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GENERAL ELECTRIC

NAS-15196
DRL T-1346
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LINE ITEM 3
CR -151746

D180-24071-1

ferred Concept
;tem Definition

Solar Power Satellite

SYSTEM DEFINITION STUDY
PART III

D180-24071-1

CONTRACT NAS9-15196
DRL T-1346
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LINE ITEM 3

Solar Power Satellite

SYSTEM DEFINITION STUDY PART III

D180-24071-1

PERFERED CONCEPT SYSTEM DEFINITION

March, 1978

Submitted To
The National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
in Fulfillment of the Requirements
of Contract NAS9-15196

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1.0 INTRODUCTION

1.1 PURPOSE

This document provides a concise but complete system description for the preferred concept SPS developed by the Solar Power Satellite System Definition Study (Contract NAS9-15196).

1.2 RATIONALE FOR SELECTION

The selection rationale was dominated by a desire to develop as much credibility and technical confidence in the results as could be achieved within the study resources available and within the understanding of the required technology. Significant selection decisions included the following:

1. Single crystal silicon solar cells
2. Glass encapsulated solar cell blankets
3. Concentration ratio 1
4. Graphite composite materials for primary structure
5. Electric propulsion for attitude control
6. Klystron RF amplifier tubes for the transmitter
7. One kilometer diameter transmitter with a design transmission link output power of 5,000 megawatts
8. Construction in low earth orbit with self-powered transfer of satellite modules to geosynchronous orbit.
9. Two-stage winged fully reusable rocket vehicle for transportation to low earth orbit.

Rationales for these were as follows:

1. Single crystal silicon solar cells were selected because their technology base is considerably more advanced than the alternatives. Promising alternatives include thin film gallium arsenide and other thin film materials. However, silicon cells nearing the performance levels desired for SPS are presently in experimental production. The paths to achieve the SPS level have been largely demonstrated experimentally. Even with this comparatively conservative technology selection, a substantial technology advancement must be accomplished in order to make the SPS system practical. Significant advancements include achievement of the desired performance level in production cells, selection of production processes and their automation, implementation of adequate capacity low cost silicon solar cell production, and implementation of SPS solar blanket production on an adequate scale. These technical challenges are sufficiently great that selection of a design requiring even further advances was felt to result in a lack of confidence in results. The more advanced technologies, however, would likely lead to improvements in SPS cost characteristics later in the program.

2. Glass encapsulation of the cells in the blanket was selected because this avoids life limitations that may exist for plastic materials and potential problems with darkening of adhesives.

   It also provides better radiation protection for the solar cells and is compatible with directed energy annealing of the solar blanket, should that be required.

3. Concentration ratio 1 was selected because low cost solar cells drive the concentration ratio trade to elimination of concentrators, because of the simplicity of the concentration ratio 1 configuration. Solar cells expensive enough to give a significant advantage to concentration lead to an overall cost preference for thermal engine systems.

4. The primary reason for selecting graphite composite materials for the SPS main structure was their achievability of very low thermal coefficients of expansion. This is highly desirable because the very low structural frequencies of an SPS satellite lead to significant concerns related to the dynamic effects of temperature changes due to changes in sun illumination.

5. The selection of klystron tubes as the power amplifiers for the microwave power transmitter was largely arbitrary. Earlier studies had concentrated on amplitron crossed-field amplifiers and it was desired to bring an understanding of the klystron system up to a comparable level. The klystron tube appears to be more flexible in operation than the amplitron tube and could lead to advantages in situations where control of the SPS power level is desired for load following or other reasons. Considerable interest has been expressed in solid state amplifiers but no solid state amplifier technology presently in the laboratory is adequate. The principal difficulty arises from the fact that solid state amplifiers must be operated at low temperatures (e.g., 50°C). This leads to severe limitations on the amount of power that can be transmitted without exceeding the allowable temperature limits on the solid state devices due to waste heat thermal rejection temperatures. For example, a one kilometer diameter power transmitter using silicon solid state devices could probably not handle more than about 1 to 1½ gigawatts of electrical input power. Size sensitivity analyses have indicated that SPS's with transmitters in this power range incur a significant penalty in terms of high capital cost.

6. The selection of the 5,000 megawatt power level per link and the 1 kilometer transmitter temperature resulted from a size sensitivity analysis reported in Appendix A of the book. The minimum system cost in terms of dollars per kilowatts of generating capacity occurs at this power level. The cost penalties for reducing this power level are relatively minor down to about 3,000 megawatts. Below 3,000 megawatts the penalties increase much more rapidly.

7. Construction in low earth orbit was selected because the availability of the electric propulsion mode reduces the number of launch vehicle flights by factor of approximately two. This *reduction* causes a reduction in transportation cost that overshadows the costs associated with increased complexity of the electric propulsion transfer mode.

8. Selection of the two-stage winged rocket launch vehicle occurred after an extended analysis and comparison of winged and ballistic single-stage and two-stage options. The single-stage options were technically marginal with the level of technology presumed available. The two-stage winged and two-stage ballistic options were essentially equal in cost as reported in earlier documentation. The winged system is believed to represent less of an operational challenge and would probably be less subject to vehicle attrition in landing accidents.

1.3 DOCUMENT DESCRIPTION

This document is organized to the current SPS work breakdown structure. The work breakdown structure is hardware-software oriented and it encompasses all elements of an SPS program. A summary of the work breakdown structure is presented in Figure 1-1. The system description is presented under each WBS item in four sub-headings. First is the work breakdown structure dictionary and description of what is included under the WBS item. Next is a description of the hardware or software item, followed by a description of the item mass when applicable, and finally, a description of the item cost. Description, mass, and cost summaries are provided at the higher WBS levels.

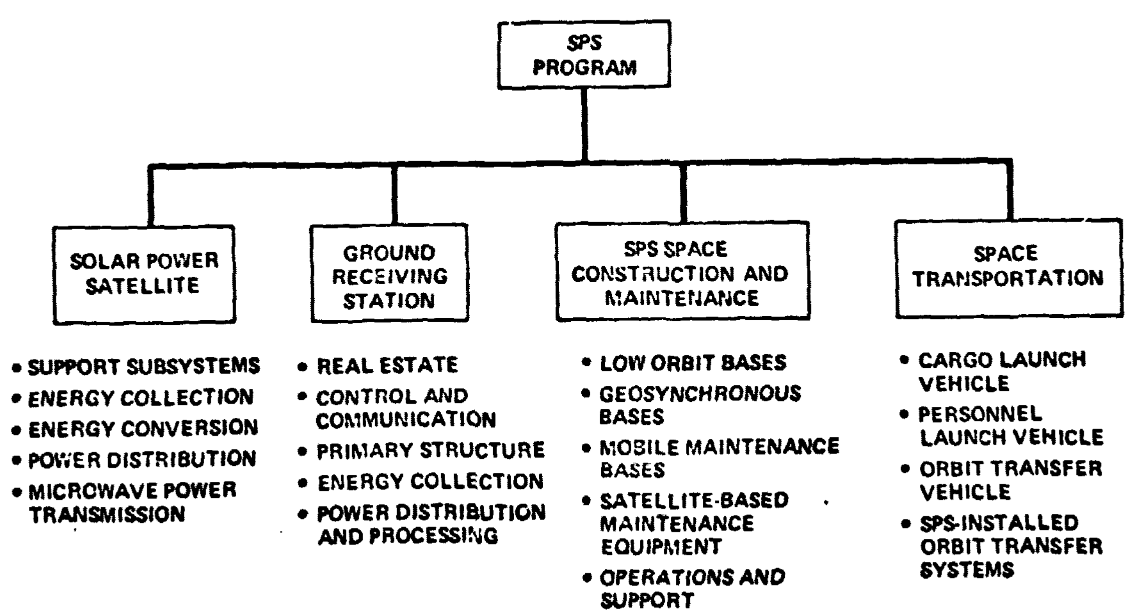

Figure 1-1 SPS Work Breakdown Structure

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2.0 SYSTEM DESCRIPTION

WBS 1.0 SPS Program

This study concentrated on analysis and description of operational SPS systems with a nominal generating capacity of 10,000 megawatts delivered through two RF power transmission links each rated at 5000 megawatts. Various rates of installation of these systems were considered with principal effort directed towards the installation rate of one per year. The complete operational SPS system includes the satellites, their ground receiving stations, space construction systems for completion for the satellites in space, space transportation systems for movement of SPS, other cargo and crews into space and into the final operational location, and miscellaneous support functions carried under these WBS items.

WBS 1.0.1 Program Integration

WBS Dictionary

This element includes those aspects of operating a commercial SPS system that cannot be conveniently accounted at the individual solar power satellite level or under the construction and transportation work breakdown structure items. An example of such an item might be governmental regulatory functions applicable to solar power satellite systems.

Description

No effort was expended under this study effort to identify or characterize any system elements that might apply to this WBS item.

WBS 1.0.2 Space Traffic Control

WBS Dictionary

This element applies to space traffic control operations that would function as an overall controlling element for the fleet of solar power satellites and their associated space operations systems including construction bases and transportation vehicles. This element would include tracking and monitoring functions as well as computing and control functions as necessary to maintain all system elements in safe and non-interfering orbits.

Description

No effort was expended under this study to identify space traffic control systems. An analyses was performed of collison hazards and potential workarounds. These results are reported in Volume 5 of the Part II final report.

WBS 1.1 Solar Power Satellite

WBS Dictionary
This element includes all hardware and resident software for operation of the solar power satellite. Maintenance equipment resident on the satellite is separately described under element 1.3.4, but is included in the summary SPS mass statement.

Element Description
The reference configuration illustrated in Figure 1.1.0-1 is a photovoltaic SPS (without solar concentrators) employing glass-encapsulated single-crystal silicon solar blankets. The nominal ground output is 10,000 megawatts through two power transmission links each rated at 5000 megawatts.

A summary of the efficiency chain and sizing requirements are presented in Tables 1.1.0-1 and 1.1.0-2.

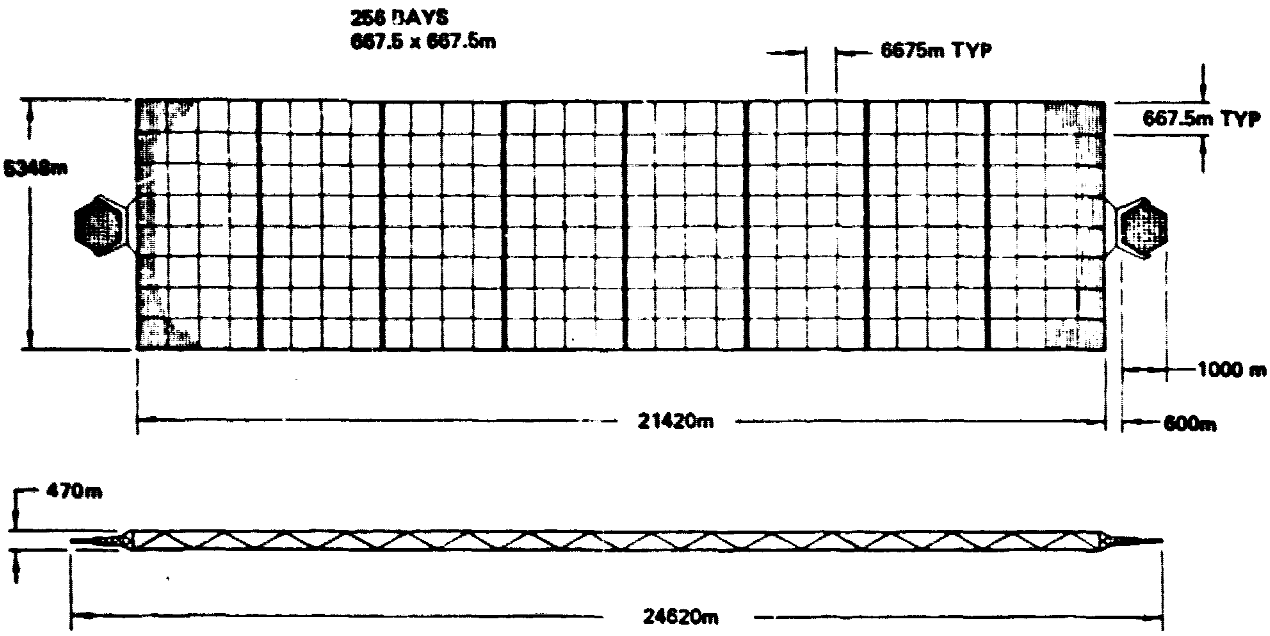
Element Mass
The element mass summary is presented in Table 1.1.0-3. This summary does not include item 1.3.4, satellite-based maintenance equipment. Mass estimating factors and/or rationales are given under the lower level element entries. The mass growth allowance was derived from the uncertainty analysis conducted in Part II. About 2/3 of the identified mass increase (relative to Part II) was incurred due to normalizing the SPS to 10,000 megawatts (the Part III reference design output was 9300 megawatts); this power deficiency was included in the Part II growth allowance, as illustrated in Figure 1.1.0-2. The other 1/3 was a result of design changes not included in the growth allowance, and represents an increase in predicted mass with growth. The result was a slight downward revision of the predicted mass growth with upward revision of identified and predicted masses.

Element Cost
The updated SPS cost summary is shown in Table 1.1.0-4. The cost estimating factors are described under lower level elements.

WBS 1.1.1 Support Subsystems

WBS Dictionary
Support subsystems are those subsystems on the solar power satellite that are not specifically allocatable to energy collection, energy conversion, power distribution or power transmission. They include primary structure, attitude control, central computing complex, communications, antenna yokes, and turntables. These items are described under the sub-headings below.

SPS-1651



TOTAL SOLAR CELL AREA: 101.8 km2
TOTAL ARRAY AREA: 110.2 km2
TOTAL SATELLITE AREA: 114.5 km2
OUTPUT: 16.93 GW MINIMUM TO SLIPRINGS

Figure 1.1.0-1 Photovoltaic Reference Configuration (5,000 MW Output Each Transmitter)

SPS-1653

Table 1.1.0-1 Nominal Efficiency Chains Photovoltaic SPS

ITEM	JSC GREEN BOOK	CURRENT NOMINAL		REASON FOR DIFFERENCE
SUMMER SOLSTICE FACTOR	NOT INCLUDED	.9765		THESE WERE INCLUDED IN ENERGY INTENSITY ON SPS
COSINE LOSS (POP)	NOT INCLUDED	.919		
SOLAR CELL EFFICIENCY		.173		
RADIATION DEGRADATION		.97		
TEMPERATURE DEGRADATION	0.103	.954	0.151	SLIGHTLY BETTER CELL; CR = 1
COVER UV DEGRADATION		.956		
CELL-TO-CELL MISMATCH		.99		
PANEL LOST AREA	NOT INCLUDED	.961		
STRING I^2R	.92	.998	.932	DISTRIBUTION OPTIMIZATION
BUS I^2R		.934		
ROTARY JOINT	1.0	1.0		
ANTENNA POWER DISTR	.98	.97		PROCESSING & TEMPERATURE
DC-RF CONVERSION	.87	.85		VARIAN ESTIMATE
WAVEGUIDE I^2R	.98			
IDEAL BEAM		.965		
INTER-SUBARRAY ERRORS	.88	.956	.86*	INTRA-SUBARRAY EFFECTS
INTRA-SUBARRAY ERRORS		.981		NOT INCLUDED IN GREEN
ATMOSPHERE ABSORP.	.98	.98		BOOK
INTERCEPT EFFICIENCY		.95		
RECTENNA RF-DC	.90	.89		NUMERICAL INTEGRATION
GRID INTERFACING	.99	.97		INCLUDES DC-DC PROCESSORS
PRODUCTS/SUMS	.0608	.0712		
SIZES (Km^2)		108.8		

* INCLUDES INTERCEPT EFFICIENCY

Table 1.1.0-2 Reference System Power Budget and Sizing Criteria

- EFFECTIVE BLANKET OUTPUT—180.6 w/m^2 (E.O.L.)
  - BASIC CELL PERFORMANCE (0.1575 @ AMO-25°C) — 213.1 w/m^2
  - 10% IMPROVED PERFORMANCE—DUE TO TEXTURED COVERS — 234.4 w/m^2
  - BLANKET FACTORS—STRING I^2R, UV LOSSES, & MISMATCH (0.9453) — 221.6 w/m^2
  - TEMPERATURE LOSSES—36.5°C @ SUMMER SOLSTICE (0.9540) — 211.4 w/m^2
  - SUMMER SOLSTICE COSINE, LOSSES (0.9190) — 194.3 w/m^2
  - APHELION INTENSITY FACTOR (0.9675) — 188 w/m^2
  - 30-YEAR NON-ANNEALABLE RADIATION DEGRADATION (0.970) — 182.3 w/m^2
  - ORBIT TRANSFER COMPENSATION (.9906) — 180.6 w/m^2
- ARRAY POWER REQUIREMENT—18.31 $(10)^9$ WATTS
  - GROUND OUTPUT — 10.0 $(10)^9$ WATTS
  - SLIP RING TO GROUND OUTPUT EFFICIENCY LINK (1.693) — 16.93 $(10)^9$ WATTS
  - SATELLITE BUS I^2R LOSSES (1.071) — 18.13 $(10)^9$ WATTS
  - OVERSIZE—REGULATION, AUX. PWR., ANNEALING (1.01) — 18.31 $(10)^9$ WATTS
- SOLAR CELL AREA REQUIREMENT—101.4 km^2
- ARRAY AREA REQUIREMENT (INCLUDES LOST AREAS ON ARRAY)—110.2 km^2
- TOTAL SATELLITE AREA (EXCLUDING ANTENNAS)—114.5 km^2

Table 1.1.0-3 Photovoltaic Reference Configuration Nominal Mass Summary Weight in Metric Tons

COMPONENT	PART II FINAL	CURRENT	REMARKS
1.0 SOLAR ENERGY COLLECTION SYSTEM	(51,782)	(55,602)	
1.1 PRIMARY STRUCTURE	5,385	7,156	CONTINUOUS CHORD BEAMS AND NORMALIZING POWER
1.2 SECONDARY STRUCTURE	—	—	
1.3 MECHANICAL SYSTEMS	67	67	NO CHANGE
1.4 MAINTENANCE STATION	—	—	
1.5 CONTROL	178	323	RE-ESTIMATED
1.6 INSTRUMENTATION/ COMMUNICATIONS	4	4	NO CHANGE
1.7 SOLAR-CELL BLANKETS	43,750	45,773	INCREASED ARRAY AREA TO NORMALIZE POWER TO 10 GW
1.8 SOLAR CONCENTRATORS	—	—	
1.9 POWER DISTRIBUTION	2,398	2,425	SLIGHT INCREASE IN TRANSMISSION LENGTH
2.0 MPTS	25,212	26,379	NORMALIZED POWER AND SQUARE SUBARRAY
SUBTOTAL	76,994	81,998	
GROWTH	20,400	17,590	NORMALIZED POWER ON GROWTH CURVE
TOTAL	97,474	99,713	

