)}$	B	$V_{mp(EOL)}$		
3. Compute/print solar array configuration		C		W	Cell power
				V	Cell voltage
				S	# cells in series
				//	# cells in parallel
				C	# cells/½-module
				W	½-module power
				V	½-module voltage
				X	# cells in L direction/module
				Y	# cells in W direction/module
				C	# cells/module

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
				M	Module width
				M	Module length
				M^2	Module area
				KG	Weight of module solar cells
				KG	Weight of module substrate
				KG	Total module weight
				W	Panel power
				V	Panel voltage
				M	Panel length
				M	Panel width
				W	Channel power
				V	Channel voltage
				W	Blanket power
				V	Blanket voltage
				M	Folded blanket length
				M	Blanket width
				M	Unfolded blanket length
				W	Wing power
				V	Wing Voltage
				W	Total array power
				V	Array bus voltage
				M^2	Total array area
1.2.9 Use of Weight Subroutine (479.59)					
1. Compute/print array weights, W/m^2 and W/KG	C			"WEIGHT"	Weights as follows:

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
				MOD	Module total/panel
				EIC1	Electrical interconnects
				PAN	Total/panel
				PAN	Panel total/blanket
				MEIC	Panel/panel mechanical interconnect
				END	Blanket end pieces (2)
				EIC	Panel/panel electrical interconnects
				BLKT	Total blanket
				BLKT	Blanket total/array
				MB	Main bus conductors
				STR	Structure total
				TOT	Total array weight
				W/m^2	Total array W/m^2
				W/KG	Total array W/KG
				R_{12} ↓ R_{59}	Stored data base -- various array parameters
2 Print data base		D		R_{12} ↓ R_{59}	

1.2.10 Use of LCCM Subroutine (479.59)

(NOTE: If solar cell, cover or cell/cover assembly component costs ≠ baseline numbers, use step 1a, 1b, or 1c as appropriate.)

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
1a. Enter solar cell unit cost	$\$_{sc}$	B	$\$_{sc}$		$\$_{sc}$ = Solar cell unit cost
1b. Enter cover unit cost	$\$_{c}$	B'	$\$_{c}$		$\$_{c}$ = Cover unit cost
1c. Enter cell/cover assembly unit cost	$\$_{CCA}$	SBR INV	$\$_{CCA}$		$\$_{CCA}$ = Cell/cover assembly unit cost
2. Compute/print life cycle cost		C		R_{53}	Total # solar cells
				R_{54}	Total area of module substrate
				R_{55}	Total # modules
				R_{56}	Total # panels
				R_{57}	Weight of structures & main bus
				R_{58}	Combined weight of blankets
				R_{59}	Weight/panel
				$R_4 \downarrow R_{29}$	LCCM cost factors
					Labor $ in millions
				L_1	L_1 = Blanket assembly
				L_2	L_2 = Cell/cover assembly
				L_3	L_3 = Module substrate
				L_4	L_4 = Module assembly
				L_5	L_5 = Panel assembly
				L_6	L_6 = Structure packaging

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
				L_7	L_7 = Blanket packaging
				L_T	L_T = Total Labor $
					Material $ in Millions
				M_1	M_1 = Blanket assembly
				M_2	M_2 = Cell/cover assembly
				M_3	M_3 = Module substrate
				M_4	M_4 = Module assembly
				M_5	M_5 = Panel assembly
				M_6	M_6 = Structure
				M_T	M_T = Total Material $
				"LCCM"	LCC $ in Millions
				35	Manufacturing direct labor
				36	Total Labor (w/burden)
				37	Manufacturing materials
				38	Materials burden
				39	Manufacturing equipment
				40	Equipment maintenance
				41	Manufacturing special equipment
				42	Surface transportation
				43	Total manufacturing non-labor
				44	Manufacturing subtotal
				45	Total manufacturing (contractor)
				46	Space transportation
				47	Space assembly/checkout
				48	Total NASA (production)
				49	Total production phase

PROCEDURE	ENTER	PRESS	DISPLAY	PRINT	REMARKS
				50	Total DDT&E phase
				51	Direct labor (O&M)
				52	Labor subtotal (O&M)
				53	Total contractor (O&M)
				54	Crew training (O&M)
				55	Crew Transport (O&M)
				56	Perform Maintenance (O&M)
				57	Total NASA (O&M)
				58	Total O&M phase
				59	Total LCC

TITLE PHYSICAL PAGE 1 OF 5

TI Programmable Coding Form

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	50	I×I	
002	44	SUM	
003	18	18	
004	32	X:T	
005	44	SUM	
006	17	17	
007	61	GTO	
008	55	÷	
009	76	LBL	
010	57	ENG	
011	44	SUM	
012	16	16	
013	32	X:T	
014	44	SUM	
015	15	15	
016	61	GTO	
017	53	(	
018	76	LBL	
019	58	FIX	
020	44	SUM	
021	14	14	
022	32	X:T	
023	44	SUM	
024	13	13	
025	61	GTO	
026	53	(	
027	76	LBL	
028	43	RCL	
029	73	RC*	
030	00	00	
031	87	IFF	
032	00	00	
033	30	TAN	
034	53	(	
035	43	RCL	
036	12	12	
037	85	+	
038	43	RCL	
039	14	14	
040	85	+	
041	43	RCL	
042	16	16	
043	54	)	
044	76	LBL	
045	30	TAN	
046	92	RTN	
047	76	LBL	
048	23	LNX	
049	03	3	
050	07	7	
051	69	OP	
052	04	04	
053	43	RCL	
054	09	09	

LOC	CODE	KEY	COMMENTS
055	87	IFF	
056	04	04	
057	49	PRD	
058	94	+/-	
059	76	LBL	
060	49	PRD	
061	98	ADV	
062	69	OP	
063	06	06	
064	92	RTN	
065	76	LBL	
066	16	A'	
067	42	STO	
068	01	01	
069	92	RTN	
070	76	LBL	
071	17	B'	
072	42	STO	
073	02	02	
074	92	RTN	
075	76	LBL	
076	18	C'	
077	42	STO	
078	03	03	
079	92	RTN	
080	76	LBL	
081	19	D'	
082	42	STO	
083	04	04	
084	92	RTN	
085	76	LBL	
086	11	A	
087	02	2	
088	07	7	
089	69	OP	
090	04	04	
091	43	RCL	
092	01	01	
093	98	ADV	
094	69	OP	
095	06	06	
096	85	+	
097	07	7	
098	05	5	
099	02	2	
100	07	7	
101	69	OP	
102	04	04	
103	43	RCL	
104	02	02	
105	69	OP	
106	06	06	
107	95	=	
108	65	×	
109	53	(	

LOC	CODE	KEY	COMMENTS
110	04	4	
111	03	3	
112	69	OP	
113	04	04	
114	43	RCL	
115	03	03	
116	69	OP	
117	06	06	
118	85	+	
119	07	7	
120	05	5	
121	04	4	
122	03	3	
123	69	OP	
124	04	04	
125	43	RCL	
126	04	04	
127	69	OP	
128	06	06	
129	95	=	
130	58	FIX	
131	03	03	
132	52	EE	
133	22	INV	
134	52	EE	
135	42	STO	
136	06	06	
137	43	RCL	
138	01	01	
139	65	×	
140	43	RCL	
141	03	03	
142	95	=	
143	52	EE	
144	22	INV	
145	52	EE	
146	22	INV	
147	58	FIX	
148	42	STO	
149	05	05	
150	01	1	
151	03	3	
152	01	1	
153	05	5	
154	69	OP	
155	04	04	
156	43	RCL	
157	05	05	
158	69	OP	
159	06	06	

MERGED CODES

62 63 64 72 73 74 83 84 92

TEXAS INSTRUMENTS INCORPORATED

TI-24161

TITLE PHYSICAL PAGE 2 OF 5 **TI Programmable Coding Form**

PROGRAMMER ____________ DATE ____________

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	55	÷		215	68	NOP		270	52	EE	
161	01	1		216	22	INV		271	22	INV	
162	03	3		217	76	LBL		272	52	EE	
163	03	3		218	68	NOP		273	22	INV	
164	06	6		219	86	STF		274	58	FIX	
165	69	OP		220	00	00		275	42	STO	
166	04	04		221	32	X:T		276	08	08	
167	43	RCL		222	01	1		277	03	3	
168	06	06		223	67	EQ		278	00	0	
169	69	OP		224	69	OP		279	69	OP	
170	06	06		225	22	INV		280	04	04	
171	95	=		226	76	LBL		281	43	RCL	
172	58	FIX		227	69	OP		282	08	08	
173	03	03		228	86	STF		283	69	OP	
174	52	EE		229	01	01		284	06	06	
175	22	INV		230	02	2		285	65	×	
176	52	EE		231	67	EQ		286	01	1	
177	22	INV		232	79	x̄		287	03	3	
178	58	FIX		233	22	INV		288	69	OP	
179	42	STO		234	76	LBL		289	04	04	
180	07	07		235	79	x̄		290	43	RCL	
181	03	3		236	86	STF		291	06	06	
182	03	3		237	02	02		292	87	IFF	
183	02	2		238	03	3		293	03	03	
184	01	1		239	67	EQ		294	22	INV	
185	69	OP		240	89	π		295	43	RCL	
186	04	04		241	22	INV		296	05	05	
187	43	RCL		242	76	LBL		297	76	LBL	
188	07	07		243	89	π		298	22	INV	
189	69	OP		244	86	STF		299	69	OP	
190	06	06		245	03	03		300	06	06	
191	92	RTN		246	71	SBR		301	55	÷	
192	76	LBL		247	23	LNX		302	01	1	
193	13	C		248	65	×		303	00	0	
194	42	STO		249	32	X:T		304	95	=	
195	09	09		250	01	1		305	58	FIX	
196	92	RTN		251	06	6		306	04	04	
197	76	LBL		252	69	OP		307	52	EE	
198	14	D		253	04	04		308	22	INV	
199	42	STO		254	43	RCL		309	52	EE	
200	10	10		255	10	10		310	22	INV	
201	92	RTN		256	69	OP		311	58	FIX	
202	76	LBL		257	06	06		312	42	STO	
203	10	E'		258	65	×		313	08	08	
204	22	INV		259	02	2		314	87	IFF	
205	76	LBL		260	05	5		315	02	02	
206	15	E		261	04	4		316	58	FIX	
207	86	STF		262	52	EE		317	87	IFF	
208	04	04		263	07	7		318	03	03	
209	98	ADV		264	94	+/-		319	57	ENG	
210	98	ADV		265	22	INV					
211	99	PRT		266	52	EE					
212	59	INT		267	95	=					
213	29	CP		268	58	FIX					
214	67	EQ		269	04	04					

MERGED CODES

TEXAS INSTRUMENTS INCORPORATED

TITLE PHYSICAL PAGE 3 OF 5 **TI Programmable Coding Form**

PROGRAMMER ____ DATE ____

LOC	CODE	KEY	COMMENTS
320	44	SUM	
321	12	12	
322	32	X:T	
323	44	SUM	
324	11	11	
325	76	LBL	
326	53	(	
327	04	4	
328	03	3	
329	69	OP	
330	04	04	
331	43	RCL	
332	08	08	
333	69	OP	
334	06	06	
335	71	SBR	
336	23	LNX	
337	65	×	
338	32	X:T	
339	01	1	
340	06	6	
341	69	OP	
342	04	04	
343	53	(	
344	43	RCL	
345	10	10	
346	22	INV	
347	87	IFF	
348	01	01	
349	33	X²	
350	65	×	
351	93	.	
352	03	3	
353	07	7	
354	05	5	
355	54	)	
356	58	FIX	
357	00	00	
358	52	EE	
359	22	INV	
360	52	EE	
361	22	INV	
362	58	FIX	
363	76	LBL	
364	33	X²	
365	69	OP	
366	06	06	
367	55	÷	
368	02	2	
369	02	2	
370	00	0	
371	00	0	
372	95	=	
373	58	FIX	
374	02	02	
375	52	EE	
376	22	INV	
377	52	EE	
378	22	INV	
379	58	FIX	
380	87	IFF	
381	00	00	
382	50	I×I	
383	44	SUM	
384	20	20	
385	32	X:T	
386	44	SUM	
387	19	19	
388	76	LBL	
389	55	÷	
390	03	3	
391	07	7	
392	06	6	
393	05	5	
394	69	OP	
395	04	04	
396	32	X:T	
397	69	OP	
398	06	06	
399	43	RCL	
400	08	08	
401	55	÷	
402	43	RCL	
403	06	06	
404	65	×	
405	01	1	
406	00	0	
407	95	=	
408	58	FIX	
409	04	04	
410	52	EE	
411	22	INV	
412	52	EE	
413	22	INV	
414	58	FIX	
415	42	STO	
416	08	08	
417	02	2	
418	00	0	
419	42	STO	
420	00	00	
421	03	3	
422	00	0	
423	87	IFF	
424	03	03	
425	34	√X	
426	03	3	
427	00	0	
428	06	6	
429	05	5	
430	76	LBL	
431	34	√X	
432	69	OP	
433	04	04	
434	43	RCL	
435	08	08	
436	98	ADV	
437	69	OP	
438	06	06	
439	92	RTN	
440	76	LBL	
441	35	1/X	
442	32	X:T	
443	01	1	
444	05	5	
445	03	3	
446	03	3	
447	69	OP	
448	04	04	
449	32	X:T	
450	69	OP	
451	06	06	
452	65	×	
453	03	3	
454	00	0	
455	01	1	
456	05	5	
457	03	3	
458	03	3	
459	69	OP	
460	04	04	
461	43	RCL	
462	08	08	
463	95	=	
464	58	FIX	
465	00	00	
466	52	EE	
467	22	INV	
468	52	EE	
469	22	INV	
470	58	FIX	
471	69	OP	
472	06	06	
473	69	OP	
474	20	20	
475	74	SM*	
476	00	00	
477	92	RTN	
478	61	GTO	
479	35	1/X	

MERGED CODES

62	72 STO	83 GTO
63	73 RCL	84
64	74 SUM	92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

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TITLE PHYSICAL PAGE 4 OF 5

PROGRAMMER DATE

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
480	76	LBL		535	52	EE		590	69	OP	
481	45	YX		536	07	7		591	06	06	
482	42	STO		537	94	+/-		592	65	×	
483	09	09		538	22	INV		593	02	2	
484	35	1/X		539	52	EE		594	02	2	
485	65	×		540	95	=		595	00	0	
486	71	SBR		541	58	FIX		596	00	0	
487	43	RCL		542	00	00		597	95	=	
488	65	×		543	52	EE		598	32	X:T	
489	01	1		544	22	INV		599	01	1	
490	00	0		545	52	EE		600	06	6	
491	95	=		546	22	INV		601	69	OP	
492	58	FIX		547	58	FIX		602	04	04	
493	04	04		548	69	OP		603	32	X:T	
494	52	EE		549	06	06		604	58	FIX	
495	22	INV		550	03	3		605	00	00	
496	52	EE		551	00	0		606	69	OP	
497	22	INV		552	69	OP		607	06	06	
498	58	FIX		553	04	04		608	22	INV	
499	42	STO		554	43	RCL		609	58	FIX	
500	10	10		555	10	10		610	03	3	
501	55	÷		556	69	OP		611	07	7	
502	03	3		557	06	06		612	06	6	
503	07	7		558	01	1		613	05	5	
504	69	OP		559	03	3		614	69	OP	
505	04	04		560	69	OP		615	04	04	
506	69	OP		561	04	04		616	69	OP	
507	30	30		562	43	RCL		617	20	20	
508	73	RC*		563	09	09		618	73	RC*	
509	00	00		564	69	OP		619	00	00	
510	87	IFF		565	06	06		620	69	OP	
511	00	00		566	04	4		621	06	06	
512	48	EXC		567	03	3		622	92	RTN	
513	53	(		568	69	OP		623	76	LBL	
514	43	RCL		569	04	04		624	12	B	
515	11	11		570	69	OP		625	86	STF	
516	85	+		571	20	20		626	00	00	
517	43	RCL		572	71	SBR		627	07	7	
518	13	13		573	43	RCL		628	07	7	
519	85	+		574	69	OP		629	04	4	
520	43	RCL		575	06	06		630	07	7	
521	15	15		576	92	RTN		631	52	EE	
522	54	)		577	76	LBL		632	06	6	
523	76	LBL		578	70	RAD		633	22	INV	
524	48	EXC		579	73	RC*		634	52	EE	
525	69	OP		580	00	00		635	98	ADV	
526	06	06		581	55	÷		636	98	ADV	
527	55	÷		582	03	3		637	69	OP	
528	01	1		583	07	7		638	00	00	
529	06	6		584	69	OP		639	69	OP	
530	69	OP		585	04	04					
531	04	04		586	69	OP					
532	02	2		587	30	30					
533	05	5		588	73	RC*					
534	04	4		589	00	00					

MERGED CODES
62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24191

TITLE PHYSICAL PAGE 5 OF 5

TI Programmable Coding Form

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
640	03	03	
641	69	OP	
642	05	05	
643	11	A	
644	01	1	
645	98	ADV	
646	99	PRT	
647	01	1	
648	02	2	
649	42	STO	
650	00	00	
651	43	RCL	
652	05	05	
653	71	SBR	
654	45	YX	
655	29	CP	
656	43	RCL	
657	13	13	
658	67	EQ	
659	60	DEG	
660	02	2	
661	98	ADV	
662	99	PRT	
663	01	1	
664	04	4	
665	42	STO	
666	00	00	
667	43	RCL	
668	05	05	
669	71	SBR	
670	45	YX	
671	76	LBL	
672	60	DEG	
673	03	3	
674	98	ADV	
675	99	PRT	
676	01	1	
677	06	6	
678	42	STO	
679	00	00	
680	43	RCL	
681	06	06	
682	71	SBR	
683	45	YX	
684	22	INV	
685	86	STF	
686	00	00	
687	05	5	
688	98	ADV	
689	99	PRT	
690	43	RCL	
691	06	06	
692	71	SBR	
693	45	YX	
694	01	1	

LOC	CODE	KEY	COMMENTS
695	08	8	
696	42	STO	
697	00	00	
698	07	7	
699	98	ADV	
700	99	PRT	
701	71	SBR	
702	70	RAD	
703	02	2	
704	44	SUM	
705	00	00	
706	08	8	
707	98	ADV	
708	99	PRT	
709	71	SBR	
710	70	RAD	
711	98	ADV	
712	02	2	
713	01	1	
714	22	INV	
715	90	LST	
716	92	RTN	
717	00	0	
718	00	0	
719	00	0	

MERGED CODES
62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE FLUENCE Φ PAGE 1 OF 3

