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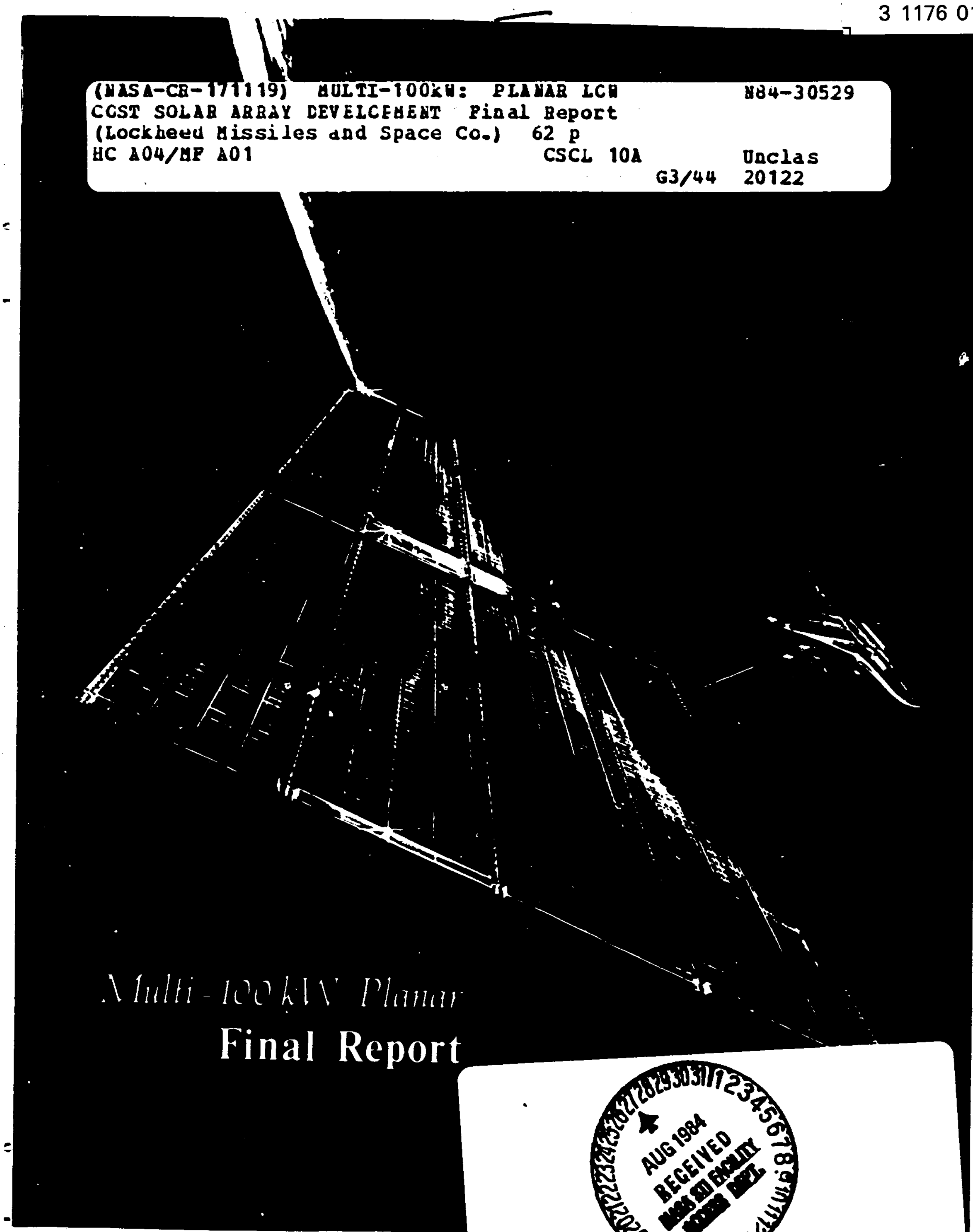
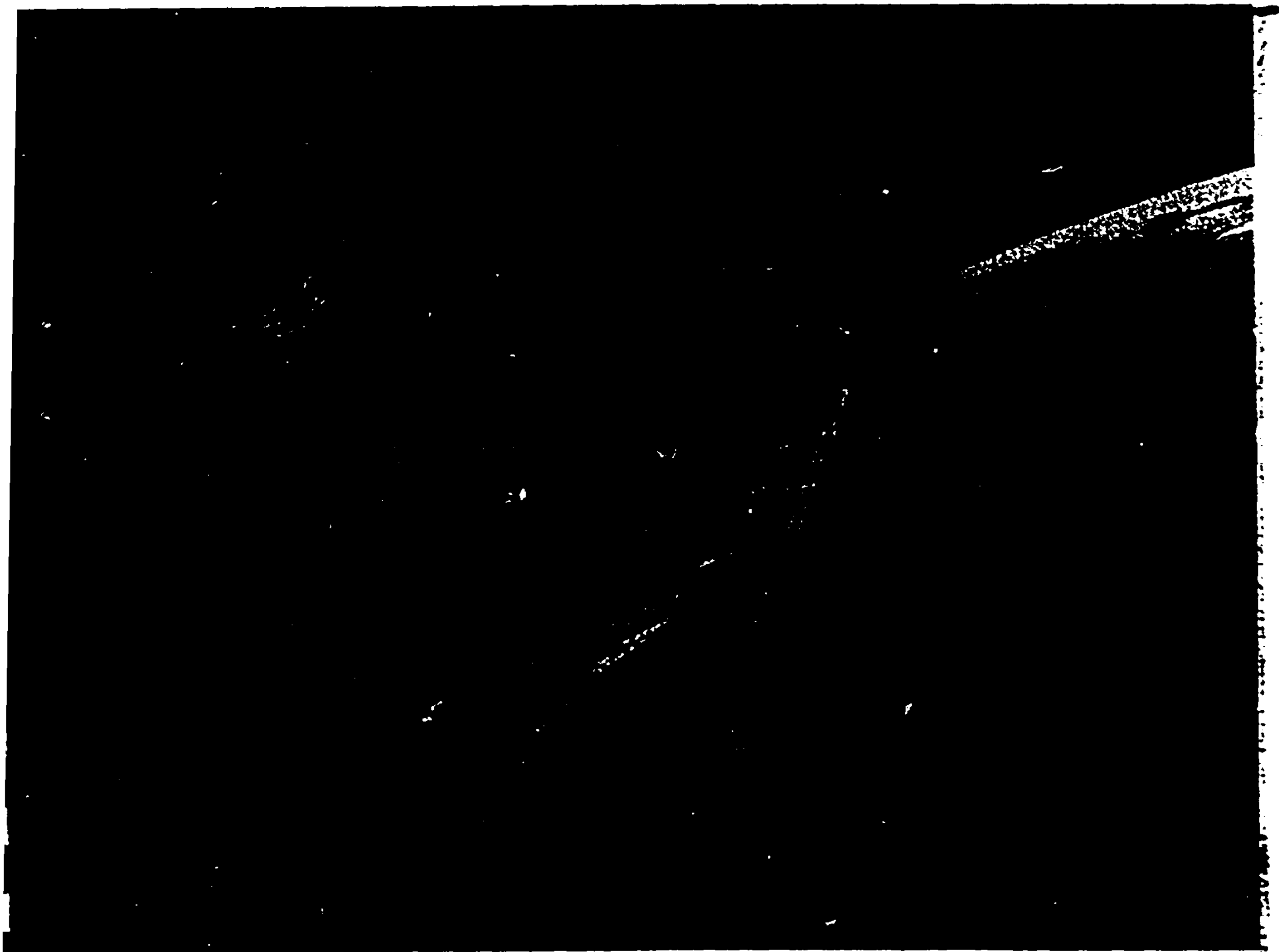


Multi-100 kW Planar
Final Report

N84-30529#



Final Report

JULY 1984

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Multi-100 kW

Planar Low Cost Solar Array Development

submitted to:

NASA

MARSHALL SPACE FLIGHT CENTER
National Aeronautics and Space Administration

Lockheed MISSILES & SPACE COMPANY, INC. SUNNYVALE, CALIFORNIA

FOREWORD

This report documents the work performed by Lockheed Missiles & Space Co., Inc., Sunnyvale, California, for Marshall Space Flight Center of the National Aeronautics and Space Administration under contract no. NAS8-32981 on the Multi-100 kW Planar, Low-Cost Solar Array Development project.

The term of this contract was 9 months beginning on 29 July 1982 and concluding on 15 April 1983. However, due to late cell deliveries a no-cost extension was requested and granted, and the contract was extended through June 1984. This report summarizes the full term effort performed on the subject contract over this entire period.

M. R. Carruth of the Astrionics Laboratory, Power Systems Branch of NASA/MSFC, provided technical direction for this work.

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ILLUSTRATIONS

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Section 1
BACKGROUND

1.1 OBJECTIVES

Spacecraft system design has historically been characterized by a constantly increasing need for power constrained by the limitations on weight and stowage volume imposed by the available expendable launch vehicles. As the industry transitions to the Shuttle as the primary launch vehicle, constraints on weight and volume are diminishing in importance while cost reductions become mandatory. Serious consideration must be given to simplifying design, minimizing material costs and automating production where possible. Maintaining reliability while substantially reducing the dollars per watt-hr to the lowest possible value will be the chief objective.

The Multi-100 kW low cost solar array program is concerned with developing the technology required to enable the design of solar arrays required to power the missions of the 1990's.

Previous phases of this program have evaluated all aspects of solar array design including planar vs concentrator, alternate materials, cells and construction methods. An analysis of planar array system design variables resulted in significant cost reductions and improvements in performance.

Several of these cost reduction suggestions have now been evaluated experimentally. Significant benefits have been realized by using large area solar cells with a superstrate covering approach. Benefits accruing from simplified manufacturing methods were verified by using a dry film adhesive; however, extensive searching has failed to identify a suitable material which is environmentally stable. Alternate contacts including copper and gridding of the back were evaluated with very encouraging results achieved with the gridded design. These design improvements and innovations have clearly established the planar, silicon solar array as the power source through the 1990's.

1.2 GUIDELINES

General guidelines were provided which formed the basis for the approach taken. These guidelines were as follows:

- Fabricate test articles incorporating previously identified design elements
- Large area, gridded back contact solar cells are to be used
- Processing to be based on established and proven procedures developed during previous add-on contracts
- Cleanliness and controls during layup emphasized

Reporting

This contract required one midterm and one final oral presentation and the submittal of a final written report. Program statusing was accomplished by monthly reporting. The basic contract was amended to incorporate LMSC's request for deletion of the midterm presentation and draft reports.

All effort including analysis, conceptual descriptions, manufacturing details, test results, cost data, assessments of modules fabricated and recommended technology for a follow-on contract are included in this final report.

Delivery

Seven 9-cell modules will be delivered to MSFC. These consist of 4 each modules fabricated with a high transmittance kapton sheet type substrate and 3 each with a unique kapton overlapping interconnect pattern.

Specific objectives of the contract phase just completed include:

- Simplify the superstrate concept by eliminating the Kapton-copper flexible blanket
- Evaluate methods of hinging superstrates together utilizing the glass as a structural element
- Evaluate erectable vs deployable arrays by analytically comparing 2 proposed point designs

1.3 SCHEDULE

The term of this contract follow-on was a 7 month period from July 1983 through February 1984. LMSC requested a no-cost extension to allow for late cell delivery. The contract was extended through 30 June 1984. All major tasks and subtasks are shown in Figure 1-1.

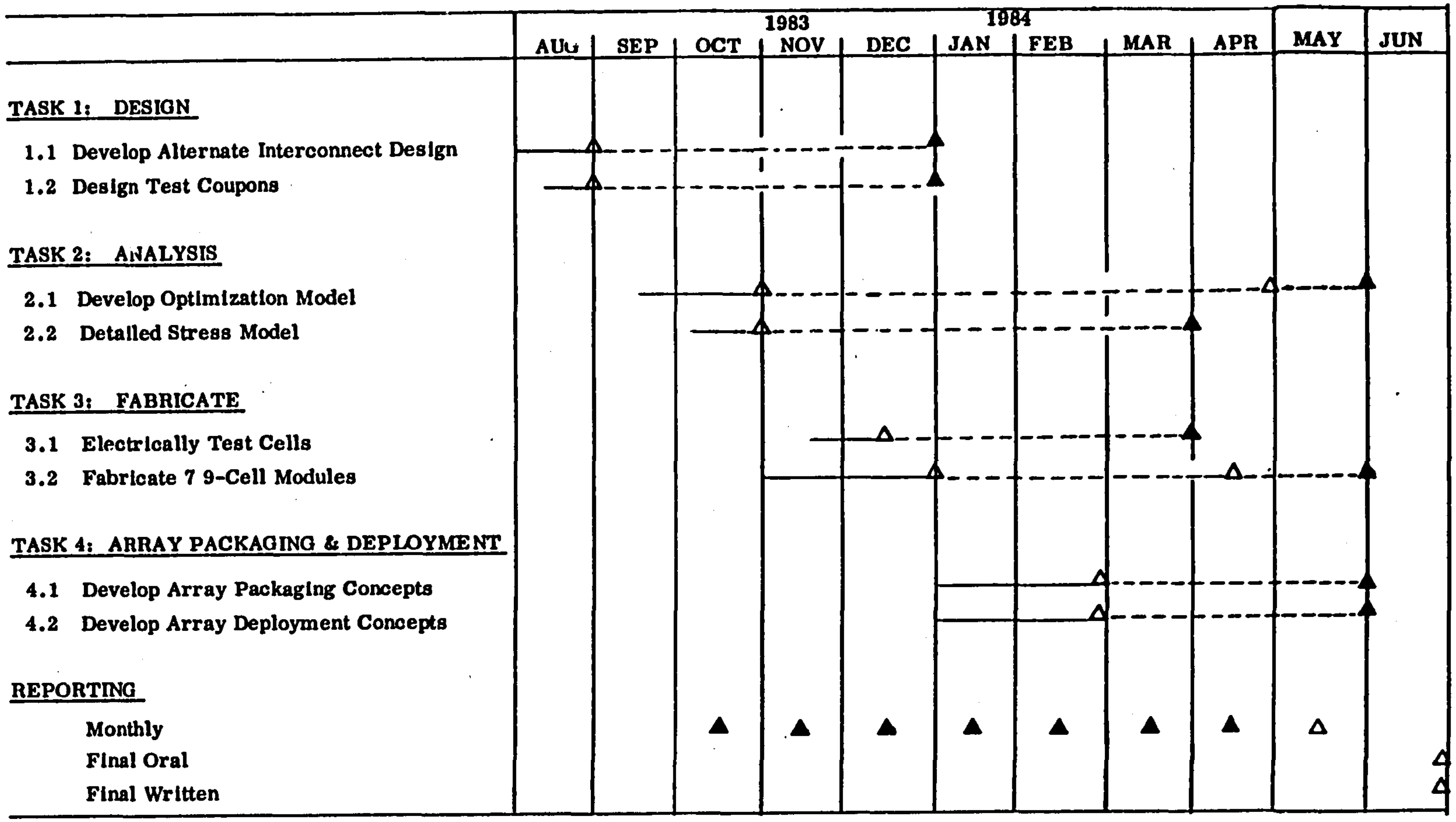

Figure 1-1 Add-On Multi-100 kW Planar Low Cost Solar Array Schedule

1.4 PROJECT ORGANIZATION

The Lockheed team was formed from experienced members of the Electrical Power Systems Group managed by Larry G. Chidester. The Multi-100 kW Planar, Low Cost Solar Array Development project was managed by George Pack with Rick Mills as Task Leader, Dan Lott as Large Area Solar Cell Consultant, and Joseph Lilly responsible for module fabrication. Project organization is shown in Figure 1-2. This team has been intact during the entire contract to ensure proper continuity. Other in-house technical and manufacturing specialists were used as necessary throughout the study term.