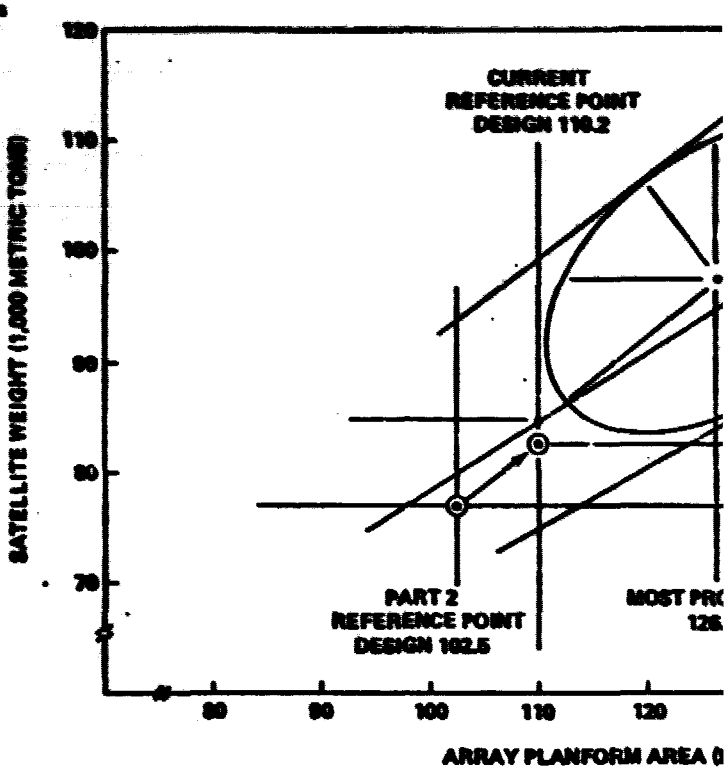


Figure 1.1.0-2 Mass/Size Uncertainty Update

Table 1.1.0-4 Capital Cost Update Summary: 1 SPS Per/Year (In Millions of 1977 $)

ITEM	PART II FINAL (9.3 GW)	PART III UPDATE (10 GW)	REASON FOR CHANGE
• SUPPORT SUBSYSTEMS	637	570	[1]
• ENERGY CONVERSION (SOLAR BLANKETS)	3,750	4,023	LARGER ARRAY FOR 10 GW
• POWER DISTRIBUTION	133	142	HIGHER POWER
• MICROWAVE POWER TRANSMISSION	2,622	2,860	HIGHER POWER:ENERGY STORAGE NEGLECTED IN PART II
• GROUND RECEIVING STATION (2)	4,442	4,520	RE-ESTIMATE
• GRID INTERFACE	—	1,348	NOT INCLUDED IN PART II
• CONSTRUCTION & SPACE SUPPORT	1,109	1,109	—
• SPACE TRANSPORTATION	6,445	6,387	INCREASED EARTH LAUNCH COST BUT SAVINGS BY ORBIT TRANSFER SYSTEM RECOVERY
• INITIAL SPARES	—	240	NEGLECTED IN PART I
• PACKAGING & OTHER	314	602	INCREASED TO 5% OF APPLICABLE ITEMS
• INTEREST DURING CONSTRUCTION	1,864	2,082	HIGHER BASE COST
• GROWTH	3,450	3,115	SOME OF PART II GROWTH INCLUDED POWER DEFICIENCY
TOTAL	24,766 ($2,663/kWe)	26,998 ($2,899/kWe)	

[1] ATTITUDE CONTROL THRUSTER COST WAS REDUCED TO REFLECT COMMONALITY WITH ORBIT TRANSFER THRUSTERS.

WBS 1.1.1.1 Primary Structure

WBS Dictionary

This includes all structure which is not unique to one of the major systems (energy collection, conversion, distribution or transmission). This includes attach points/fixtures for the major systems.

Element Description

The reference satellite configuration was illustrated in Figure 1.1.0-1. The satellite is comprised of 256 bays, each 667.5 meters square. The bays are arranged eight wide by thirty-two long to provide an aspect ratio of four.

It was attractive to use a modular structural concept for construction in LEO with transfer and final assembly in GEO. The satellite was sectioned into eight modules of equal size, each module is four bays by eight bays. When joined along eight bay edges, the desired satellite configuration is formed.

A typical module was used to perform a loads analysis to identify the critical beams. The basic structural configuration of the module is shown in Figure 1.1.1-1 with typical beam lengths shown in Figure 1.1.1-2. The critical beams, upper surface beams in bending, were noted and the structure was sized accordingly. The edge load (3.5 N/M) on these members is the result of array catenary loading on the primary structural beams.

A typical section of 7.5 meter beam is shown, in Figure 1.1.1-3, with end-fitting and loading points noted. This beam is fabricated by a continuous chord process which will be discussed in section 1.3. The element configuration for this beam, with basic dimensions and materials, is shown in Figure 1.1.1-4.

The end-fitting shown in Figure 1.1.1-4 is that for a centroidal-joint, beam-to-beam connector. An illustration of an edge beam intersection, using this approach, is shown in Figure 1.1.1-5. This type of joint permits centroidal beam-to-beam load transmittal and is also consistent with current construction techniques and construction facility sizing.

Element Mass

The final primary structural mass estimate is shown in Table 1.1.1-1 and a comparison of the Part II final mass estimate. The increase in mass, from the Part II final, is broken into two categories; that resulting from increased bay size to normalize power output (6.1 percent); and that resulting from a change to continuous chord beams (93.9 percent).

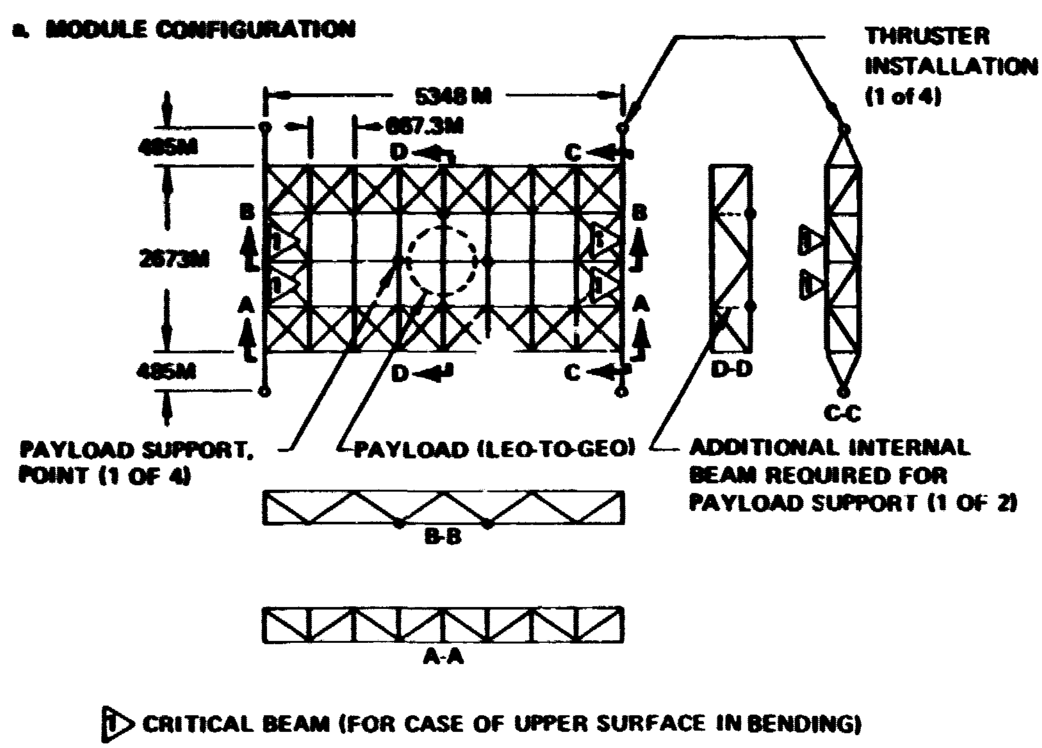


Figure 1.1.1-1 Loads Analysis and Loads/Sizing Summary for Critical Beam in Upper Surface

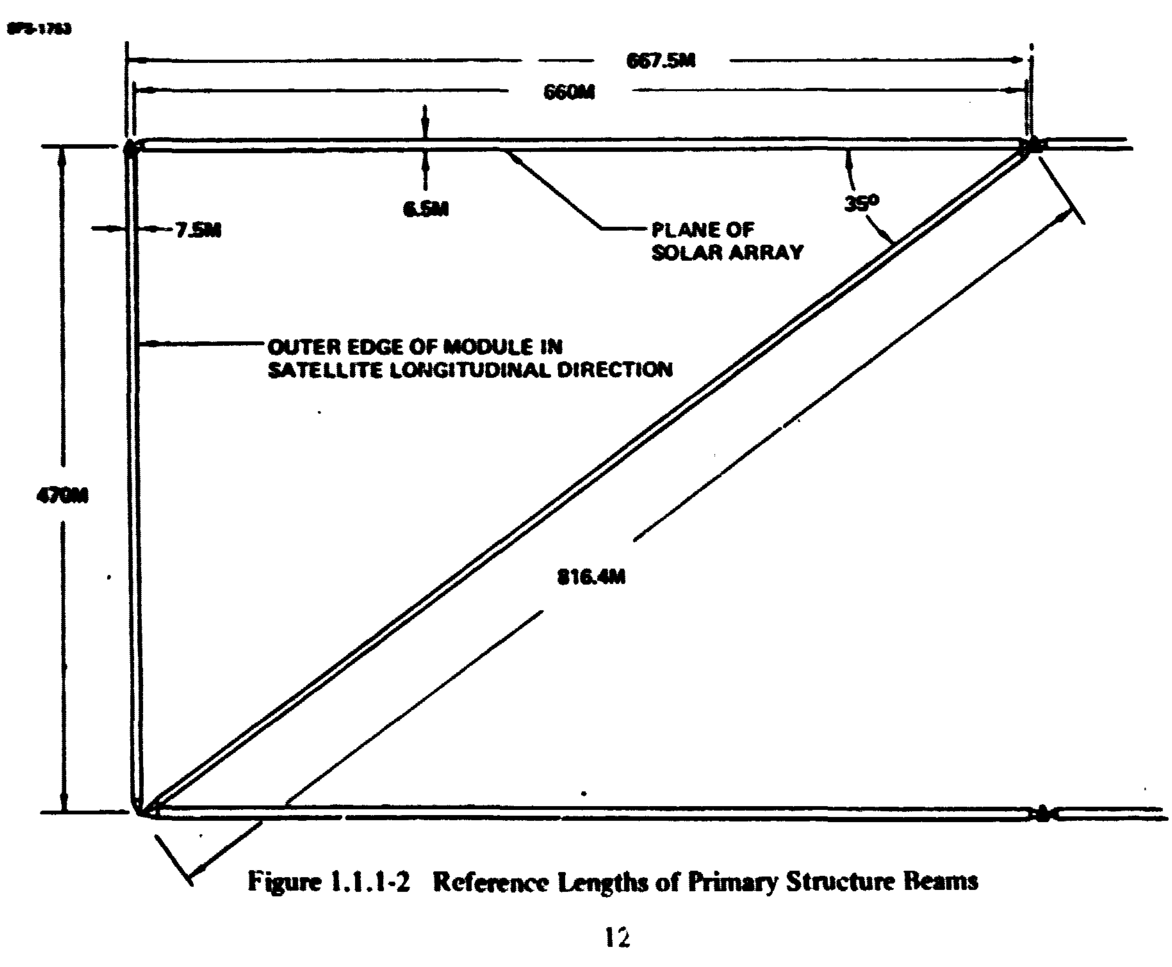


Figure 1.1.1-2 Reference Lengths of Primary Structure Beams

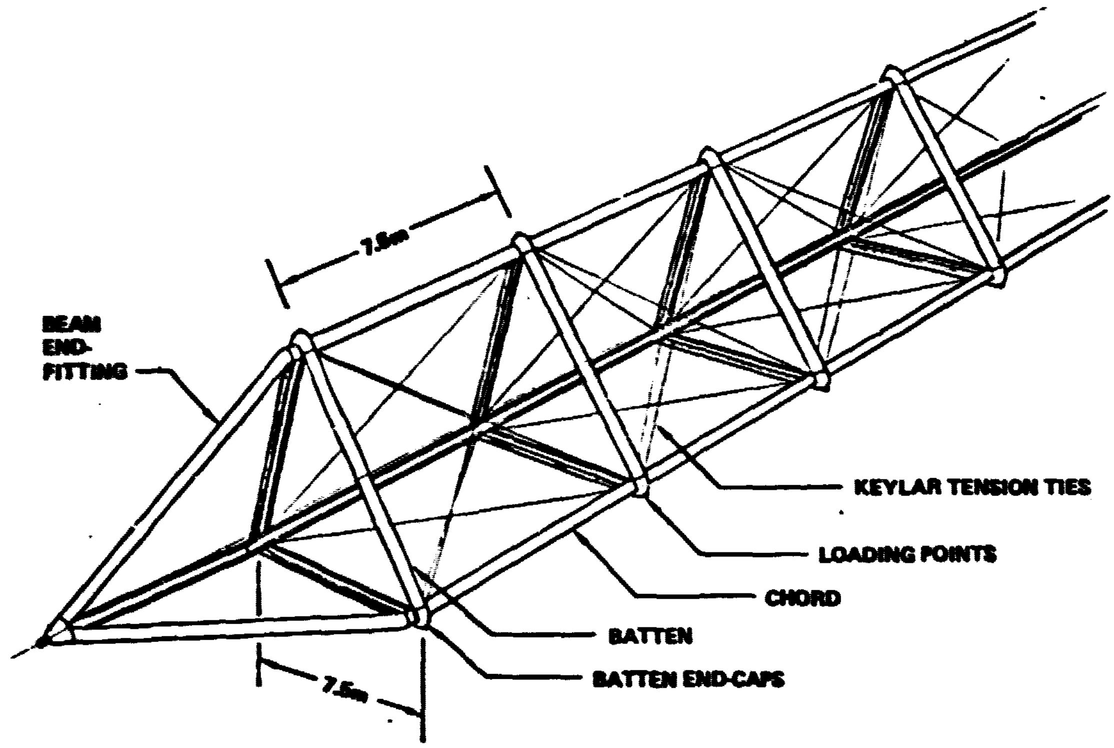
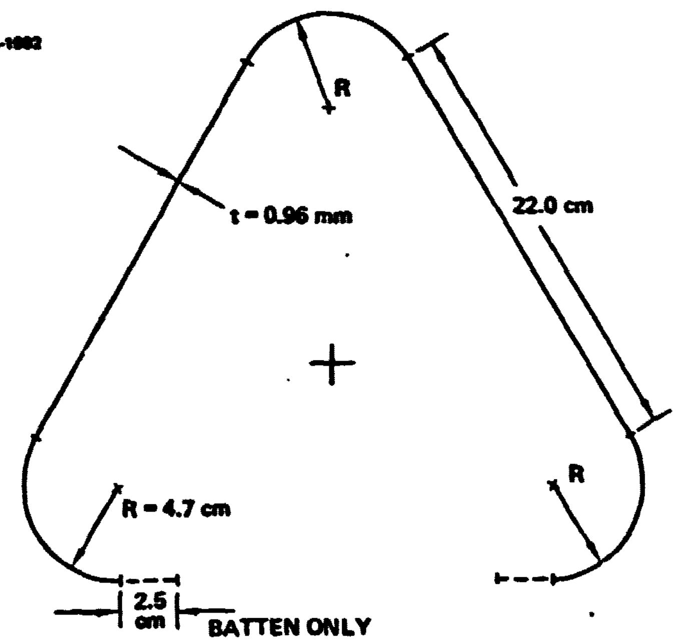


Figure 1.1.1-3 Continuous Chord Beam Approach



MATERIAL:	P-1700 GRAPHITE (POLYSULFONE IMPREG) E-181 GLASS COVER
BEAM:	WIDTH–7.5m BATTEN SPACING–7.5m MASS/LENGTH–6.54 kg/m

Figure 1.1.1-4 Continuous Chord/Batten Configuration

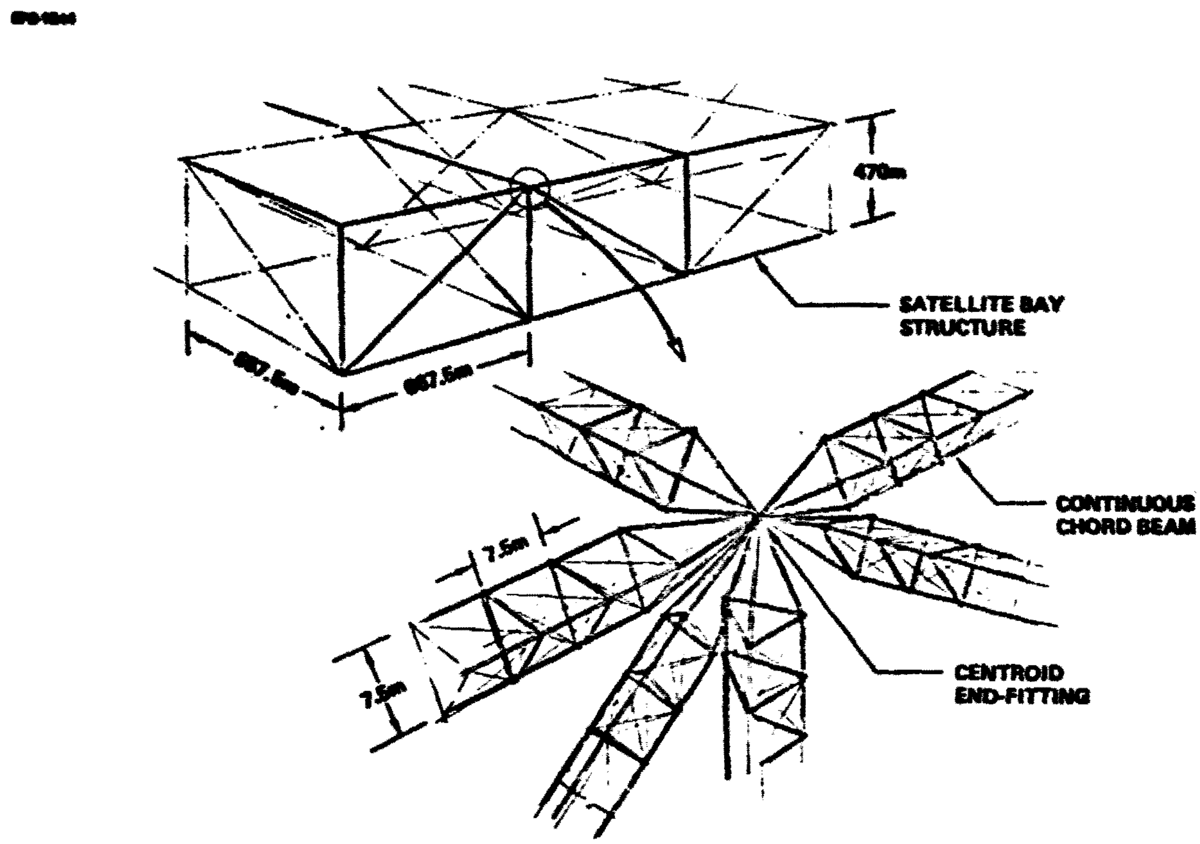


Figure 1.1.1-5 Continuous Chord Beam-Beam Intersections

Table 1.1.1-1 Primary Structural Mass Comparison

CURRENT MASS ESTIMATE (MT)	PART II FINAL MASS ESTIMATE (MT)	CHANGE (MT)
7155	5385	1770

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Element Cost
The cost estimating factor used for primary structural members is 55$/kg. This factor was based on mature industry projections and was verified by detailed manufacturing and fabrication analysis. The updated SPS cost summary was shown in Table 1.1.0-4.

WBS 1.1.1.2 Attitude Control

WBS Dictionary
The attitude control subsystem includes all operational elements and software required to maintain orbit station keeping and attitude control of the SPS in the operational orbit or to establish attitude control from an initially uncontrolled condition.