TI Programmable Coding Form

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	99	PRT	
002	02	2	
003	06	6	
004	03	3	
005	00	0	
006	69	OP	
007	04	04	
008	43	RCL	
009	13	13	
010	98	ADV	
011	98	ADV	
012	69	OP	
013	06	06	
014	04	4	
015	05	5	
016	03	3	
017	05	5	
018	03	3	
019	06	6	
020	69	OP	
021	04	04	
022	43	RCL	
023	45	45	
024	69	OP	
025	06	06	
026	92	RTN	
027	76	LBL	
028	69	OP	
029	73	RC*	
030	00	00	
031	42	STO	
032	32	32	
033	59	INT	
034	55	÷	
035	01	1	
036	00	0	
037	95	=	
038	69	OP	
039	29	29	
040	72	ST*	
041	09	09	
042	92	RTN	
043	76	LBL	
044	60	DEG	
045	69	OP	
046	12	12	
047	69	OP	
048	29	29	
049	72	ST*	
050	09	09	
051	32	X:T	
052	69	OP	
053	29	29	
054	72	ST*	
055	09	09	
056	92	RTN	
057	76	LBL	
058	68	NOP	
059	23	LNX	
060	32	X:T	
061	43	RCL	
062	32	32	
063	22	INV	
064	59	INT	
065	65	×	
066	01	1	
067	00	0	
068	00	0	
069	00	0	
070	00	0	
071	95	=	
072	42	STO	
073	32	32	
074	59	INT	
075	55	÷	
076	01	1	
077	00	0	
078	95	=	
079	78	Σ+	
080	92	RTN	
081	76	LBL	
082	67	EQ	
083	36	PGM	
084	01	01	
085	71	SBR	
086	25	CLR	
087	03	3	
088	07	7	
089	00	0	
090	71	SBR	
091	68	NOP	
092	05	5	
093	05	5	
094	06	6	
095	71	SBR	
096	68	NOP	
097	71	SBR	
098	60	DEG	
099	92	RTN	
100	76	LBL	
101	78	Σ+	
102	69	OP	
103	29	29	
104	73	RC*	
105	09	09	
106	23	LNX	
107	32	X:T	
108	69	OP	
109	29	29	
110	73	RC*	
111	09	09	
112	85	+	
113	69	OP	
114	29	29	
115	73	RC*	
116	09	09	
117	65	×	
118	43	RCL	
119	13	13	
120	23	LNX	
121	95	=	
122	23	LNX	
123	78	Σ+	
124	92	RTN	
125	76	LBL	
126	33	X²	
127	43	RCL	
128	46	46	
129	42	STO	
130	00	00	
131	76	LBL	
132	24	CE	
133	03	3	
134	03	3	
135	42	STO	
136	09	09	
137	69	OP	
138	20	20	
139	71	SBR	
140	69	OP	
141	22	INV	
142	77	GE	
143	24	CE	
144	71	SBR	
145	67	EQ	
146	69	OP	
147	30	30	
148	61	GTO	
149	35	1/X	
150	76	LBL	
151	57	ENG	
152	04	4	
153	08	8	
154	42	STO	
155	46	46	
156	05	5	
157	01	1	
158	61	GTO	
159	50	I×I	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE FLUENCE Φ PAGE 2 OF 3

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
160	76	LBL	
161	58	FIX	
162	05	5	
163	02	2	
164	42	STO	
165	46	46	
166	05	5	
167	05	5	
168	61	GTO	
169	50	I×I	
170	76	LBL	
171	59	INT	
172	05	5	
173	06	6	
174	42	STO	
175	46	46	
176	05	5	
177	09	9	
178	61	GTO	
179	50	I×I	
180	76	LBL	
181	16	A'	
182	36	PGM	
183	24	24	
184	10	E'	
185	36	PGM	
186	24	24	
187	14	D	
188	58	FIX	
189	00	00	
190	52	EE	
191	22	INV	
192	52	EE	
193	76	LBL	
194	11	A	
195	42	STO	
196	13	13	
197	22	INV	
198	58	FIX	
199	06	6	
200	69	OP	
201	17	17	
202	43	RCL	
203	13	13	
204	92	RTN	
205	76	LBL	
206	12	B	
207	32	X:T	
208	02	2	
209	93	.	
210	05	5	
211	67	EQ	
212	57	ENG	
213	05	5	
214	67	EQ	

LOC	CODE	KEY	COMMENTS
215	58	FIX	
216	01	1	
217	00	0	
218	67	EQ	
219	59	INT	
220	29	CP	
221	76	LBL	
222	50	I×I	
223	42	STO	
224	47	47	
225	32	X:T	
226	42	STO	
227	45	45	
228	92	RTN	
229	76	LBL	
230	14	D	
231	32	X:T	
232	71	SBR	
233	99	PRT	
234	32	X:T	
235	76	LBL	
236	19	D'	
237	42	STO	
238	33	33	
239	76	LBL	
240	89	π	
241	43	RCL	
242	33	33	
243	32	X:T	
244	06	6	
245	77	GE	
246	33	X^2	
247	43	RCL	
248	47	47	
249	42	STO	
250	00	00	
251	76	LBL	
252	28	LOG	
253	03	3	
254	03	3	
255	42	STO	
256	09	09	
257	69	OP	
258	30	30	
259	71	SBR	
260	69	OP	
261	77	GE	
262	28	LOG	
263	71	SBR	
264	67	EQ	
265	69	OP	
266	20	20	
267	76	LBL	
268	35	1/X	
269	71	SBR	

LOC	CODE	KEY	COMMENTS
270	69	OP	
271	71	SBR	
272	67	EQ	
273	03	3	
274	03	3	
275	42	STO	
276	09	09	
277	36	PGM	
278	01	01	
279	71	SBR	
280	25	CLR	
281	71	SBR	
282	78	Σ+	
283	71	SBR	
284	78	Σ+	
285	69	OP	
286	12	12	
287	22	INV	
288	23	LNX	
289	65	×	
290	22	INV	
291	58	FIX	
292	03	3	
293	07	7	
294	06	6	
295	05	5	
296	69	OP	
297	04	04	
298	43	RCL	
299	33	33	
300	98	ADV	
301	69	OP	
302	06	06	
303	45	Y^X	
304	32	X:T	
305	95	=	
306	32	X:T	
307	02	2	
308	01	1	
309	69	OP	
310	04	04	
311	32	X:T	
312	58	FIX	
313	02	02	
314	52	EE	
315	22	INV	
316	52	EE	
317	69	OP	
318	06	06	
319	22	INV	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE FLUENCE Φ PAGE 3 OF 3 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	58	FIX		375	85	+	
321	92	RTN		376	43	RCL	
322	76	LBL		377	14	14	
323	15	E		378	95	=	
324	25	CLR		379	55	÷	
325	42	STO		380	01	1	
326	33	33		381	00	0	
327	01	1		382	00	0	
328	08	8		383	00	0	
329	42	STO		384	85	+	
330	07	07		385	43	RCL	
331	71	SBR		386	16	16	
332	99	PRT		387	65	×	
333	76	LBL		388	01	1	
334	45	Y^x		389	52	EE	
335	01	1		390	04	4	
336	44	SUM		391	22	INV	
337	33	33		392	52	EE	
338	71	SBR		393	95	=	
339	89	π		394	42	STO	
340	97	DSZ		395	11	11	
341	07	07		396	43	RCL	
342	45	Y^x		397	13	13	
343	92	RTN		398	42	STO	
344	76	LBL		399	12	12	
345	13	C		400	43	RCL	
346	25	CLR		401	18	18	
347	43	RCL		402	14	D	
348	01	01		403	42	STO	
349	85	+		404	10	10	
350	43	RCL		405	43	RCL	
351	02	02		406	20	20	
352	95	=		407	19	D'	
353	65	×		408	44	SUM	
354	01	1		409	10	10	
355	00	0		410	07	7	
356	00	0		411	07	7	
357	00	0		412	02	2	
358	85	+		413	01	1	
359	53	(		414	69	OP	
360	43	RCL		415	04	04	
361	03	03		416	43	RCL	
362	85	+		417	10	10	
363	43	RCL		418	98	ADV	
364	04	04		419	69	OP	
365	54	)		420	06	06	
366	55	÷		421	92	RTN	
367	01	1		422	00	0	
368	00	0		423	00	0	
369	00	0		424	00	0	
370	95	=					
371	42	STO					
372	08	08					
373	43	RCL					
374	12	12					

MERGED CODES
62 63 64 72 73 74 83 84 92

TEXAS INSTRUMENTS INCORPORATED

TI-24181

DATA BASE

FOR

FLUENCE, Φ

PROGRAM

0.	30
0.	31
0.	32
0.	33
0.	34
0.	35
0.	36
0.	37
0.	38
0.	39
0.	40
0.	41
0.	42
0.	43
0.	44
10.	45
56.	46
59.	47
30.0250032	48
60.0130016	49
120.00550071	50
157.00390051	51
30.0280041	52
60.0140021	53
120.00610093	54
157.00430067	55
30.0330059	56
60.01700296	57
120.00730137	58
157.005201	59

TITLE RADIATION PAGE 1 OF 3

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	12	B	
002	42	STO	
003	39	39	
004	92	RTN	
005	76	LBL	
006	16	A'	
007	22	INV	
008	58	FIX	
009	69	OP	
010	04	04	
011	32	X:T	
012	69	OP	
013	06	06	
014	92	RTN	
015	76	LBL	
016	55	−	
017	73	RC*	
018	30	30	
019	59	INT	
020	23	LNX	
021	32	X:T	
022	73	RC*	
023	30	30	
024	22	INV	
025	59	INT	
026	78	Σ+	
027	92	RTN	
028	76	LBL	
029	45	YX	
030	01	1	
031	22	INV	
032	87	IFF	
033	00	00	
034	98	ADV	
035	94	+/-	
036	61	GTO	
037	98	ADV	
038	76	LBL	
039	44	SUM	
040	01	1	
041	87	IFF	
042	00	00	
043	98	ADV	
044	94	+/-	
045	76	LBL	
046	98	ADV	
047	44	SUM	
048	30	30	
049	44	SUM	
050	31	31	
051	92	RTN	
052	76	LBL	
053	61	GTO	
054	69	OP	
055	12	12	
056	85	+	
057	32	X:T	
058	65	×	
059	43	RCL	
060	32	32	
061	23	LNX	
062	76	LBL	
063	34	√X	
064	95	=	
065	58	FIX	
066	03	03	
067	52	EE	
068	22	INV	
069	52	EE	
070	92	RTN	
071	76	LBL	
072	33	X²	
073	36	PGM	
074	01	01	
075	71	SBR	
076	25	CLR	
077	43	RCL	
078	41	41	
079	32	X:T	
080	43	RCL	
081	39	39	
082	22	INV	
083	77	GE	
084	28	LOG	
085	22	INV	
086	76	LBL	
087	28	LOG	
088	86	STF	
089	01	01	
090	73	RC*	
091	31	31	
092	22	INV	
093	59	INT	
094	78	Σ+	
095	43	RCL	
096	40	40	
097	87	IFF	
098	01	01	
099	29	CP	
100	43	RCL	
101	42	42	
102	76	LBL	
103	29	CP	
104	32	X:T	
105	73	RC*	
106	31	31	
107	59	INT	
108	55	÷	
109	43	RCL	
110	43	43	
111	95	=	
112	42	STO	
113	33	33	
114	22	INV	
115	59	INT	
116	87	IFF	
117	01	01	
118	37	P/R	
119	43	RCL	
120	33	33	
121	59	INT	
122	55	÷	
123	43	RCL	
124	43	43	
125	95	=	
126	76	LBL	
127	37	P/R	
128	78	Σ+	
129	69	OP	
130	12	12	
131	85	+	
132	32	X:T	
133	65	×	
134	43	RCL	
135	39	39	
136	71	SBR	
137	34	√X	
138	92	RTN	
139	76	LBL	
140	15	E	
141	01	1	
142	19	D'	
143	01	1	
144	00	0	
145	14	D	
146	02	2	
147	00	0	
148	14	D	
149	04	4	
150	00	0	
151	14	D	
152	01	1	
153	00	0	
154	00	0	
155	14	D	
156	02	2	
157	00	0	
158	00	0	
159	14	D	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-44181

TITLE RADIATION PAGE 2 OF 3

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
160	04	4	
161	00	0	
162	00	0	
163	14	D	
164	43	RCL	
165	43	43	
166	14	D	
167	92	RTN	
168	76	LBL	
169	13	C	
170	43	RCL	
171	10	10	
172	19	D'	
173	92	RTN	
174	76	LBL	
175	19	D'	
176	22	INV	
177	76	LBL	
178	14	D	
179	86	STF	
180	02	02	
181	42	STO	
182	32	32	
183	22	INV	
184	58	FIX	
185	87	IFF	
186	02	02	
187	39	COS	
188	03	3	
189	05	5	
190	69	OP	
191	00	00	
192	69	OP	
193	02	02	
194	01	1	
195	03	3	
196	01	1	
197	06	6	
198	00	0	
199	00	0	
200	00	0	
201	00	0	
202	00	0	
203	00	0	
204	69	OP	
205	03	03	
206	98	ADV	
207	98	ADV	
208	69	OP	
209	05	05	
210	98	ADV	
211	43	RCL	
212	39	39	
213	32	X:T	
214	01	1	

LOC	CODE	KEY	COMMENTS
215	05	5	
216	03	3	
217	07	7	
218	16	A'	
219	76	LBL	
220	39	COS	
221	98	ADV	
222	43	RCL	
223	32	32	
224	32	X:T	
225	07	7	
226	07	7	
227	02	2	
228	01	1	
229	16	A'	
230	32	X:T	
231	04	4	
232	00	0	
233	77	GE	
234	57	ENG	
235	22	INV	
236	76	LBL	
237	57	ENG	
238	86	STF	
239	00	00	
240	05	5	
241	02	2	
242	87	IFF	
243	00	00	
244	97	DSZ	
245	05	5	
246	09	9	
247	76	LBL	
248	97	DSZ	
249	42	STO	
250	30	30	
251	75	-	
252	08	8	
253	95	=	
254	42	STO	
255	31	31	
256	76	LBL	
257	53	(	
258	71	SBR	
259	44	SUM	
260	73	RC*	
261	30	30	
262	59	INT	
263	22	INV	
264	87	IFF	
265	00	00	
266	38	SIN	
267	22	INV	
268	76	LBL	
269	38	SIN	

LOC	CODE	KEY	COMMENTS
270	77	GE	
271	53	(	
272	36	PGM	
273	01	01	
274	71	SBR	
275	25	CLR	
276	71	SBR	
277	55	÷	
278	71	SBR	
279	45	Y^X	
280	71	SBR	
281	55	÷	
282	71	SBR	
283	61	GTO	
284	42	STO	
285	10	10	
286	71	SBR	
287	33	X^2	
288	42	STO	
289	34	34	
290	71	SBR	
291	44	SUM	
292	71	SBR	
293	33	X^2	
294	42	STO	
295	35	35	
296	36	PGM	
297	01	01	
298	71	SBR	
299	25	CLR	
300	73	RC*	
301	30	30	
302	59	INT	
303	23	LNX	
304	32	X:T	
305	43	RCL	
306	35	35	
307	78	Σ+	
308	71	SBR	
309	45	Y^X	
310	73	RC*	
311	30	30	
312	59	INT	
313	23	LNX	
314	32	X:T	
315	43	RCL	
316	34	34	
317	78	Σ+	
318	71	SBR	
319	61	GTO	

MERGED CODES

62 63 64 72 73 74 83 84 92

TEXAS INSTRUMENTS INCORPORATED

TI-84101

TITLE RADIATION PAGE 3 OF 3

TI Programmable Coding Form

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
320	32	X:T	
321	02	2	
322	01	1	
323	03	3	
324	03	3	
325	16	A'	
326	65	×	
327	43	RCL	
328	43	43	
329	85	+	
330	43	RCL	
331	10	10	
332	32	X:T	
333	02	2	
334	01	1	
335	04	4	
336	02	2	
337	16	A'	
338	55	÷	
339	01	1	
340	00	0	
341	95	=	
342	42	STO	
343	10	10	
344	92	RTN	
345	00	0	
346	00	0	
347	00	0	
348	00	0	
349	00	0	
350	00	0	

MERGED CODES
62 63 64 72 73 74 83 84 92

TEXAS INSTRUMENTS INCORPORATED

TI-24191

DATA BASE

FOR

RATIATION

PROGRAM

0.	30
0.	31
0.	32
0.	33
0.	34
0.	35
0.	36
0.	37
0.	38
8.	39
3.4	40
5.7	41
11.8	42
1000.	43
995995.995	44
883977.966	45
841960.934	46
795928.893	47
723878.811	48
661824.749	49
604746.685	50
517647.586	51
1.995	52
10.991	53
20.982	54
40.969	55
100.946	56
200.923	57
400.898	58
1000.863	59

TITLE THERMAL PAGE 1 OF 3

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	34	ΓX	
002	58	FIX	
003	01	01	
004	69	OP	
005	22	22	
006	73	RC*	
007	02	02	
008	52	EE	
009	22	INV	
010	52	EE	
011	22	INV	
012	58	FIX	
013	72	ST*	
014	02	02	
015	92	RTN	
016	76	LBL	
017	88	DMS	
018	98	ADV	
019	99	PRT	
020	43	RCL	
021	06	06	
022	99	PRT	
023	65	×	
024	43	RCL	
025	07	07	
026	99	PRT	
027	85	+	
028	43	RCL	
029	05	05	
030	99	PRT	
031	65	×	
032	53	(	
033	01	1	
034	75	-	
035	43	RCL	
036	07	07	
037	54	)	
038	99	PRT	
039	95	=	
040	58	FIX	
041	03	03	
042	52	EE	
043	22	INV	
044	52	EE	
045	99	PRT	
046	22	INV	
047	58	FIX	
048	92	RTN	
049	76	LBL	
050	86	STF	
051	43	RCL	
052	07	07	
053	99	PRT	
054	65	×	

LOC	CODE	KEY	COMMENTS
055	43	RCL	
056	06	06	
057	99	PRT	
058	65	×	
059	43	RCL	
060	05	05	
061	99	PRT	
062	95	=	
063	58	FIX	
064	03	03	
065	52	EE	
066	22	INV	
067	52	EE	
068	22	INV	
069	58	FIX	
070	92	RTN	
071	76	LBL	
072	22	INV	
073	36	PGM	
074	24	24	
075	10	E'	
076	36	PGM	
077	24	24	
078	14	D	
079	58	FIX	
080	00	00	
081	52	EE	
082	22	INV	
083	52	EE	
084	22	INV	
085	58	FIX	
086	76	LBL	
087	32	X:T	
088	42	STO	
089	12	12	
090	92	RTN	
091	76	LBL	
092	23	LNX	
093	42	STO	
094	07	07	
095	92	RTN	
096	76	LBL	
097	12	B	
098	42	STO	
099	06	06	
100	92	RTN	
101	76	LBL	
102	13	C	
103	42	STO	
104	05	05	
105	92	RTN	
106	76	LBL	
107	14	D	
108	42	STO	
109	04	04	

LOC	CODE	KEY	COMMENTS
110	92	RTN	
111	76	LBL	
112	24	CE	
113	42	STO	
114	03	03	
115	92	RTN	
116	76	LBL	
117	11	A	
118	69	OP	
119	00	00	
120	03	3	
121	07	7	
122	02	2	
123	03	3	
124	01	1	
125	07	7	
126	69	OP	
127	02	02	
128	03	3	
129	05	5	
130	03	3	
131	00	0	
132	01	1	
133	03	3	
134	02	2	
135	07	7	
136	00	0	
137	00	0	
138	69	OP	
139	03	03	
140	98	ADV	
141	98	ADV	
142	69	OP	
143	05	05	
144	00	0	
145	98	ADV	
146	99	PRT	
147	09	9	
148	00	0	
149	75	-	
150	53	(	
151	06	6	
152	03	3	
153	07	7	
154	02	2	
155	55	÷	
156	53	(	
157	24	CE	
158	85	+	
159	43	RCL	

MERGED CODES

62 | 72 STO | 83 GTO
63 | 73 RCL | 84
64 | 74 SUM | 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE THERMAL PAGE 2 OF 3