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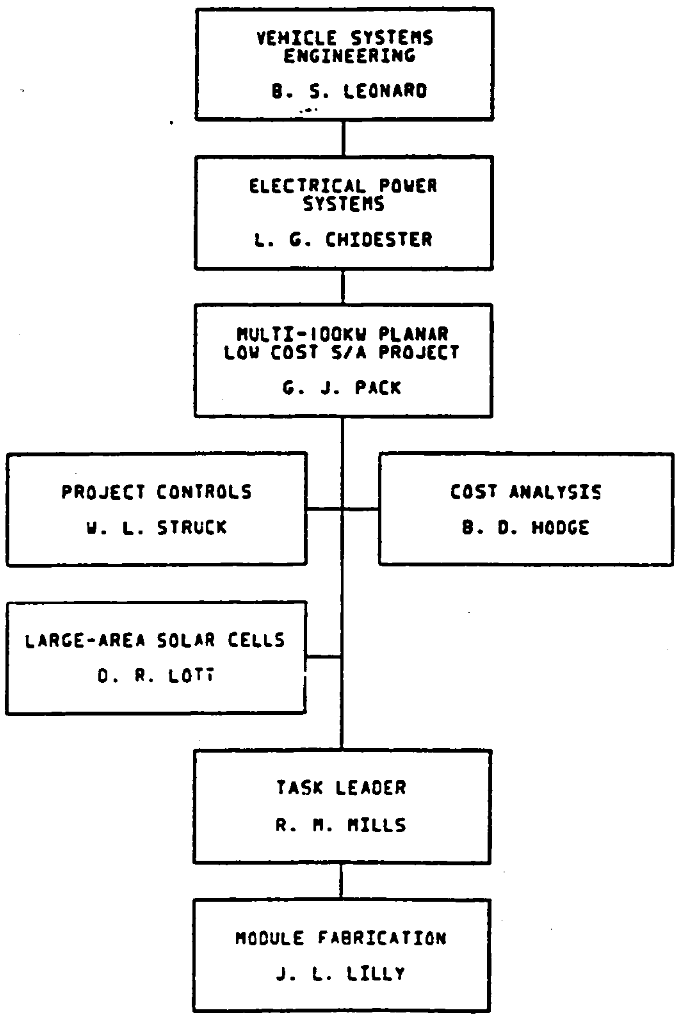

Figure 1-2 Project Organization

1.5 SUMMARY

Seven (7) modules were fabricated and delivered to MSFC for testing. Two different interconnect patterns were used demonstrating alternate approaches to increasing transparency and reducing costs.

In addition, two deployment schemes were analytically evaluated. One of the approaches was a derivative of a conventional flex array design using a coilable longeron mast and autonomous deployment. The second approach considered the use of a Stac Beam for inherently high natural frequency response. This design requires astronaut assistance during erection.

Section 2
TASK 1: TEST COUPON DESIGN

As proposed, the test coupons consist of a 5.9 x 5.9 cm^2 solar cells mounted to an ~8 x 8 in^2 superstrate. A primary task on this contract was to evaluate alternate contacting methods in an effort to increase array transparency by reducing absorbing surfaces in the optical path. The following sections describe the resulting design and expected performance.

2.1 INTERCONNECT DESIGN

The baseline Multi-100 kW planar solar array design uses the superstrate as the primary load carrying member with the interconnect/blanket assembly only required for electrical continuity and isolation. This contrasts with conventional flex array approaches where the interconnect/blanket must withstand a high tensile load. During this study, two additional constraints were imposed on the interconnect--minimizing intrusion into the optical path and minimizing cost by simplifying or automating fabrication and assembly. Two promising interconnect designs which satisfy all conditions were developed and fabricated.

Figure 2-1 shows the first interconnect design which is a straightforward derivative of the conventional printed circuit substrate. The pattern of the copper traces has been designed to overlay the cell contact pattern or to be within the intercell space. This results in no additional IR absorption by the metal interconnect. Kapton residing within the optical path which is not needed as insulation is cut away as shown, which further reduces IR absorption. Tension loads, required to prevent wrinkles during assembly, are carried by the kapton bands in the intercell spaces and across the weld pads. Conventional printed circuit substrate processing is used.

Figure 2-2 shows the second interconnect design which was also fabricated. This design is compared to the baseline sheet interconnect in Table 2-1. This design involves a significant departure from the sheet interconnect approach used in the

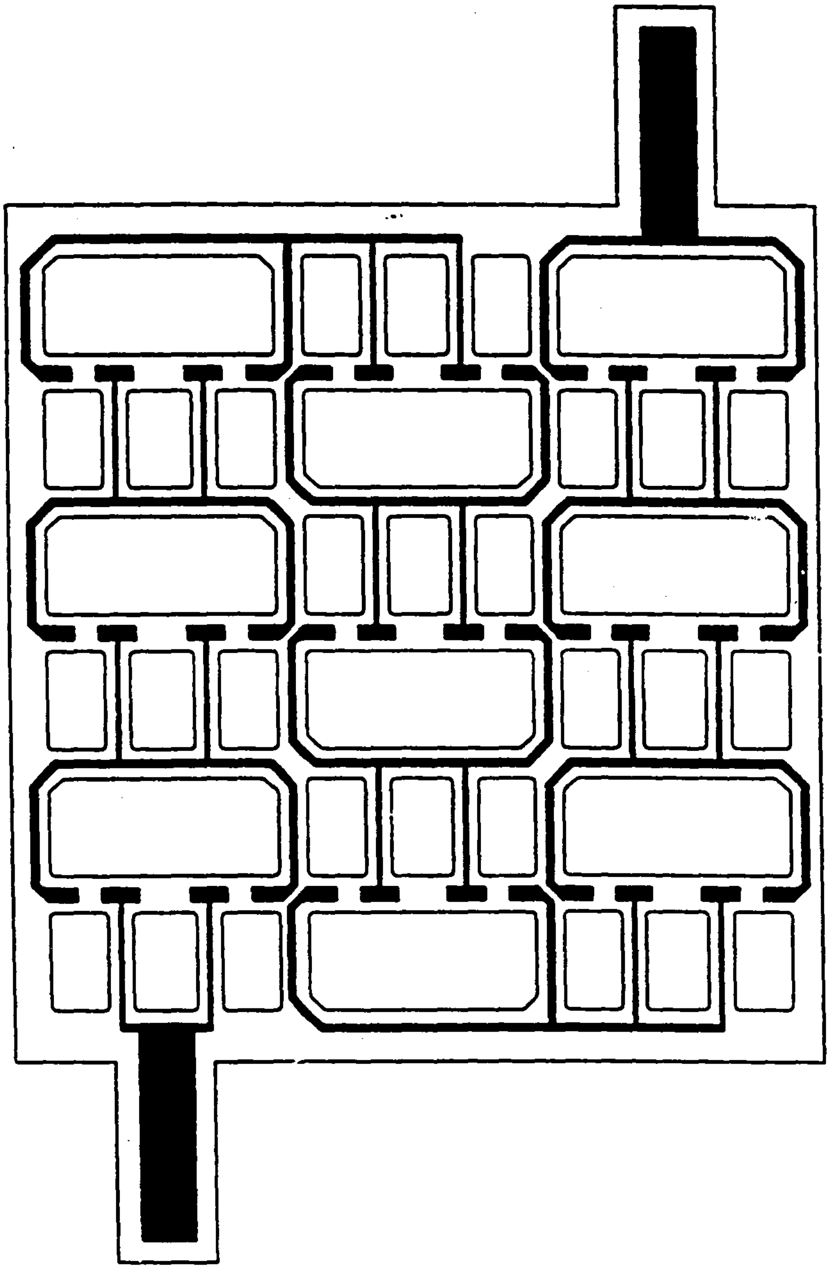

Figure 2-1 Sheet Interconnect

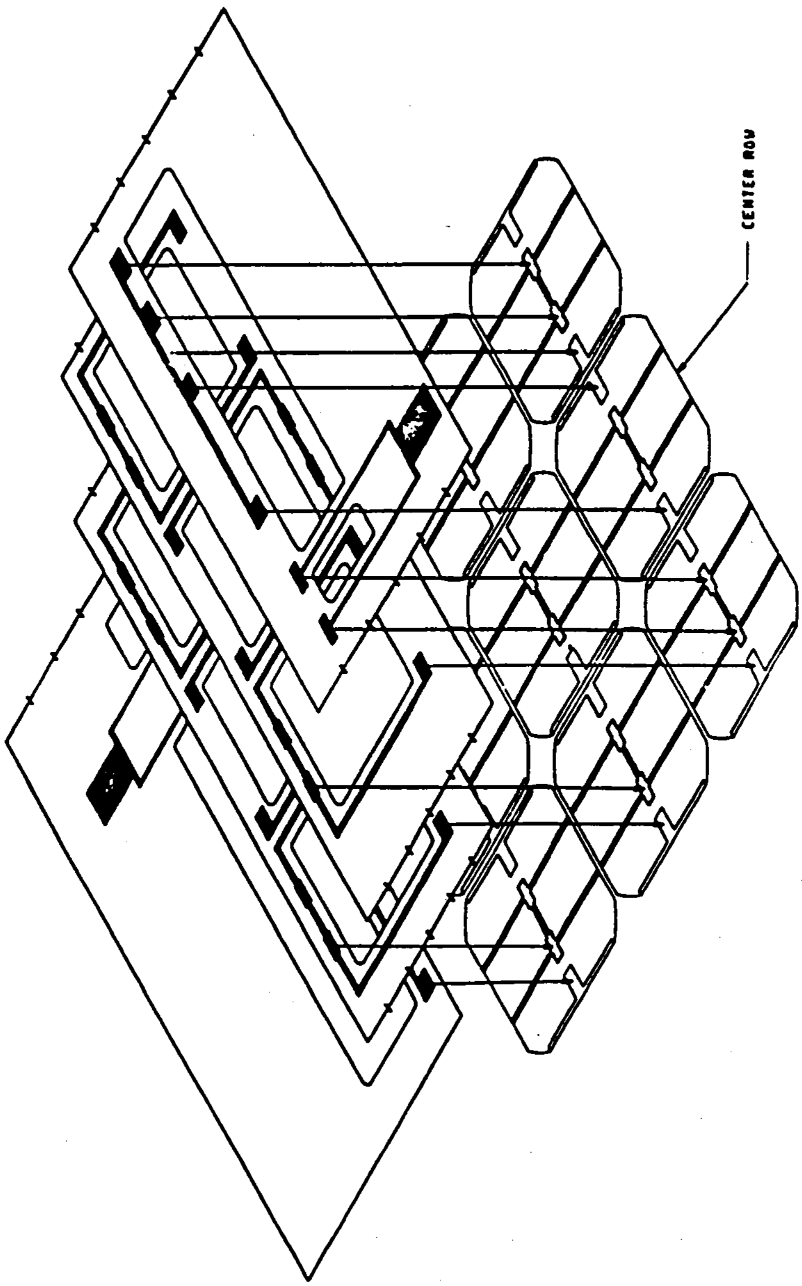

Figure 2-2 Overlapping Interconnect

first design. Internally designated as an "overlapping" design, this approach appears to offer potential for automation.

TABLE 2-1
INTERCONNECT DESIGN FEATURES

FEATURE	INTERCONNECT BASELINE: SHEET	INTERCONNECT OVERLAPPING
Percent Voltage Loss	3.4	1.0
Percent of Cell Covered by Kapton	43	26
Copper Weight	.000727 lb	.000732 lb
Kapton Weight	.00376 lb	.00517 lb
Redundancy	Dual Electrical Paths	Dual Electrical Path
Fabrication	Must use 12" wide Kapton	3" wide Kapton may be used

The overlapping interconnect circuit pattern chosen uses more copper than the sheet interconnect thus reducing the voltage loss in the interconnect from a calculated 3.4% to 1%. This approach has also been designed with less kapton insulation to interfere with the optical path through the cell thus increasing the transparency. The sheet interconnect kapton covers 43% of the back side of the cell compared to 26% for the overlapping interconnect. In both interconnect patterns a 0.1 inch kapton border remains around the copper trace.

A problem with the overlapping interconnect pattern became evident during assembly. The center row of cells (rows are from upper left to lower right) require the interconnects to be layered in the opposite direction (from lower right to upper left). In order to use these interconnect patterns the kapton was cut in order to achieve the proper overlapping sequence for the center row of interconnects. A solution to this problem would be to offset the weld pads from the centerline of the cell as shown in Figure 2-3. This modification would retain the characteristics of the overlapping interconnect pattern but would allow the interconnect to be fabricated in either the layered approach or the sheet approach.

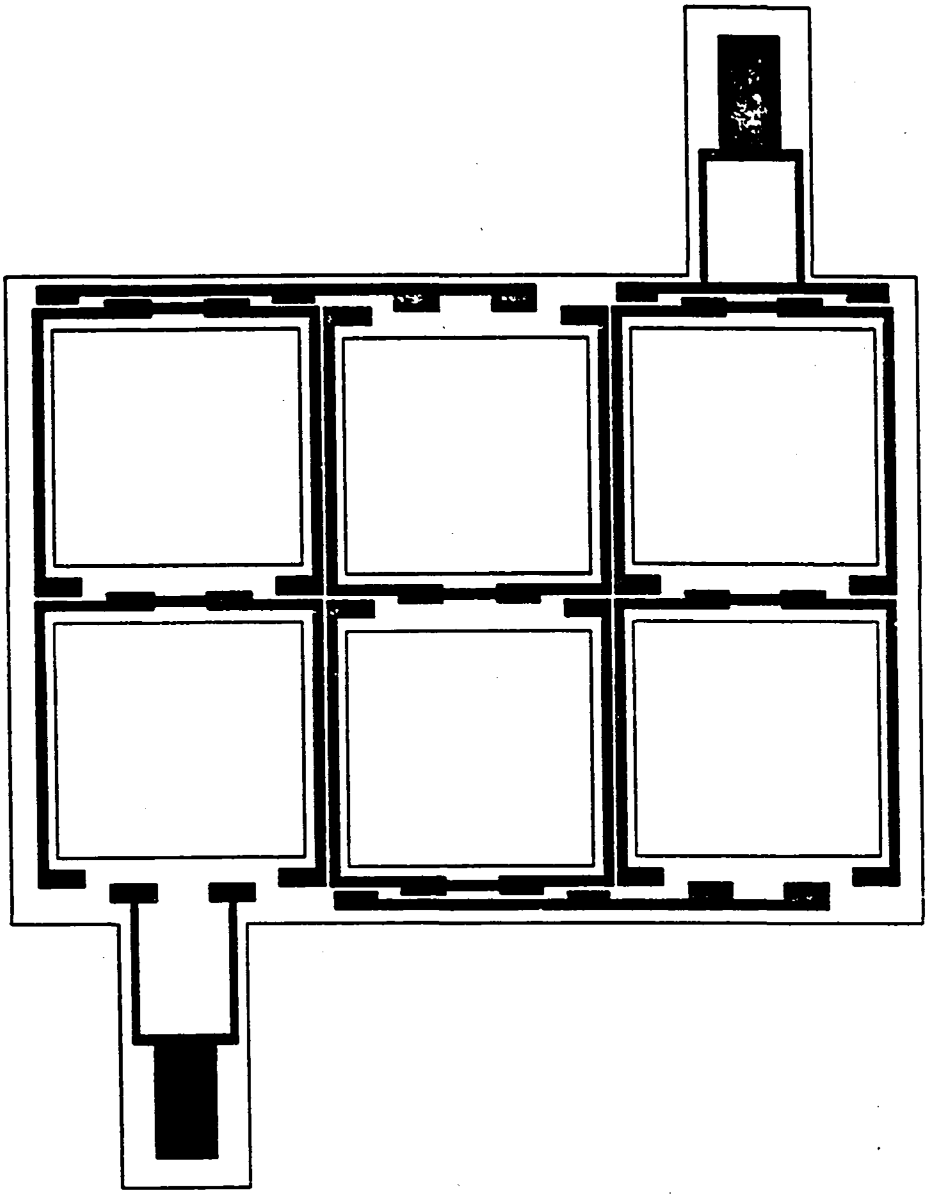

Figure 2-3 Offset Weld Pad Interconnect

Layering the interconnects could be advantageous in automating the module assembly as shown in Figure 2-4. In this concept the interconnects could be die cut patterns, with an insulating coating applied. The interconnects would be positioned on a removable carrier and stored on a roll. (The rolls would be attached to a feed mechanism and the cell matrix would move via an x-y table). During the assembly the interconnects would be fed into position and be tensioned by the roller mechanism. Insulation could be cleaned from the weld pad area by an eximer laser. Welding and removing the carrier would complete one cycle.