Description
The attitude control system is an electric propulsion system with four installations, one at each corner of the SPS energy conversion system. A typical corner installation is illustrated in Figure 1.1.1-6 (blue book). The attitude control system includes thrusters, power processors, structure, propellant feed and control systems and instrumentation and control.

Mass
A mass summary of the attitude control system is given in Table 1.1.1-2. This mass estimate is based on Part II results described in Volumes 5 and 6 of the Part II Final Report.

Cost
A cost summary for the attitude control system is given in Table 1.1.1-3. The cost data represents an update from the Part II Final Report results given in Volume 6.

WBS 1.1.1.2.1 Thrusters

WBS Dictionary
Thrusters include the primary electric thrusters for maintenance of attitude control, and auxiliary chemical thrusters required for establishment of attitude control when electric power is not generated by the SPS.

Description
The electric thrusters are 100 centimeter diameter ion thrusters operated on argon as primary propellant. A typical thruster is illustrated in Figure 1.1.1-7. Performance characteristics for such a thruster are illustrated in Figure 1.1.1-8. Chemical thrusters are small pressure-fed oxygen/hydrogen thrusters operating at a mixture ratio of 4 to 1 with a specific impulse of approximately 400 seconds. Illustrations or technical details for these thrusters were not developed. They would represent a negligible mass, volume, or cost contribution to the attitude control system.

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SPS SYSTEMS DEFINITION STATUS REPORT	SATELLITE SYSTEMS	
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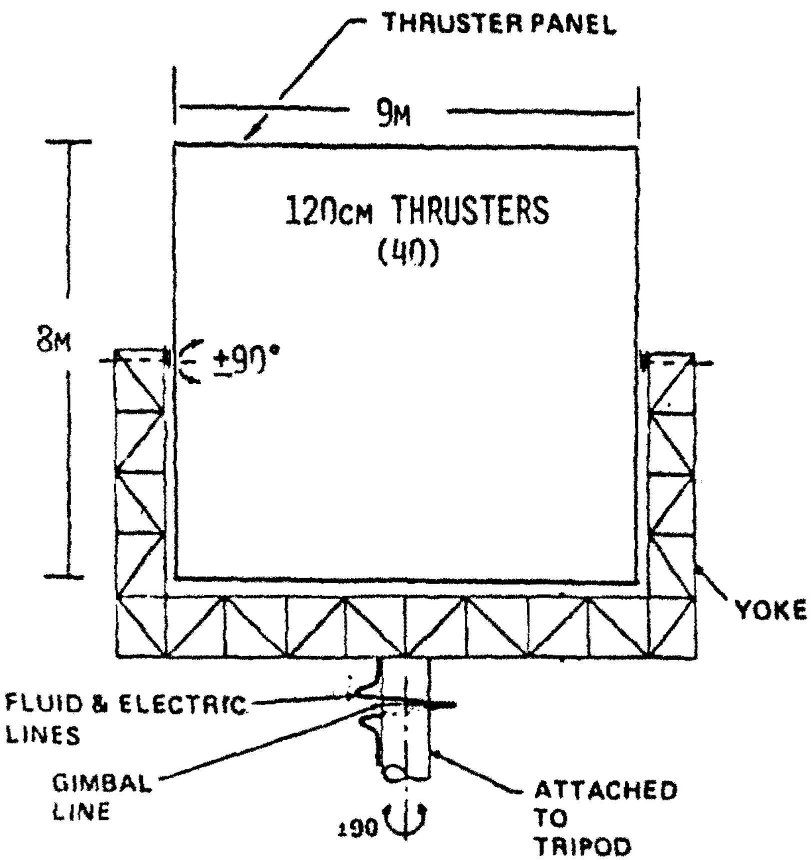
ATTITUDE CONTROL SYSTEM THRUSTERS



ELECTRIC THRUSTERS

- 4 PANELS (ONE AT EACH CORNER)
- THRUST/PANEL - 150N
- 25 OPERATING THRUSTERS/PANEL (40 TOTAL)
- I_{SP} = 20,000 SEC
- ARGON PROPELLANT (41,000 - 80,000 KG/YEAR)
- OPERATING LIFE - 2 YEARS (0.5 DUTY CYCLE AND 80A BEAM CURRENT)

CHEMICAL THRUSTERS (LO_2/LH_2)

- CONTROL DURING EQUINOCTAL OCCULTATIONS
- I_{SP} = 400
- 1500 - 3000 KG/YEAR

Figure 1.1.1-6 SPS Systems Definition Status Report

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Table 1.1.1-2 Flight Controls System Mass

THRUSTERS	50 kg x 40 x 4 CORNER	=	8,000 kg
PROCESSORS	15,583 kg x 12	=	187,000
INST'L =	15 TONS x 4	=	60,000
TANKS	1.5 TONS x 4	=	6,000
CONTROL			2
			263 TONS
	PLUS ANNUAL PROPELLANT		60
			323 TONS

Table 1.1.1-3 Flight Controls System Cost

THRUSTERS 160 X $10,000*	= $ 1.6 MILLION
PROCESSORS $3.57M EACH X 12	= $42.84 MILLION
INSTALLATION	= $25.0 MILLION
TANKS	= $ 5.8 MILLION
CONTROL	= $12.6 MILLION
	$85.0 MILLION

*LOW COST RESULTS FROM COMMONALITY WITH ORBIT TRANSFER THRUSTERS. THEY ARE THE SAME EXCEPT FOR ACCELERATION VOLTAGE AND OPTICS.

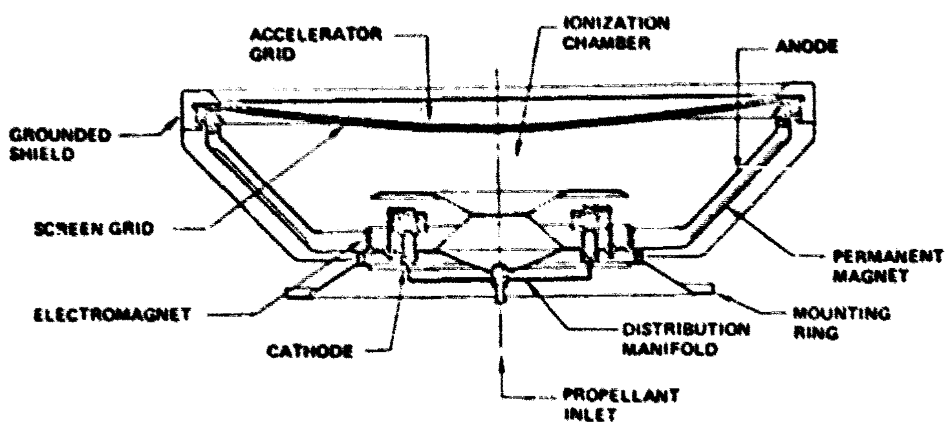

Figure 1.1.1-7 120 CM Argon Ion Thruster

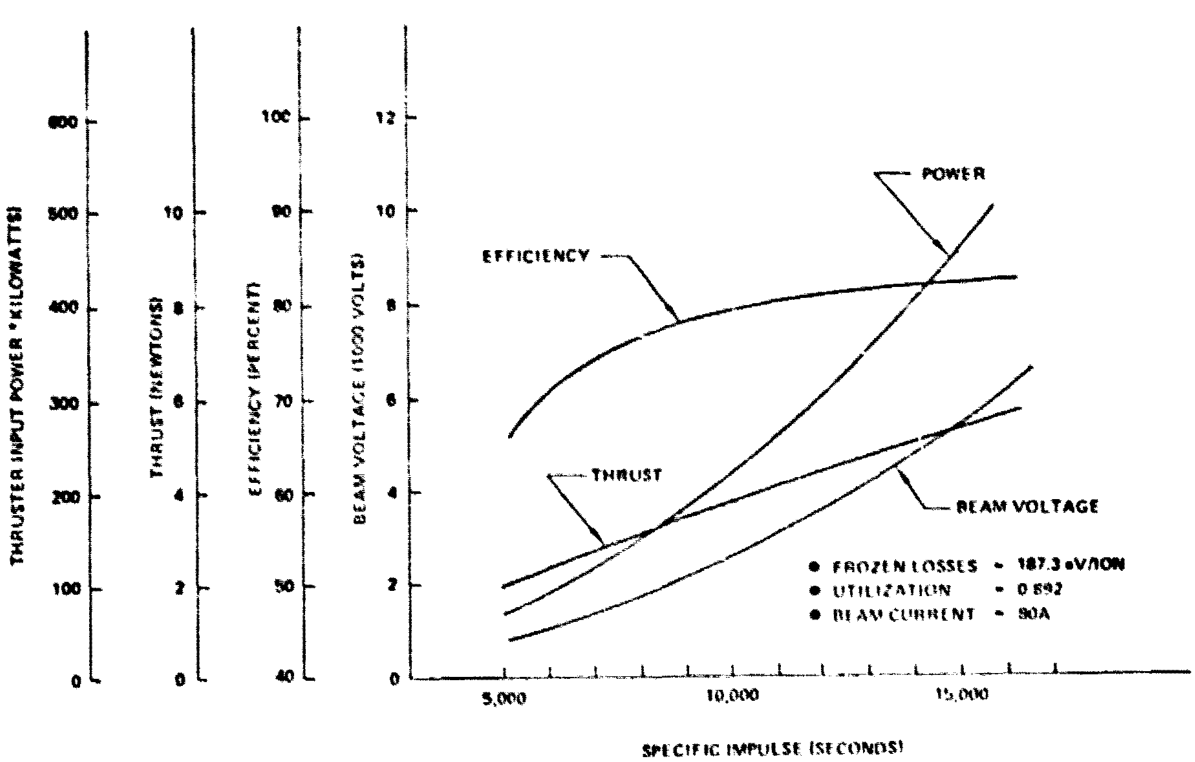

Figure 1.1.1-8 120-CM Argon Ion Thruster Performance

Mass
Electric thruster mass was estimated at 50 kilograms each based on extrapolations from the 30 centimeter thrusters presently in experimental production.

Cost
The thruster cost estimate was derived from an electro-mechanical cost estimating relationship and a mature industry extrapolation. A cost check was made between this result and a cost estimate provided to NASA by the thruster manufacturer (Hughes) with good agreement.

WBS 1.1.1.2.2 Power Processors

WBS Dictionary
The power processor element includes all power processing required to convert the SPS-generated electrical power (at 40,000 volts) to the voltages and conditions required by the attitude control system, including thruster requirements, control requirements, as well as computing and other requirements.

Description
Power processors are solid state electronic processors that convert the 40,000 volts from the SPS to the lower voltages required by thrusters and other equipment. There are a total of 12 processors, three at each corner.

Mass
Mass of each power processor was estimated as 15,583 kilograms based on a mass scaling relationship of 1.7 kilograms per kilowatt. This estimate includes the thermal control that would be required for these processors.

Cost
Each processor was estimated to cost $3.57 million dollars based on a mature industry scaling from cost estimate projections derived for similar hardware in commercial production. This is about $230/kg.

WBS 1.1.1.2.3 Structure and Installation Hardware

WBS Dictionary
This element includes all structure and attitude control installation hardware not accounted for under other WBS items. As such, it includes all structural equipment and standoffs added to the basic SPS structure to mount the attitude control systems. Also included are secondary structure for support of propellant tanks and other equipment, and the gimbal system and thruster panels required to control the thrust vector direction of the thrusters.

Description

The structure was illustrated earlier in Figure 1.1.1-6. The structure would be similar to the SPS primary structure including truss beams with suitable terminations to form the tripod-like standoff. The gimbal system is a 2-axis motor-driven slow rate gimbal system. Gimbal commands are derived from the instrumentation and control system. The thruster panels provide mounting for the thrusters and support routing for the electric power feeds from the power processors.

Mass

Each structural installation was estimated at 15,000 kg.

Cost

The four structural installations were estimated to cost $25 million, approximately 1670/kg, including the gimbal system.

WBS 1.1.1.2.4 Propellant Tanks

WBS Dictionary

This element includes the argon, oxygen, and hydrogen propellant tanks for the SPS attitude control thrusters. It also includes tank-mounted equipment such as propellant gauging and vent valves and the multilayer insulation on the tank.

Description

The propellant containers are spherical aluminum tanks located near each thruster installation. Tanks are sized to hold one year's supply of propellant plus a 20% margin. The oxygen and hydrogen tanks include a 20,000 kilogram maneuvering reserve in addition to the normal control propellant. This is sufficient to re-establish the SPS normal attitude from any initial attitude.

Because of the long propellant storage time the tanks are designed with a light-weight hard-shelled vacuum jacket that includes approximately 50 layers of multilayer insulation. The tanks are designed to be refilled from a tanker or removed and exchanged with new tanks brought from Earth.

Mass

The mass of the propellant tanks was estimated as 10% of the fluid contained. The total mass is 1500 kilograms per corner not including contained propellant. The contained propellant is 60,000 kg including the maneuvering reserve.

Cost

The cost of the tanks was estimated using a cost estimating relationship for tank structures. The total cost for all tankage was estimated at $5.8 million, about $970/kg.

WBS 1.1.1.2.5 Propellant Feed and Thrust Control System

WBS Dic' ·nary

This element includes all propellant feedlines and thrust control electronics and instrumentation.

Description

The propellant feedlines are uninsulated aluminum lines. Propellant pressure is controlled to the pressure required for the thrusters by regulators. A shutoff valve is included in each line for each thruster so that any malfunctioning thruster can be isolated from propellant feed. The feedlines include flexible elements and gimbals to cross the thruster panel gimbal joint. Electric thrust control is provided by startup and shutdown of individual thrusters. Oxygen/hydrogen thruster thrust control is provided by operating the thrusters in pulse mode.

Mass

The mass of the propellant feed and thrust control system was estimated at $12.5 million, an average of $6250/kg.

WBS 1.1.1.3 Central Computing Complex

WBS Dictionary

The Central Computing Complex includes all computers and centralized data processing required for overall onboard management of the satellite configuration operation and flight control. (This element excludes antenna-dedicated computing and data processing. The latter is separately covered under element 1.1.5.1.4.)

Description

The Central Computing Complex consists of a triply redundant solid-state computer system with supporting equipment. Relatively little effort was invested in defining computing requirements or the computer complex. A rough order of magnitude estimate suggests that the computer capacity of this complex need be no greater than the capacity of the space shuttle computers. The computer system was assumed to employ advanced large-scale integration.

Mass

A rough estimate of mass suggested 225 kg per computer, including a significant allowance for radiation shielding of the computer complex to ensure long life and minimum difficulties and failures.

Cost

The cost of the Central Computing Complex was estimated using a CER at approximately $28 million.

WBS 1.1.1.4 Communications

WBS Dictionary

The Communications subsystem provides a communications link between the satellites and the ground receiving station for overall satellite control purposes. This communications link does not include specialized antenna phase control communications services. It is tied in with the onboard central computing complex and includes all onboard data bussing for condition and performance monitoring of the energy conversion subsystem.

Description

The Communications system includes a triply redundant transmitter/receiver system operating on a frequency sufficiently removed from the power transmission frequency to avoid interference. A KU-band link is a likely candidate. The communications system also includes data, bussing, and collection. This system interfaces with the Central Computing Complex for onboard control. Data bussing means has not been selected but will probably employ fiber optics.

Mass

The Communications system mass was estimated as 2720 kg.

Cost

The Communications system was estimated to cost $74 million, an average of $27,000/kg. Aerospace communications cost estimating relationships were used.

WBS 1.1.1.5 Antenna Yokes and Turntables

WBS Dictionary

Th[illegible]ment includes all production hardware required to mechanically interface the satellite pri-ma[illegible]ucture with the MPTS structure. Subelements include the mechanical rotary joint and drive system, the elevation yoke joint, and interface structure between the satellite and MPTS systems.

Element Description

The MPTS antenna is attached to the satellite primary structure by the use of an antenna yoke, yoke support structure, a mechanical rotary joint and an elevation joint (figure 1.1.1-9). The entire MPTS support structure is hinged at the edge of the satellite structure for LEO/GEO transport configuration (section 1.3).

The yoke support structure is composed of the 7.5 meter beams baselined for the satellite primary structure (section 1.1.1.1). The support structure beams join to form a hexagonal interface that provides eight support points for the mechanical rotary joint circular beam (figure 1.1.1-10). On the satellite side, these beams join to the hinged platform that will allow the complete antenna and support system to rotate under the end modules of the satellite.

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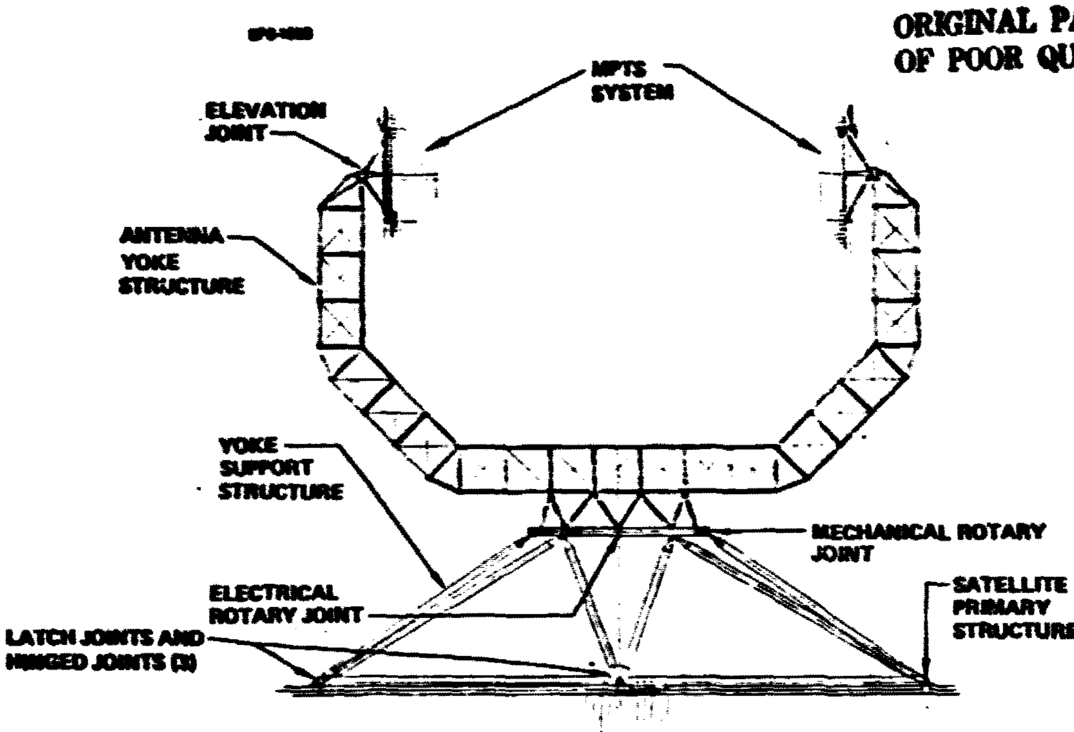