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
160	12	12	
161	99	PRT	
162	54	)	
163	42	STO	
164	14	14	
165	54	)	
166	22	INV	
167	38	SIN	
168	42	STO	
169	04	04	
170	95	=	
171	99	PRT	
172	42	STO	
173	13	13	
174	43	RCL	
175	14	14	
176	52	EE	
177	03	3	
178	45	YX	
179	03	3	
180	65	×	
181	08	8	
182	93	.	
183	06	6	
184	05	5	
185	03	3	
186	52	EE	
187	01	1	
188	04	4	
189	94	+/-	
190	22	INV	
191	52	EE	
192	95	=	
193	34	√X	
194	55	÷	
195	06	6	
196	00	0	
197	95	=	
198	58	FIX	
199	02	02	
200	52	EE	
201	22	INV	
202	52	EE	
203	99	PRT	
204	42	STO	
205	14	14	
206	75	-	
207	24	CE	
208	65	×	
209	43	RCL	
210	04	04	
211	55	÷	
212	01	1	
213	08	8	
214	00	0	
215	95	=	
216	52	EE	
217	22	INV	
218	52	EE	
219	99	PRT	
220	22	INV	
221	58	FIX	
222	92	RTN	
223	76	LBL	
224	16	A'	
225	01	1	
226	71	SBR	
227	88	DMS	
228	42	STO	
229	15	15	
230	42	STO	
231	17	17	
232	92	RTN	
233	76	LBL	
234	17	B'	
235	02	2	
236	98	ADV	
237	99	PRT	
238	43	RCL	
239	07	07	
240	42	STO	
241	09	09	
242	71	SBR	
243	86	STF	
244	99	PRT	
245	65	×	
246	32	X:T	
247	01	1	
248	00	0	
249	00	0	
250	00	0	
251	95	=	
252	44	SUM	
253	09	09	
254	32	X:T	
255	22	INV	
256	58	FIX	
257	22	INV	
258	44	SUM	
259	15	15	
260	92	RTN	
261	76	LBL	
262	18	C'	
263	32	X:T	
264	03	3	
265	98	ADV	
266	99	PRT	
267	32	X:T	
268	58	FIX	
269	03	03	
270	99	PRT	
271	42	STO	
272	16	16	
273	65	×	
274	02	2	
275	00	0	
276	08	8	
277	93	.	
278	02	2	
279	49	PRD	
280	17	17	
281	95	=	
282	42	STO	
283	18	18	
284	43	RCL	
285	15	15	
286	99	PRT	
287	22	INV	
288	58	FIX	
289	92	RTN	
290	76	LBL	
291	19	D'	
292	25	CLR	
293	42	STO	
294	19	19	
295	93	.	
296	07	7	
297	05	5	
298	42	STO	
299	03	03	
300	04	4	
301	71	SBR	
302	88	DMS	
303	42	STO	
304	20	20	
305	92	RTN	
306	76	LBL	
307	15	E	
308	22	INV	
309	76	LBL	
310	10	E'	
311	86	STF	
312	00	00	
313	32	X:T	
314	05	5	
315	98	ADV	
316	99	PRT	
317	32	X:T	
318	99	PRT	
319	65	×	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE THERMAL PAGE 3 OF 3 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
320	43	RCL	
321	03	03	
322	99	PRT	
323	95	=	
324	58	FIX	
325	03	03	
326	99	PRT	
327	98	ADV	
328	22	INV	
329	58	FIX	
330	42	STO	
331	19	19	
332	44	SUM	
333	20	20	
334	93	.	
335	00	0	
336	02	2	
337	05	5	
338	87	IFF	
339	00	00	
340	03	03	
341	44	44	
342	71	SBR	
343	86	STF	
344	99	PRT	
345	49	PRD	
346	19	19	
347	85	+	
348	01	1	
349	95	=	
350	49	PRD	
351	20	20	
352	05	5	
353	93	.	
354	06	6	
355	06	6	
356	09	9	
357	07	7	
358	52	EE	
359	08	8	
360	94	+/-	
361	22	INV	
362	52	EE	
363	49	PRD	
364	19	19	
365	49	PRD	
366	20	20	
367	05	5	
368	00	0	
369	87	IFF	
370	00	00	
371	03	03	
372	75	75	
373	43	RCL	
374	04	04	
375	98	ADV	
376	99	PRT	
377	85	+	
378	02	2	
379	07	7	
380	03	3	
381	95	=	
382	33	X²	
383	33	X²	
384	49	PRD	
385	19	19	
386	01	1	
387	06	6	
388	42	STO	
389	02	02	
390	71	SBR	
391	34	√X	
392	71	SBR	
393	34	√X	
394	71	SBR	
395	34	√X	
396	52	EE	
397	58	FIX	
398	02	02	
399	71	SBR	
400	00	00	
401	04	04	
402	98	ADV	
403	98	ADV	
404	03	3	
405	69	OP	
406	17	17	
407	08	8	
408	22	INV	
409	90	LST	
410	04	4	
411	69	OP	
412	17	17	
413	92	RTN	
414	76	LBL	
415	44	SUM	
416	04	4	
417	04	4	
418	04	4	
419	71	SBR	
420	32	X:T	
421	11	A	
422	93	.	
423	09	9	
424	01	1	
425	42	STO	
426	07	07	
427	93	.	
428	07	7	
429	08	8	
430	12	B	
431	93	.	
432	04	4	
433	05	5	
434	13	C	
435	16	A'	
436	93	.	
437	04	4	
438	05	5	
439	12	B	
440	93	.	
441	01	1	
442	02	2	
443	02	2	
444	13	C	
445	17	B'	
446	93	.	
447	04	4	
448	05	5	
449	18	C'	
450	93	.	
451	08	8	
452	02	2	
453	12	B	
454	93	.	
455	08	8	
456	13	C	
457	19	D'	
458	93	.	
459	08	8	
460	76	LBL	
461	43	RCL	
462	32	X:T	
463	93	.	
464	00	0	
465	05	5	
466	42	STO	
467	07	07	
468	04	4	
469	05	5	
470	38	SIN	
471	12	B	
472	13	C	
473	05	5	
474	00	0	
475	14	D	
476	32	X:T	
477	15	E	
478	92	RTN	
479	00	0	

MERGED CODES

62 | 63 | 64 | 72 STO | 73 RCL | 74 SUM | 83 GTO | 84 | 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE TEMPERATURE PAGE 1 OF 4

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	43	RCL		110	02	02	
001	43	RCL		056	32	32		111	75	-	
002	85	+		057	58	FIX		112	09	9	
003	43	RCL		058	01	01		113	00	0	
004	13	13		059	99	PRT		114	95	=	
005	95	=		060	92	RTN		115	50	I×I	
006	65	×		061	87	IFF		116	42	STO	
007	43	RCL		062	06	06		117	35	35	
008	14	14		063	00	00		118	87	IFF	
009	55	÷		064	79	79		119	04	04	
010	03	3		065	43	RCL		120	01	01	
011	06	6		066	30	30		121	51	51	
012	00	0		067	71	SBR		122	87	IFF	
013	95	=		068	00	00		123	06	06	
014	58	FIX		069	89	89		124	01	01	
015	02	02		070	39	COS		125	51	51	
016	52	EE		071	65	×		126	06	6	
017	22	INV		072	93	.		127	03	3	
018	52	EE		073	03	3		128	07	7	
019	76	LBL		074	06	6		129	02	2	
020	89	π		075	85	+		130	42	STO	
021	42	STO		076	01	1		131	01	01	
022	37	37		077	95	=		132	85	+	
023	71	SBR		078	65	×		133	43	RCL	
024	03	03		079	43	RCL		134	12	12	
025	94	94		080	31	31		135	95	=	
026	43	RCL		081	95	=		136	42	STO	
027	07	07		082	58	FIX		137	06	06	
028	32	X:T		083	00	00		138	36	PGM	
029	43	RCL		084	52	EE		139	11	11	
030	37	37		085	22	INV		140	10	E'	
031	77	GE		086	52	EE		141	36	PGM	
032	89	π		087	99	PRT		142	11	11	
033	42	STO		088	92	RTN		143	15	E	
034	07	07		089	65	×		144	09	9	
035	71	SBR		090	03	3		145	00	0	
036	03	03		091	06	6		146	75	-	
037	95	95		092	00	0		147	43	RCL	
038	92	RTN		093	55	÷		148	05	05	
039	43	RCL		094	43	RCL		149	95	=	
040	30	30		095	14	14		150	50	I×I	
041	22	INV		096	75	-		151	42	STO	
042	58	FIX		097	43	RCL		152	34	34	
043	98	ADV		098	13	13		153	92	RTN	
044	98	ADV		099	87	IFF		154	43	RCL	
045	99	PRT		100	05	05		155	30	30	
046	87	IFF		101	01	01		156	85	+	
047	04	04		102	07	07		157	43	RCL	
048	00	00		103	75	-		158	07	07	
049	55	55		104	01	1		159	95	=	
050	71	SBR		105	08	8					
051	00	00		106	00	0					
052	61	61		107	95	=					
053	42	STO		108	50	I×I					
054	36	36		109	42	STO					

MERGED CODES

62 | 72 STO | 83 GTO
63 | 73 RCL | 84
64 | 74 SUM | 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE TEMPERATURE PAGE 2 OF 4 **TI Programmable Coding Form**

PROGRAMMER ________ DATE ________

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	55	÷		215	32	32		270	78	Σ+	
161	02	2		216	85	+		271	43	RCL	
162	71	SBR		217	43	RCL		272	34	34	
163	00	00		218	33	33		273	32	X⇌T	
164	89	89		219	54	)		274	69	OP	
165	87	IFF		220	55	÷		275	20	20	
166	04	04		221	02	2		276	73	RC*	
167	01	01		222	54	)		277	00	00	
168	93	93		223	42	STO		278	78	Σ+	
169	43	RCL		224	35	35		279	53	(	
170	15	15		225	33	X²		280	69	OP	
171	85	+		226	33	X²		281	12	12	
172	93	.		227	95	=		282	85	+	
173	03	3		228	65	×		283	32	X⇌T	
174	06	6		229	06	6		284	65	×	
175	65	×		230	00	0		285	43	RCL	
176	43	RCL		231	55	÷		286	35	35	
177	34	34		232	36	PGM		287	95	=	
178	39	COS		233	01	01		288	92	RTN	
179	65	×		234	71	SBR		289	76	LBL	
180	43	RCL		235	25	CLR		290	11	A	
181	16	16		236	53	(		291	42	STO	
182	87	IFF		237	53	(		292	30	30	
183	06	06		238	53	(		293	59	INT	
184	01	01		239	43	RCL		294	42	STO	
185	88	88		240	35	35		295	07	07	
186	43	RCL		241	75	-		296	69	OP	
187	15	15		242	07	7		297	27	27	
188	95	=		243	03	3		298	43	RCL	
189	65	×		244	54	)		299	30	30	
190	43	RCL		245	55	÷		300	92	RTN	
191	31	31		246	02	2		301	76	LBL	
192	85	+		247	05	5		302	12	B	
193	43	RCL		248	54	)		303	42	STO	
194	18	18		249	59	INT		304	31	31	
195	87	IFF		250	42	STO		305	92	RTN	
196	06	06		251	00	00		306	76	LBL	
197	02	02		252	65	×		307	18	C'	
198	01	01		253	02	2		308	85	+	
199	43	RCL		254	05	5		309	02	2	
200	17	17		255	42	STO		310	07	7	
201	65	×		256	34	34		311	03	3	
202	43	RCL		257	85	+		312	95	=	
203	35	35		258	01	1		313	76	LBL	
204	39	COS		259	07	7		314	13	C	
205	85	+		260	44	SUM		315	42	STO	
206	43	RCL		261	00	00		316	32	32	
207	19	19		262	07	7		317	42	STO	
208	75	-		263	03	3		318	33	33	
209	43	RCL		264	54	)		319	92	RTN	
210	20	20		265	44	SUM					
211	65	×		266	34	34					
212	53	(		267	32	X⇌T					
213	53	(		268	73	RC*					
214	43	RCL		269	00	00					

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE TEMPERATURE PAGE 3 OF 4 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	22	INV		375	01	1		430	97	97	
321	87	IFF		376	95	=		431	43	RCL	
322	04	04		377	32	X:T		432	33	33	
323	03	03		378	43	RCL		433	75	-	
324	26	26		379	07	07		434	43	RCL	
325	94	+/-		380	77	GE		435	32	32	
326	85	+		381	03	03		436	95	=	
327	43	RCL		382	91	91		437	50	I×I	
328	32	32		383	71	SBR		438	32	X:T	
329	95	=		384	04	04		439	02	2	
330	42	STO		385	45	45		440	05	5	
331	33	33		386	02	2		441	22	INV	
332	86	STF		387	05	5		442	77	GE	
333	07	07		388	61	GTO		443	03	03	
334	71	SBR		389	03	03		444	20	20	
335	01	01		390	20	20		445	43	RCL	
336	54	54		391	32	X:T		446	30	30	
337	35	1/X		392	42	STO		447	59	INT	
338	65	×		393	07	07		448	85	+	
339	53	(		394	22	INV		449	01	1	
340	43	RCL		395	86	STF		450	95	=	
341	33	33		396	07	07		451	48	EXC	
342	75	-		397	71	SBR		452	07	07	
343	43	RCL		398	01	01		453	58	FIX	
344	32	32		399	54	54		454	03	03	
345	54	)		400	65	×		455	52	EE	
346	85	+		401	53	(		456	22	INV	
347	43	RCL		402	43	RCL		457	52	EE	
348	30	30		403	07	07		458	22	INV	
349	85	+		404	75	-		459	58	FIX	
350	32	X:T		405	43	RCL		460	98	ADV	
351	43	RCL		406	30	30		461	99	PRT	
352	07	07		407	54	)		462	87	IFF	
353	95	=		408	85	+		463	07	07	
354	55	÷		409	43	RCL		464	04	04	
355	02	2		410	32	32		465	68	68	
356	95	=		411	85	+		466	69	OP	
357	48	EXC		412	32	X:T		467	27	27	
358	07	07		413	43	RCL		468	75	-	
359	75	-		414	33	33		469	48	EXC	
360	93	.		415	95	=		470	30	30	
361	00	0		416	55	÷		471	95	=	
362	00	0		417	02	2		472	87	IFF	
363	00	0		418	95	=		473	04	04	
364	05	5		419	48	EXC		474	04	04	
365	32	X:T		420	33	33		475	93	93	
366	95	=		421	75	-		476	32	X:T	
367	50	I×I		422	93	.		477	71	SBR	
368	77	GE		423	00	0		478	00	00	
369	03	03		424	05	5		479	61	61	
370	32	32		425	32	X:T					
371	43	RCL		426	95	=					
372	30	30		427	50	I×I					
373	59	INT		428	77	GE					
374	85	+		429	03	03					

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24191

TITLE TEMPERATURE PAGE 4 OF 4

PROGRAMMER DATE

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
480	85	+	
481	48	EXC	
482	36	36	
483	95	=	
484	55	÷	
485	02	2	
486	95	=	
487	32	X:T	
488	65	×	
489	32	X:T	
490	95	=	
491	44	SUM	
492	38	38	
493	43	RCL	
494	33	33	
495	58	FIX	
496	01	01	
497	52	EE	
498	22	INV	
499	52	EE	
500	99	PRT	
501	85	+	
502	48	EXC	
503	32	32	
504	95	=	
505	87	IFF	
506	04	04	
507	05	05	
508	16	16	
509	55	÷	
510	02	2	
511	65	×	
512	32	X:T	
513	95	=	
514	44	SUM	
515	39	39	
516	92	RTN	
517	76	LBL	
518	10	E'	
519	25	CLR	
520	22	INV	
521	86	STF	
522	05	05	
523	22	INV	
524	86	STF	
525	06	06	
526	71	SBR	
527	06	06	
528	06	06	
529	76	LBL	
530	15	E	
531	25	CLR	
532	11	A	
533	42	STO	
534	38	38	

LOC	CODE	KEY	COMMENTS
535	42	STO	
536	39	39	
537	22	INV	
538	86	STF	
539	04	04	
540	86	STF	
541	05	05	
542	22	INV	
543	86	STF	
544	06	06	
545	71	SBR	
546	00	00	
547	39	39	
548	25	CLR	
549	71	SBR	
550	43	RCL	
551	86	STF	
552	06	06	
553	09	9	
554	00	0	
555	71	SBR	
556	43	RCL	
557	01	1	
558	08	8	
559	00	0	
560	71	SBR	
561	43	RCL	
562	22	INV	
563	86	STF	
564	05	05	
565	22	INV	
566	86	STF	
567	06	06	
568	01	1	
569	08	8	
570	00	0	
571	85	+	
572	43	RCL	
573	13	13	
574	71	SBR	
575	43	RCL	
576	43	RCL	
577	38	38	
578	55	÷	
579	43	RCL	
580	37	37	
581	95	=	
582	58	FIX	
583	00	00	
584	52	EE	
585	22	INV	
586	52	EE	
587	98	ADV	
588	98	ADV	
589	99	PRT	

LOC	CODE	KEY	COMMENTS
590	42	STO	
591	38	38	
592	43	RCL	
593	39	39	
594	55	÷	
595	43	RCL	
596	37	37	
597	95	=	
598	58	FIX	
599	01	01	
600	52	EE	
601	22	INV	
602	52	EE	
603	99	PRT	
604	42	STO	
605	39	39	
606	86	STF	
607	04	04	
608	71	SBR	
609	00	00	
610	39	39	
611	02	2	
612	07	7	
613	00	0	
614	71	SBR	
615	43	RCL	
616	43	RCL	
617	14	14	
618	71	SBR	
619	89	π	
620	76	LBL	
621	14	D	
622	22	INV	
623	58	FIX	
624	03	3	
625	69	OP	
626	17	17	
627	98	ADV	
628	98	ADV	
629	98	ADV	
630	08	8	
631	22	INV	
632	90	LST	
633	04	4	
634	69	OP	
635	17	17	
636	92	RTN	
637	00	0	
638	00	0	
639	00	0	

MERGED CODES

62 | 72 STO | 83 GTO
63 | 73 RCL | 84
64 | 74 SUM | 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE MAIN BUS PAGE 1 OF 2 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	16	A'	
002	42	STO	
003	23	23	
004	92	RTN	
005	76	LBL	
006	17	B'	
007	42	STO	
008	24	24	
009	92	RTN	
010	76	LBL	
011	18	C'	
012	42	STO	
013	25	25	
014	92	RTN	
015	76	LBL	
016	25	CLR	
017	42	STO	
018	26	26	
019	92	RTN	
020	76	LBL	
021	13	C	
022	42	STO	
023	27	27	
024	92	RTN	
025	76	LBL	
026	22	INV	
027	42	STO	
028	48	48	
029	92	RTN	
030	76	LBL	
031	23	LNX	
032	42	STO	
033	49	49	
034	92	RTN	
035	76	LBL	
036	24	CE	
037	42	STO	
038	50	50	
039	92	RTN	
040	76	LBL	
041	11	A	
042	22	INV	
043	52	EE	
044	22	INV	
045	58	FIX	
046	06	6	
047	69	OP	
048	17	17	
049	25	CLR	
050	92	RTN	
051	76	LBL	
052	15	E	
053	43	RCL	
054	50	50	

LOC	CODE	KEY	COMMENTS
055	55	÷	
056	02	2	
057	95	=	
058	42	STO	
059	28	28	
060	92	RTN	
061	76	LBL	
062	10	E'	
063	65	×	
064	43	RCL	
065	48	48	
066	65	×	
067	43	RCL	
068	49	49	
069	95	=	
070	42	STO	
071	29	29	
072	92	RTN	
073	76	LBL	
074	33	X²	
075	43	RCL	
076	49	49	
077	65	×	
078	43	RCL	
079	30	30	
080	85	+	
081	99	PRT	
082	33	X²	
083	99	PRT	
084	44	SUM	
085	26	26	
086	92	RTN	
087	76	LBL	
088	12	B	
089	43	RCL	
090	08	08	
091	59	INT	
092	65	×	
093	43	RCL	
094	08	08	
095	22	INV	
096	59	INT	
097	55	÷	
098	01	1	
099	52	EE	
100	05	5	
101	95	=	
102	58	FIX	
103	03	03	
104	52	EE	
105	22	INV	
106	52	EE	
107	22	INV	
108	58	FIX	
109	16	A'	

LOC	CODE	KEY	COMMENTS
110	43	RCL	
111	11	11	
112	59	INT	
113	55	÷	
114	01	1	
115	52	EE	
116	07	7	
117	22	INV	
118	52	EE	
119	85	+	
120	43	RCL	
121	11	11	
122	22	INV	
123	59	INT	
124	95	=	
125	17	B'	
126	92	RTN	
127	76	LBL	
128	44	SUM	
129	93	.	
130	01	1	
131	02	2	
132	02	2	
133	76	LBL	
134	45	YX	
135	42	STO	
136	16	16	
137	93	.	
138	04	4	
139	07	7	
140	09	9	
141	42	STO	
142	18	18	
143	12	B	
144	05	5	
145	07	7	
146	05	5	
147	03	3	
148	42	STO	
149	25	25	
150	01	1	
151	06	6	
152	09	9	
153	01	1	
154	01	1	
155	06	6	
156	42	STO	
157	26	26	
158	02	2	
159	93	.	