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Figure 2-4 Automation of Module Assembly

2.2 DESIGN TEST COUPONS

Eight 9-cell modules were designed using previously developed superstrate methods as shown in Figure 2-5. For ease of handling, the superstrate chosen was .020" thick Corning 0211 microsheet cut to size. A production module would have a border on two sides of 0.4" to allow attachment of the hinge to the superstrate. (In production, if a .010" superstrate is used, as assumed in Task 4, this is 50% of the module weight). Dow Corning 93-500 silicone adhesive is used with a Craneglass scrim cloth to bond the cells to the superstrate. The cells used for these modules are 8 mil, 2 ohm-cm, 5.9 x 5.9 cm^2 gridded P contact, wraparound N contact, with a multi-layer AR coating on the front and back sides. The interconnect is welded to the cell using eight welds.

The primary emphasis in this design is to allow as much IR energy to pass through the module thereby reducing the operating temperature of the cells. The AR coating on the backside of the cell is used to allow additional reflected light to reach the solar cell junction.

Electrical connections between modules can easily be made by minor changes to these interconnect patterns as shown in Figure 2-6.

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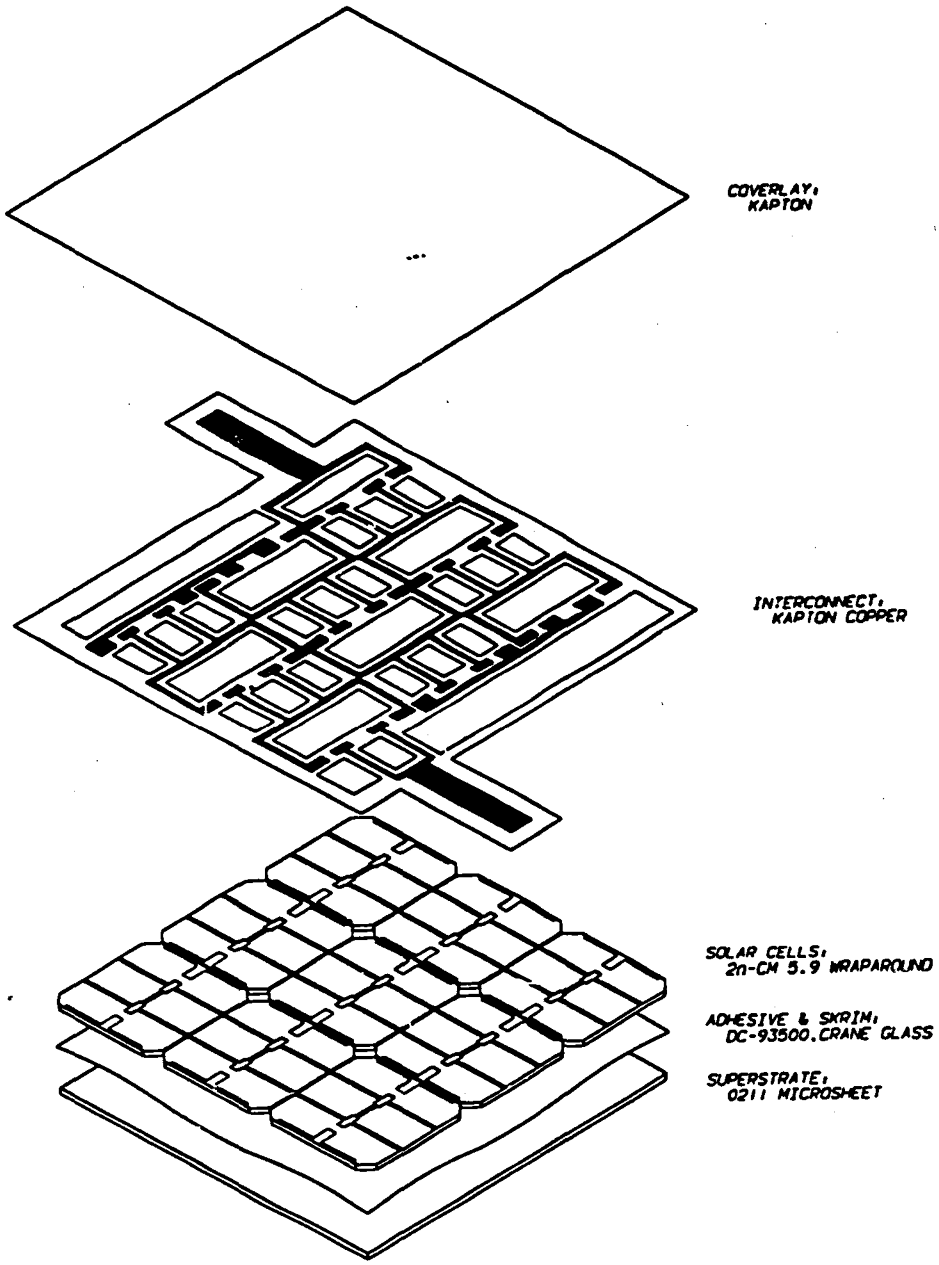


Figure 2-5 Nine-Cell Coupon Design

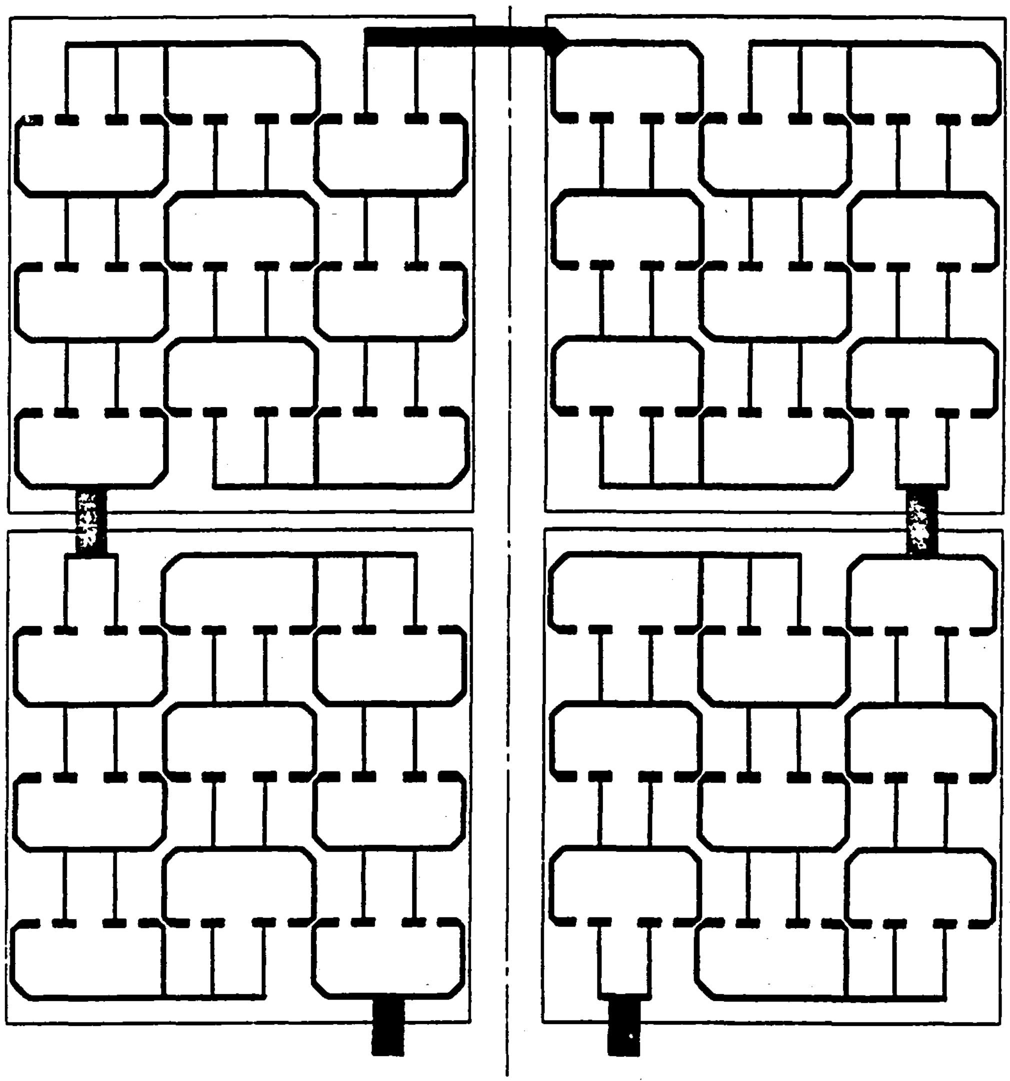


Figure 2-6 Module Connections

Section 3
TASK 2: ANALYTICAL MODELING

3.1 OPTIMIZATION MODEL

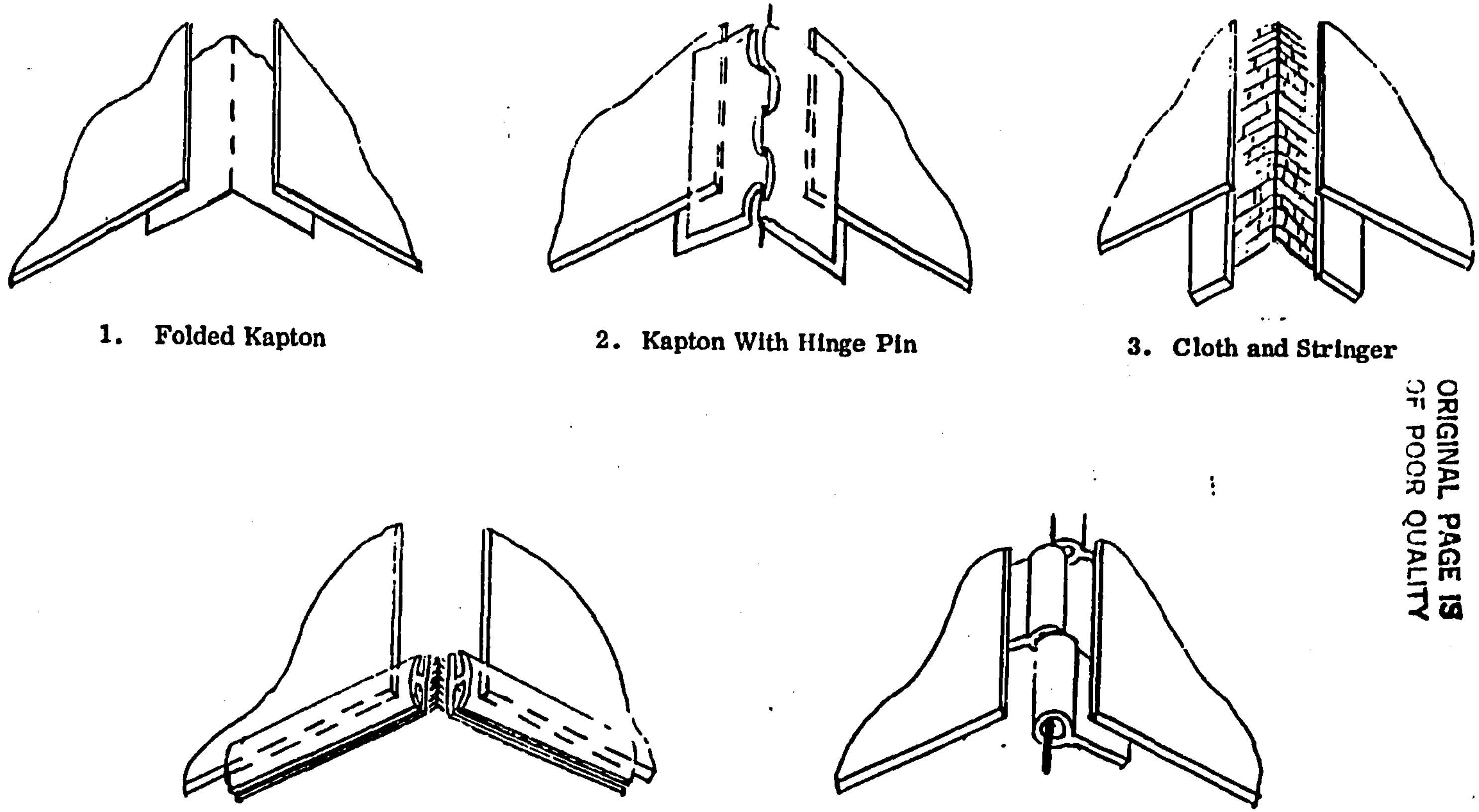
The objective of this task was to develop a relatively simple analytical model relating solar absorptance, efficiency and orbital operating temperature to doping density of the back surface field. Early in the modeling effort, it became apparent that there is insufficient experimental data to relate these three properties in any realistic fashion. Consequently, this effort was cancelled until a later time.

3.2 HINGE STRESS MODEL

A primary problem which must be addressed if the superstrate is to be used as a structural member is the minimization of stresses on the glass when two modules are connected. The stresses at the hinge module interface depends on the details of the hinge design. The following eight design requirements were chosen:

- Non retractable
- During deployment (erection) will not apply a moment to the superstrate
- After deployment (erection) able to be tensioned to approximately .2 lb/linear inch perpendicular to the hingeline
- Able to be stowed superstrate to superstrate and interconnect without stress risers
- After deployment (erection) will not apply a moment to the superstrate
- Must allow for module substitutions
- Adaptable to various series parallel configurations
- Thermal expansion stresses must be accounted for

Five hinge concepts shown in Figure 3-1 are compared to the above eight requirements in Table 3-1. The simplest hinge concept, the folded kapton film, was analyzed with the results shown in Table 3-2. A problem with this design, which is also common to hinge 2, kapton with hinge pin, and hinge 3, cloth and stringer, is the combination of stresses at the glass/adhesive interface due to thermal expansion mismatch and blanket tension. This combination of stresses should be analyzed further and tested to demonstrate survivability.



1. Folded Kapton

2. Kapton With Hinge Pin

3. Cloth and Stringer

4. Stringer Perpendicular to Hingeline

5. Small Piano Hinge (Beads)

Figure 3-1 Multi 100 kW Hinge Concepts

TABLE 3-1

HINGE CONCEPT REQUIREMENT MATRIX

Concept \ Requirement	1. Retractable	2. Moments during deployment	3. Tension to .2 lb/in*	4. Acceptable stowage	5. Moments when tensioned	6. Module substitution	7. Parallel series configuration	8. Thermal stresses
1. Folded Kapton	No provision	No	Yes	Yes	Small	Unbond hinge	Yes	
2. Kapton with hinge pin	No provision	No	Yes	With provisions for hinge pin thickness	No	Unbond hinge	Yes	
3. Cloth and stringer	No provision	No	Yes	Stack height affected by stringer thickness	Small	Unbond hinge	Yes	See Analysis
4. Stringer ⊥ to hingeline	No provision	No	Yes	Stack height affected by stringer thickness	No	Detach stringer	Yes	
5. Piano hinge	No provision	Only if binding occurs	Yes	Stack height affected by hinge diameter	Small	Unbond hinge	Yes	

*Blanket tension perpendicular to the hingeline. 0.2 lb per linear inch of hinge is the shuttle flight experiment requirement.