Figure 1.1.1-9 Antenna Yoke and Turntables

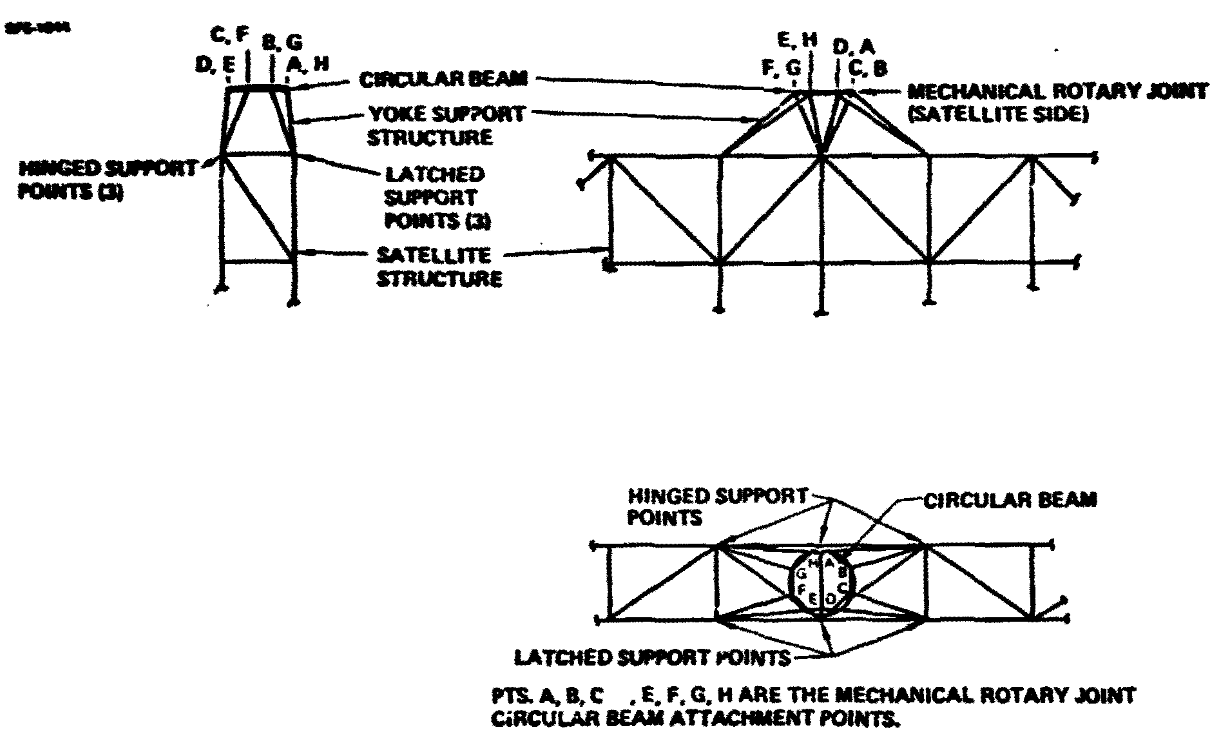


Figure 1.1.1-10 Yoke Support Structure

The mechanical rotary joint is composed of two segmented circular beams (one on the satellite side and one on the yoke side), a section of which is shown in figure 1.1.1-11. Each circular beam is supported at eight points, every 45 degrees, to its adjacent support structure. The inner and outer base chords of each circular beam are arranged adjacent to each other. Between each set of base chords, a drive ring and roller assembly is attached (figure 1.1.1-12) to provide relative movement between the satellite and MPTS system. The antenna yoke attaches to its circular beam in a similar method as described for the yoke support structure.

The yoke is composed of one hundred meter trusses made up of the same beams as that for the MPTS primary structure (section 1.1.5.1.1). At the antenna end of the yoke, a special end fitting is provided to interface with the antenna elevation joint. The elevation joint provides for a small pointing angle adjustment (approximately 7 degrees) of the MPTS system for alternate rectenna transmission capabilities.

There is an electrical rotary joint at the interface of the yoke and yoke support structure. The electrical connection across the elevation joint uses flex cables because of the small angle adjustment involved. These electrical elements are detailed in section 1.1.4.4.

Element Mass
The mass of the antenna yoke and turntable, for one MPTS, is listed in Table 1.1.1-4. Included in these masses are the attachment provisions and mechanical elements necessary for the subelement supports.

Element Cost
The element costs estimating factors, for the items listed in Table 1.1.1-4, are listed in Table 1.1.1-5. Also listed is the total cost for one MPTS antenna yoke and turntable system.

WBS 1.1.2 Energy Collection

WBS Dictionary
The Energy Collection System includes all reflectors or concentrators used to concentrate solar energy on the Energy Conversion System and a secondary structure required to support the concentrator system.

Description
The concentration ratio 1 preferred concept requires no energy collection system.

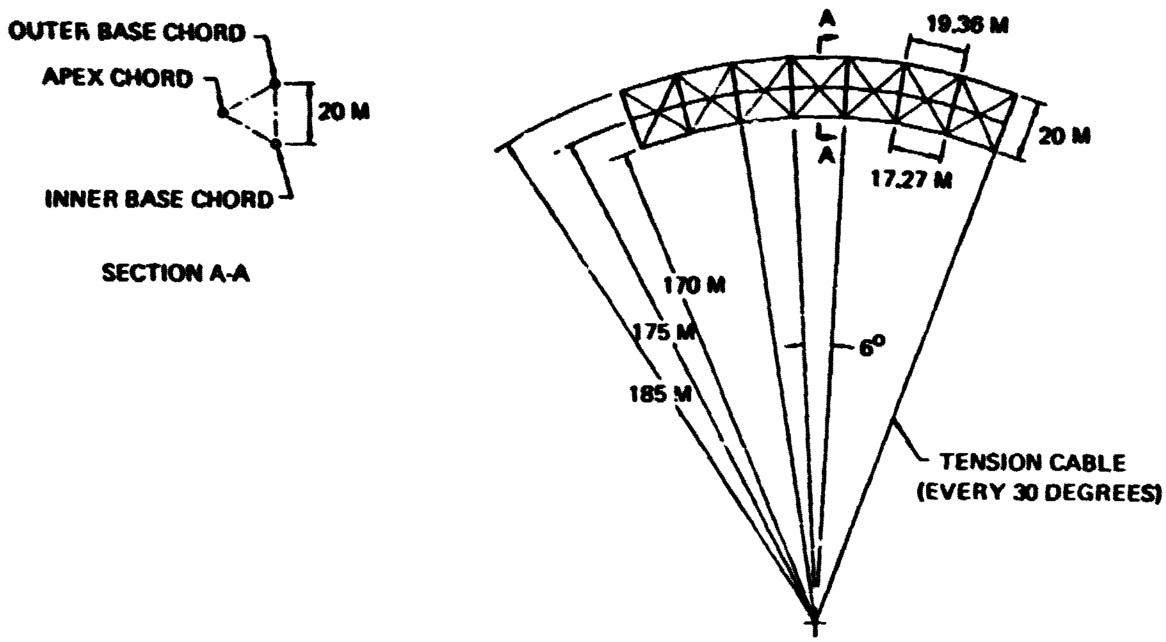
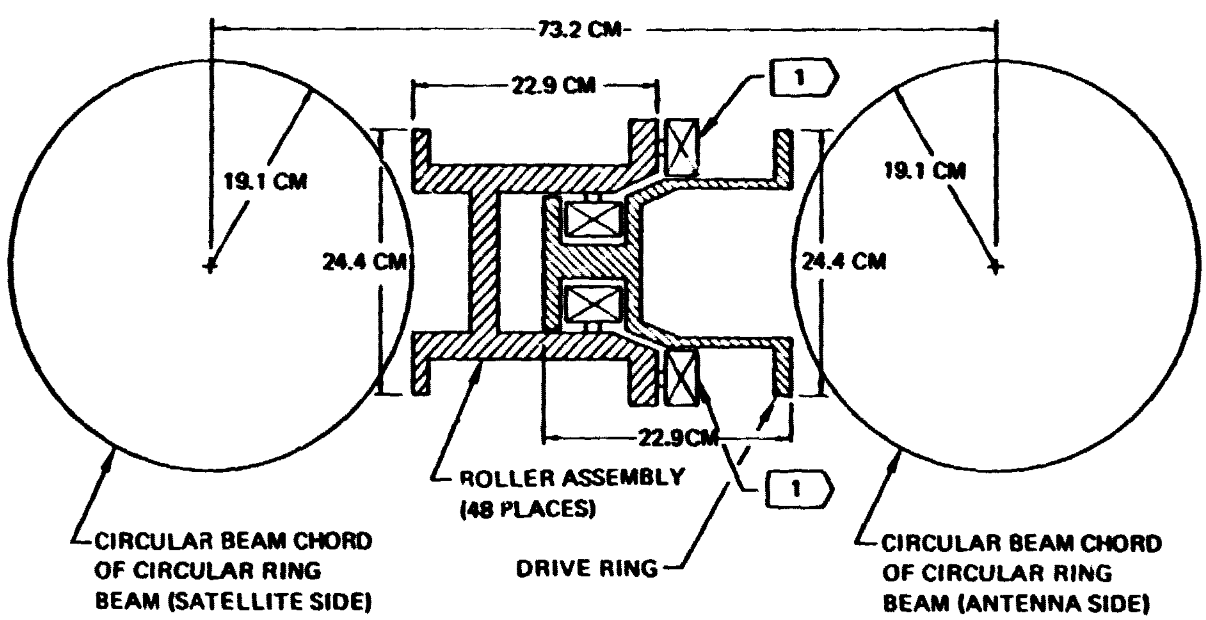


Figure 1.1.1-11 Circular Ring Beam Geometry



[1] A ROLLER/DRIVE ASSEMBLY IS LOCATED AT 12 PLACES (EVERY TENSION CABLE) AROUND THE PERIPHERY OF THE CIRCULAR BEAM (SATELLITE SIDE). THIS ASSEMBLY IS SIMILAR TO THAT SHOWN EXCEPT THAT THE WHEELS INDICATED BY FLAG [1] ARE MOTOR DRIVEN FRICTION WHEELS WHICH ARE SPRING LOADED ACROSS THE ASSEMBLY.

Figure 1.1.1-12 Drive Ring and Roller Assembly Location Relative Base Chords of Circular Ring Beams

Table 1.1.1-4 Antenna Yoke and Turntable Mass Estimate

ANTENNA SUPPORT STRUCTURE	53.0 MT
MECHANICAL ROTARY JOINT	33.4 MT
ANTENNA YOKE	41.2 MT
TOTAL	127.6 MT

Table 1.1.1-5 Antenna Yoke and Turntable Cost Estimate

ELEMENT	CER ($/KG)	COST ($10^{-6})
ANTENNA SUPPORT STRUCTURE	111	5.87
MECHANICAL ROTARY JOINT	340	11.36
ANTENNA YOKE	128	5.27
TOTAL COST		22.5X10^{-6}

WBS 1.1.3 Energy Conversion

WBS Dictionary
This element includes all production hardware required to convert incident sunlight into electrical power at the required voltage and deliver this power to the distribution system. There are three primary subelements: the solar blankets, the catenary support system, and interbay jumbers.

Element Description
The reference energy conversion system configuration was illustrated in figure 1.1.0-1. A summary of the efficiency chain and sizing requirements were presented in Tables 1.1.0-1 and 1.1.0-2. A more detailed description will be given under each of the subelements.

Element Mass
The energy conversion mass summary was given in Table 1.1.0-3. The mass estimating factors will be discussed in the subelement entries.

Element Cost
The updated SPS cost summary was shown in Table 1.1.0-4. The cost estimating factors will be described in the subelement entries.

WBS 1.1.3.1 Solar Blankets

WBS Dictionary
This element includes all production hardware required to convert incident sunlight into the required electrical power. Subelements include solar cell panels, panel interconnects, provisions for interbay interconnects, and support device interfaces.

Element Description
An illustration of the solar cell blanket is provided in figure 1.1.3-1. A silicon solar cell must be provided with a cover to increase front-surface emittance from around 0.25 to around 0.85, and to protect the cell from low-energy proton irradiation.

Cerium-doped borosilicate glass is a good cover material because it costs only a fraction of the best alternate, 7940 fused silica, matches the coefficient of thermal expansion of silicon, and yet resists darkening by ultravoilet light. Borosilicate glass can be electrostatically bonded to silicon to form a strong and permanent adhesiveless joint. In ATS-6 flight tests the cells having integral 7070 borosilicate glass covers lost only 0.8 ± 1.1 percent of their output because of ultraviolet degradation. These cells had no cover adhesive. Other cells having cell-to-cover adhesives degraded twice as much. Jena Glaswerk Schoot & Gen. Inc., in West Germany, expects to be able to manufacture 75 μm borosilicate glass sheets one meter wide by several meters long.

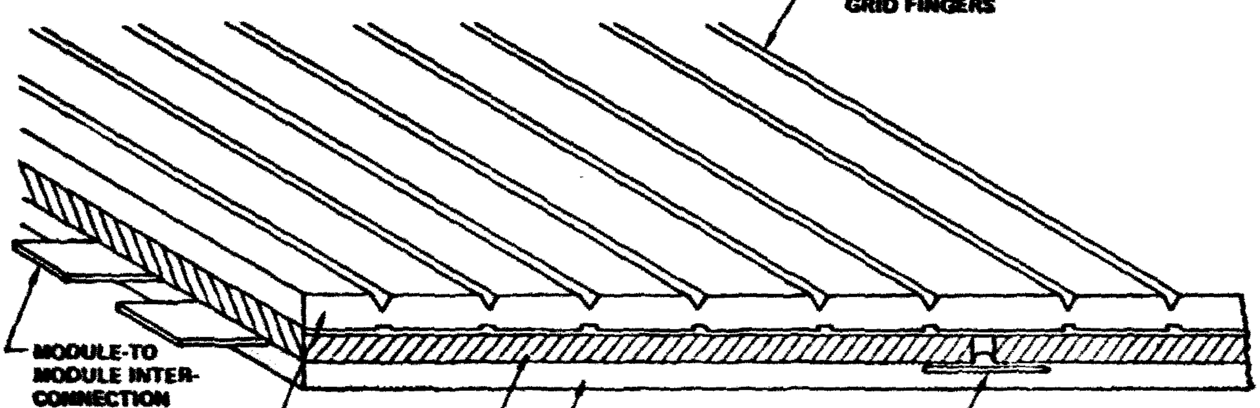


Figure 1.1.3-1 Solar Array Blanket

The cell cover is embossed during bonding with grooves which refract sunlight away from the grid lines and buses on the cell surface. COMSAT Labs expects an 8 to 12 percent increase in cell output from this feature in cell covers.

Solar cells only 50 μm thick recently made by Solarex had an air-mass-zero efficiency of 12.5 percent without a back-surface field or cover glasses. Improved efficiency can be obtained by using textured cover glasses. Texturing the sun-facing surface makes the incoming light arrive at the back surface of the cell at an angle over 31°, so the light rays that have not been absorbed are reflected off the back surface with virtually no loss, the critical angle in a silicon-air junction being 15.3 degrees. This feature not only improves photon collection efficiency, when compared with thicker cells, by lengthening the light path in silicon for infrared photons, but also improves radiation resistance. Since all charge carries are generated within 50 μm of the P-N junction, which is 0.2 μm under the sun-facing surface, the cell can absorb radiation damage until the diffusion length in the bulk silicon is reduced to 50 μm by radiation generated recombination centers.

The cells are designed with both P and N terminals brought to the backs of the cells. This feature makes it possible to use simple 12.5 μm silver-plated copper interconnections which are formed on the substrate glass. Complete panels are assembled electrically by welding together the module-to-module interconnections.

Glass was chosen for the substrate to enable annealing of radiation damage by heating. With all glass-to-silicon bonds made by the electro-static process there are no elements in the blanket which cannot withstand the 773°K (931°F) annealing temperature, which at present seems to be required. One researcher suggests that 773°K (931°F) may not be needed for annealing out the radiation damage from solar-flare protons. However, his theory has not yet been confirmed by experiment.

The basic panel adopted for design studies (figure 1.1.3-2) has a matrix of 224 solar cells, each 6.55 by 7.44 cm in size, connected in groups of 14 cells in parallel by 16 cells in a series. Spacing between cell and edge spacings are as shown. Tabs are brought out at two edges of the panel for electrically connecting panels in series. Cells within the panel are interconnected by conducting elements printed on the glass substrate.

Important panel requirements were these:

- The panel components and processes should be compatible with thermal annealing at 500°C.
- Presence of charge-exchange plasma during ion-engine operation may necessitate insulating the electrical conductors on the panel.
- The panel design should be appropriate for the high-speed automatic assembly required for making the same 93 million panels required for each satellite.
- Low weight and low cost are important.

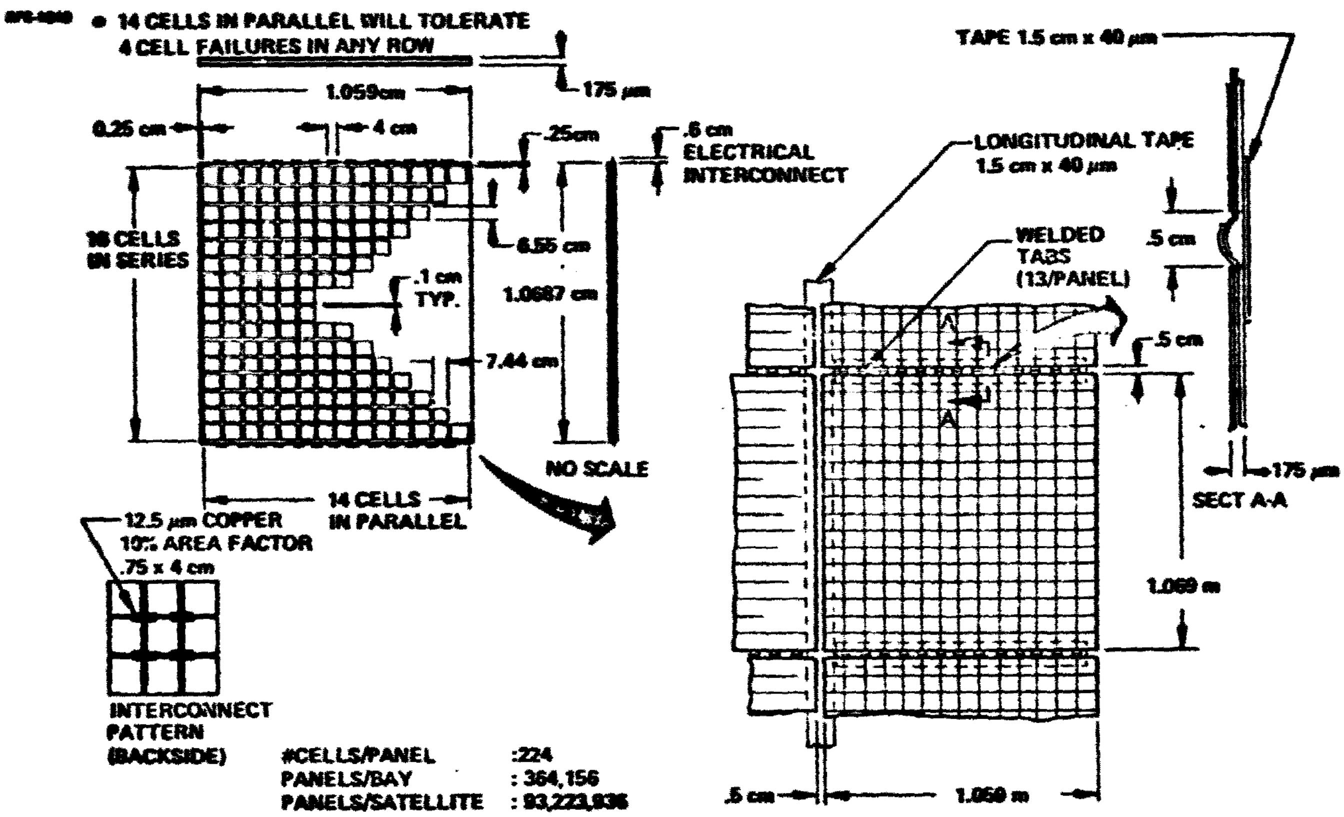


Figure 1.1.3-2 Array Blanket Description

Also shown (figure 1.1.3-2) is the way panels would be assembled to form larger elements of the solar array. The interconnecting tabs of one panel are welded to the tabs of the next panel in the string and then the interconnections are covered with a tape that also carries structural tension between panels. The 0.5 cm spacing between panels provides room for the welding electrodes, and also permits reasonable tolerances in the large sheet of 75 μm glass that covers the cells and the 50μm sheets of substrate glass.