MERGED CODES

62 · 63 · 64 · 72 STO · 73 RCL · 74 SUM · 83 GTO · 84 · 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE MAIN BUS PAGE 2 OF 2 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
160	06	6	
161	00	0	
162	03	3	
163	52	EE	
164	08	8	
165	94	+/-	
166	42	STO	
167	27	27	
168	02	2	
169	04	4	
170	42	STO	
171	28	28	
172	06	6	
173	00	0	
174	00	0	
175	42	STO	
176	29	29	
177	76	LBL	
178	43	RCL	
179	11	A	
180	42	STO	
181	12	12	
182	42	STO	
183	13	13	
184	42	STO	
185	14	14	
186	42	STO	
187	15	15	
188	42	STO	
189	17	17	
190	42	STO	
191	19	19	
192	42	STO	
193	21	21	
194	42	STO	
195	22	22	
196	03	3	
197	69	OP	
198	17	17	
199	98	ADV	
200	98	ADV	
201	08	8	
202	22	INV	
203	90	LST	
204	11	A	
205	92	RTN	
206	76	LBL	
207	19	D'	
208	42	STO	
209	30	30	
210	76	LBL	
211	14	D	
212	11	A	
213	43	RCL	
214	50	50	
215	55	÷	
216	04	4	
217	75	-	
218	01	1	
219	95	=	
220	42	STO	
221	01	01	
222	06	6	
223	85	+	
224	98	ADV	
225	98	ADV	
226	99	PRT	
227	33	X²	
228	99	PRT	
229	42	STO	
230	26	26	
231	29	CP	
232	43	RCL	
233	01	01	
234	67	EQ	
235	34	ΓX	
236	76	LBL	
237	32	X↕T	
238	71	SBR	
239	33	X²	
240	44	SUM	
241	26	26	
242	97	DSZ	
243	01	01	
244	32	X↕T	
245	76	LBL	
246	34	ΓX	
247	71	SBR	
248	33	X²	
249	25	CLR	
250	43	RCL	
251	26	26	
252	58	FIX	
253	00	00	
254	52	EE	
255	22	INV	
256	52	EE	
257	22	INV	
258	58	FIX	
259	98	ADV	
260	99	PRT	
261	42	STO	
262	26	26	
263	92	RTN	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE SOLAR CELL PAGE 1 OF 3 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL		055	00	0		110	22	INV	
001	22	INV		056	95	=		111	54	)	
002	01	1		057	72	ST*		112	58	FIX	
003	00	0		058	03	03		113	03	03	
004	00	0		059	92	RTN		114	99	PRT	
005	00	0		060	76	LBL		115	65	×	
006	92	RTN		061	14	D		116	53	(	
007	76	LBL		062	16	A'		117	43	RCL	
008	11	A		063	17	B'		118	31	31	
009	42	STO		064	76	LBL		119	22	INV	
010	12	12		065	15	E		120	59	INT	
011	92	RTN		066	07	7		121	65	×	
012	76	LBL		067	18	C'		122	01	1	
013	12	B		068	76	LBL		123	00	0	
014	42	STO		069	13	C		124	54	)	
015	14	14		070	98	ADV		125	99	PRT	
016	92	RTN		071	43	RCL		126	54	)	
017	76	LBL		072	14	14		127	58	FIX	
018	16	A'		073	33	X²		128	00	00	
019	42	STO		074	33	X²		129	52	EE	
020	01	01		075	75	-		130	22	INV	
021	92	RTN		076	53	(		131	52	EE	
022	76	LBL		077	53	(		132	99	PRT	
023	17	B'		078	71	SBR		133	42	STO	
024	42	STO		079	03	03		134	13	13	
025	02	02		080	26	26		135	75	-	
026	92	RTN		081	65	×		136	42	STO	
027	76	LBL		082	43	RCL		137	17	17	
028	19	D'		083	16	16		138	43	RCL	
029	42	STO		084	54	)		139	09	09	
030	16	16		085	52	EE		140	59	INT	
031	92	RTN		086	22	INV		141	55	÷	
032	76	LBL		087	52	EE		142	71	SBR	
033	10	E'		088	98	ADV		143	22	INV	
034	42	STO		089	98	ADV		144	65	×	
035	18	18		090	99	PRT		145	43	RCL	
036	92	RTN		091	65	×		146	12	12	
037	76	LBL		092	43	RCL		147	54	)	
038	18	C'		093	09	09		148	55	÷	
039	85	+		094	22	INV		149	43	RCL	
040	03	3		095	59	INT		150	14	14	
041	01	1		096	65	×		151	58	FIX	
042	95	=		097	53	(		152	01	01	
043	42	STO		098	43	RCL		153	99	PRT	
044	03	03		099	12	12		154	43	RCL	
045	43	RCL		100	58	FIX		155	20	20	
046	01	01		101	00	00		156	95	=	
047	65	×		102	99	PRT		157	34	√x	
048	71	SBR		103	65	×		158	34	√x	
049	22	INV		104	53	(		159	52	EE	
050	85	+		105	43	RCL					
051	43	RCL		106	31	31					
052	02	02		107	59	INT					
053	55	÷		108	55	÷					
054	01	1		109	71	SBR					

MERGED CODES

62, 63, 64, 72 STO, 73 RCL, 74 SUM, 83 GTO, 84, 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE SOLAR CELL PAGE 2 OF 3

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
160	22	INV	
161	52	EE	
162	99	PRT	
163	42	STO	
164	15	15	
165	85	+	
166	02	2	
167	95	=	
168	55	÷	
169	02	2	
170	05	5	
171	42	STO	
172	07	07	
173	85	+	
174	59	INT	
175	49	PRD	
176	07	07	
177	03	3	
178	05	5	
179	95	=	
180	42	STO	
181	00	00	
182	71	SBR	
183	03	03	
184	58	58	
185	42	STO	
186	21	21	
187	69	OP	
188	20	20	
189	71	SBR	
190	03	03	
191	58	58	
192	71	SBR	
193	04	04	
194	32	32	
195	65	×	
196	71	SBR	
197	22	INV	
198	85	+	
199	32	X⇌T	
200	43	RCL	
201	32	32	
202	22	INV	
203	59	INT	
204	95	=	
205	48	EXC	
206	32	32	
207	59	INT	
208	22	INV	
209	67	EQ	
210	00	00	
211	71	71	
212	71	SBR	
213	03	03	
214	26	26	
215	08	8	
216	44	SUM	
217	00	00	
218	73	RC*	
219	00	00	
220	42	STO	
221	21	21	
222	69	OP	
223	20	20	
224	73	RC*	
225	00	00	
226	71	SBR	
227	04	04	
228	32	32	
229	55	÷	
230	01	1	
231	00	0	
232	85	+	
233	43	RCL	
234	32	32	
235	59	INT	
236	95	=	
237	42	STO	
238	32	32	
239	71	SBR	
240	03	03	
241	27	27	
242	65	×	
243	43	RCL	
244	18	18	
245	95	=	
246	52	EE	
247	22	INV	
248	52	EE	
249	42	STO	
250	19	19	
251	01	1	
252	75	-	
253	53	(	
254	53	(	
255	43	RCL	
256	17	17	
257	65	×	
258	43	RCL	
259	23	23	
260	54	)	
261	52	EE	
262	22	INV	
263	52	EE	
264	42	STO	
265	17	17	
266	98	ADV	
267	99	PRT	
268	55	÷	
269	43	RCL	
270	24	24	
271	65	×	
272	43	RCL	
273	25	25	
274	65	×	
275	43	RCL	
276	26	26	
277	65	×	
278	43	RCL	
279	27	27	
280	55	÷	
281	43	RCL	
282	28	28	
283	54	)	
284	34	√X	
285	55	÷	
286	43	RCL	
287	19	19	
288	99	PRT	
289	55	÷	
290	43	RCL	
291	29	29	
292	95	=	
293	52	EE	
294	22	INV	
295	52	EE	
296	22	INV	
297	58	FIX	
298	16	A'	
299	17	B'	
300	92	RTN	
301	69	OP	
302	21	21	
303	53	(	
304	73	RC*	
305	01	01	
306	22	INV	
307	59	INT	
308	65	×	
309	01	1	
310	00	0	
311	54	)	
312	87	IFF	
313	00	00	
314	03	03	
315	24	24	
316	53	(	
317	73	RC*	
318	01	01	
319	59	INT	

MERGED CODES
62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE SOLAR CELL PAGE 3 OF 3 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
320	55	÷	
321	71	SBR	
322	22	INV	
323	54	)	
324	99	PRT	
325	92	RTN	
326	22	INV	
327	86	STF	
328	00	00	
329	03	3	
330	01	1	
331	16	A'	
332	01	1	
333	00	0	
334	17	B'	
335	58	FIX	
336	03	03	
337	98	ADV	
338	53	(	
339	71	SBR	
340	03	03	
341	01	01	
342	65	×	
343	97	DSZ	
344	02	02	
345	03	03	
346	39	39	
347	09	9	
348	16	A'	
349	71	SBR	
350	03	03	
351	01	01	
352	54	)	
353	52	EE	
354	22	INV	
355	52	EE	
356	99	PRT	
357	92	RTN	
358	36	PGM	
359	01	01	
360	71	SBR	
361	25	CLR	
362	01	1	
363	03	3	
364	05	5	
365	03	3	
366	32	X:T	
367	43	RCL	
368	13	13	
369	22	INV	
370	77	GE	
371	03	03	
372	74	74	
373	22	INV	
374	86	STF	

LOC	CODE	KEY	COMMENTS
375	01	01	
376	73	RC*	
377	00	00	
378	22	INV	
379	59	INT	
380	65	×	
381	01	1	
382	00	0	
383	95	=	
384	78	Σ+	
385	09	9	
386	06	6	
387	06	6	
388	87	IFF	
389	01	01	
390	03	03	
391	96	96	
392	02	2	
393	04	4	
394	01	1	
395	06	6	
396	32	X:T	
397	73	RC*	
398	00	00	
399	59	INT	
400	55	÷	
401	43	RCL	
402	30	30	
403	95	=	
404	42	STO	
405	22	22	
406	22	INV	
407	59	INT	
408	87	IFF	
409	01	01	
410	04	04	
411	18	18	
412	43	RCL	
413	22	22	
414	59	INT	
415	55	÷	
416	43	RCL	
417	30	30	
418	65	×	
419	01	1	
420	00	0	
421	95	=	
422	78	Σ+	
423	69	OP	
424	12	12	
425	85	+	
426	32	X:T	
427	65	×	
428	43	RCL	
429	13	13	

LOC	CODE	KEY	COMMENTS
430	95	=	
431	92	RTN	
432	42	STO	
433	22	22	
434	36	PGM	
435	01	01	
436	71	SBR	
437	25	CLR	
438	43	RCL	
439	07	07	
440	75	-	
441	02	2	
442	95	=	
443	32	X:T	
444	43	RCL	
445	21	21	
446	78	Σ+	
447	43	RCL	
448	07	07	
449	85	+	
450	02	2	
451	03	3	
452	95	=	
453	32	X:T	
454	43	RCL	
455	22	22	
456	78	Σ+	
457	69	OP	
458	12	12	
459	85	+	
460	32	X:T	
461	65	×	
462	43	RCL	
463	15	15	
464	95	=	
465	58	FIX	
466	03	03	
467	52	EE	
468	22	INV	
469	52	EE	
470	92	RTN	
471	00	0	
472	00	0	
473	00	0	
474	00	0	
475	00	0	
476	00	0	
477	00	0	
478	00	0	
479	00	0	

MERGED CODES

62 · 72 STO · 83 GTO
63 · 73 RCL · 84
64 · 74 SUM · 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

DATA BASE

FOR

SOLAR CELL

PROGRAM

10000.	30
1017.087	31
717.0759	32
965.1	33
993.0993	34
999.0999	35
999.0999	36
999.0999	37
961.0957	38
988.0988	39
1000.1	40
800.1	41
23100935.1290	42
22900930.1280	43
22300905.1245	44
21400865.1195	45
20050812.1120	46
17900725.1000	47
15650635.0875	48
13450545.0750	49
10900442.0610	50
1.455	51
1.395	52
1.32	53
1.23	54
1.125	55
1.	56
0.88	57
0.745	58
0.615	59

TITLE SOLAR ARRAY PAGE 1 OF 3

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	11	A	
002	42	STO	
003	17	17	
004	92	RTN	
005	76	LBL	
006	12	B	
007	42	STO	
008	19	19	
009	92	RTN	
010	76	LBL	
011	16	A'	
012	32	X:T	
013	03	3	
014	00	0	
015	18	C'	
016	92	RTN	
017	76	LBL	
018	19	D'	
019	58	FIX	
020	40	IND	
021	00	00	
022	52	EE	
023	22	INV	
024	52	EE	
025	92	RTN	
026	76	LBL	
027	17	B'	
028	32	X:T	
029	02	2	
030	06	6	
031	02	2	
032	02	2	
033	76	LBL	
034	18	C'	
035	22	INV	
036	58	FIX	
037	69	OP	
038	04	04	
039	32	X:T	
040	69	OP	
041	06	06	
042	92	RTN	
043	76	LBL	
044	39	COS	
045	32	X:T	
046	05	5	
047	02	2	
048	42	STO	
049	01	01	
050	05	5	
051	42	STO	
052	02	02	
053	32	X:T	
054	76	LBL	
055	30	TAN	
056	69	OP	
057	21	21	
058	64	PD*	
059	01	01	
060	97	DSZ	
061	02	02	
062	30	TAN	
063	92	RTN	
064	76	LBL	
065	38	SIN	
066	71	SBR	
067	39	COS	
068	98	ADV	
069	00	0	
070	76	LBL	
071	22	INV	
072	42	STO	
073	00	00	
074	43	RCL	
075	17	17	
076	65	×	
077	43	RCL	
078	53	53	
079	95	=	
080	19	D'	
081	32	X:T	
082	04	4	
083	03	3	
084	18	C'	
085	43	RCL	
086	29	29	
087	65	×	
088	43	RCL	
089	19	19	
090	95	=	
091	32	X:T	
092	04	4	
093	02	2	
094	18	C'	
095	92	RTN	
096	76	LBL	
097	37	P/R	
098	85	+	
099	43	RCL	
100	43	43	
101	65	×	
102	02	2	
103	85	+	
104	02	2	
105	42	STO	
106	00	00	
107	93	.	
108	00	0	
109	00	0	
110	05	5	
111	54	)	
112	19	D'	
113	16	A'	
114	92	RTN	
115	76	LBL	
116	13	C	
117	98	ADV	
118	98	ADV	
119	43	RCL	
120	17	17	
121	32	X:T	
122	04	4	
123	03	3	
124	18	C'	
125	43	RCL	
126	19	19	
127	32	X:T	
128	04	4	
129	02	2	
130	18	C'	
131	43	RCL	
132	51	51	
133	55	÷	
134	43	RCL	
135	49	49	
136	55	÷	
137	43	RCL	
138	47	47	
139	55	÷	
140	43	RCL	
141	19	19	
142	85	+	
143	01	1	
144	95	=	
145	59	INT	
146	98	ADV	
147	32	X:T	
148	03	3	
149	06	6	
150	18	C'	
151	42	STO	
152	29	29	
153	32	X:T	
154	05	5	
155	77	GE	
156	28	LOG	
157	22	INV	
158	76	LBL	
159	28	LOG	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE SOLAR ARRAY PAGE 2 OF 3 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
160	86	STF	
161	00	00	
162	43	RCL	
163	52	52	
164	55	÷	
165	43	RCL	
166	50	50	
167	55	÷	
168	43	RCL	
169	49	49	
170	55	÷	
171	43	RCL	
172	48	48	
173	55	÷	
174	43	RCL	
175	17	17	
176	55	÷	
177	32	X:T	
178	85	+	
179	01	1	
180	95	=	
181	59	INT	
182	32	X:T	
183	06	6	
184	03	3	
185	06	6	
186	03	3	
187	18	C'	
188	65	×	
189	43	RCL	
190	29	29	
191	95	=	
192	32	X:T	
193	01	1	
194	05	5	
195	18	C'	
196	42	STO	
197	53	53	
198	01	1	
199	71	SBR	
200	22	INV	
201	43	RCL	
202	53	53	
203	55	÷	
204	04	4	
205	00	0	
206	87	IFF	
207	00	00	
208	29	CP	
209	04	4	
210	02	2	
211	76	LBL	
212	29	CP	
213	42	STO	
214	14	14	

LOC	CODE	KEY	COMMENTS
215	65	×	
216	02	2	
217	55	÷	
218	43	RCL	
219	44	44	
220	85	+	
221	01	1	
222	95	=	
223	59	INT	
224	65	×	
225	43	RCL	
226	44	44	
227	95	=	
228	98	ADV	
229	32	X:T	
230	04	4	
231	04	4	
232	18	C'	
233	42	STO	
234	13	13	
235	43	RCL	
236	14	14	
237	32	X:T	
238	04	4	
239	05	5	
240	18	C'	
241	43	RCL	
242	53	53	
243	65	×	
244	02	2	
245	65	×	
246	32	X:T	
247	01	1	
248	05	5	
249	18	C'	
250	42	STO	
251	53	53	
252	43	RCL	
253	11	11	
254	22	INV	
255	59	INT	
256	95	=	
257	42	STO	
258	12	12	
259	53	(	
260	43	RCL	
261	13	13	
262	65	×	
263	43	RCL	
264	08	08	
265	59	INT	
266	55	÷	
267	01	1	
268	52	EE	
269	05	5	

LOC	CODE	KEY	COMMENTS
270	22	INV	
271	52	EE	
272	71	SBR	
273	37	P/R	
274	42	STO	
275	13	13	
276	65	×	
277	53	(	
278	43	RCL	
279	14	14	
280	65	×	
281	43	RCL	
282	08	08	
283	22	INV	
284	59	INT	
285	71	SBR	
286	37	P/R	
287	42	STO	
288	14	14	
289	95	=	
290	19	D'	
291	32	X:T	
292	03	3	
293	00	0	
294	07	7	
295	00	0	
296	18	C'	
297	42	STO	
298	54	54	
299	65	×	
300	53	(	
301	43	RCL	
302	11	11	
303	59	INT	
304	55	÷	
305	53	(	
306	43	RCL	
307	08	08	
308	59	INT	
309	65	×	
310	43	RCL	
311	08	08	
312	22	INV	
313	59	INT	
314	54	)	
315	19	D'	
316	54	)	
317	19	D'	
318	55	÷	
319	03	3	