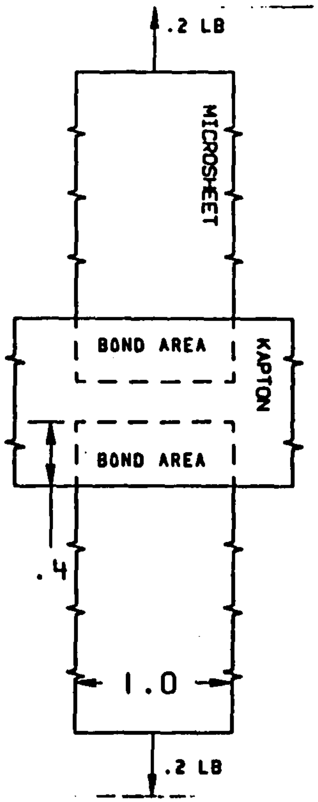


TABLE 3-2
FOLDED KAPTON HINGE: EXPECTED LOADS

MATERIAL	LOADING	EXPECTED AMOUNT	CAPACITY	SOURCE	SAFETY
0211 Microsheet	Tension	10 psi	1000 psi	Telecom w/ Corning	100
Kapton Tape	Tension	100 psi	6000 psi at 200°C	CHR Ind data	60
Acrylic Adhesive	Peel	Handling	1.6 lb/in 180° peel	CHR Ind data	A primary concern in handling
	High temp creep	.2 lb/ linear in.	No creep at .55 lb per linear in at 350°F	M&P	2.7
Bond Area	Area .4 in^2 per in		SAFE used .25 in		
	Thermal Shear	.48 lb at 100°C over 8 in		Calculated	Possibly a source of unbonding or bending
Out of Plane Moments	Eccentric Loading	.0028 in-lb	2.3 in-lb w/o breaking	Tested	
	Thermal Mismatch	.0034 in-lb	2.3 in-lb w/o breaking	Tested	

Section 4
TASK 3: MODULE FABRICATION

The basic manufacturing steps required to manufacture the nine-cell modules are similar to the sequence reported in a previous phase of this study. A simplified flow diagram is given in Figure 4-1.

Six Lockheed CADAM drawings were provided to advanced manufacturing to fabricate the interconnect patterns. The interconnect hole pattern templates and x-y coordinates for each hole are used to program a numerically controlled drill. Programming the x-y coordinate of each hole onto an N-C tape is time consuming and could be bypassed by using an N-C drill which is compatible with the numerical control programming feature in the Lockheed CADAM system. Once the tape is made and the weld holes in the required number of sheets are drilled in the kapton, the copper is roll laminated to the kapton using a polyester adhesive. The desired copper pattern is obtained using the artmasters in a photo-etch process. Finally a second N-C drill operation is used to radius the corners of the kapton cutaway areas, and the kapton is cut away. After a cleaning step the interconnects are ready to be welded.

A record of electrical output for each of the 75 cells was received from ASEC. A sample of 15 cells were tested to verify the recorded output. Nine cells with similar output were welded to the interconnect pattern using a parallel gap feedback controlled weld station developed by Lockheed.

The next step in the module fabrication was to position the superstrate, scrim cloth, adhesive and cell/interconnect assembly in preparation for bonding. This stack is then vacuum bagged and placed in an autoclave to cure the adhesive.

The completed modules were electrically tested and corrected to 28°C using a LAPSS system. The results of this testing (Table 4-1) did not show a significant difference in fill factors between the sheet interconnect and the overlapping interconnect. No power differences could be determined between the interconnect pattern from these 8 modules. The I-V curves are given in Appendix A.

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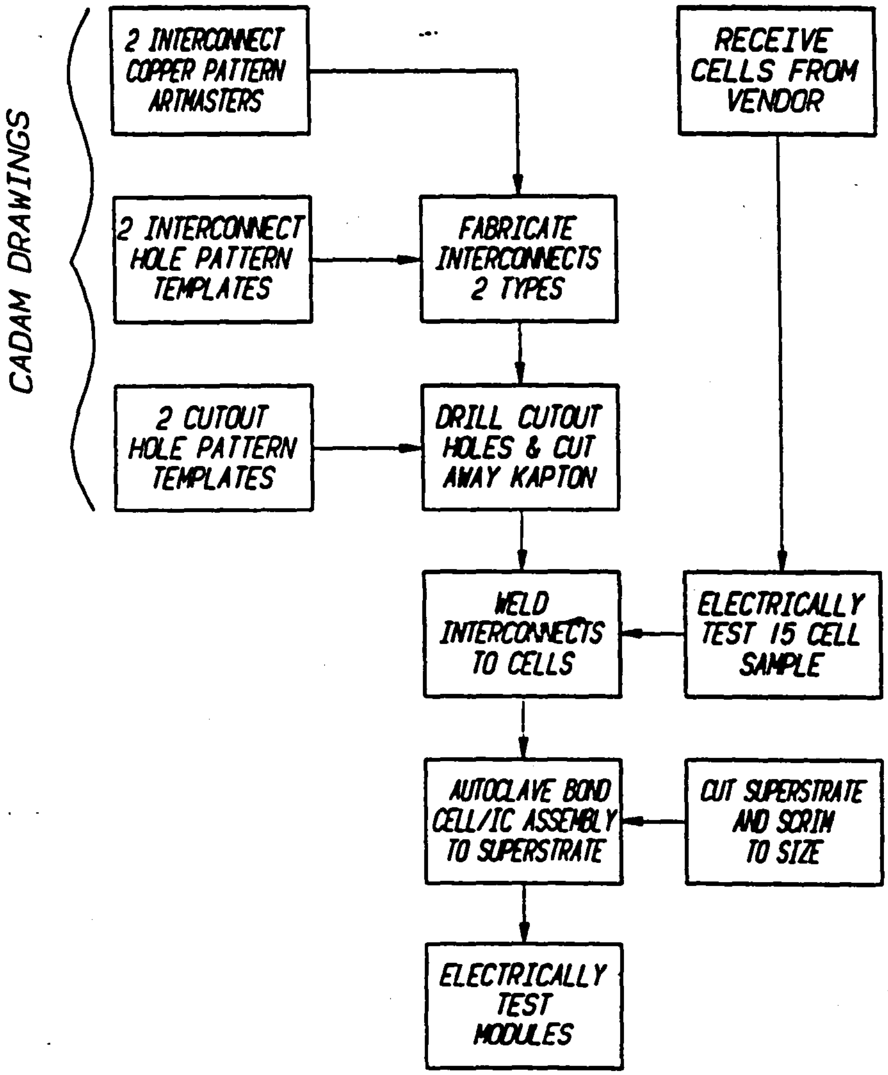

Figure 4-1 Flow Diagram

TABLE 4-1
MODULE OUTPUT SUMMARY

MODULE NUMBER	INTERCONNECT TYPE	I_{sc} (AMPS)	V_{oc} (VOLTS)	P_{mp} (WATTS)	FILL FACTOR
1	SHEET	1.39	5.38	4.58	.61
2	SHEET	1.41	5.36	5.35	.70
3	SHEET	1.40	5.32	4.68	.63
4	SHEET	1.40	4.93	4.50	.65
5	OVERLAPPING	1.38	5.34	4.94	.67
6	OVERLAPPING	1.39	5.34	4.98	.67
7	OVERLAPPING	1.38	5.27	4.48	.62
8	SHEET	1.39	5.32	4.50	.61

Section 5
TASK 4: ARRAY PACKAGING AND DEPLOYMENT

In lieu of a mid-term presentation, the contract was modified to incorporate a brief evaluation of packaging and deployment concepts. Three stowage and deployment concepts were investigated and compared in this task. The first concept, described in a previous phase of this study, uses six collable longeron masts which deploy sixteen flat folded wings. The second concept is a simplified scheme to deploy the same array. The third concept uses an erectable STAC (Stacking Triangular Articulated Compact) beam to build the frame to which the flat folded blanket segments are attached. For each concept an array on the order of 200-kilowatts BOL at 28°C was sized. For this size array the stowed configurations and envelopes were determined and deployment schemes investigated. Expected performance of each of the three arrays is compared.

5.1 PACKAGING

A viable Multi-100 kW array must collapse to a high density, low volume package for stowage in the Shuttle. Figures 5-1 through 5-3 show the stowed configuration for the three array concepts being considered. The stowed array shown in Figure 5-1 is the Lockheed space frame concept which was reported on in previous phases of this study. A 200 kW array of this type would require sixteen blankets. The blankets are folded between a cover and baseplate to form the container shown. The cover and baseplate also serve as structural members when the array is deployed. The stack height in this container is: base - 3 inches, blanket - 5 inches, and cover - 3 inches. This stowage envelope volume is 425 ft^3 of which approximately half is unused space. A lightweight truss structure could be used to support the cover and baseplate as well as the frame structure. A truss could be incorporated without significantly changing this stowage envelope. The stowage envelope size is determined by locating two mast canisters end to end on the upper wing container layer. One wing baseplate is permanently attached to each mast container.

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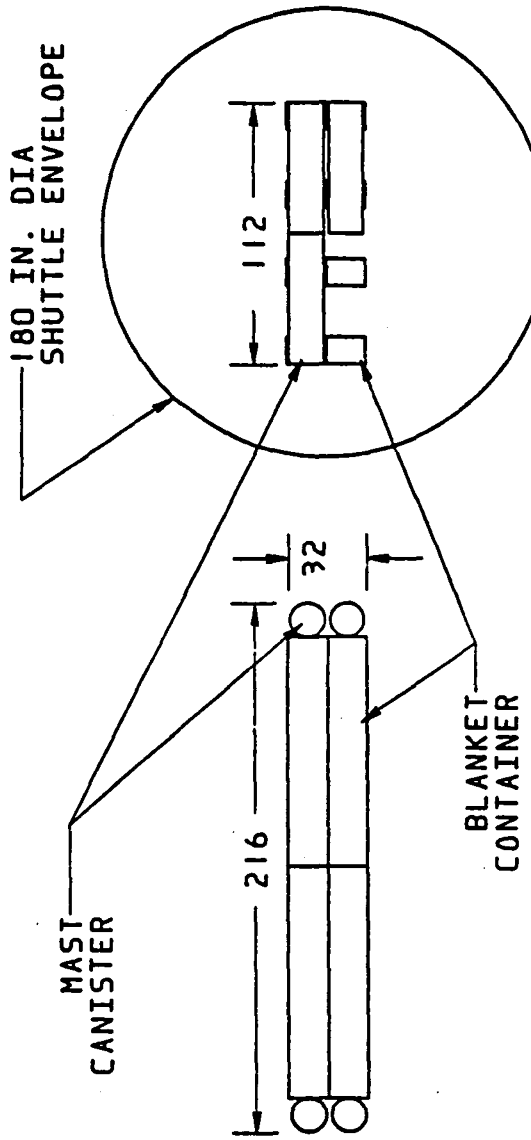

Figure 5-1 Space Frame Stowage Envelope

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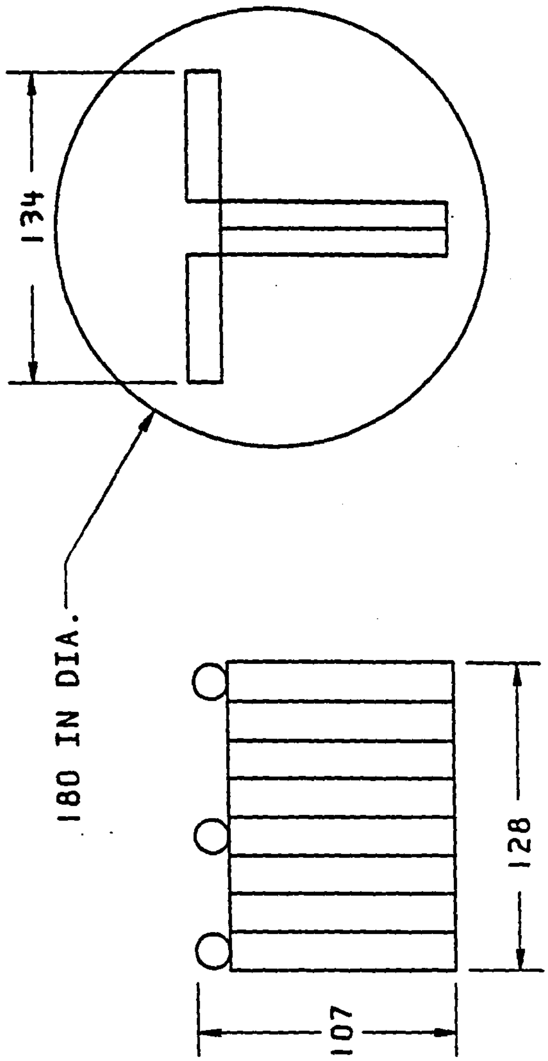

Figure 5-2 Stowed Size: Simplified Deployment Scheme

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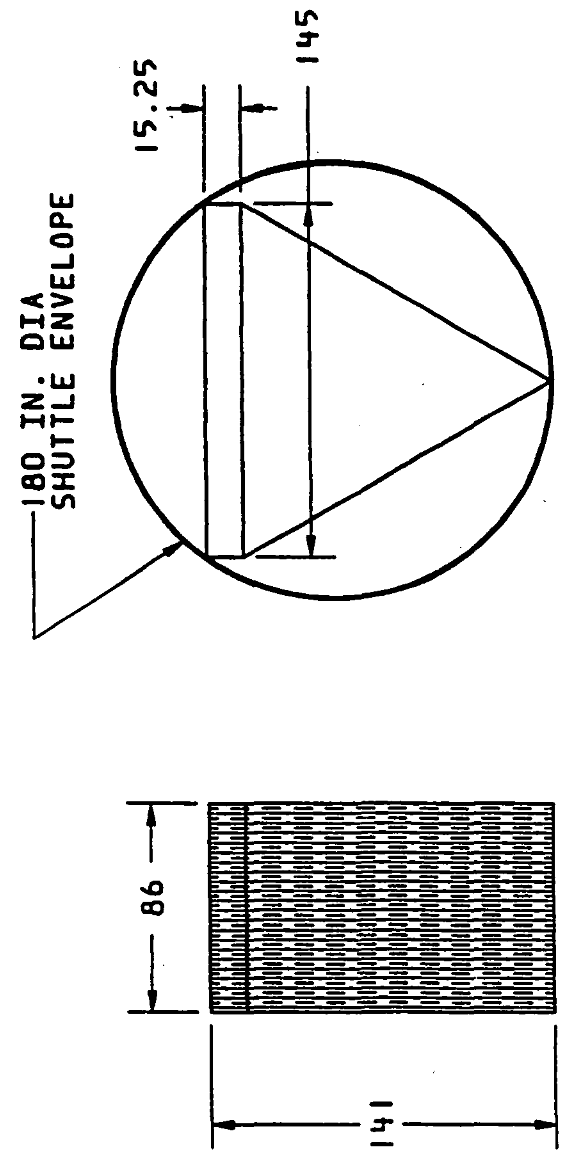

Figure 5-3 STAC Beam Stowage Envelope

The second array which is shown stowed in Figure 5-2 uses the same elements as the array discussed previously, six masts and sixteen blanket containers but by stowing as shown the deployment is simplified. This stowed array requires 210 ft^3 and will easily fit inside the 180 inch diameter Shuttle bay and is determined by rigidly locating the mast, canisters to the first, fourth and eighth wing container pairs.