The panels are joined in a matrix that is 14.9 meters wide by 656 meters long to form blanket segments (figure 1.1.3-3). After assembly, the segment is accordion folded, at panel intersections, into a compact package for transport to the low-Earth-orbit assembly station. Packaging is given more detail in Section 1.3.

Provisions are made for connection of the blanket segments with interbay jumpers to form power sectors. Power sector definition will be discussed in Section 1.1.4. Conductor strips will be used to join strings, with provisions for welding strips to join blanket segments, to form power sectors. The conducting strips also have a bossed section to connect with interbay jumpers.

The tapes, at the end of blanket segments, are extended and have attachment rings to connect to the tensioning springs of the catenary support system.

Element Mass

The total energy conversion system mass was shown in Table 1.1.0-3. A more complete mass breakdown of the solar blanket is provided in Table 1.1.3-1. Also included in this table are the mass estimates for the array support system.

Element Cost

The cost estimating factors for the solar blanket elements are the same as those given in the final documentation of Part 2. The mature industry projection cost estimating factor for the reference solar blanket is \$35/m^2.

WBS 1.1.3.2 Catenary Support System

WBS Dictionary

This element includes all production hardware required to support the solar blanket within the satellite primary structure including attachments to both the structure and solar blanket.

Element Description

The Part II silicon photovoltaic system provided an output of 4650 megawatts per antenna. To normalize this output to 5000 megawatts it was necessary to increase the satellite bay size to 667.5 meters which was more than adequate to satisfy the increased area requirement.

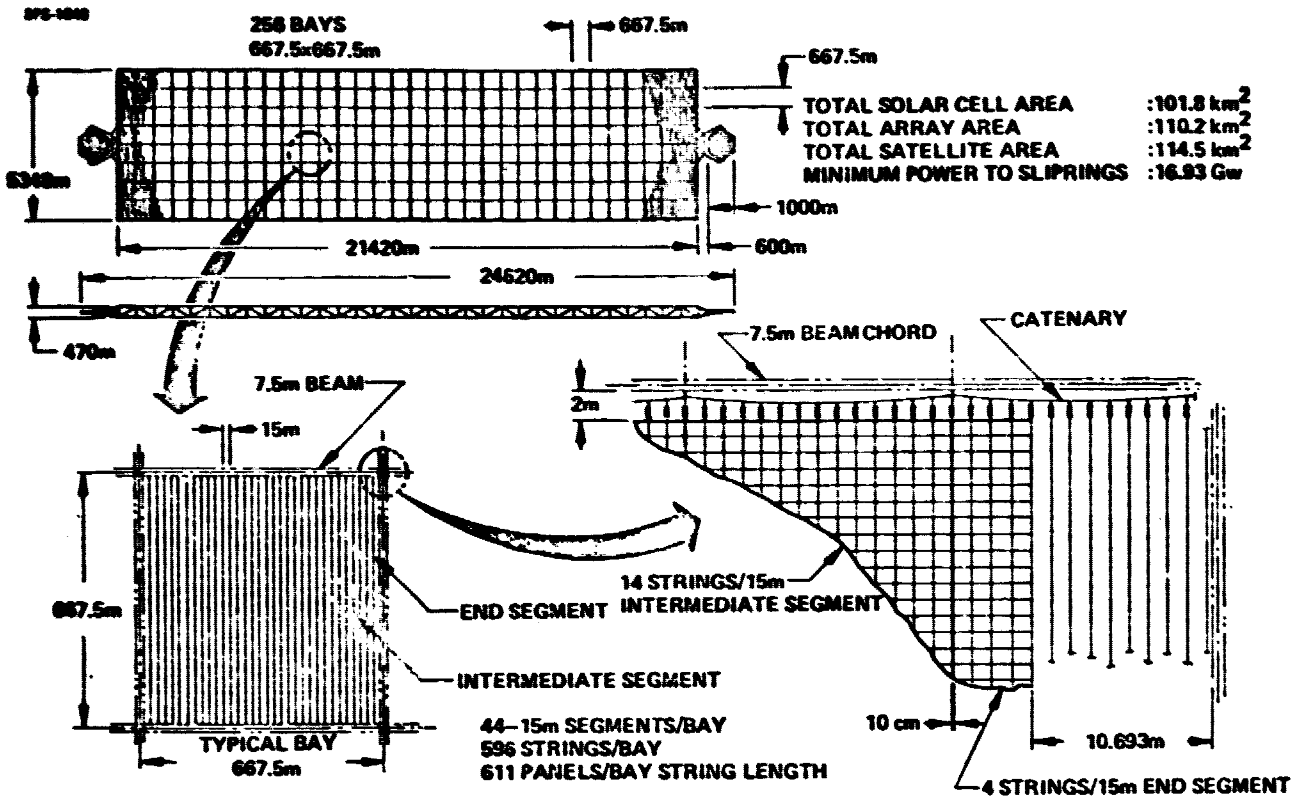


Figure 1.1.3-3 Reference Photovoltaic System Description

Table 1.1.3-1 Silicon Solar Cell Blanket Mass

AVAILABLE BLANKET @ PART II MIDTERM					
COVERS–FUSED SILICA	2.20	55.88	3.0	1.0	167.64
CELLS–SILICON	2.36	59.94	2.0	0.9607	115.17
INTERCONNECTS–COPPER	8.94	227.08	.5	0.100	11.35
SUBSTRATE–FUSED SILICA	2.20	55.88	2.0	1.0	111.76

7 MILS	3 MILS COVER
	2 MILS CELL
	2 MILS SUBSTRATE & INTERCONNECTS

THEORETICAL PANEL WEIGHT	405.92
TOLERANCES ALLOWANCE (5%)	20.30
ESTIMATED PANEL WEIGHT	426.22
PANEL AREA FACTOR (.9913)	422.51
SEGMENTS AREA FACTOR (.9972)	421.33
JOINT/SUPPORT TAPES	2.93
CATENARY SYSTEM	2.52
ESTIMATED ARRAY WEIGHT	426.78

The array segment width was changed to 14.9 meters. This change provided better packaging for transport but made it necessary to provide 15 meter catenary attachment points on the structural beams. A 10 cm spacing was provided between array segments for clearance during array deployment.

The method of supporting the solar blanket within the primary structural bays was shown in figure 1.1.3-3. This method of support will provide a uniform tension to the end of each solar array segment by the use of constant-force blanket tensioning springs at each blanket support tape (figure 1.1.3-4). These springs are also attached to a catenary cable that is then attached to the primary structure, upper surface, beams at 15 meter intervals. The springs are in compression, for better reliability, and exert a uniaxial force of approximately 3.5N to each blanket support tape.

A uniaxial blanket support was selected over the biaxial support shown in Part II of this study. This change was the result of analysis of construction techniques and associated blanket uniformity problems. It will be necessary to provide batten tapes between blanket segments, at a few intervals along the segment length, to provide correct segment-segment orientation.

Element Mass
The mass of this element was included in Table 1.1.3-1 and represents small fraction of the energy conversion system mass (less than 0.5 percent).

Element Cost
The cost of this element was included in the solar blanket cost factors.

WBS 1.1.3.3 Interbay Jumpers

WBS Dictionary
This element includes all production hardware required to provide for interbay power distribution within a power sector of the solar blanket.

Element Description
The formulation of high voltage in the solar array is accomplished by connecting approximately 78,000 sets of solar cells in series. Since the strings of solar cells start at the centerline of the satellite, goes to the outer edge and then back to the centerline, it must cross the primary structural beams, between bays, eight times. The purpose of the interbay jumpers is to provide a means of electrically connecting strings in one bay to the appropriate strings in the next bay of the string length.

The interbay jumpers (figure 1.1.3-5) are No. 12 aluminum cable. One-blanket segments jumpers are collected and run along the catenary cable to an end-connector. This end connector is joined with the next bays jumper end connector in the beam framework near the catenary support point. This method was chosen as a less complicated construction/maintenance scheme while still providing the necessary function.

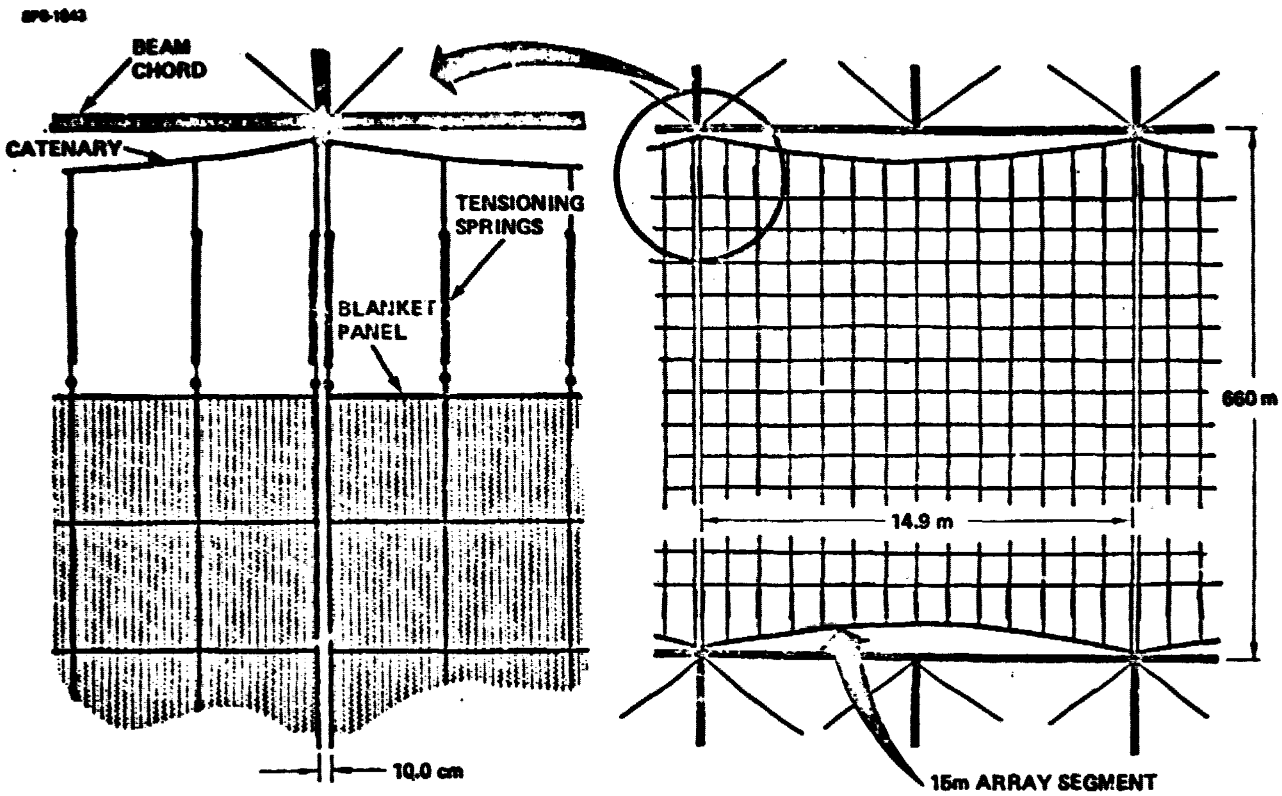


Figure 1.1.3-4 Reference Array Blanket Support

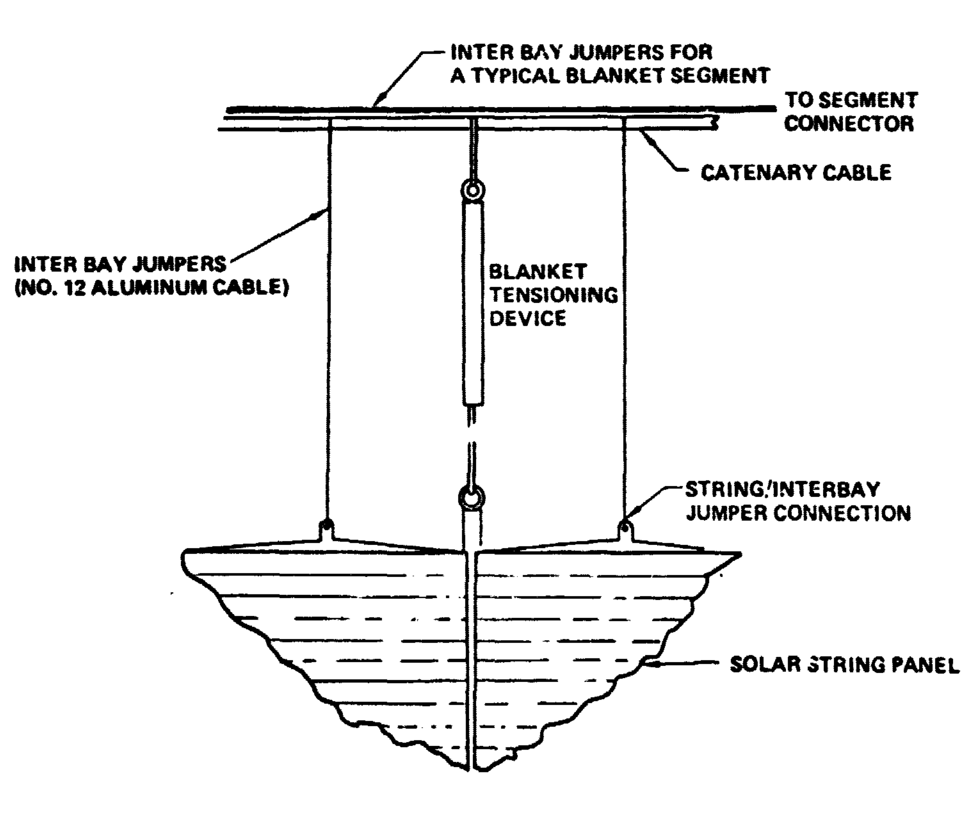


Figure 1.1.3-5 Inter Bay Jumpers

Element Mass
The mass of interbay jumpers was estimated to be 34,401 kg, based on using No. 12 aluminum cable. The average length of each cable is 20.4 meters and there are 192,080 cables.

Element Cost
The cost estimating factor used for the interbay jumpers was 45 $/kg.

WBS 1.1.4 Power Distribution
The prime function of the Power Distribution subsystem is to accumulate and control prime power from the silicon solar cell collector panels; control, condition, and regulate the quantity and quality of the electrical power generated for the klystron microwive generators; provide for the required energy storage during solar energy occultation or system maintenance shut-down; and provide for monitoring fault detection, and fault isolation disconnects. Figure 1.1.4-1 shows a simplified functional system block diagram of the SPS from end-to-end.

For power management and power distribution, the photovoltaic SPS is divided into typically 228 power sectors. Each power sector is switchable and can be isolated from the main power bus, facilitating annealing or other servicing. Main features of the power distribution system are shown in figure 1.1.4-2. Power transfer across the rotary joint is accomplished by a skip ring/brush assembly. Mechanical rotation and drive is provided by a mechanical turntable 350m in diameter. The antenna is suspended in the yoke by a soft mechanical joint to isolate the antenna from turntable vibrations. The antenna is mechanically aimed by CMG's installed on its structure. A position feedback with a low frequency passband allows the mechanical turntable to drive the yoke to follow the antenna and also provide sufficient torque through the soft joint to keep the CMG's desaturated.

Figure 1.1.4-3 is an electrical schematic of the SPS. The "satellite" is defined as the large collector solar array, its power generation modules and control, altitude control, and stationkeeping power processing; thermal control, telemetry and control, data, power processing, etc.; and DC/DC conversion and energy storage for the satellite. The rotary joint is the interface between the "satellite" and the "antenna".

Table 1.1.4-1 gives the Calculated Power Distribution System weight (mass) and power loss for the "satellite" connection locations and components. The total losses are approximately 200 megawatts per SPS "satellite" (less antenna losses).

Solar cell strings approximately 5.1 km long were selected for the reference photovoltaic system configuration. This permits generating the required voltage directly from the solar array without intervening power electronics. All solar cell strings are identical. Current generated by the solar cells are carried by conductors or by the solar cells themselves. The configuration in figure 1.1.4-4 uses the solar cells to the maximum possible extent for carrying the current. It is noted that no conductors are needed for bringing in the current from the edges of the array, the solar cell strings being arranged in loops which start from one center bus loop around the edge of the array, and return to the other bus at the center of the array.

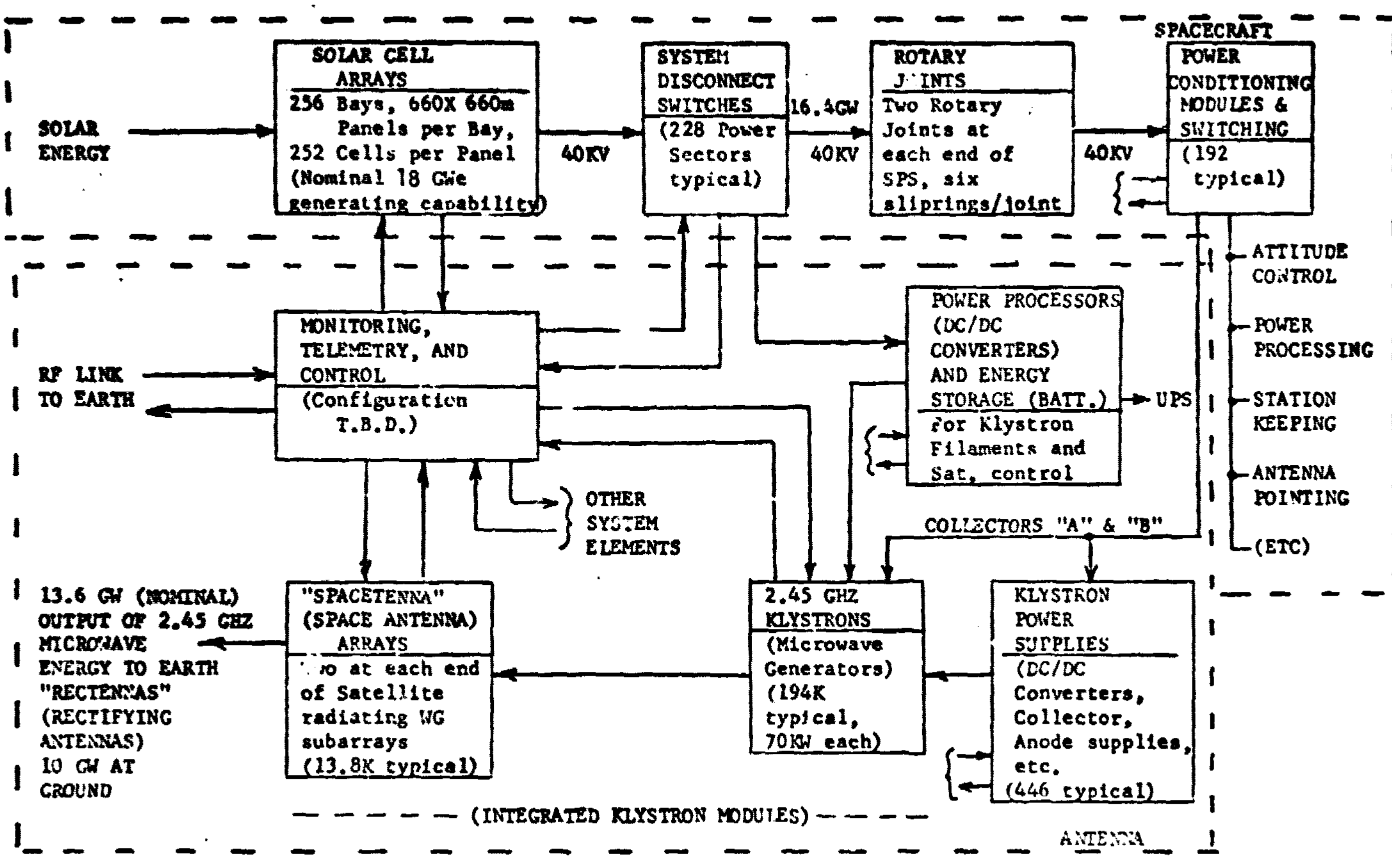


Figure 1.1.4-1 Simplified SPS Functional System Block Diagr.