MERGED CODES

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE SOLAR ARRAY PAGE 3 OF 3

PROGRAMMER ______ DATE ______

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
320	42	STO	
321	00	00	
322	01	1	
323	00	0	
324	00	0	
325	95	=	
326	19	D'	
327	85	+	
328	48	EXC	
329	12	12	
330	19	D'	
331	17	B'	
332	95	=	
333	48	EXC	
334	12	12	
335	17	B'	
336	43	RCL	
337	12	12	
338	17	B'	
339	43	RCL	
340	47	47	
341	49	PRD	
342	29	29	
343	43	RCL	
344	13	13	
345	75	-	
346	43	RCL	
347	43	43	
348	95	=	
349	65	×	
350	43	RCL	
351	46	46	
352	71	SBR	
353	39	COS	
354	42	STO	
355	55	55	
356	85	+	
357	43	RCL	
358	43	43	
359	95	=	
360	42	STO	
361	13	13	
362	43	RCL	
363	14	14	
364	75	-	
365	43	RCL	
366	43	43	
367	95	=	
368	65	×	
369	43	RCL	
370	45	45	
371	71	SBR	
372	39	COS	
373	85	+	
374	43	RCL	

LOC	CODE	KEY	COMMENTS
375	43	43	
376	95	=	
377	42	STO	
378	14	14	
379	85	+	
380	43	RCL	
381	34	34	
382	95	=	
383	42	STO	
384	30	30	
385	00	0	
386	98	ADV	
387	71	SBR	
388	22	INV	
389	43	RCL	
390	13	13	
391	16	A'	
392	43	RCL	
393	14	14	
394	16	A'	
395	43	RCL	
396	49	49	
397	49	PRD	
398	29	29	
399	71	SBR	
400	39	COS	
401	42	STO	
402	56	56	
403	00	0	
404	98	ADV	
405	71	SBR	
406	22	INV	
407	43	RCL	
408	50	50	
409	55	÷	
410	04	4	
411	95	=	
412	71	SBR	
413	38	SIN	
414	43	RCL	
415	30	30	
416	16	A'	
417	43	RCL	
418	13	13	
419	16	A'	
420	65	×	
421	53	(	
422	43	RCL	
423	14	14	
424	65	×	
425	43	RCL	
426	56	56	
427	85	+	
428	53	(	
429	43	RCL	

LOC	CODE	KEY	COMMENTS
430	56	56	
431	75	-	
432	01	1	
433	54	)	
434	65	×	
435	43	RCL	
436	34	34	
437	85	+	
438	02	2	
439	65	×	
440	01	1	
441	42	STO	
442	00	00	
443	43	RCL	
444	33	33	
445	54	)	
446	19	D'	
447	16	A'	
448	42	STO	
449	14	14	
450	95	=	
451	42	STO	
452	57	57	
453	02	2	
454	71	SBR	
455	38	SIN	
456	02	2	
457	71	SBR	
458	38	SIN	
459	00	0	
460	42	STO	
461	00	00	
462	43	RCL	
463	54	54	
464	19	D'	
465	42	STO	
466	54	54	
467	43	RCL	
468	57	57	
469	19	D'	
470	42	STO	
471	15	15	
472	32	X:T	
473	03	3	
474	00	0	
475	07	7	
476	00	0	
477	18	C'	
478	92	RTN	
479	00	0	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

DATA BASE

FOR

SOLAR ARRAY

PROGRAM

0.	30
154.	31
.7927135678	32
0.5	33
0.025	34
0.86	35
0.	36
0.	37
0.	38
0.	39
0.	40
0.	41
0.026	42
0.05	43
3.	44
3.	45
5.	46
30.	47
30.	48
4.	49
48.	50
180.	51
480000.	52
0.	53
0.	54
0.	55
0.	56
0.	57
0.	58
0.	59

TITLE WEIGHT PAGE 1 OF 3 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	16	A'	
002	32	X:T	
003	03	3	
004	03	3	
005	01	1	
006	03	3	
007	03	3	
008	01	1	
009	76	LBL	
010	18	C'	
011	22	INV	
012	58	FIX	
013	69	OP	
014	04	04	
015	32	X:T	
016	58	FIX	
017	40	IND	
018	00	00	
019	52	EE	
020	22	INV	
021	52	EE	
022	69	OP	
023	06	06	
024	92	RTN	
025	76	LBL	
026	17	B'	
027	32	X:T	
028	01	1	
029	04	4	
030	02	2	
031	07	7	
032	02	2	
033	06	6	
034	03	3	
035	07	7	
036	61	GTO	
037	18	C'	
038	76	LBL	
039	13	C	
040	22	INV	
041	58	FIX	
042	04	4	
043	03	3	
044	01	1	
045	07	7	
046	02	2	
047	04	4	
048	69	OP	
049	00	00	
050	69	OP	
051	02	02	
052	02	2	
053	02	2	
054	02	2	

LOC	CODE	KEY	COMMENTS
055	03	3	
056	03	3	
057	07	7	
058	00	0	
059	00	0	
060	00	0	
061	00	0	
062	69	OP	
063	03	03	
064	98	ADV	
065	98	ADV	
066	98	ADV	
067	69	OP	
068	05	05	
069	43	RCL	
070	45	45	
071	65	×	
072	43	RCL	
073	46	46	
074	65	×	
075	02	2	
076	42	STO	
077	00	00	
078	43	RCL	
079	12	12	
080	95	=	
081	98	ADV	
082	32	X:T	
083	03	3	
084	00	0	
085	03	3	
086	02	2	
087	01	1	
088	06	6	
089	18	C'	
090	42	STO	
091	59	59	
092	43	RCL	
093	47	47	
094	75	-	
095	01	1	
096	95	=	
097	65	×	
098	43	RCL	
099	42	42	
100	95	=	
101	32	X:T	
102	01	1	
103	07	7	
104	02	2	
105	04	4	
106	01	1	
107	05	5	
108	00	0	
109	02	2	

LOC	CODE	KEY	COMMENTS
110	18	C'	
111	44	SUM	
112	59	59	
113	29	CP	
114	43	RCL	
115	48	48	
116	55	÷	
117	43	RCL	
118	47	47	
119	75	-	
120	01	1	
121	95	=	
122	67	EQ	
123	22	INV	
124	85	+	
125	03	3	
126	05	5	
127	95	=	
128	42	STO	
129	22	22	
130	73	RC*	
131	22	22	
132	32	X:T	
133	01	1	
134	07	7	
135	02	2	
136	04	4	
137	01	1	
138	05	5	
139	00	0	
140	03	3	
141	18	C'	
142	44	SUM	
143	59	59	
144	76	LBL	
145	22	INV	
146	43	RCL	
147	49	49	
148	65	×	
149	43	RCL	
150	50	50	
151	55	÷	
152	04	4	
153	95	=	
154	42	STO	
155	22	22	
156	65	×	
157	43	RCL	
158	59	59	
159	16	A'	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE WEIGHT PAGE 2 OF 3 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
160	32	X:T	
161	00	0	
162	42	STO	
163	00	00	
164	32	X:T	
165	95	=	
166	98	ADV	
167	16	A'	
168	42	STO	
169	58	58	
170	43	RCL	
171	22	22	
172	75	-	
173	01	1	
174	95	=	
175	65	×	
176	53	(	
177	43	RCL	
178	34	34	
179	85	+	
180	02	2	
181	65	×	
182	43	RCL	
183	43	43	
184	54	)	
185	65	×	
186	43	RCL	
187	13	13	
188	65	×	
189	07	7	
190	93	.	
191	05	5	
192	95	=	
193	32	X:T	
194	03	3	
195	00	0	
196	01	1	
197	07	7	
198	02	2	
199	04	4	
200	01	1	
201	05	5	
202	18	C'	
203	44	SUM	
204	58	58	
205	43	RCL	
206	33	33	
207	65	×	
208	43	RCL	
209	13	13	
210	65	×	
211	07	7	
212	93	.	
213	05	5	
214	65	×	

LOC	CODE	KEY	COMMENTS
215	02	2	
216	95	=	
217	32	X:T	
218	01	1	
219	07	7	
220	03	3	
221	01	1	
222	01	1	
223	06	6	
224	18	C'	
225	44	SUM	
226	58	58	
227	43	RCL	
228	49	49	
229	75	-	
230	01	1	
231	95	=	
232	65	×	
233	43	RCL	
234	50	50	
235	55	÷	
236	04	4	
237	65	×	
238	43	RCL	
239	35	35	
240	95	=	
241	32	X:T	
242	01	1	
243	07	7	
244	02	2	
245	04	4	
246	01	1	
247	05	5	
248	18	C'	
249	44	SUM	
250	58	58	
251	43	RCL	
252	58	58	
253	17	B'	
254	65	×	
255	04	4	
256	95	=	
257	98	ADV	
258	17	B'	
259	42	STO	
260	58	58	
261	42	STO	
262	22	22	
263	43	RCL	
264	28	28	
265	65	×	
266	53	(	
267	43	RCL	
268	53	53	
269	55	÷	

LOC	CODE	KEY	COMMENTS
270	43	RCL	
271	50	50	
272	65	×	
273	43	RCL	
274	17	17	
275	55	÷	
276	43	RCL	
277	19	19	
278	55	÷	
279	43	RCL	
280	29	29	
281	54	)	
282	33	X^2	
283	65	×	
284	43	RCL	
285	27	27	
286	65	×	
287	43	RCL	
288	25	25	
289	65	×	
290	43	RCL	
291	26	26	
292	55	÷	
293	43	RCL	
294	17	17	
295	65	×	
296	43	RCL	
297	24	24	
298	95	=	
299	34	√X	
300	58	FIX	
301	00	00	
302	52	EE	
303	22	INV	
304	52	EE	
305	65	×	
306	04	4	
307	93	.	
308	01	1	
309	95	=	
310	32	X:T	
311	03	3	
312	00	0	
313	01	1	
314	04	4	
315	18	C'	
316	44	SUM	
317	22	22	
318	42	STO	
319	57	57	

MERGED CODES

62 ▪ ▪ 72 STO ▪ 83 GTO ▪
63 ▪ ▪ 73 RCL ▪ 84 ▪ ▪
64 ▪ ▪ 74 SUM ▪ 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE WEIGHT PAGE 3 OF 3

TI Programmable Coding Form

PROGRAMMER ____ DATE ____

LOC	CODE	KEY	COMMENTS
320	43	RCL	
321	14	14	
322	55	÷	
323	01	1	
324	05	5	
325	00	0	
326	95	=	
327	45	Y^x	
328	03	3	
329	65	×	
330	43	RCL	
331	32	32	
332	65	×	
333	53	(	
334	43	RCL	
335	57	57	
336	85	+	
337	43	RCL	
338	58	58	
339	95	=	
340	52	EE	
341	22	INV	
342	52	EE	
343	85	+	
344	53	(	
345	43	RCL	
346	50	50	
347	55	÷	
348	04	4	
349	08	8	
350	65	×	
351	43	RCL	
352	31	31	
353	54	)	
354	52	EE	
355	22	INV	
356	52	EE	
357	95	=	
358	32	X:T	
359	03	3	
360	06	6	
361	03	3	
362	07	7	
363	03	3	
364	05	5	
365	18	C'	
366	44	SUM	
367	57	57	
368	44	SUM	
369	22	22	
370	43	RCL	
371	22	22	
372	32	X:T	
373	03	3	
374	07	7	

LOC	CODE	KEY	COMMENTS
375	03	3	
376	02	2	
377	03	3	
378	07	7	
379	18	C'	
380	43	RCL	
381	53	53	
382	65	×	
383	43	RCL	
384	17	17	
385	95	=	
386	52	EE	
387	22	INV	
388	52	EE	
389	42	STO	
390	21	21	
391	55	÷	
392	02	2	
393	42	STO	
394	00	00	
395	43	RCL	
396	15	15	
397	95	=	
398	98	ADV	
399	32	X:T	
400	04	4	
401	03	3	
402	06	6	
403	03	3	
404	03	3	
405	00	0	
406	07	7	
407	00	0	
408	18	C'	
409	48	EXC	
410	21	21	
411	55	÷	
412	43	RCL	
413	22	22	
414	95	=	
415	98	ADV	
416	32	X:T	
417	04	4	
418	03	3	
419	06	6	
420	03	3	
421	02	2	
422	06	6	
423	02	2	
424	02	2	
425	18	C'	
426	42	STO	
427	22	22	
428	76	LBL	
429	15	E	

LOC	CODE	KEY	COMMENTS
430	22	INV	
431	58	FIX	
432	01	1	
433	06	6	
434	01	1	
435	03	3	
436	69	OP	
437	00	00	
438	69	OP	
439	02	02	
440	03	3	
441	07	7	
442	01	1	
443	03	3	
444	52	EE	
445	06	6	
446	22	INV	
447	52	EE	
448	69	OP	
449	03	03	
450	98	ADV	
451	98	ADV	
452	98	ADV	
453	98	ADV	
454	69	OP	
455	05	05	
456	98	ADV	
457	01	1	
458	02	2	
459	22	INV	
460	90	LST	
461	92	RTN	
462	00	0	
463	00	0	
464	00	0	
465	00	0	
466	00	0	
467	00	0	
468	00	0	
469	00	0	
470	00	0	
471	00	0	
472	00	0	
473	00	0	
474	00	0	
475	00	0	
476	00	0	
477	00	0	
478	00	0	
479	00	0	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TITLE LCCM PAGE 1 OF 3

TI Programmable **Coding Form**

PROGRAMMER ______________ DATE ______________

LOC	CODE	KEY	COMMENTS
000	76	LBL	
001	52	EE	
002	54	)	
003	58	FIX	
004	03	03	
005	52	EE	
006	22	INV	
007	52	EE	
008	22	INV	
009	58	FIX	
010	92	RTN	
011	76	LBL	
012	37	P/R	
013	53	(	
014	53	(	
015	43	RCL	
016	57	57	
017	85	+	
018	43	RCL	
019	58	58	
020	85	+	
021	43	RCL	
022	59	59	
023	65	×	
024	43	RCL	
025	25	25	
026	54	)	
027	65	×	
028	69	OP	
029	21	21	
030	73	RC*	
031	01	01	
032	71	SBR	
033	52	EE	
034	92	RTN	
035	76	LBL	
036	28	LOG	
037	42	STO	
038	01	01	
039	05	5	
040	02	2	
041	42	STO	
042	02	02	
043	73	RC*	
044	03	03	
045	65	×	
046	04	4	
047	71	SBR	
048	52	EE	
049	98	ADV	
050	98	ADV	
051	99	PRT	
052	72	ST*	
053	00	00	
054	76	LBL	
055	29	CP	
056	69	OP	
057	23	23	
058	73	RC*	
059	03	03	
060	65	×	
061	69	OP	
062	22	22	
063	73	RC*	
064	02	02	
065	71	SBR	
066	52	EE	
067	99	PRT	
068	74	SM*	
069	00	00	
070	97	DSZ	
071	01	01	
072	29	CP	
073	92	RTN	
074	76	LBL	
075	17	B'	
076	85	+	
077	04	4	
078	93	.	
079	07	7	
080	03	3	
081	61	GTO	
082	22	INV	
083	76	LBL	
084	12	B	
085	85	+	
086	03	3	
087	93	.	
088	01	1	
089	00	0	
090	76	LBL	
091	22	INV	
092	95	=	
093	42	STO	
094	04	04	
095	65	×	
096	32	X:T	
097	01	1	
098	93	.	
099	02	2	
100	09	9	
101	09	9	
102	09	9	
103	06	6	
104	03	3	
105	02	2	
106	52	EE	
107	06	6	
108	94	+/-	
109	22	INV	
110	52	EE	
111	95	=	
112	42	STO	
113	13	13	
114	32	X:T	
115	92	RTN	
116	76	LBL	
117	13	C	
118	25	CLR	
119	22	INV	
120	58	FIX	
121	98	ADV	
122	98	ADV	
123	98	ADV	
124	05	5	
125	03	3	
126	22	INV	
127	90	LST	
128	98	ADV	
129	98	ADV	
130	03	3	
131	69	OP	
132	17	17	
133	05	5	
134	42	STO	
135	03	03	
136	04	4	
137	22	INV	
138	90	LST	
139	06	6	
140	69	OP	
141	17	17	
142	03	3	
143	05	5	
144	42	STO	
145	00	00	
146	06	6	
147	71	SBR	
148	28	LOG	
149	43	RCL	
150	35	35	
151	99	PRT	
152	65	×	
153	02	2	
154	93	.	
155	06	6	
156	07	7	
157	71	SBR	
158	52	EE	
159	42	STO	

MERGED CODES

62 63 64 72 73 74 83 84 92

TEXAS INSTRUMENTS INCORPORATED

TI-24191

TITLE LCCM PAGE 2 OF 3 **TI Programmable Coding Form**

PROGRAMMER ______ DATE ______

LOC	CODE	KEY	COMMENTS
160	36	36	
161	01	1	
162	02	2	
163	42	STO	
164	03	03	
165	03	3	
166	07	7	
167	42	STO	
168	00	00	
169	05	5	
170	71	SBR	
171	28	LOG	
172	43	RCL	
173	37	37	
174	99	PRT	
175	85	+	
176	53	(	
177	24	CE	
178	65	×	
179	93	.	
180	01	1	
181	71	SBR	
182	52	EE	
183	42	STO	
184	38	38	
185	85	+	
186	53	(	
187	43	RCL	
188	18	18	
189	65	×	
190	43	RCL	
191	53	53	
192	71	SBR	
193	52	EE	
194	42	STO	
195	39	39	
196	85	+	
197	53	(	
198	43	RCL	
199	39	39	
200	65	×	
201	93	.	
202	00	0	
203	07	7	
204	71	SBR	
205	52	EE	
206	42	STO	
207	40	40	
208	85	+	
209	43	RCL	
210	19	19	
211	42	STO	
212	41	41	
213	85	+	
214	01	1	

LOC	CODE	KEY	COMMENTS
215	09	9	
216	42	STO	
217	01	01	
218	71	SBR	
219	37	P/R	
220	42	STO	
221	42	42	
222	95	=	
223	42	STO	
224	43	43	
225	85	+	
226	43	RCL	
227	36	36	
228	95	=	
229	42	STO	
230	44	44	
231	65	×	
232	01	1	
233	93	.	
234	01	1	
235	00	0	
236	06	6	
237	65	×	
238	01	1	
239	93	.	
240	01	1	
241	05	5	
242	71	SBR	
243	52	EE	
244	42	STO	
245	45	45	
246	85	+	
247	53	(	
248	71	SBR	
249	37	P/R	
250	42	STO	
251	46	46	
252	85	+	
253	43	RCL	
254	22	22	
255	44	SUM	
256	46	46	
257	85	+	
258	69	OP	
259	21	21	
260	71	SBR	
261	37	P/R	
262	42	STO	
263	47	47	
264	85	+	
265	43	RCL	
266	24	24	
267	44	SUM	
268	47	47	
269	85	+	