The third array, STAC beam concept, is shown stowed in Figure 5-3. The array blanket stowage envelope is 566 ft^3 and will also fit in the 180 inch Shuttle envelope. This envelope is determined by the 145 inch width of the blanket and the 145 inch equilateral triangle STAC beam. The STAC beam longerons are folded into the center of the triangle.

5.2 DEPLOYABLE CONCEPTS

The deployment of the three concepts, the space frame, simplified space frame and the STACbeam were investigated.

The original space frame concept requires three major phases as shown in Figure 5-4. From the stowed configuration the upper layer of 8 wing containers would hinge about an axis along the length of the stowed package. This first phase would be achieved by the use of cable loop drives or similar flight proven methods. The second phase is a pantograph extension about hinge points located halfway between the wing containers. The third phase is to simultaneously extend the six masts 132 ft to form rigid beams by the blanket covers and baseplates. When fully deployed and tensioned the lightweight masts are placed in compression. At the outer wing ends the wing base containers must be attached to form a beam across the end of four wings.

The stiffness required for this beam is shown in Figure 5-5. This figure shows for various beam lengths, corresponding to adding an additional 30-cell module to each panel, the deflection of the beam with a given stiffness. For example, a 200 kW array would use sixteen blankets with 104 panels per blanket and would deploy 132 ft. Each panel would consist of seven 30-cell modules and wire harness.

The panel determines the beam length, in this case, 32 ft. The figure shows deflection vs stiffness (EI). The stiffness of a graphite epoxy honeycomb sandwich with the dimensions shown has an EI of 6.3 x 10^6 lb-in^2 (vertical line) and would deflect three inches (assuming infinitely stiff hinge connections and .2 lb/linear inch). The stiffness characteristics of this array is shown in Figure 5-6. To contain a 132 foot extendable mast the container must be 56 inches long and 14 inches in diameter. The base beams and cover beams are not limited to graphite/epoxy honeycomb. A similar analysis can be used to determine the requirements for an array size and structural elements being considered.

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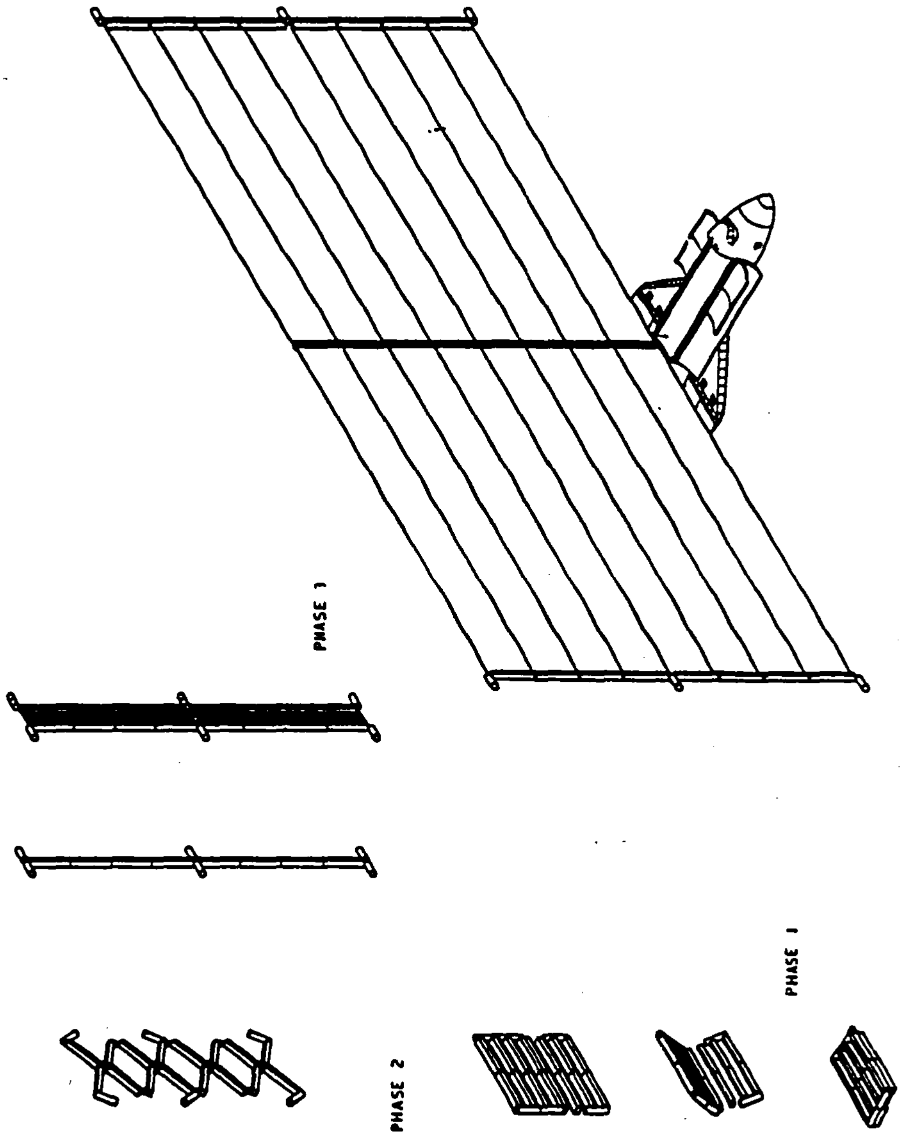

Figure 5-4 Space Frame Deployment

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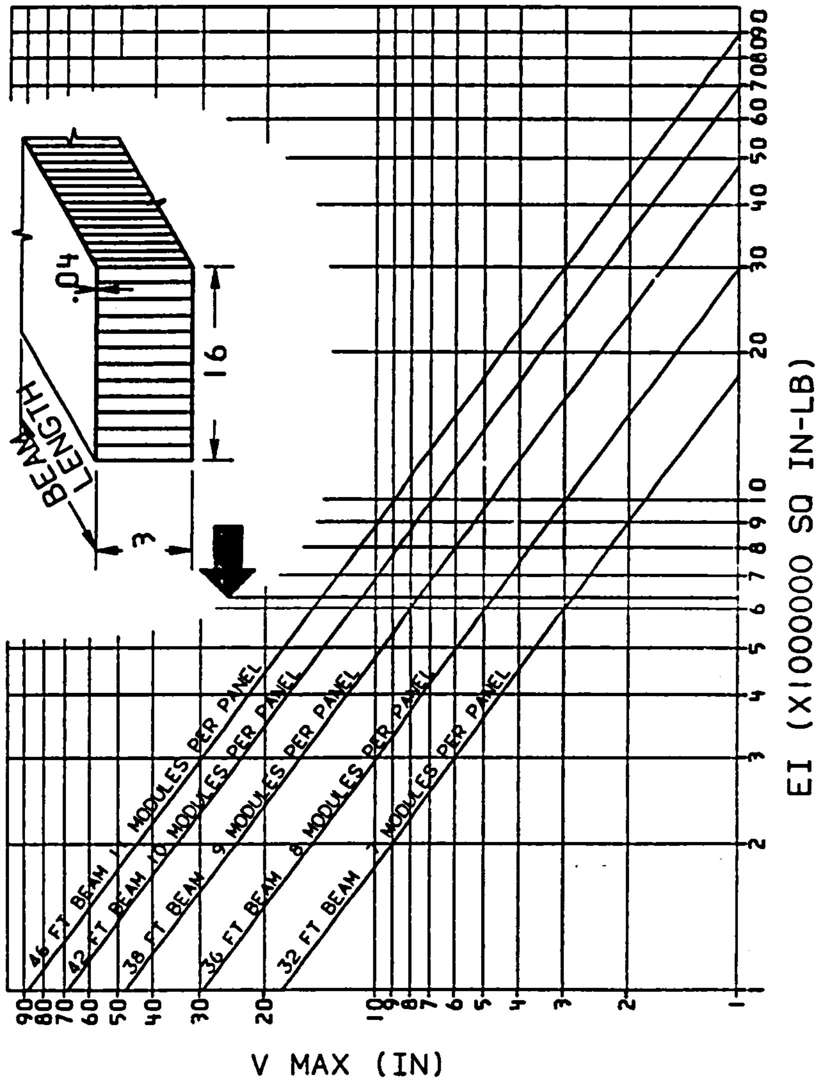

Figure 5-5 Beam Stiffness vs Deflection

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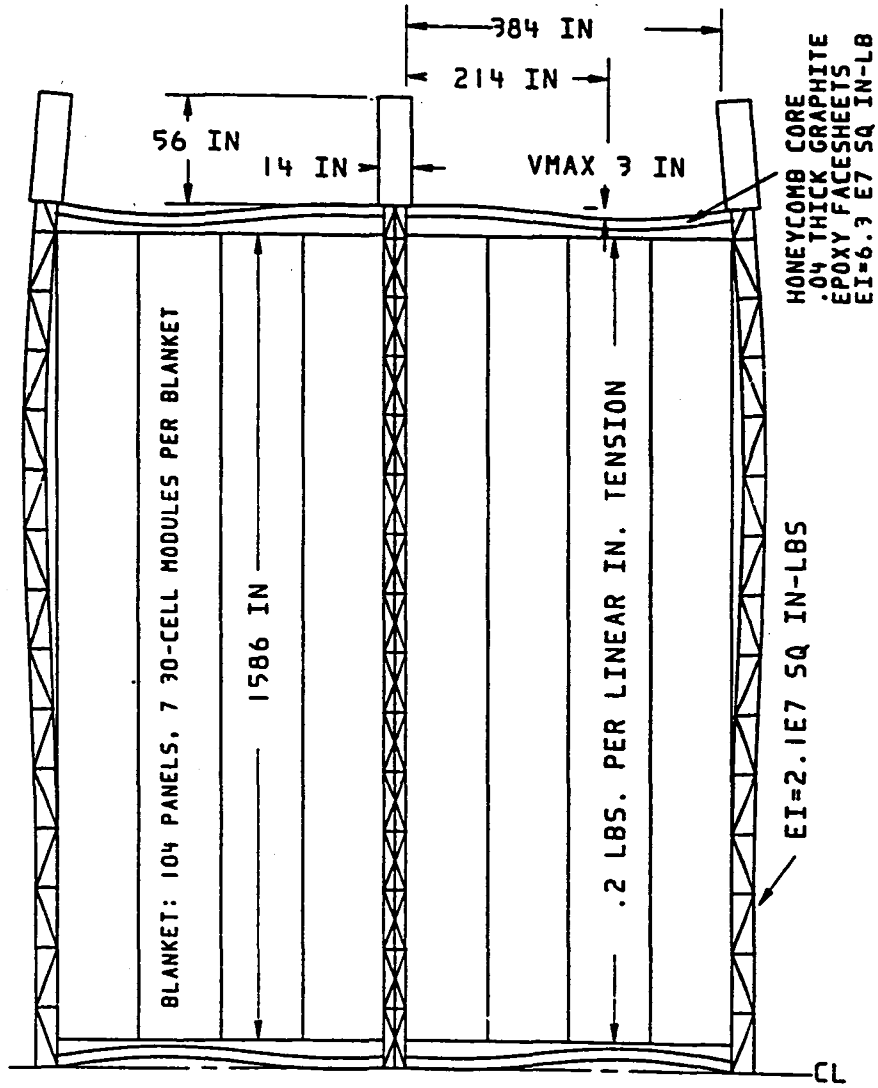

Figure 5-6 Array Stiffness Characterization

The simplified space frame concept would deploy the same array. The previous size, stiffness characteristics and analysis would be applicable to this array. Starting from the stowed configuration previously discussed the deployment is accomplished in three phases as shown in Figure 5-7. The first phase is to rotate the whole package through 90°. The second phase is to extend the wing containers by unfolding. Each container would rotate through 90° about a simple hinge located at opposite corners of the container. The final phase would be to simultaneously extend the six masts and baseplate beams 132 ft. This deployment sequence would simplify the mechanical elements of the array. Since the cover plates of two blankets do not separate, a common cover plate could be used.

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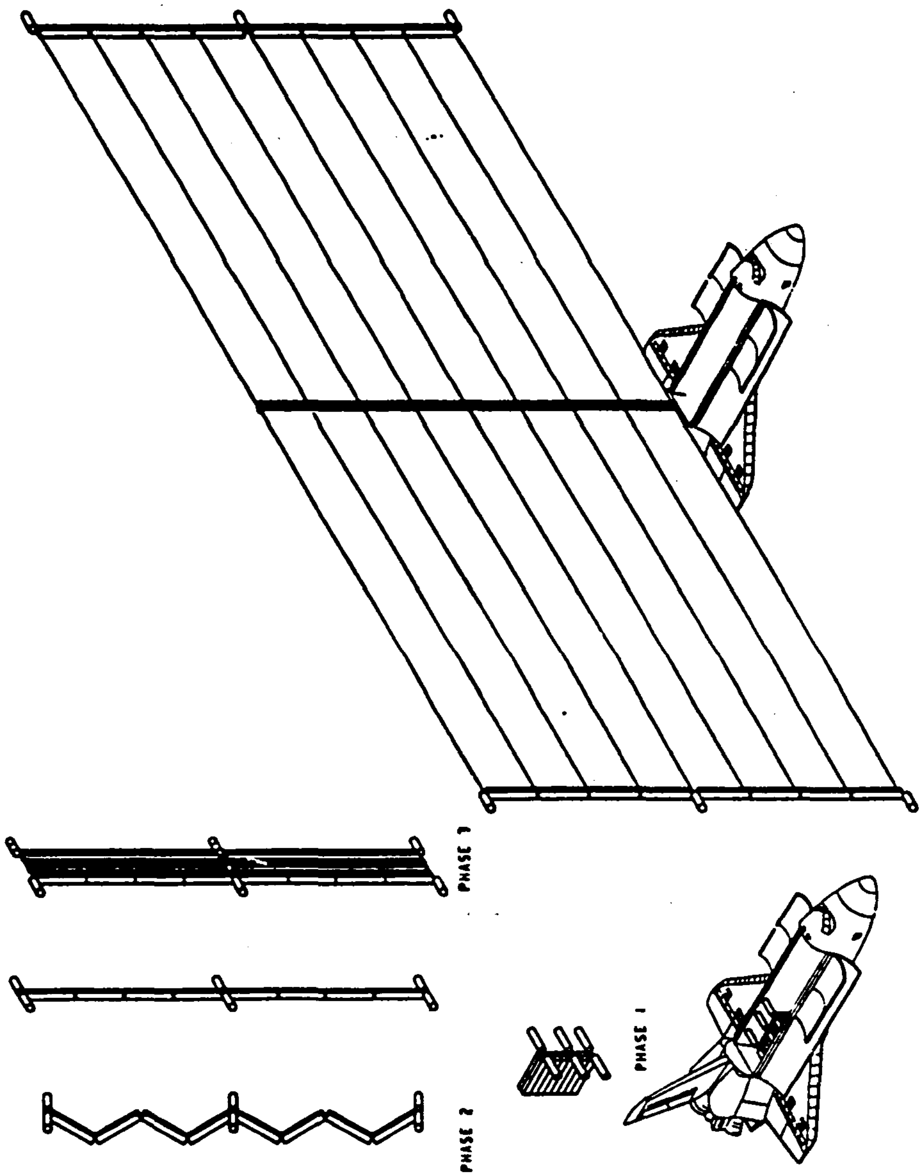

Figure 5-7 Simplified Space Frame Deployment

5.3 AN ERECTABLE CONCEPT

The STACbeam concept would deploy as shown in Figure 5-8. This concept would require Extra Vehicular Activity (EVA) to accomplish the wing intermediate deployment and would involve attaching the five subwings together. EVA would also be required to deploy the extension booms, attach the wings to the utility module and deploy each wing. The deployment operations could be accomplished using a portable astromast deployer. Rigidity in the transverse direction would be accomplished by attaching the corners of the honeycomb panels together (not shown).