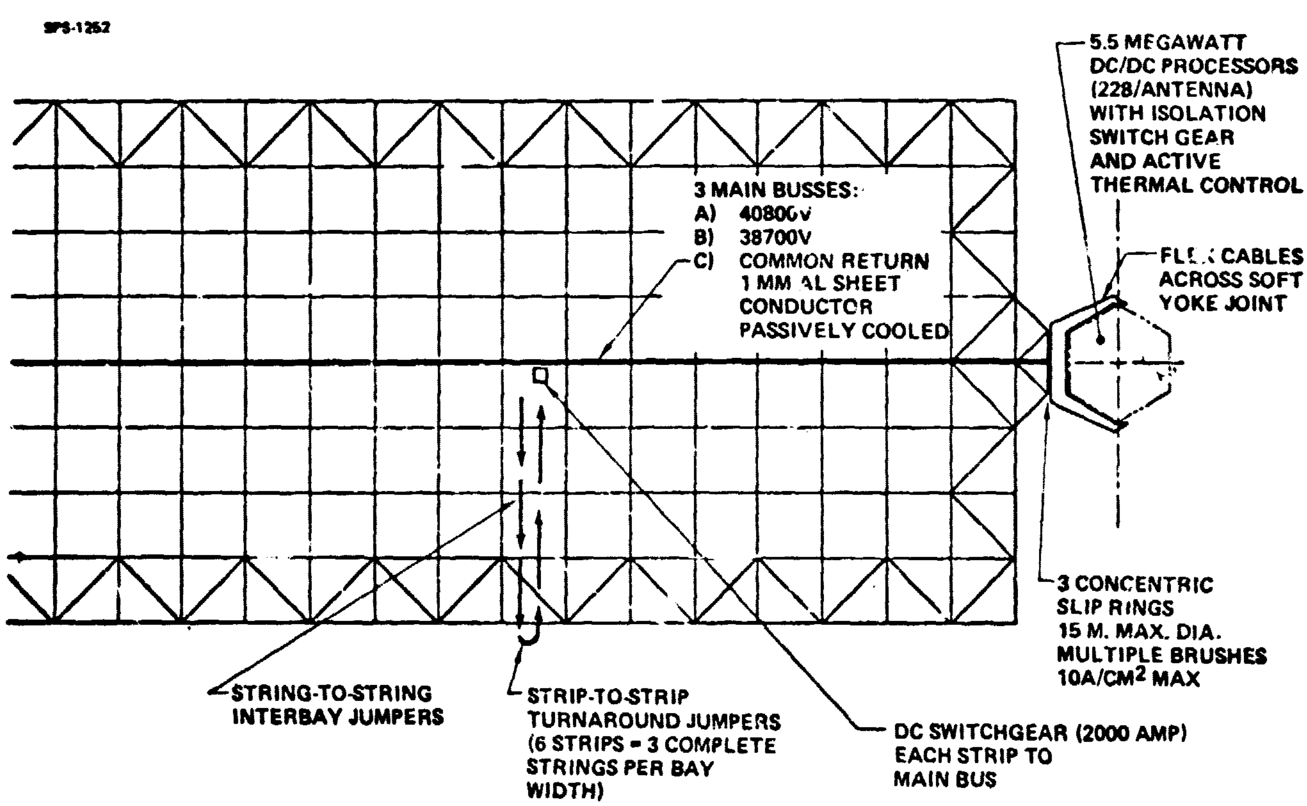


Figure 1.1.4-2 SPS Power Distribution

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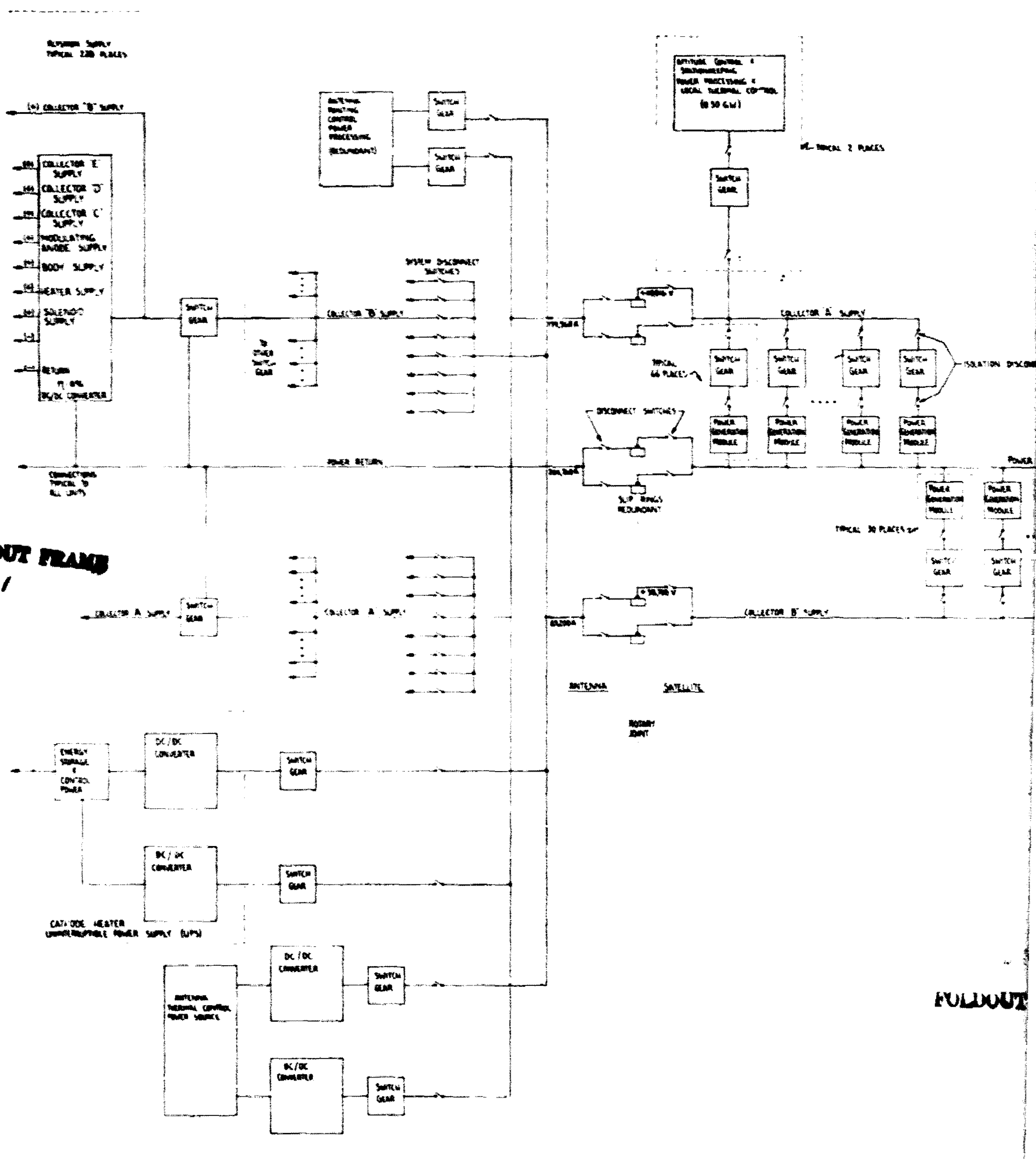

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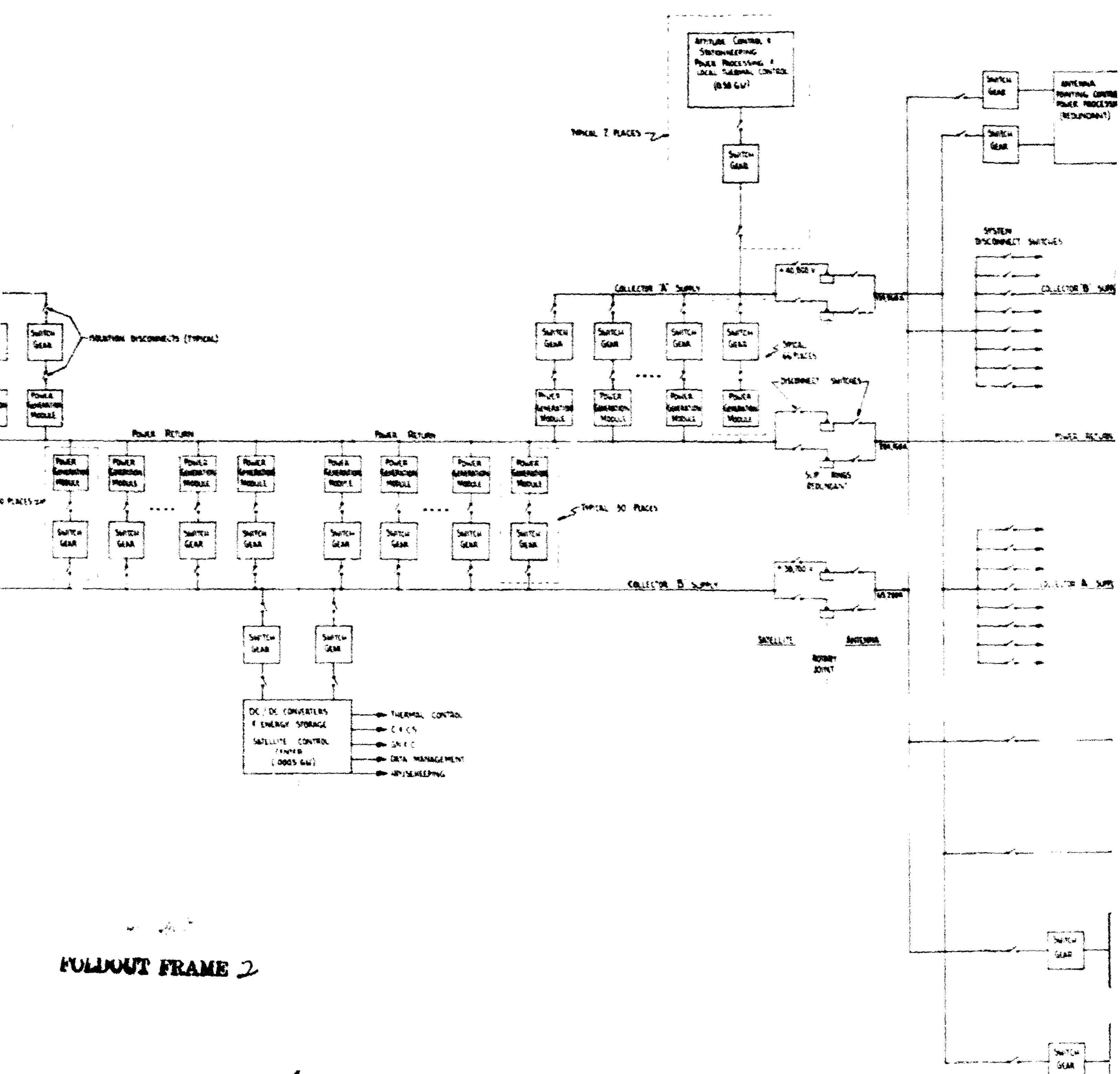

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Figure 1.1.4-3 Electrical Sc

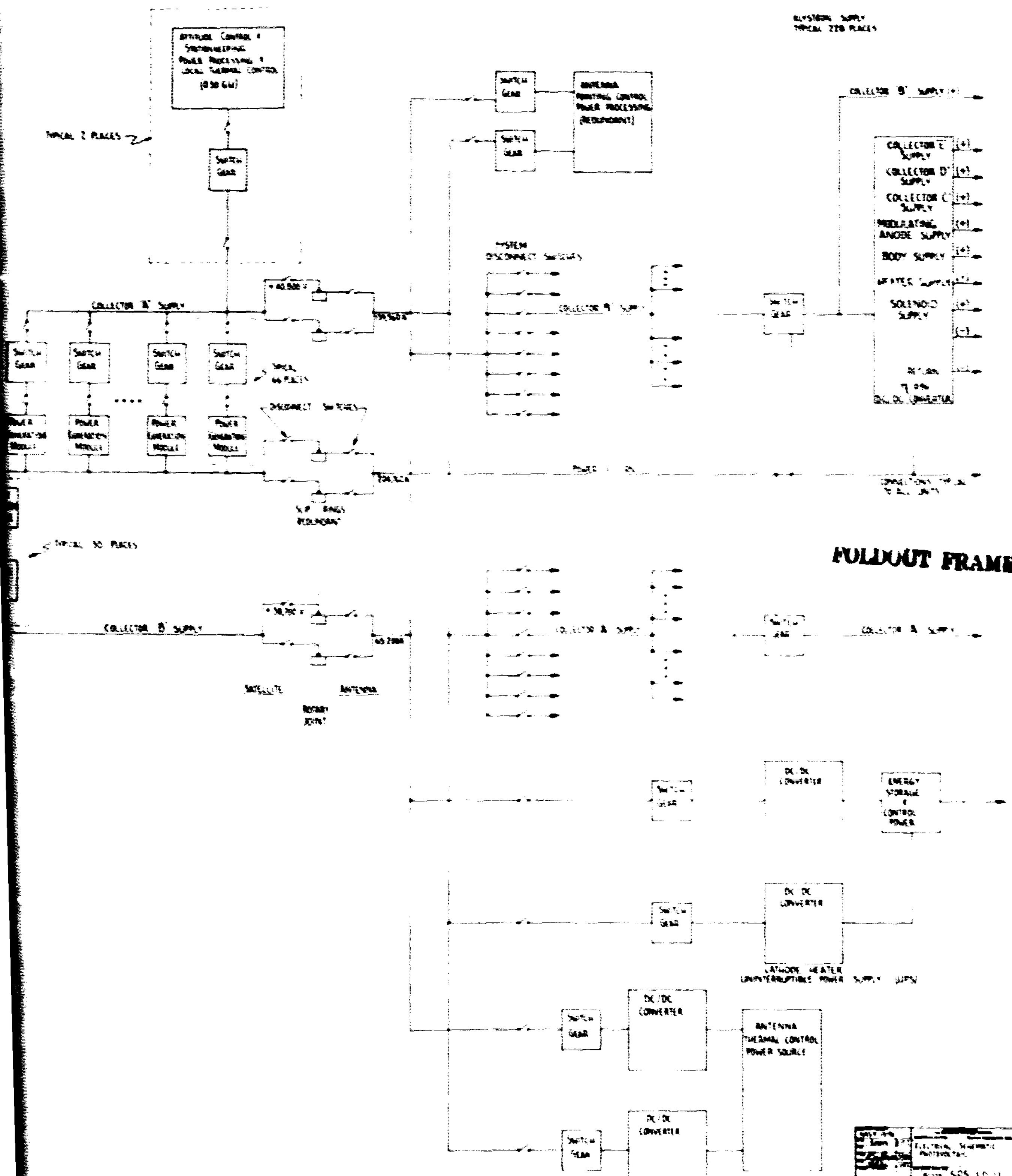

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Figure 1.1.4-3 Electrical Schematic Photovoltaic

Table 1.1.4-1 Calculated Power Distribution System Mass and Loss Summary

LOCATION	CONNECTIONS & COMPONENTS	MASS (KG)	I^2R LOSS (WATTS)
"SATELLITE"	ROTARY JOINT TO POWER SECTOR CONTROL	270,577	145,453,890
"SATELLITE"	SECTOR CONTROL TO SUBARRAYS	109,722	49,903,520

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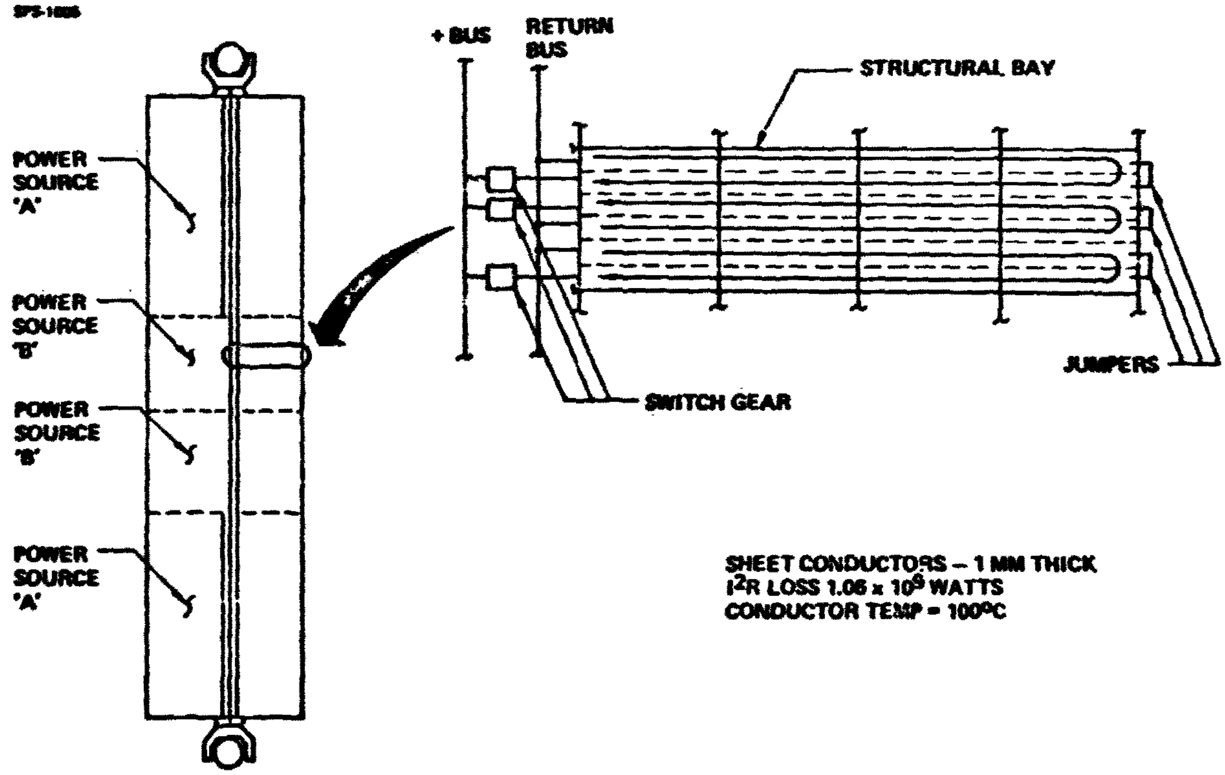

Figure 1.1.4-4 Reference Photovoltaic Power Collection

Solar array power is controlled by vacuum circuit breakers near the buses. Voltage is controlled by turning groups of strings on or off, depending on load requirements. Two sections of the array provide the required voltage at the sliprings using the sheet conductor voltage drop to achieve the required voltage at the sliprings.