LOC	CODE	KEY	COMMENTS
270	53	(	
271	43	RCL	
272	24	24	
273	65	×	
274	93	.	
275	00	0	
276	07	7	
277	71	SBR	
278	52	EE	
279	44	SUM	
280	47	47	
281	54	)	
282	42	STO	
283	48	48	
284	95	=	
285	42	STO	
286	49	49	
287	65	×	
288	93	.	
289	03	3	
290	05	5	
291	71	SBR	
292	52	EE	
293	42	STO	
294	50	50	
295	43	RCL	
296	26	26	
297	42	STO	
298	51	51	
299	65	×	
300	01	1	
301	93	.	
302	09	9	
303	02	2	
304	71	SBR	
305	52	EE	
306	42	STO	
307	52	52	
308	65	×	
309	01	1	
310	93	.	
311	01	1	
312	05	5	
313	71	SBR	
314	52	EE	
315	42	STO	
316	53	53	
317	85	+	
318	53	(	
319	43	RCL	

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24161

TITLE LCCM PAGE 3 OF 3 **TI Programmable Coding Form**

PROGRAMMER DATE

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	27	27		375	05	5	
321	42	STO		376	22	INV	
322	54	54		377	90	LST	
323	85	+		378	92	RTN	
324	43	RCL					
325	28	28					
326	42	STO					
327	55	55					
328	85	+					
329	43	RCL					
330	29	29					
331	42	STO					
332	56	56					
333	54	)					
334	42	STO					
335	57	57					
336	95	=					
337	42	STO					
338	58	58					
339	85	+					
340	43	RCL					
341	49	49					
342	85	+					
343	43	RCL					
344	50	50					
345	95	=					
346	42	STO					
347	59	59					
348	76	LBL					
349	14	D					
350	98	ADV					
351	98	ADV					
352	98	ADV					
353	02	2					
354	07	7					
355	01	1					
356	05	5					
357	69	OP					
358	00	00					
359	69	OP					
360	02	02					
361	01	1					
362	05	5					
363	03	3					
364	00	0					
365	52	EE					
366	06	6					
367	22	INV					
368	52	EE					
369	69	OP					
370	03	03					
371	69	OP					
372	05	05					
373	98	ADV					
374	03	3					

LOC	CODE	KEY	COMMENTS

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

 TI-24181

DATA BASE

FOR

LCCM

PROGRAM

0.	00
0.	01
0.	02
0.	03
7.75	04
0.3665	05
.0000003058	06
.0000433167	07
.0012857639	08
0.022421875	09
.0000031583	10
.0000049925	11
0.07775	12
.0000100747	13
.0001848798	14
.0002572917	15
.0102604167	16
.0003639953	17
.0000156013	18
0.945	19
.0000028278	20
.0027517805	21
4.228	22
.0000274403	23
0.18	24
23.	25
0.408	26
2.5	27
146.25	28
11.	29

APPENDIX D

AVERAGE TEMPERATURE VARIATIONS

The data in Appendix D consists of

- Sample temperature profiles plotted from data points calculated by temperature subroutine of SACPM program (D-3)
- Average temperature curves showing the effect of various parameters on solar array average operating temperature (D-4 thru D-12)

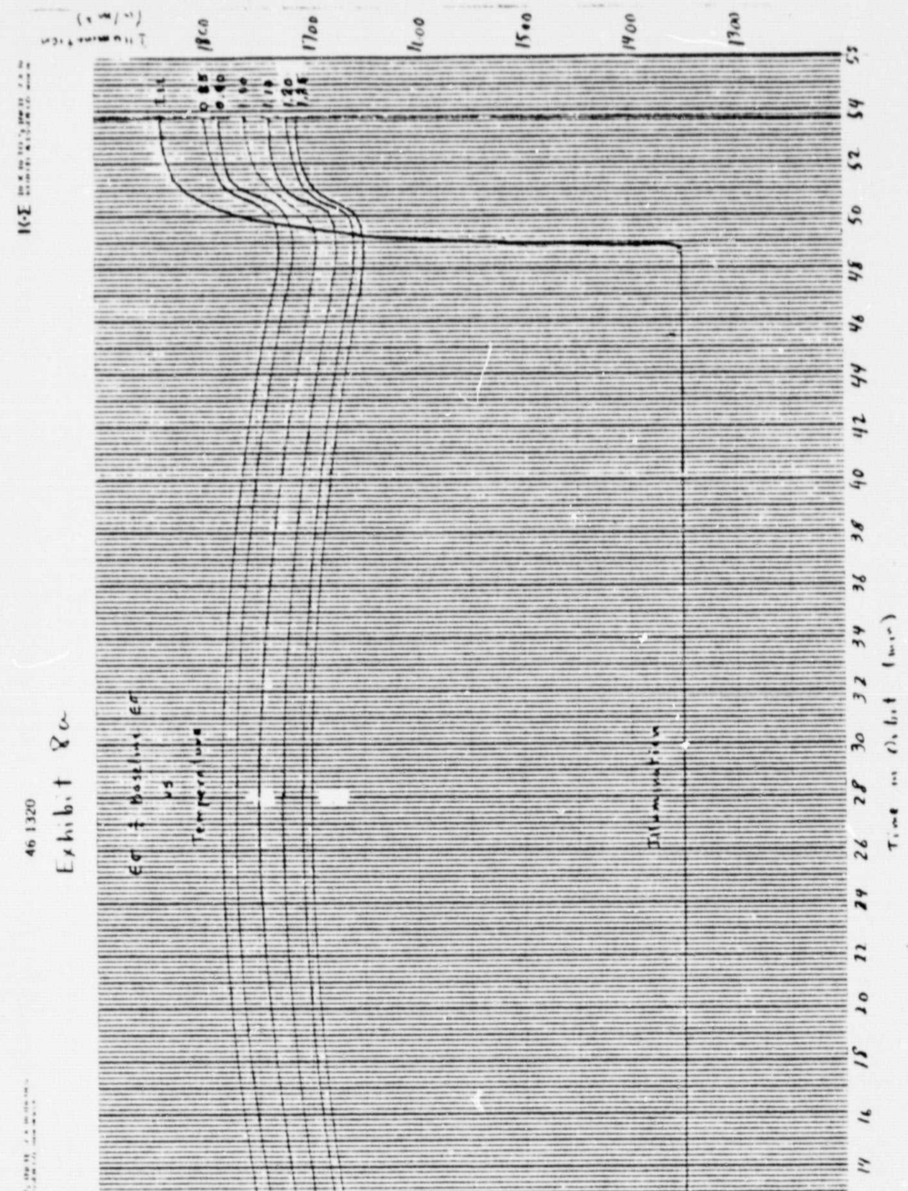
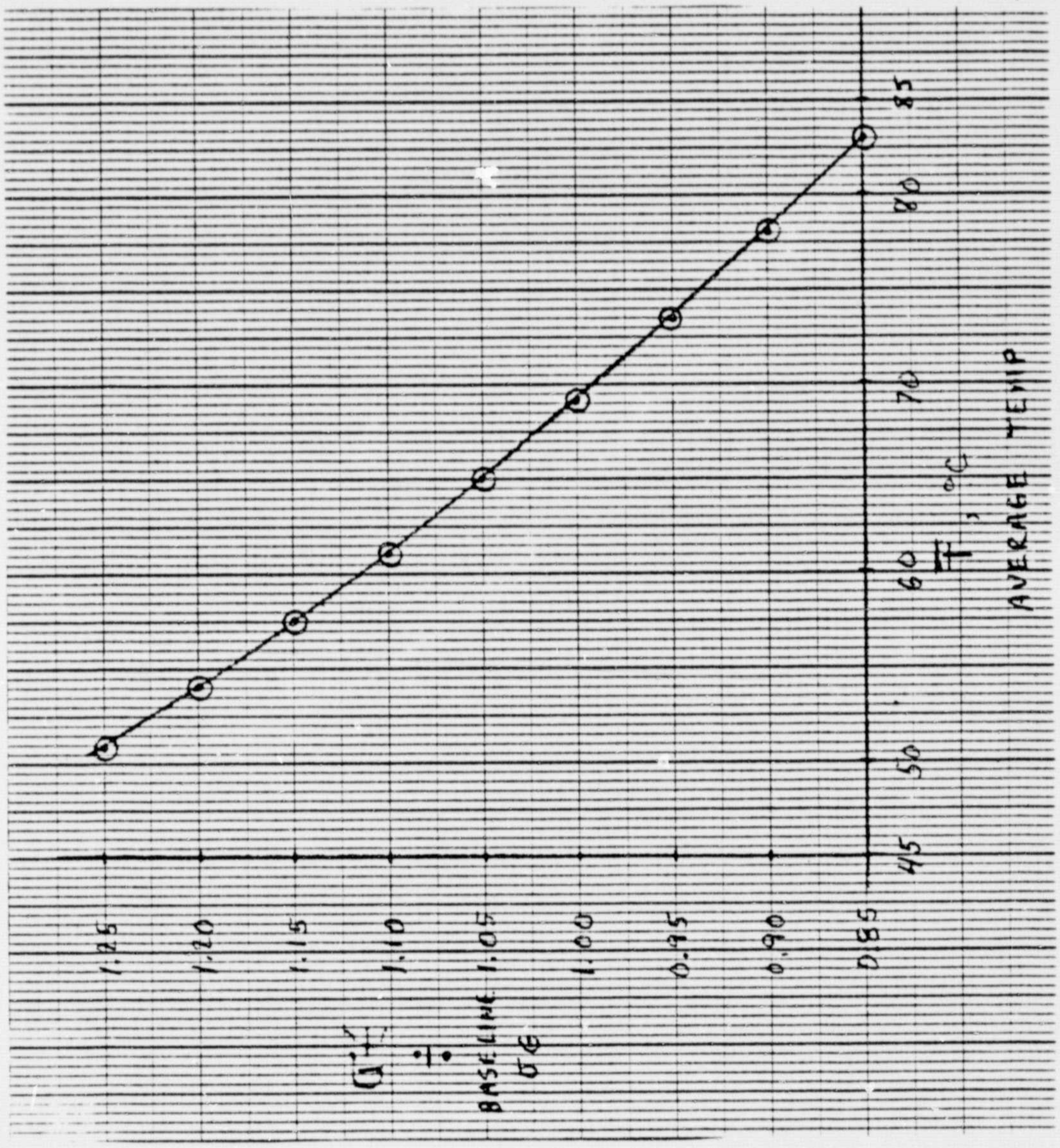
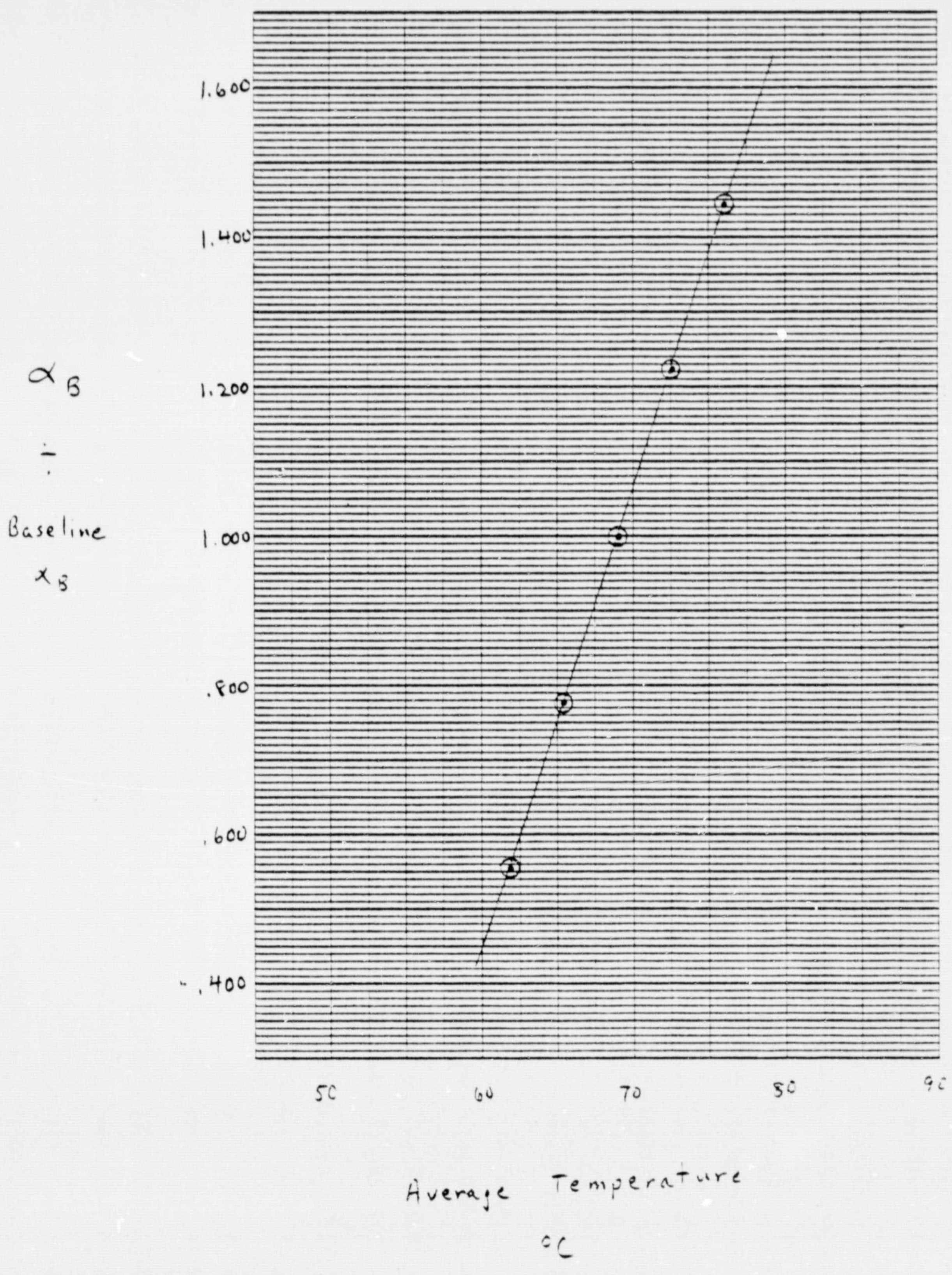
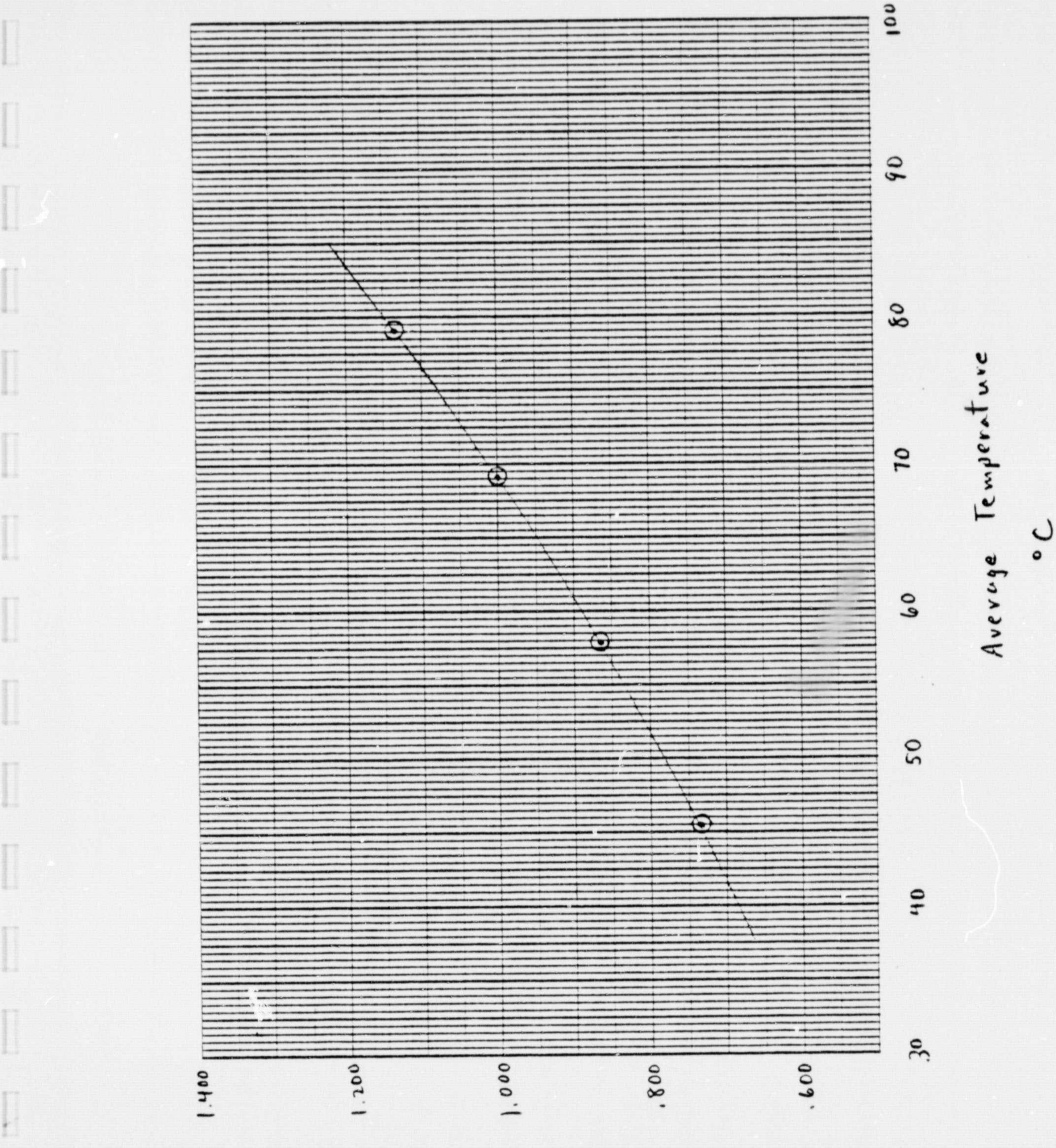