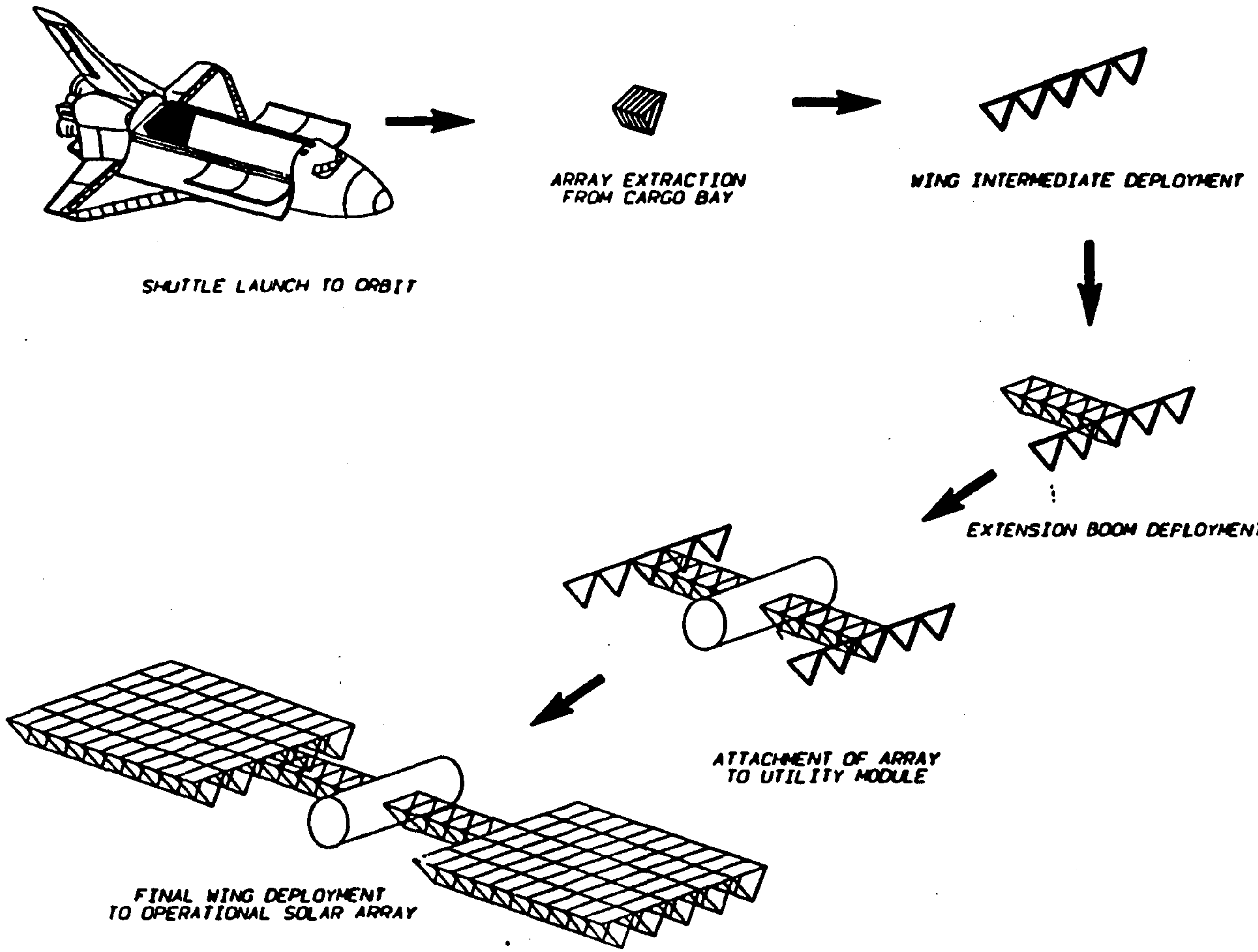

Figure 5-8 STACbeam Deployment

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5.4 CONCEPT COMPARISON

The three array concepts were targeted to produce 200 kilowatts of power. The weights of these concepts were estimated and summarized in Table 5-1. A method was devised to optimize the copper conductor weight in the harness with its voltage loss versus additional solar panel weight to make up the loss.

TABLE 5-1

WEIGHT SUMMARY

SPACE FRAME		STACBEAM	
30-Cell Modules	4064	30-Cell Modules	4188
Panel Hinges	16	Panel Hinges	16
Honeycomb Cover and Baseplates	396	Honeycomb Cover and Baseplates	220
Masts	193	Foam	92
Canisters	189	Fittings	132
Hardware, Hinges, Latches	100	Booms	317
Conductor	193 lb	Hardware Blanket to Boom	40
Insulation	16	Conductor	200
Connectors	50	Insulation	16
		Connectors	50
	5024		5271

An ongoing problem of concern for all solar arrays is how to arrive at the optimum harness which minimizes both harness weight and power loss. For this study, a first-order method was developed. This method is based on the assumption that for a small perturbation about the minima, the weight penalty associated with the harness loss is just the weight of the array generating an equivalent amount of power. This assumption can be expressed analytically as:

$$W_T = W_H + W_A \tag{1}$$

where

W_T = Total weight associated with the harness

W_H = Direct harness weight, i.e., copper and insulation

W_A = Weight of array making up harness loss

Figure 5-9 shows an application of equation (1) to 3 point designs considered.

Minimizing the harness weight is then accomplished by taking the derivative W.R.T. the fractional power loss (F_p) and equating the resulting expression to zero, i.e.,

$$\frac{\partial W_T}{\partial f_p} = 0 = \frac{\partial W_H}{\partial f_p} + \frac{\partial W_A}{\partial f_p} \tag{2}$$

Both terms on the right of equation (1) are easily expressed in terms of f_p the average length (ℓ), operating voltage (V) and material properties as expressed in equations (3) and (4).

$$W_H = \frac{4\, p_d \;\; p_e \;\; P}{f_p} \left[\frac{L}{V}\right]^2 \tag{3}$$

$$W_A = \frac{Pf_p}{S_p} \tag{4}$$

where:

p_d = density of copper

p_e = resistivity

S_p = Specific power

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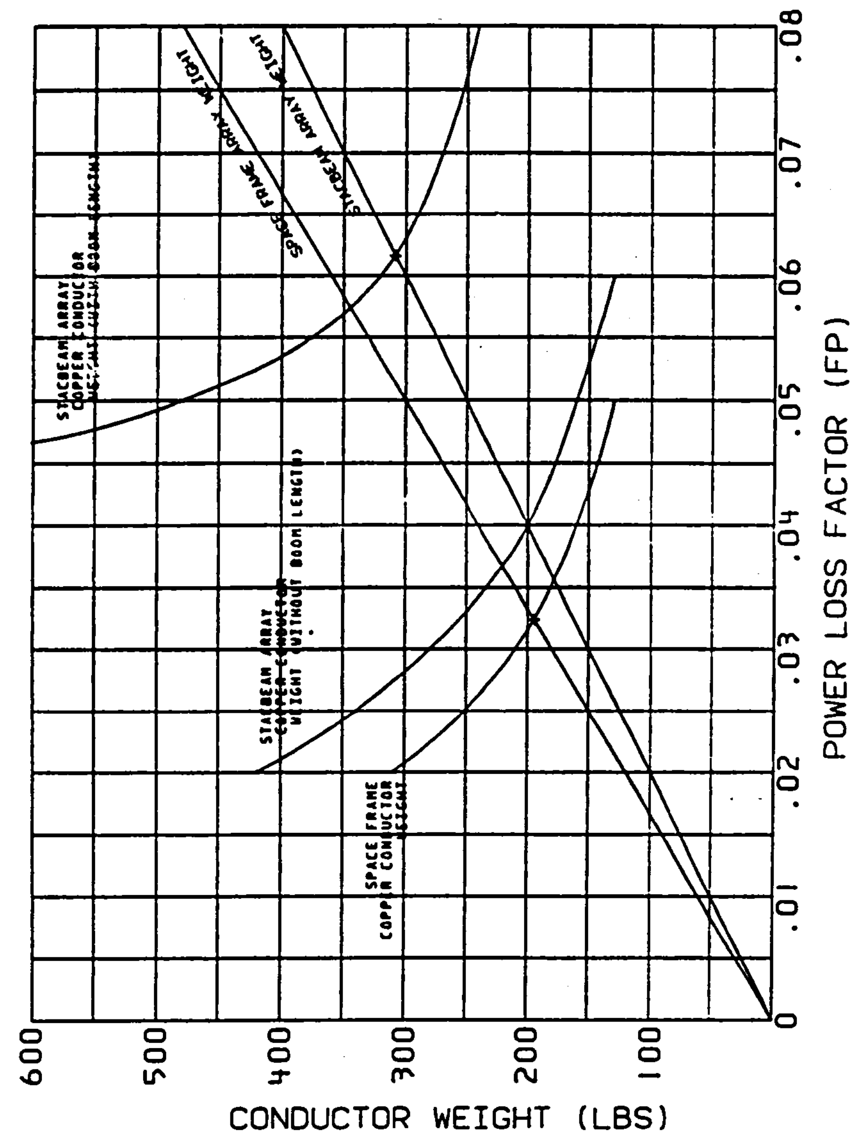

Figure 5-9 Conductor Weight Optimization

Substituting and rearranging terms results in the optimization relationship

$$f_p = (4\, p_d\, p_e\, S_p)^{1/2}\ \frac{L}{V} \qquad (5)$$

which is shown graphically in Figure 5-10.

For this study the array power loss and conductor weight were calculated but no additional array was added. Table 5-2 summarizes the performance of each array concept, the previously reported Lockheed Space Frame, the simplified Space Frame and the stack beam concepts. In each concept a 30-cell .010 glass superstrate I-R transparent module was used as the array building block. The packing factor reflects the panel area required for the wire harness for the Space Frame concepts but the stackbeam concept assumes the harness integral with the frame hence the higher packing factor. The BOL Array Power at 28°C uses presently available 5.9 cm x 5.9 cm silicon solar cells and includes interconnect and harness losses. The stackbeam concept has a higher power output and more weight which give the same specific power as the Space Frame concepts. The higher packing factor of the stackbeam array is also reflected in the array power density. The advantage of the Simplified Deployment Space Frame over the pantograph deployed Space Frame is the reduction of deployment mechanism weight and smaller stowage volume.

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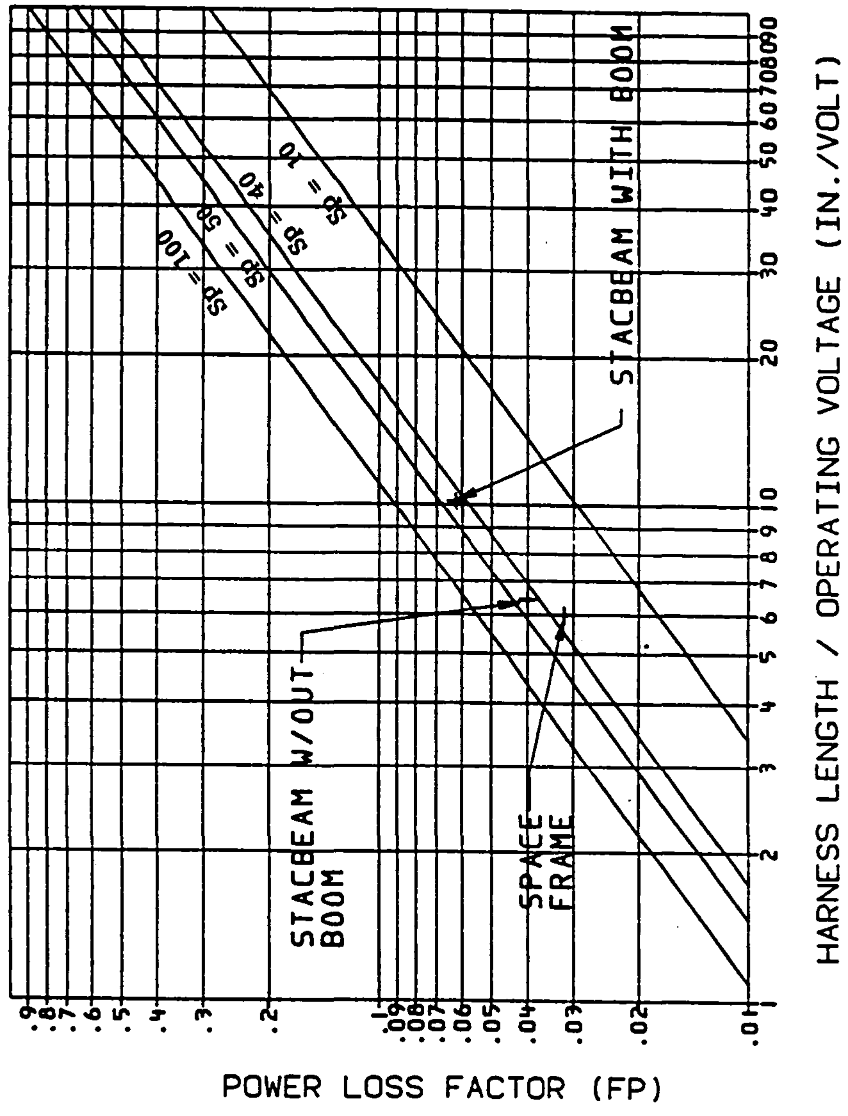

Figure 5-10 Power Loss Factor Optimization

TABLE 5-2
PERFORMANCE COMPARISON

Parameter	Space Frame	Space Frame Simple Deployment	STACbeam
Cell type	5.9 cm^2 Si 2 ohm-cm	5.9 cm^2 Si 2 ohm-cm	5.9 cm^2 Si 2 ohm-cm
Solar Absorptance (α)	.6	.6	.6
Efficiency	13.5% at 28°C	13.5% at 28°C	13.5% at 28°C
Packing Factor	.93 blanket	.93 blanket	.96 bay
Harness wire loss	.03	.03	.09
BOL Array Power (watts) at 28°C	228777	196797	224399
Weight (lb)	5024	5024	5271
Specific Power at 28°C (W/lb)	45.5	45.5	42.6
Operating Temp (°C)	12	12	12
Power at Operating Temp (watts)	247417	247417	252732
Specific Power at 12°C (W/lb)	49.2	49.2	47.9
Array Power Density (W/ft^2)	16.6	16.6	16.91
Stowage Volume ft^3	425	210	566

Section 6
SUMMARY

This report documents the results of an ongoing study to examine Low Cost Multi-100 kW Planar Solar Arrays. Seven modules of two different designs were fabricated to demonstrate advanced solar array construction practices. Both module types utilized second generation gridded back cells featuring high efficiency and IR transparency. A simple SiO_2 AR coating optimized for transmission at $\lambda = 1.7\mu$ was applied to the back surface. Two interconnect types, a single sheet printed circuit and a roll type, were designed and fabricated. A high degree of transparency was achieved with both designs.

An analytical task was also pursued examining 1) hinge stresses and 2) electrical power optimization. The first analysis identified limiting factors in the hinge design. The second analysis was abandoned when insufficient data was found to support the modeling effort.

Array system design for a 200 kW power level was studied by evaluating two proposed point designs. The first design is an extension of current flex array approaches and is distinguished by being fully deployable in an autonomous fashion. A second LMSC design approach uses a STACbeam with an integrated blanket requiring astronaut assistance and assembly on orbit. Feasible designs were developed for both approaches.