Power source 'A' provides power directly to the fifth stage of the klystron depressed collector. Power source 'B' provides power directly to the fourth stage of the klystron depressed collector and to the MPTS DC/DC converters which supply all other klystron element power requirements.

The collection and distribution approach selected for the reference configuration meets the photovoltaic energy conversion subsystem requirements delineated below:

1. The photovoltaic system shall be modularized into space installable blanket array configurations.

2. The photovoltaic system shall employ radiation shielding and/or annealing as appropriate for minimum power cost.

3. Individual converters (cells) shall be wired into the blanket array such that either open or short-circuit failures of individual converters do not cause loss of array output (disproportionate to the loss of the individual converter's contribution) or arcing.

4. The photovoltaic system shall be designed such that a solar blanket power sector and/or its switchgear can be isolated from the operating onboard electric power distribution system, and its generated electrical potential reduced to safe levels, so that it may be serviced without shutdown of the entire photovoltaic energy conversion subsystem.

WBS 1.1.4.1 Switchgear

The silicon cell panels and bays form the power generation modules shown in the photovoltaic electrical schematic in figure 1.1.4-1. These modules are fed to vacuum circuit breaker switchgear controlled by load and system demands. The satellite switchgear is rated at 2,200 amps and 40 kv and is similar to the antenna switchgear. (For more details see Section 1.1.5.2.3).

WBS 1.1.4.2 Main Buses

The main bus subsystem outlined here covers the portion of the power distribution subsystem from the solar cell interconnections to the antenna sliprings. The buildup of solar cells into strings, within each bay was described in Section 1.1.3.1. The strings on each side of the satellite longitudinal centerline are connected in series to form a half string 39,104 (9776 x 4) cells in length. To obtain the 40,000 volts needed to operate the klystrons of the MPTS, the half strings are connected together at the outer edge of the satellite by triangular jumpers. This gives 298 series strings (for each four bays center to edge) each 78,208 cells long. Note that, to provide cell failure protection, each string is really 14 cells wide.

For voltage control and fault protection each "end" of the satellite is isolated into 96 load sectors by vacuum circuit breakers. This is done by subdividing each bay length into three load sectors; i.e., each end of the SPS is 16 bays long and 8 bays wide. Thus there are 32 "bay sides" to each end, each with 3 load sectors. Each load sector provides an average current of about 2100 amps at about 40,000 volts to either bus A or bus B. The current is collected from the ~100 strings in each bay side via copper connectors from the solar array strings to acquisition buses. Each acquisition bus is controlled/isolated from the main buses by switchgear. This whole configuration of strings, jumpers, acquisition bus, switchgear, and main bus is shown in figure 1.1.4-5. Since the current along the acquisition bus increases as strings are added, these conductors are approximately triangular in shape.

To minimize satellite mass, conductor grade aluminum sheet was selected for the main and acquisition buses. Analysis of conductor operating temperature vs. mass led to the choice of a conductor operating temperature of 100°C. A one millimeter conductor thickness was selected as the minimum gauge on the basis of handling and assembly. This leads to the result that the buses are 0.01581 centimeters wide for each ampere carried. Hence the main common bus reaches a maximum width of 3237 cm (for 204,760 A) at the slipring ends of the satellite. It reaches this maximum in a series of steps, one increase for each added load sector from the center of the satellite. The conductors for buses A and B are smaller, corresponding to their lower currents, and bus A only extends about two thirds of the distance from the antennas toward the center of the satellite.

Operating power for the satellite housekeeping and central functions is drawn from buses B and common. To provide this power redundantly from both ends of the satellite these two buses run the full satellite length. To provide this redundancy and allow some load transfer from one MPTS to the other to meet load demands, a minimum bus conductor of 3 meters was selected for the center connection of buses B and common. This current capability of 19,000 A (750 MW) at nominal current density would not only supply all SPS control needs, but allow about 8% load sharing to occur. Under emergency conditions this could be increased to over a third load sharing between the MPTS without overheating the main buses to the point of permanent damage.

Details of the mechanical arrangement of the bus section are contained in Section 1.1.4.3, Bus Support.

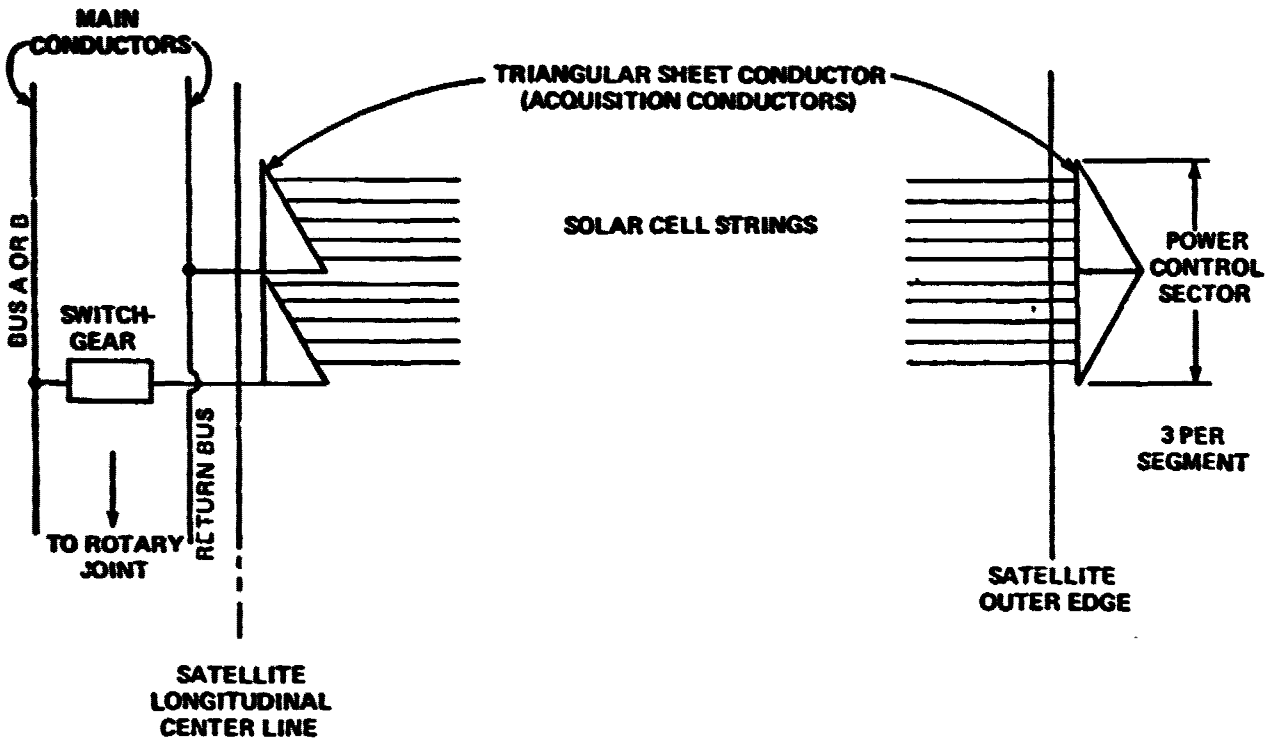

Figure 1.1.4-5 Satellite Bus Configuration

WBS 1.1.4.3 Bus Support

The basic requirements for the bus support subsystem are easily stated:

- o Provide a natural frequency, substantially higher than the satellite.
- o Accommodate thermal expansion without applying large loads to the main satellite structure.
- o Be light weight.
- o Have low ground fabrication cost.
- o Be easy to assemble in orbit, using mostly automated methods.

The support design presented here satisfies these basic requirements, but it is recognized that further study might lead to a better design.

The principal loads on the bus conductors are illustrated in Figure 1.1.4-6. The "compression" and "cooling" loads are generated within the conductors and must be resisted by the conductors, with whatever form of reinforcement is provided. Fortunately, these forces are relatively small so the resulting stress level is very low. The elastic stability of the thin sheet conductors is a concern, however.

The major load on the main bus conductors is the magnetic force repelling two conductors carrying current in opposite directions. This load is so large that, for the current density being used, the bending stress in the sheet conductors over the span of a segment would almost certainly cause elastic instability in the compression side of the bus bar, especially when combined with the compression and curling forces. Fortunately, the force is replusion, so it can be reduced by adding tension ties between the conductors at points intermediate to the supports at the main structure at segment joints. This reaction means that at the ends of the satellite where there are three buses: A, B, and common, the common bus must be located between buses A and B so that tension rather than compression loads are generated in the intermediate supports.

The final force acting on the conductors is caused by the interaction of the bus magnetic field and the earth's field. In operation at geosynchronous altitude this force is extremely small, because the earth field is weak (138 n T) and nearly aligned with the bus conductor. In comparison with the other forces this one may be neglected. During self transportation from low orbit the forces are substantially higher, but still small.

The other major factor which determines the design is the differential thermal expansion between the graphite-eopxy structure and the aluminum bus. The temperature variation between eclipse and full sunlight is from about 123K to 373K. Over the span of a full segment this results in a differential thermal expansion of a little over four meters. For the one millimeter thick sheet conductor a load of 443 kN for each meter of conductor width (stress of 443 MPa) would be required to overcome this change in length. Since the return bus is over 32 meters wide at the slip-ring end,

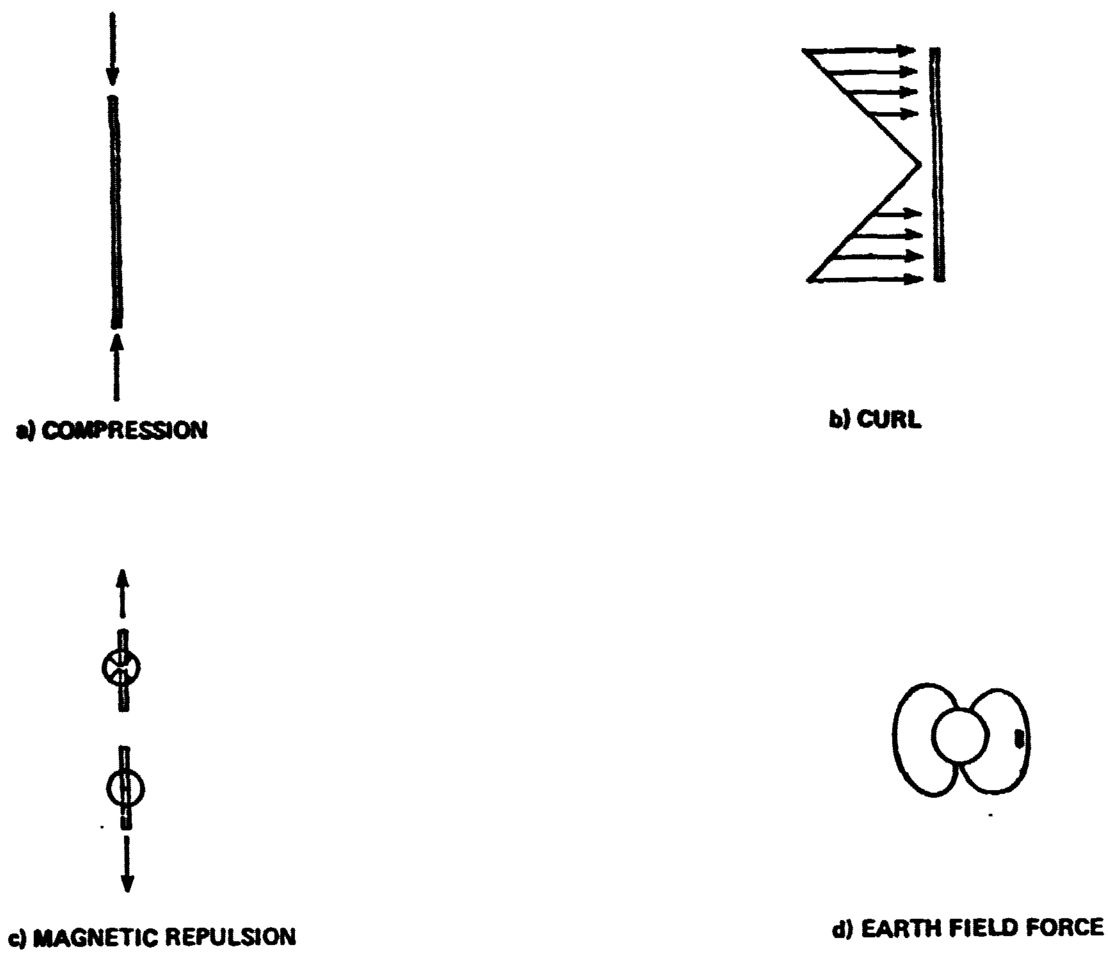

Figure 1.1.4-6 Sheet Conductor Loads

a total load in excess of 14 million Newtons would be developed! This is an unreasonably large load to impose upon the structure, so provisions for thermal expansion must be made. After considering several alternatives, the design selected is to allow a thermal expansion curve at each bay joint, as shown in Figure 1.1.4-7.

The selected method of keeping the natural frequency of the sheet conductors about that of the satellite is to keep the bus conductors in tension. A preliminary analysis indicates that modest forces (of the close order of one Newton per centimeter of conductor width) will keep the natural frequency of the bus an order of magnitude higher than that of the satellite. (The satellite frequency is about 0.005 Hz). To maintain this load in the conductors while allowing for thermal expansion requires springs. The easiest way to provide this spring action is to use high stresses in low modulus materials, such as Kevlar^R or E-glass. (A stress going from 250 to 500 MPa in a 200 m Kevlar tension support will provide the four meter extension needed to accommodate thermal expansion, while varying the load on the bus by only a factor of two).

These factors led to the final selection of the main bus configuration shown in Figure 1.1.4-8. This view shows several bays near the slip-ring end of the satellite, where there are three parallel buses. The three point spring cable ties to the main structure are shown, and the tension ties to react the bus magnetic repulsion forces can be seen.

Not shown in Figure 1.1.4-8 is the fact that each bus is divided into several parallel segments. This is done for both transportation convenience and for assembly reasons. The common bus increases (in steps) from a meter (or so, depending upon the load sharing between the two MPTS) to over 30 meters. Rolled up as a single sheet, the roll would be 30 meters long, volumetrically very poor, and too heavy for a single HLLV launch. Further, for self transportation, it must be divided into at least four segments for each "End" of the satellite. Hence at least eight segments will be used for the main and B buses; further study may show that even greater subdivision is desirable. The individual sheets, each only 8m wide (maximum) are joined by the stretchers at the bay sides which support and tension them, and at intermediate points by the tension ties.

The acquisition buses, which are triangular in shape, are suspended within the center 7.5 meter beam by guy wires, as shown in Figure 1.1.4-9. These acquisition buses are also aluminum. Making the connection between the copper pigtails that interconnect the individual strings of solar cells and the aluminum acquisition bus is a problem that requires further study. Even though the joint is made and kept in vacuum so that galvanic corrosion and oxidation are eliminated as problems, differential expansion remains a problem that will make good joint design difficult. From that initial connection, subsequent connections will be aluminum to aluminum and will be welded.

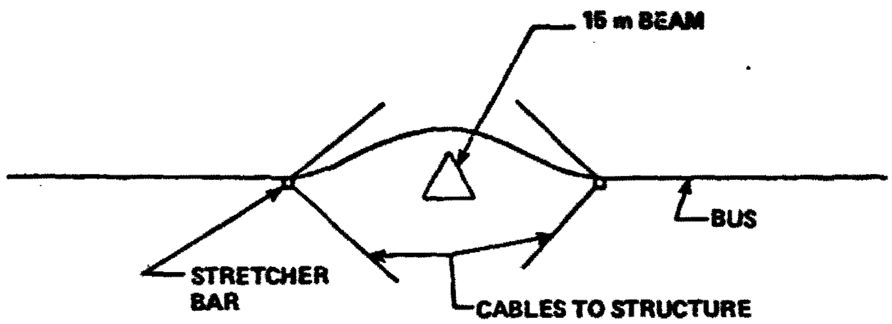

Figure 1.1.4-7 Bus Expansion Slack

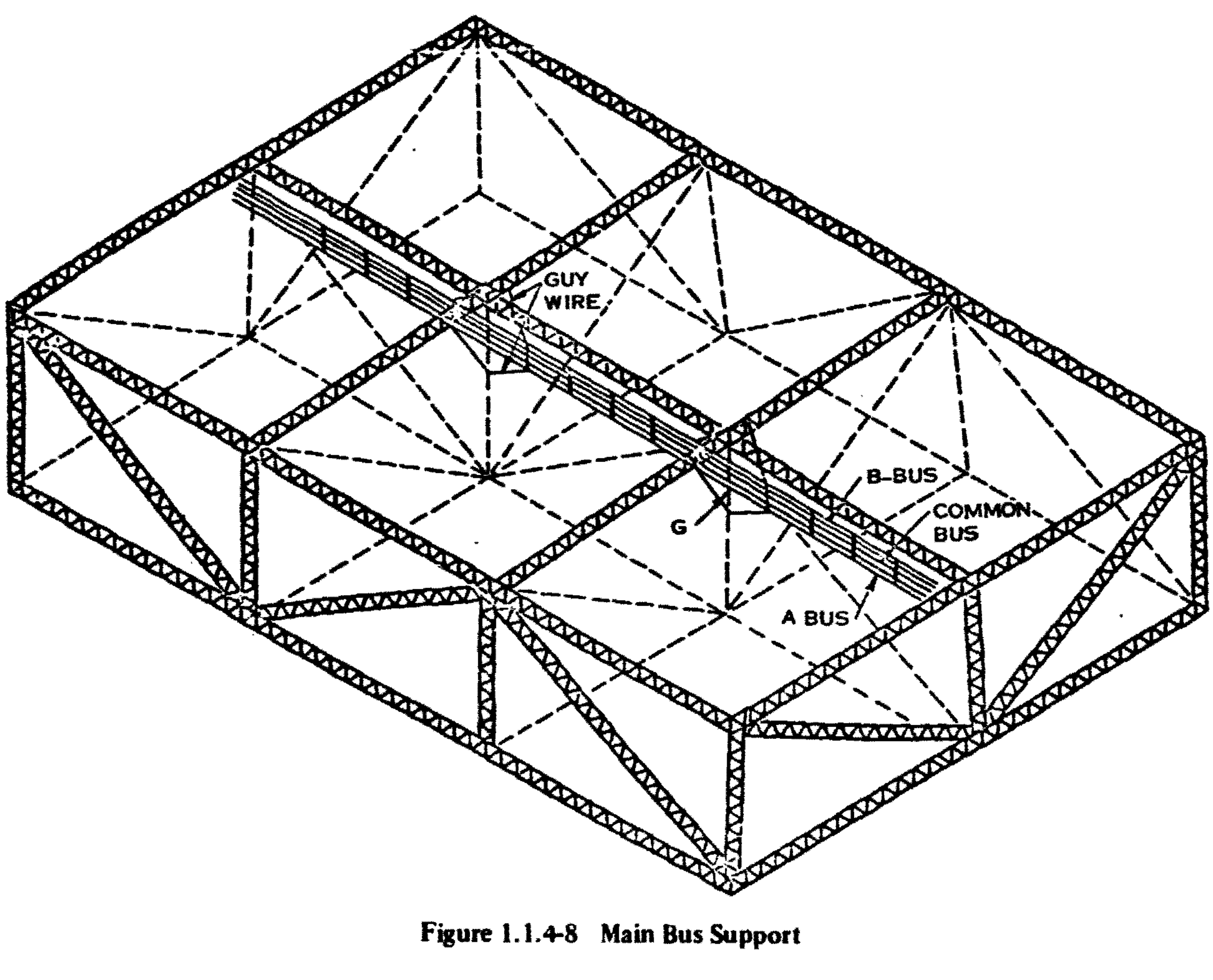

Figure 1.1.4-8 Main Bus Support

Figure 1.1.4-9 Acquisition Bus and Switchgear Support

WBS 1.1.4.4 Electrical Rotary Joint

The MPTS antenna-to-satellite interface requires 360^o rotation about the spacecraft central axis with limited motion for elevation steering while maintaining structural and electrical integrity between the satellite and the antenna. Figure 1.1.1-9 illustrated the rotary joint in relationship to the basic "satellite" structure.