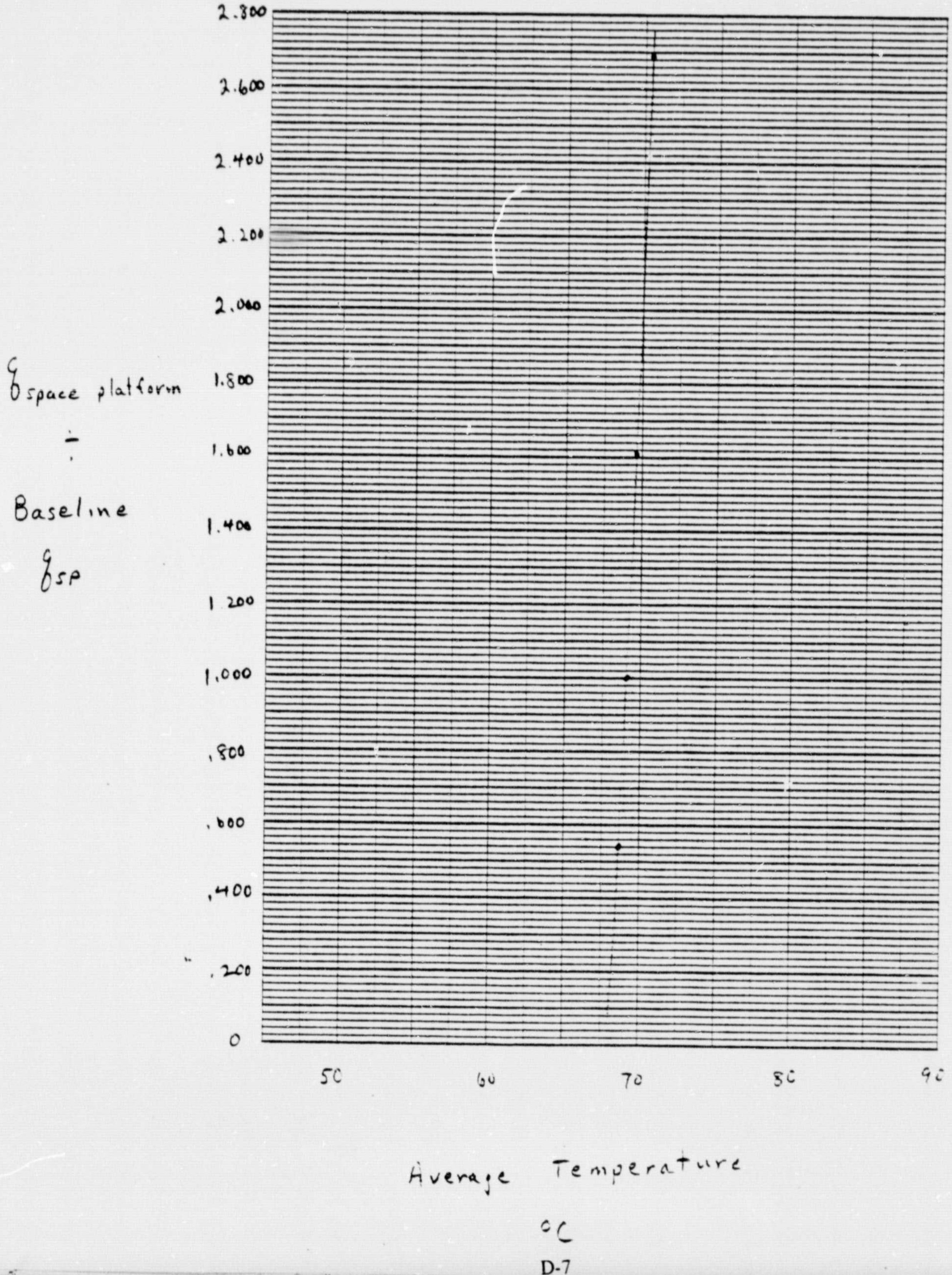
Exhibit 8a
Ea & Baseline Ea vs Temperature
Illumination
Time in Orbit (min)


1.25
1.20
1.15
1.10
BASELINE 1.05
GE
1.00
0.95
0.90
0.85
45
50
60
70
80
85
T, °C
AVERAGE TEMP

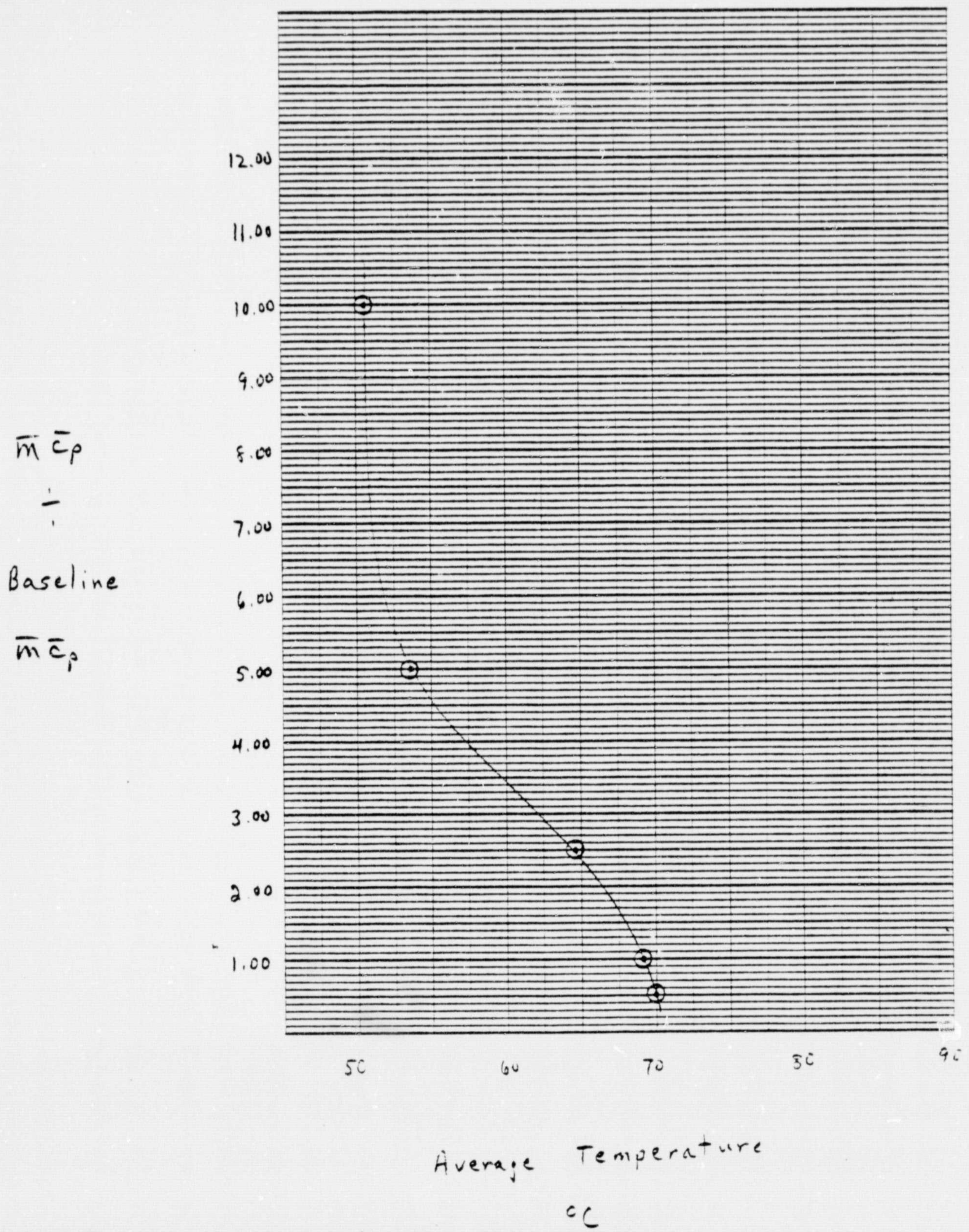


1.600
1.400
1.200
1.000
.800
.600
-.400
50
60
70
80
90
α B
÷
Baseline
α B
Average Temperature
°C

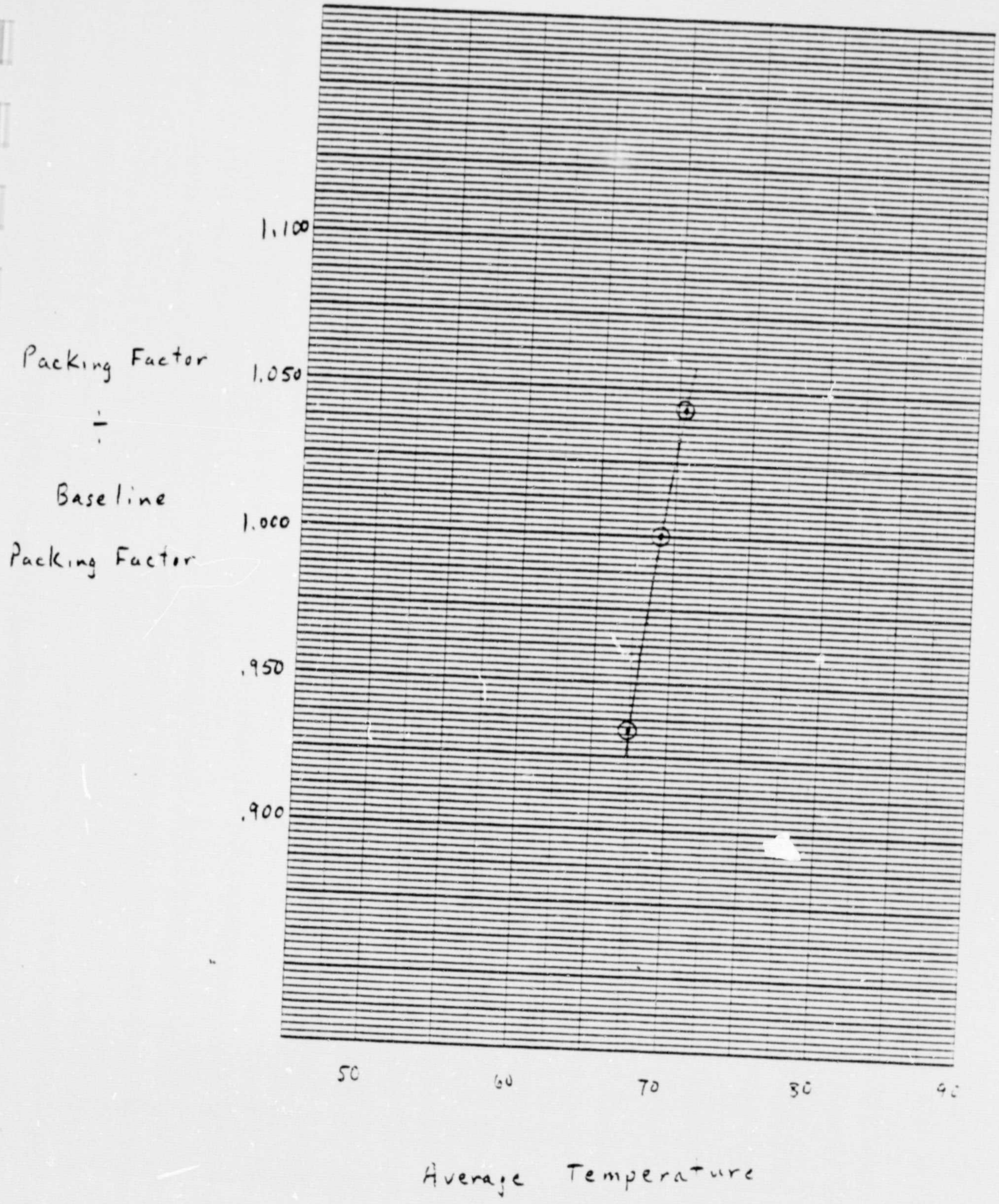

1.400
1.200
1.000
.800
.600
30
40
50
60
70
80
90
100
Average Temperature
°C
α_F
÷
Baseline
α_F

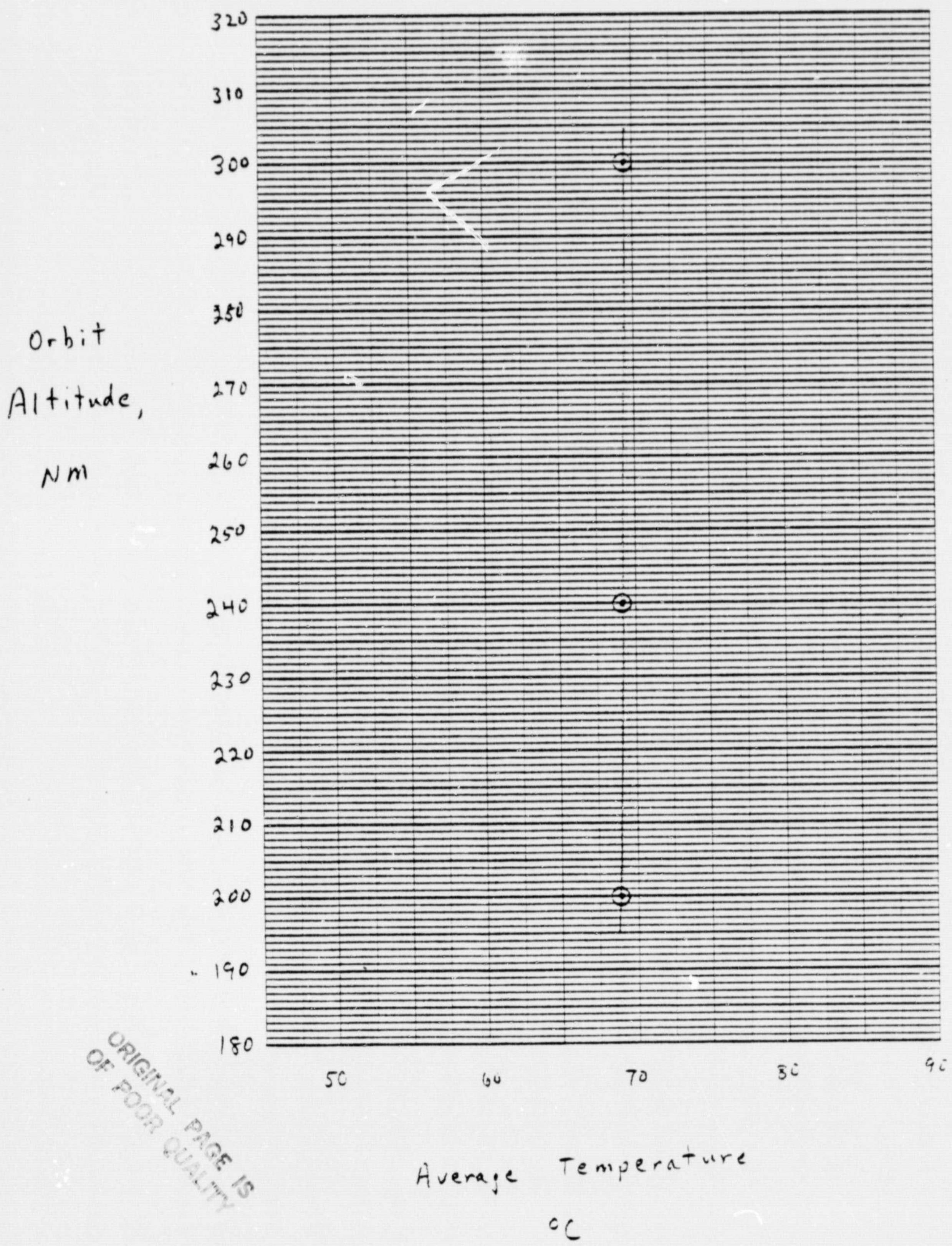


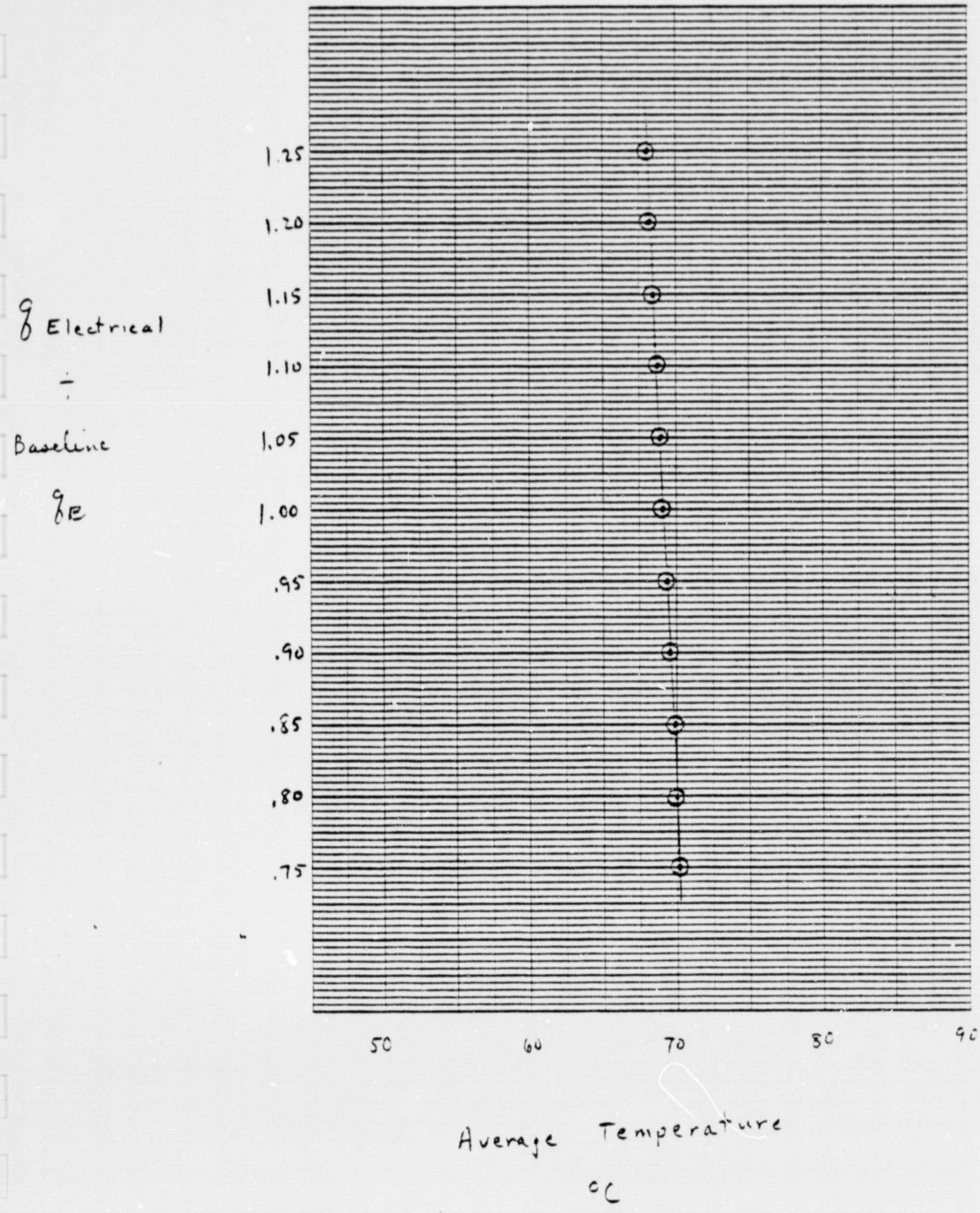
2.800
2.600
2.400
2.200
2.000
1.800
1.600
1.400
1.200
1.000
.800
.600
.400
.200
0
50
60
70
80
90
q space platform ÷ Baseline q SP
Average Temperature °C