Section 7

RECOMMENDATIONS

Significant progress has been made in this and previous contract phases in developing new technology to increase performance and reduce costs of planar solar arrays. As a result of this work, it has been conclusively demonstrated that planar arrays will be the most cost effective design for use on the space station or other high power applications.

It is expected that continuation of this study will result in additional performance improvements and cost reductions. Key areas to be investigated are stowage, deployment and orbital control of the large structures being considered. Preliminary studies of two point designs during this phase have identified areas where improvements would be highly desireable. Due to the size and cost of the systems being discussed, these additional studies would, of necessity, be performed by parametric analysis and mathematical modeling.

Dynamics and controls of the large areas being considered is of special interest. Studies by several contractors investigating both planar and concentrator arrays has resulted in a multitude of designs and performance claims. A significant difference is the specific power (W/kg) ranging from 192 for planar down to ~20 for concentrator arrays. Since it is clear that the Shuttle launch capability is sufficient for either case, an evaluation of the designs based upon frequency response and control system complexity will be a more reasonable performance indicator.

APPENDIX A

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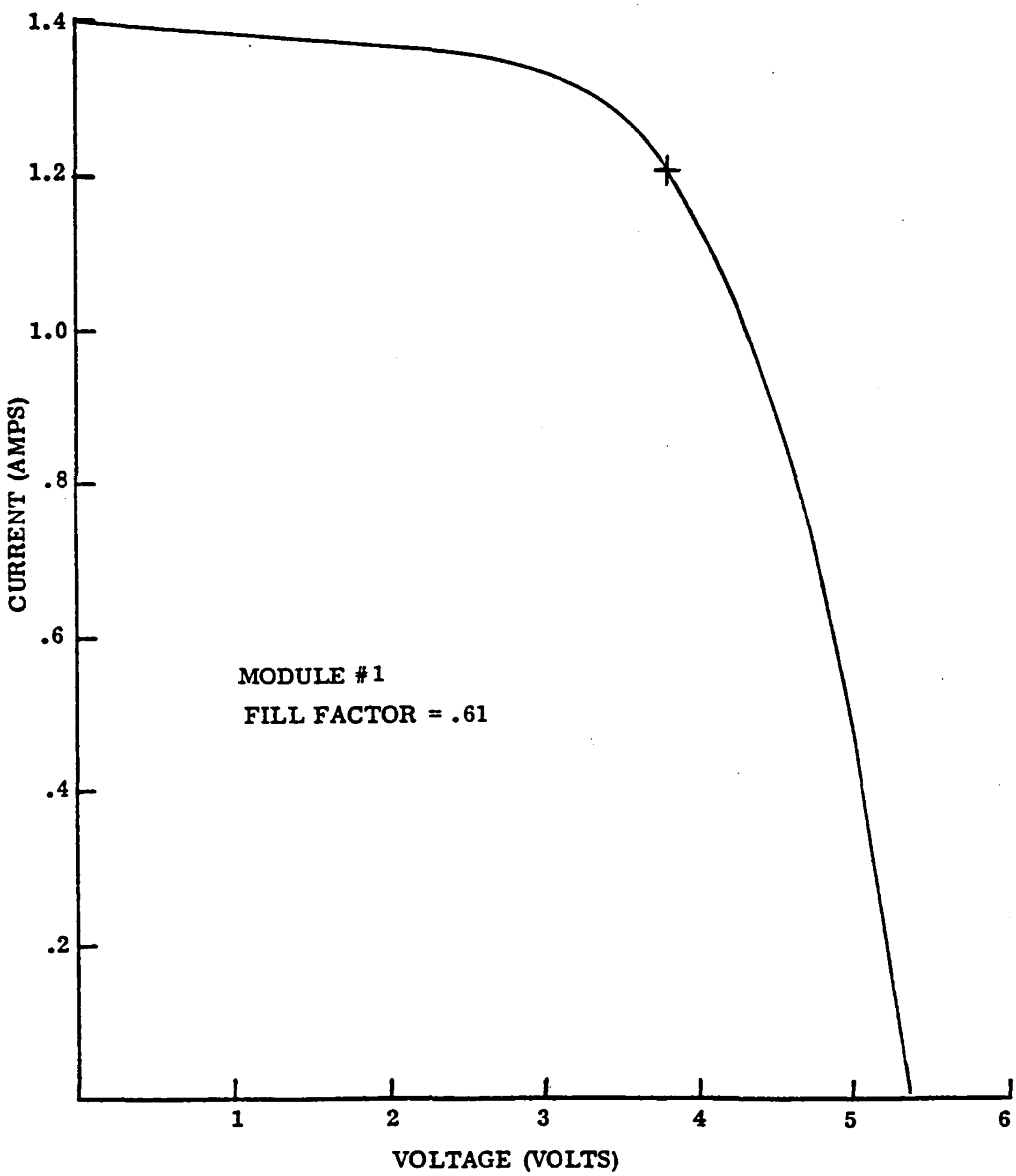

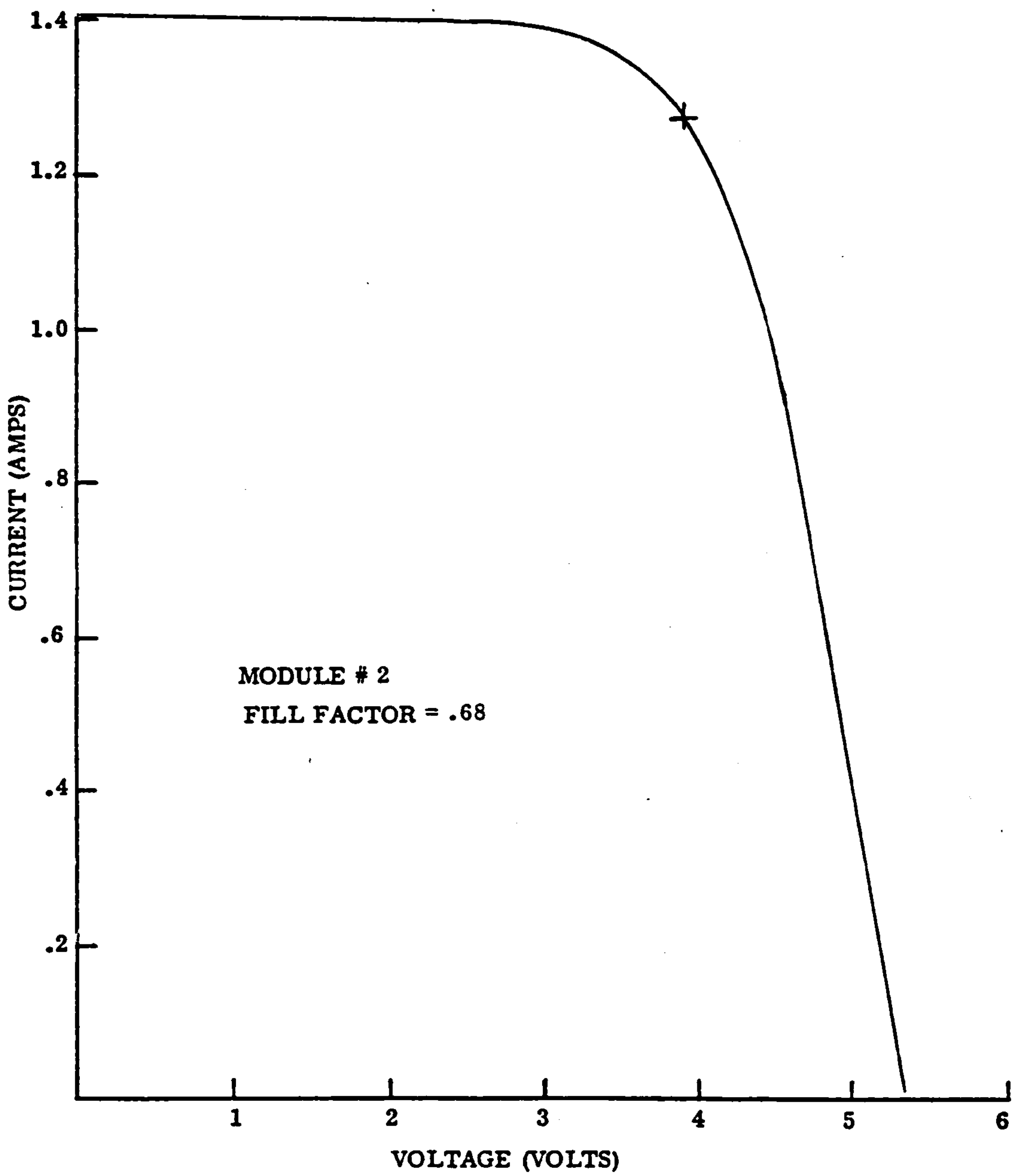
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VOLTAGE (VOLTS)

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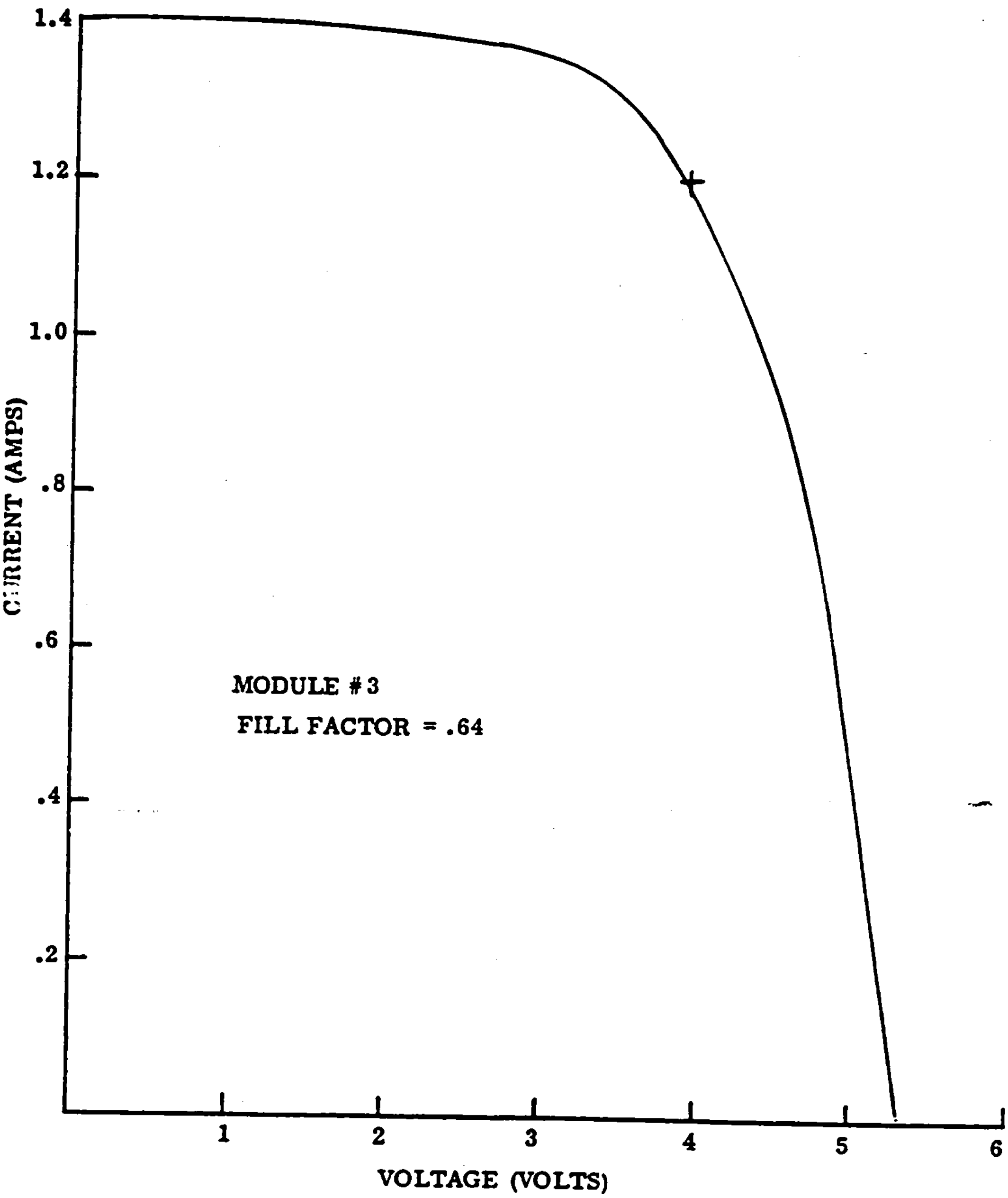

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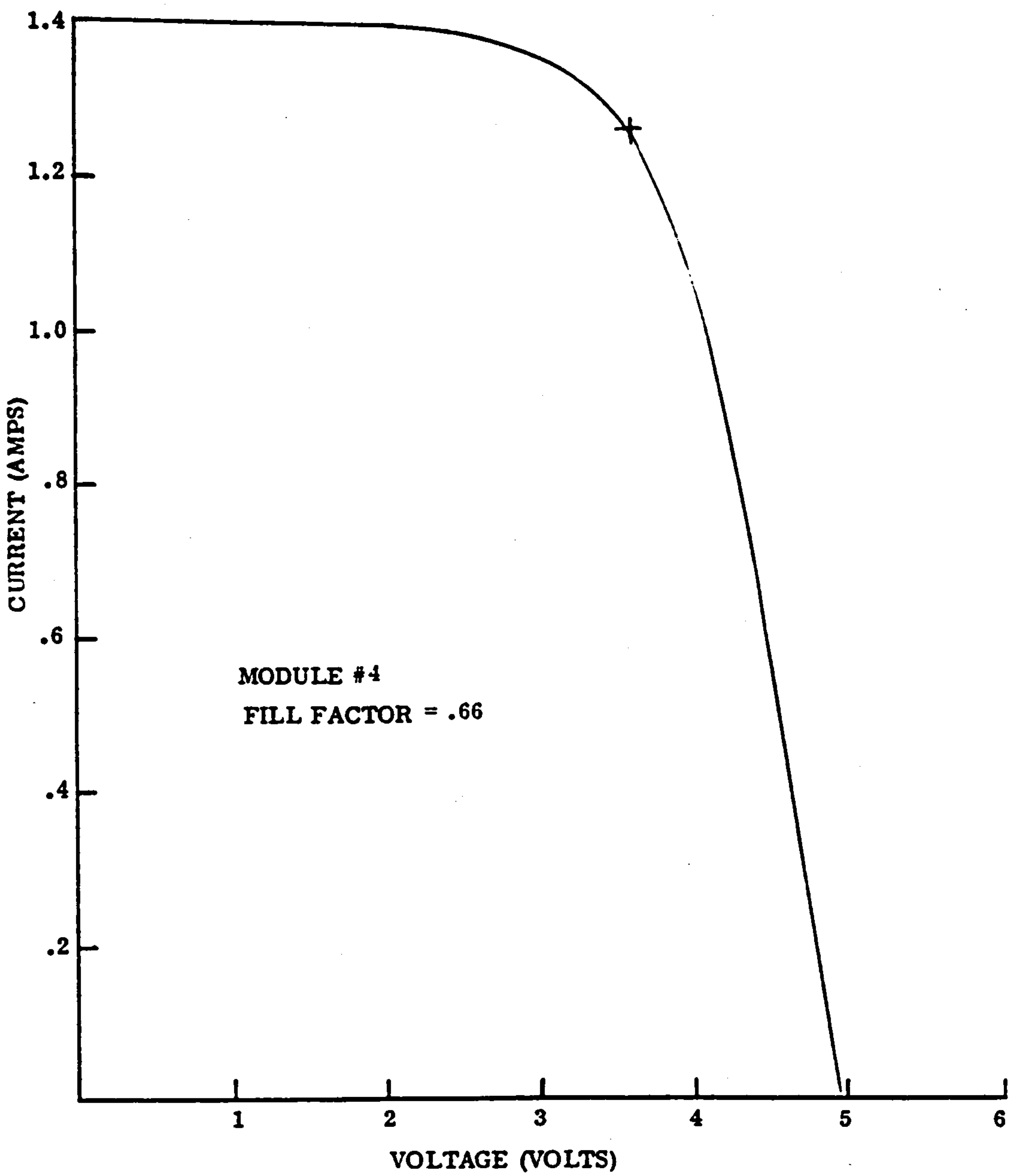