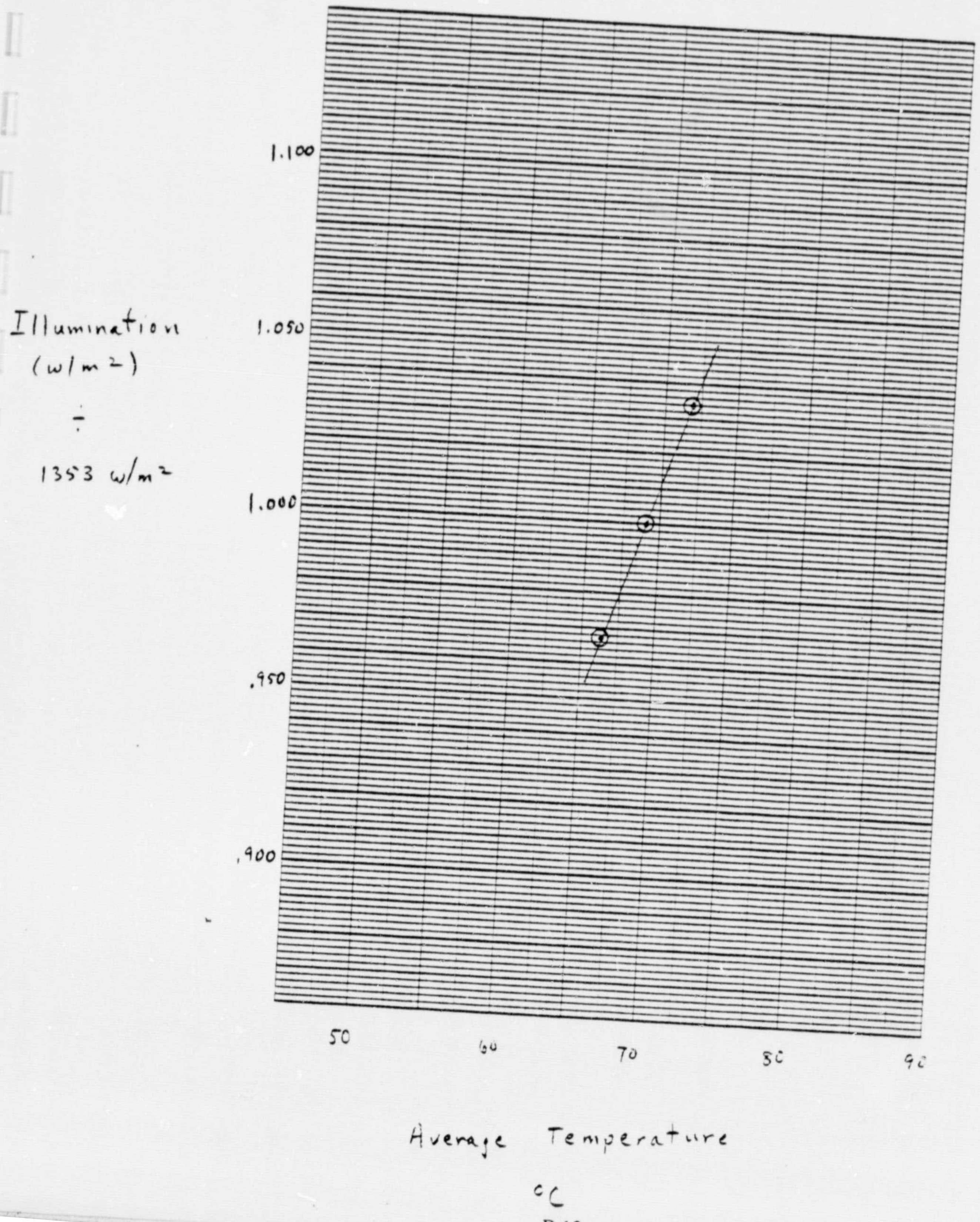
m̄ c̄p ÷ Baseline m̄ c̄p
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
50
60
70
80
90
Average Temperature
°C


Packing Factor
÷
Baseline
Packing Factor
1.100
1.050
1.000
.950
.900
50
60
70
80
90
Average Temperature
°C


Orbit
Altitude,
NM
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
50
60
70
80
90
Average Temperature
°C



q Electrical
÷
Baseline
q E
1.25
1.20
1.15
1.10
1.05
1.00
.95
.90
.85
.80
.75
50
60
70
80
90
Average Temperature
°C



Illumination
(w/m²)
÷
1353 w/m²
1.100
1.050
1.000
.950
.900
50
60
70
80
90
Average Temperature
°C

APPENDIX E

SACPM PROGRAM DATA PRINTOUT (TI-59)

Appendix E consists of a sample TI-59 SACPM program printout for the solar array baseline described in Section 2.0 of this report. The program used to generate the printout is described in Appendix C of this report. A plot of the temperature profile calculated by the temperature subroutine is shown on page D-3 in Appendix D.

PHYSICAL SUBROUTINE

4.	L
0.13	L
2.022	W
0.13	W
8.088	AC
8.888	HS
0.91	PF
0.	
6.	T
2200.	D
0.3353	M
8.088	A
0.2712	W
6.	T
2200.	D
6.	T'
0.3051	M'
475.	CP
145.	MCP
510.	CP
156.	MCP
575.	CP
175.	MCP
625.	CP
191.	MCP
675.	CP
206.	MCP
720.	CP
220.	MCP
765.	CP
233.	MCP
800.	CP
244.	MCP
850.	CP
259.	MCP

0.1	
2.	T
1080.	D
0.0549	M
8.088	A
0.04[illegible]4	W
2.	T
1080.	D
0.98	T'
0.05	M'
660.	CP
33.	MCP
725.	CP
36.	MCP
795.	CP
40.	MCP
865.	CP
43.	MCP
910.	CP
46.	MCP
945.	CP
47.	MCP
985.	CP
49.	MCP
1000.	CP
50.	MCP
1015.	CP
51.	MCP

1.	
8.	T
2600.	D
0.5283	M
8.088	A
0.4273	W
8.	T
975.	D
3.55	T'
0.4808	M'
500.	CP
240.	MCP
560.	CP
269.	MCP
615.	CP
296.	MCP
650.	CP
313.	MCP
700.	CP
337.	MCP
720.	CP
346.	MCP
725.	CP
349.	MCP
735.	CP
353.	MCP
750.	CP
361.	MCP

3.1	
0.5	T
1400.	D
0.0178	M
8.888	A
0.0158	W
0.5	T
1400.	D
0.32	T'
0.0178	M
725.	CP
13.	MCP
800.	CP
14.	MCP
875.	CP
16.	MCP
950.	CP
17.	MCP
1000.	CP
18.	MCP
1040.	CP
19.	MCP
1085.	CP
19.	MCP
1100.	CP
20.	MCP
1115.	CP
20.	MCP

PHYSICAL SUBROUTINE (CONTINUED)

3.2		3.3		3.4		3.5	
0.5	T	1.	T	0.5	T	0.5	T
1420.	D	2963.	D	1420.	D	1400.	D
0.018	M	0.0753	M	0.018	M	0.0178	M
8.888	A	8.888	A	8.888	A	8.888	A
0.016	W	0.0669	W	0.016	W	0.0158	W
0.5	T	1.	T	0.5	T	0.5	T
1420.	D	2963.	D	1420.	D	1400.	D
0.32	T'	1.35	T'	0.32	T'	0.32	T'
0.018	M	0.0753	M	0.018	M	0.0178	M
725.	CP	315.	CP	725.	CP	725.	CP
13.	MCP	24.	MCP	13.	MCP	13.	MCP
800.	CP	320.	CP	800.	CP	800.	CP
14.	MCP	24.	MCP	14.	MCP	14.	MCP
875.	CP	330.	CP	875.	CP	875.	CP
16.	MCP	25.	MCP	16.	MCP	16.	MCP
950.	CP	335.	CP	950.	CP	950.	CP
17.	MCP	25.	MCP	17.	MCP	17.	MCP
1000.	CP	350.	CP	1000.	CP	1000.	CP
18.	MCP	26.	MCP	18.	MCP	18.	MCP
1040.	CP	380.	CP	1040.	CP	1040.	CP
19.	MCP	29.	MCP	19.	MCP	19.	MCP
1085.	CP	415.	CP	1085.	CP	1085.	CP
20.	MCP	31.	MCP	20.	MCP	19.	MCP
1100.	CP	440.	CP	1100.	CP	1100.	CP
20.	MCP	33.	MCP	20.	MCP	20.	MCP
1115.	CP	495.	CP	1115.	CP	1115.	CP
20.	MCP	37.	MCP	20.	MCP	20.	MCP

PHYSICAL SUBROUTINE (CONTINUED)

Σ+	
4.	L
0.13	ΔL
2.022	W
0.13	ΔW
8.088	AC
8.888	AS
0.91	PF
1.	
16.	T
2260.	D
0.9185	M
8.088	A
0.7429	W
3.	
3.	T
1927.	D
0.1468	M
8.888	A
0.1305	W
5.	
19.	T
2036.	D
0.9627	M
8.888	A
0.8734	W
7.	
8.	T
1920.	D
6.98	T'
8.	
11.	T
1236.	D
6.18	T'

494.	21
541.	22
600.	23
640.	24
687.	25
718.	26
740.	27
760.	28
788.	29

FLUENCE SUBROUTINE

444.	KM
10.	YRS
6.98	T'
19.01	F
6.18	T'
21.88	F
40.89	ΣF

RADIATION SUBROUTINE

RAD	
8.	CT
40.89	ΣF
0.854	FP
0.968	FV

THERMAL SUBROUTINE

THERMAL
0.
444.
20.79459764
87.24
53.70
1.
0.78
0.91
0.45
0.09
0.750
2.
0.91
0.45
0.122
0.05
3.
0.450
0.700
4.
0.82
0.91
0.8
0.09
0.818
5.
0.8
0.75
0.600
0.05
.7071067812
.7071067812
0.025

50.	
4130.02152	08
50.91	09
854.0968	10
1305.000743	11
444.	12
20.79459764	13
87.24	14
0.7	15
0.45	16
156.2	17
93.7	18
9.3	19
.0000000824	20
494.	21
541.	22
600.	23
640.	24
687.	25
718.	26
740.	27
760.	28
788.	29

TEMPERATURE SUBROUTINE (MINIMUM ILLUMINATION)

0.	1780.	185.6	5.04	1309.	342.1	15.	1309.	340.7	25.	1309.	349.2
0.191	1780.	210.6	6.	1309.	332.2	16.	1309.	342.0	26.	1309.	349.4
0.418	1780.	235.6	7.	1309.	329.7	17.	1309.	343.2	26.85	1309.	349.5
0.687	1780.	260.6	8.	1309.	330.0	18.	1309.	344.3	27.	1309.	349.5
1.	1779.	283.9	9.	1309.	331.3	19.	1309.	345.3	28.	1309.	349.6
1.452	1777.	308.9	10.	1309.	332.9	20.	1309.	346.2	29.	1309.	349.5
2.	1772.	328.5	11.	1309.	334.5	21.	1309.	347.0	30.	1309.	349.3
3.	1751.	345.3	12.	1309.	336.2	22.	1309.	347.7	31.	1309.	349.0
4.	1671.	348.5	13.	1309.	337.8	23.	1309.	348.3	32.	1309.	348.6
5.	1329.	342.7	14.	1309.	339.3	24.	1309.	348.8	33.	1309.	348.1

TEMPERATURE SUBROUTINE (MINIMUM ILLUMINATION) (CONTINUED)

34. 1309. 347.4	44. 1309. 335.7	53. 1780. 353.4	57. 232.2
35. 1309. 346.7	45. 1309. 334.1	53.7 1780. 354.2	58. 220.8
36. 1309. 345.8	46. 1309. 332.4	1383. 339.5	59. 213.4
37. 1309. 344.9	47. 1309. 330.6	53.7 354.2	60. 208.8
38. 1309. 343.9	48. 1309. 328.8	53.998 329.2	61. 206.1
39. 1309. 342.7	48.66 1309. 327.6	54. 329.0	62. 204.7
40. 1309. 341.5	49. 1476. 328.5	54.404 304.0	63. 204.3
41. 1309. 340.2	50. 1708. 339.5	54.973 279.0	64. 204.5
42. 1309. 338.8	51. 1760. 347.6	55. 278.0	65. 205.2
43. 1309. 337.3	52. 1775. 351.5	55.858 253.0	66. 206.1
		56. 249.8	67. 207.1
			68. 208.0
			69. 208.9

TEMPERATURE SUBROUTINE (MINIMUM ILLUMINATION) (CONTINUED)	
70. 209.6	82. 201.3
70.47 209.9	83. 198.9
71. 210.2	84. 196.3
72. 210.6	85. 193.3
73. 210.7	86. 190.1
74. 210.7	87. 186.5
75. 210.4	87.24 185.6
76. 209.9	
77. 209.1	
78. 208.1	
79. 206.8	
80. 205.2	
81. 203.4	

TEMPERATURE SUBROUTINE (MAXIMUM ILLUMINATION)	
0. 1903. 185.6	5. 1421. 348.3
0.178 1903. 210.6	5.04 1399. 347.6
0.388 1902. 235.6	6. 1399. 337.4
0.635 1902. 260.6	7. 1399. 335.0
0.943 1901. 285.6	8. 1399. 335.4
1. 1901. 289.6	9. 1399. 336.7
1.432 1899. 314.6	10. 1399. 338.3
2. 1894. 335.5	11. 1399. 340.0
3. 1871. 351.9	12. 1399. 341.6
4. 1786. 354.6	13. 1399. 343.2

TEMPERATURE SUBROUTINE (MAXIMUM ILLUMINATION) (CONTINUED)

14.	1399.	344.7	24.	1399.	354.2	33.	1399.	353.4	43.	1399.	342.6
15.	1399.	346.1	25.	1399.	354.6	34.	1399.	352.8	44.	1399.	341.0
16.	1399.	347.4	26.	1399.	354.8	35.	1399.	352.0	45.	1399.	339.4
17.	1399.	348.6	26.85	1399.	354.9	36.	1399.	351.2	46.	1399.	337.7
18.	1399.	349.7	27.	1399.	354.9	37.	1399.	350.2	47.	1399.	335.9
19.	1399.	350.7	28.	1399.	355.0	38.	1399.	349.2	48.	1399.	334.1
20.	1399.	351.6	29.	1399.	354.9	39.	1399.	348.1	48.66	1399.	332.9
21.	1399.	352.4	30.	1399.	354.7	40.	1399.	346.8	49.	1577.	333.9
22.	1399.	353.1	31.	1399.	354.4	41.	1399.	345.5	50.	1826.	345.4
23.	1399.	353.7	32.	1399.	354.0	42.	1399.	344.1	51.	1881.	353.6

TEMPERATURE SUBROUTINE (MAXIMUM ILLUMINATION) (CONTINUED)

52. 1897. 357.4	56. 251.3	69. 208.9	81. 203.4
53. 1902. 359.2	57. 233.2	70. 209.6	82. 201.3
53.7 1903. 360.0	58. 221.5	70.47 209.9	83. 198.9
1478. 344.9	59. 213.9	71. 210.2	84. 196.3
53.7 360.0	60. 209.1	72. 210.6	85. 193.3
53.979 335.0	61. 206.3	73. 210.7	86. 190.1
54. 333.4	62. 204.9	74. 210.7	87. 186.5
54.383 308.4	63. 204.5	75. 210.4	87.24 185.6
54.918 283.4	64. 204.7	76. 209.9	
55. 280.3	65. 205.3	77. 209.1	
55.827 255.3	66. 206.1	78. 208.1	
	67. 207.1	79. 206.8	
	68. 208.0	80. 205.2	

MAIN BUS
SUBROUTINE

4130.02152	08
50.71	09
854.0968	10
1305.000743	11
0.	12
0.	13
0.	14
0.	15
0.122	16
0.	17
0.479	18
0.	19
.0000000824	20
0.	21
0.	22
0.0008888	23
0.0008734	24
5753.	25
169116.	26
0.000000026	27
24.	28
600.	29

SOLAR CELL SUBROUTINE P_{mp} (EOL)

0.738 0.965 0.993 0.999 0.999 0.999 0.955 0.988 1.000 0.800 0.854 0.455 0.056 1383. 1.017 0.870 1224. 339.5 340.0 0.718 0.965 0.993 0.999 0.999 0.999 0.955 0.988 1.000 0.800 0.854 0.442	0.054 1383. 1.017 0.870 1224. 339.5 340.2 0.717 0.965 0.993 0.999 0.999 0.999 0.955 0.988 1.000 0.800 0.854 0.442 0.054 1383. 1.017 0.870 1224. 339.5 340.2 0.717 0.965 0.993 0.999 0.999 0.999 0.955 0.988 1.000 0.800 0.854 0.442	0.787 1.000 0.993 0.999 0.999 0.999 0.955 0.988 1,000 1.000 0.968 0.712 0.053 0.341 0.717 0.965 0.993 0.999 0.999 0.999 0.961 0.988 1.000 0.800 0.854 0.444 0.054 1383. 1.017 0.870 1224. 339.5 340.2	0.717 0.965 0.993 0.999 0.999 0.999 0.961 0.988 1.000 0.800 0.854 0.444 0.787 1.000 0.993 0.999 0.999 0.999 0.961 0.988 1.000 1.000 0.968 0.716 0.053 0.343

SOLAR CELL SUBROUTINE $V_{mp(EOL)}$

0.717
0.965
0.993
0.999
0.999
0.999
0.961
0.988
1.000
0.800
0.854
0.444

0.054
1478.
1.017
0.870
1308.
344.9
345.6

0.738
0.965
0.993
0.999
0.999
0.999
0.961
0.988
1.000
0.800
0.854
0.457

0.056
1478.
1.017
0.870
1308.
344.9
345.4

0.739
0.965
0.993
0.999
0.999
0.999
0.961
0.988
1.000
0.800
0.854
0.458

0.056
1478.
1.017
0.870
1308.
344.9
345.4

0.739
0.965
0.993
0.999
0.999
0.999
0.961
0.988
1.000
0.800
0.854
0.458

0.759
1.000
0.993
0.999
0.999
0.999
0.961
0.988
1.000
1.000
0.968
0.691

0.059
0.331

0.739
0.965
0.993
0.999
0.999
0.999
0.957
0.988
1.000
0.800
0.854
0.456

0.056
1478.
1.017
0.870
1308.
344.9
345.4

0.739
0.965
0.993
0.999
0.999
0.999
0.957
0.988
1.000
0.800
0.854
0.456

0.759
1.000
0.993
0.999
0.999
0.999
0.957
0.988
1.000
1.000
0.968
0.688

0.059
0.330 ←

SOLAR ARRAY SUBROUTINE	
0.053	W
0.33	V
5.	S
315.	//
1575.	C
83.5	W
1.65	V
81.	X
40.	Y
3150.	C
3.45	M
0.97	M
3.35	M²
2.34	KG
0.492	KG
2.832	KG
2504.	W
49.5	V
17.05	M
2.81	M
10017.	W
198.	V
120204.	W
198.	V
2.835	M
17.05	M
137.1	M
240408.	W
198.	V
480816.	W
198.	V
9350.	M²

WEIGHT SUBROUTINE

WEIGHT	
42.48	MOD
0.75	EIC1
43.23	PAN
2075.	PAN
751.	MEIC
128.	EHD
31.	EIC
2985.	BLKT
11940.	BLKT
656.	MB
7778.	STR
20374.	TOT
51.42	W/M²
23.60	W/KG

DATA	
2.832	12
17.05	13
137.1	14
9350.	15
0.122	16
0.053	17
0.479	18
0.33	19
.0000000824	20
51.42	21
23.6	22
0.0008888	23
0.0008734	24
5753.	25
169116.	26
0.000000026	27
24.	28
600.	29
2.835	30
154.	31
.7927135678	32
0.5	33
0.025	34
0.86	35
0.	36
0.	37
0.	38
0.	39
0.	40
0.	41
0.026	42
0.05	43
3.	44
3.	45
5.	46
30.	47
30.	48
4.	49
48.	50
180.	51
480000.	52
9072000.	53
9648.	54
2880.	55
192.	56
8434.	57
11940.	58
43.23	59

LCCM SUBROUTINE

9072000.	53
9648.	54
2880.	55
192.	56
8434.	57
11940.	58
43.23	59
7.75	04
0.3665	05
.0000003058	06
.0000433167	07
.0012857639	08
0.022421875	09
.0000031583	10
.0000049925	11
0.07775	12
.0000100747	13
.0001848798	14
.0002572917	15
.0102604167.	16
.0003639953	17
.0000156013	18
0.945	19
.0000028278	20
.0027517805	21
4.228	22
.0000274403	23
0.18	24
23.	25
0.408	26
2.5	27
146.25	28
11:	29

1.466
2.774
0.418
3.703
4.305
0.027
0.06
12.753
0.311
91.398
1.784
0.741
1.97
3.07
99.274

LCCM	
12.753	35
34.051	36
99.274	37
9.927	38
141.535	39
9.907	40
0.945	41
0.06	42
261.648	43
295.699	44
376.1	45
63.029	46
0.779	47
63.808	48
439.908	49
153.968	50
0.408	51
0.783	52
0.9	53
2.5	54
146.25	55
11.	56
159.75	57
160.65	58
754.526	59