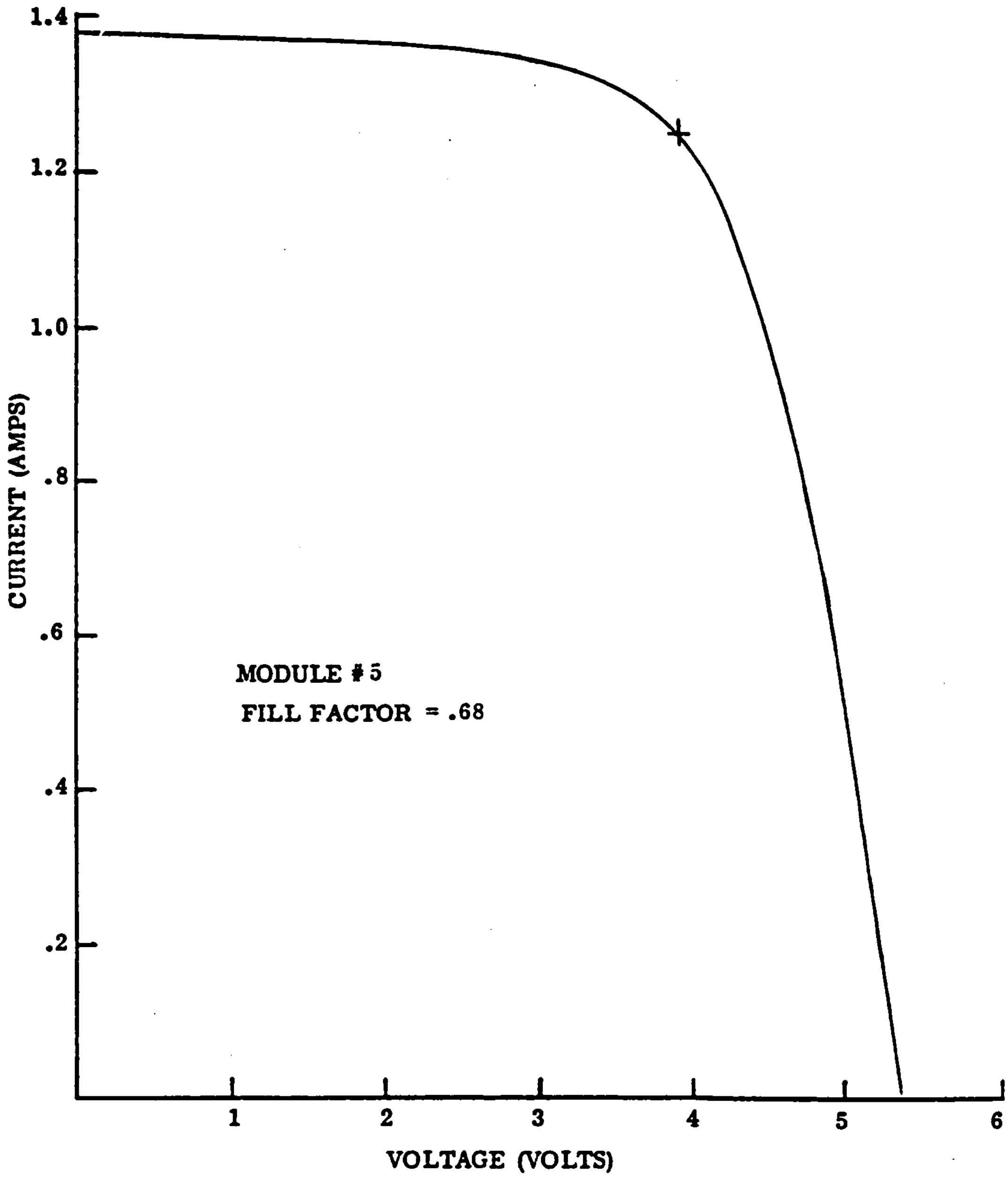
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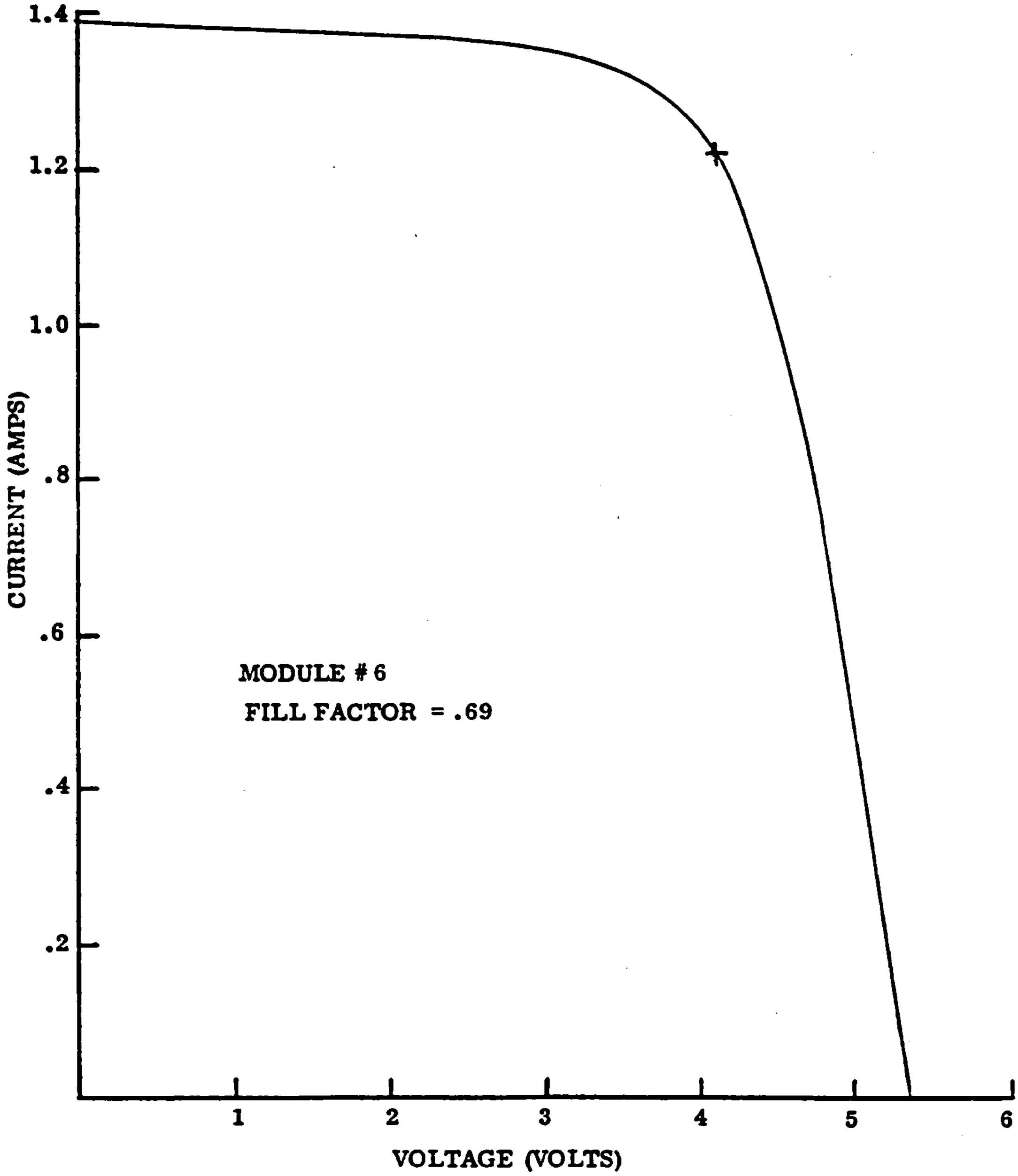
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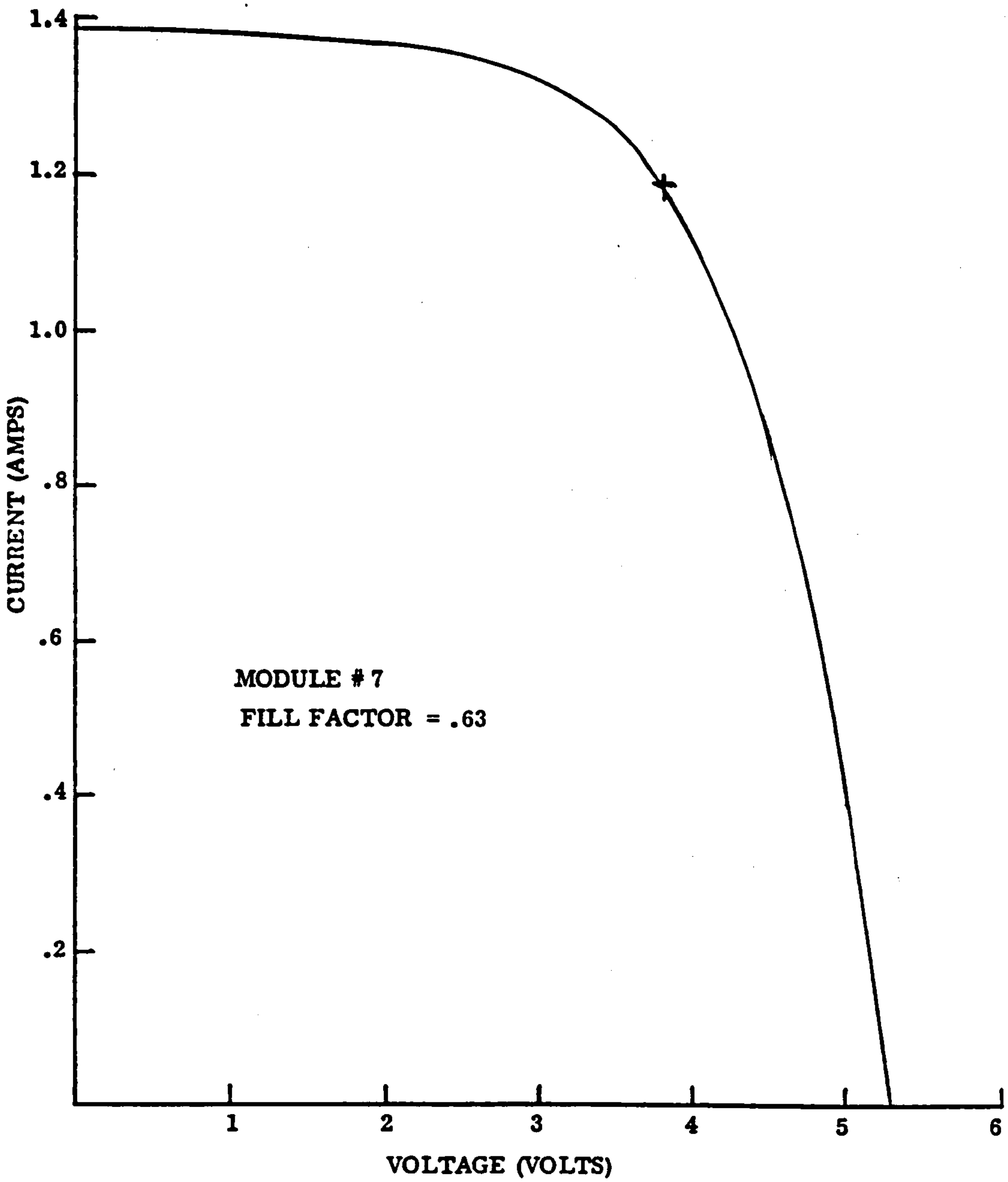

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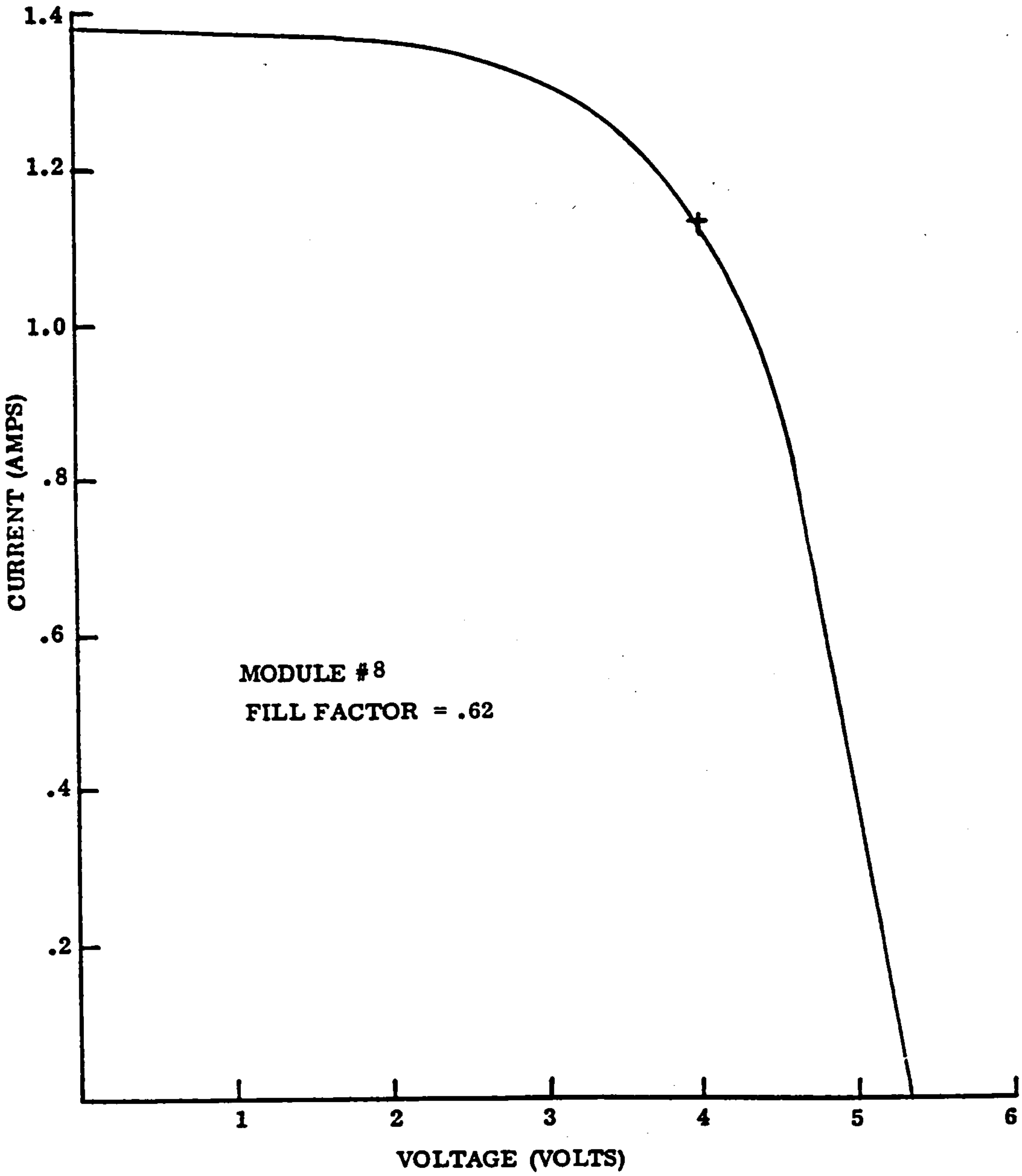

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