Coin silver (90% silver and 10% copper) was selected for the slip-ring material and a silver-molybdenum disulfide brush with 3% graphite was selected. The characteristics of this combination are shown in Figure 1.1.4-10. With a design using a brush current density of 20 amps/cm^2 only about 40 kW of power is dissipated in the rotary joint.

The installation of a single brush assembly on a circular slip-ring causes unwanted deflections due to assymetrical loading. For this reason, the slip-ring/brush assembly was designed for symmetical loading as shown in Figure 1.1.4-11. Brush drag (with a coefficient of friction of 0.14) at a brush pressure of 4 PSI (25.6KPa) was computed to be 307N, 387N and 463N (69, 87 and 104 pounds force) for each inner, middle and outer slip-ring brush assembly.

The coin-silver slip-ring is a bright surface and, hence, rejects heat very poorly. Coin silver is a very good conductor. However, the combinations of the two results in fairly high slip-ring temperatures as is shown in Figure 1.1.4-12. It was assumed that no heat is rejected through the slip-ring feeders. Actual operating temperatures will thus be somewhat lower than shown since the feeders are designed to operate at a much lower temperature and will help in removing slip-ring waste heat.

Feeders from the main power distribution buses to the slip-ring are designed to operate at a current density of only 100 amps/cm^2. Feeders are spaced 45 degrees apart (centerline to centerline) and are spaced at 15 degree intervals as shown in Figure 1.1.4-13. The temperature of the feeders is shown in Figure 1.1.4-14.

The projected brush/slip-ring wear is very small (.0289 to .0617 cm^3/year).

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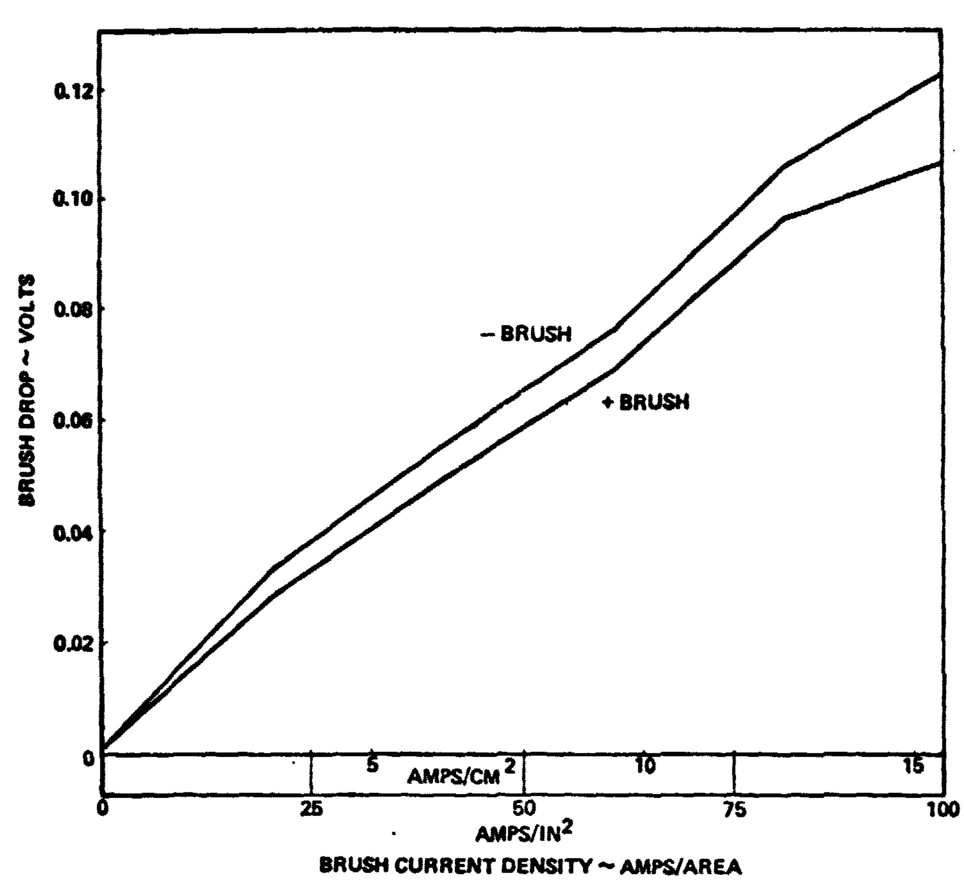

Figure 1.1.4-10 Sliver Slip-Ring Grade 26 Brush 85 Ag 3 GR 12 Mo S_2

SPS-1022

ELECTRICAL ROTARY JOINT MASS SUMMARY

SLIP RINGS	– 11,810 kg
BRUSH ASSEMBLY	– 1,970 kg
FEEDERS	– 3,840 kg
STRUCTURAL SUPPORT	– 900 kg
ASSY. & INSTL. HARDWARE	– 200 kg
CONTINGENCY ALLOWANCE	– 900 kg
TOTAL	– 19,600 kg

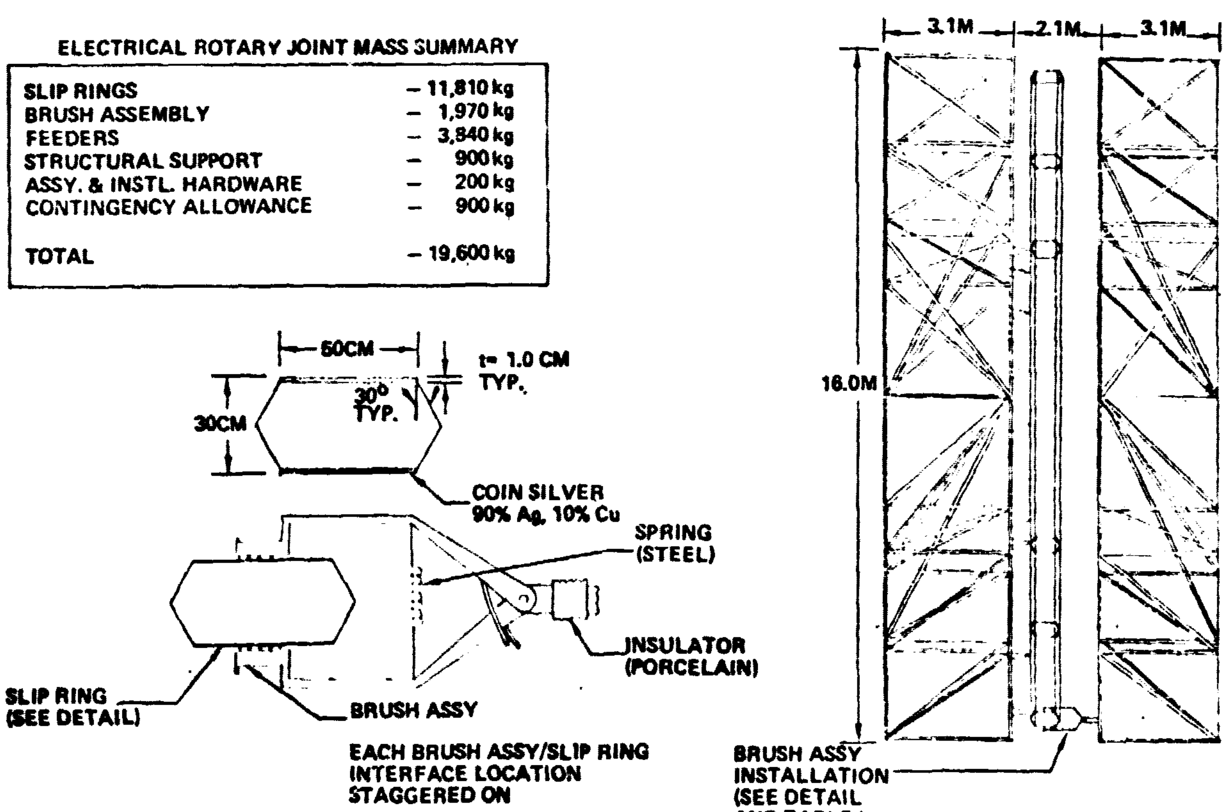

Figure 1.1.4-11 Electrical Rotary Joint and Mass

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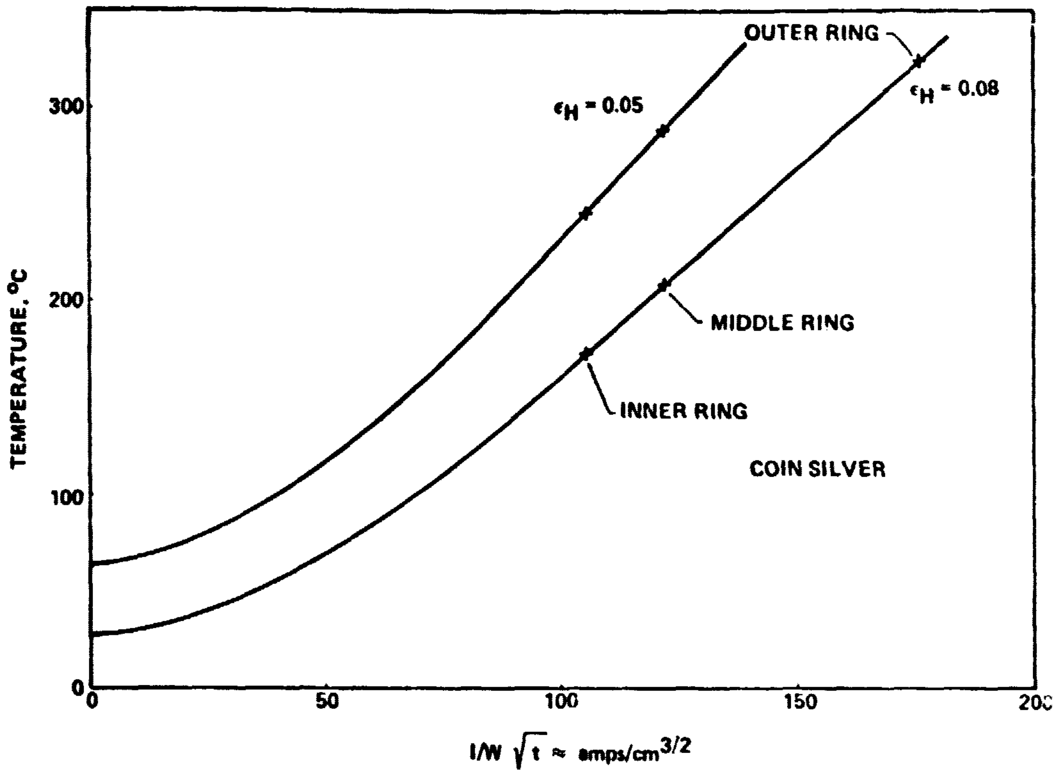

Figure 1.1.4-12 Slip-Ring Temperatures

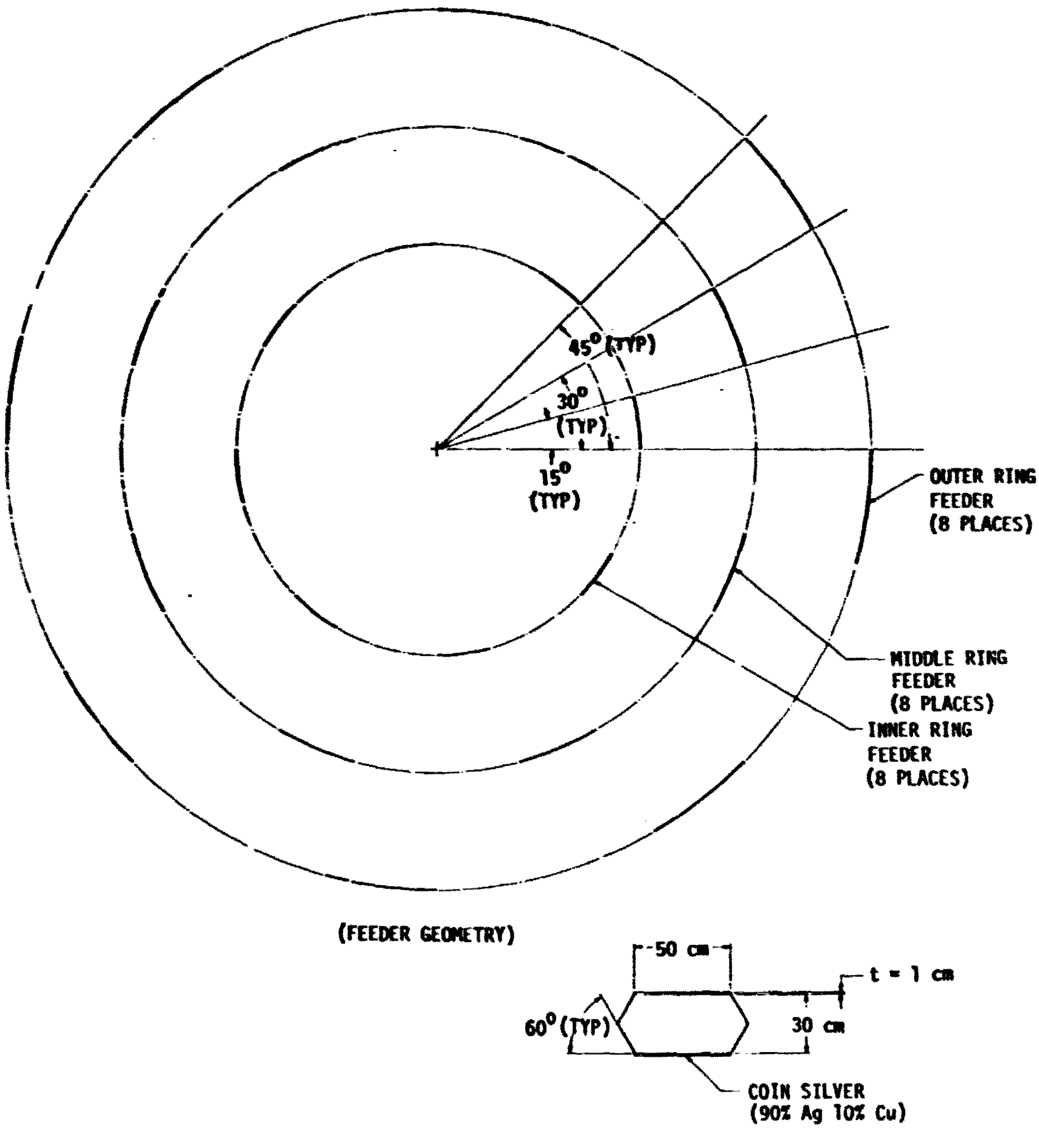

Figure 1.1.4-13 Ring Feeders

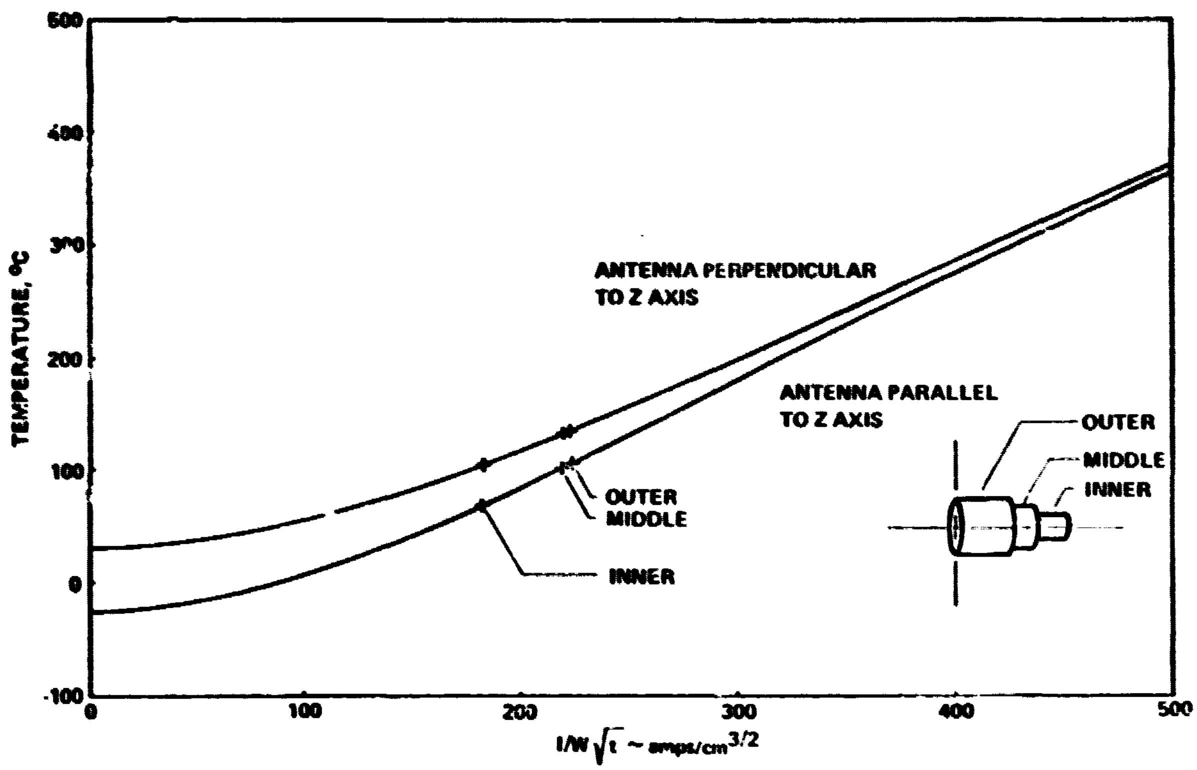

Figure 1.1.4-14 Gimbal Assembly Feeder Conductor Temperatures

WBS 1.1.5 Microwave Power Transmission System

WBS Dictionary

This element includes the entire spaceborne phased array power transmitter. This includes the dc distribution system from the rotary joint to the rf transmitters, the rf transmitters themselves (klystrons), their dc and rf control and monitor circuitry, and the rf antenna elements composed of slotted waveguides, support structure, rf feed circuits, mechanical pointing control, and all the components required for distribution and control of the phase of the retrodirective antenna subarrays.

Element Description

The MPTS system serves the basic function of converting dc power to microwave power in space, transmitting it through the medium with a minimum of environmental impact and converting it back to dc on the ground. The baseline approach utilizes a retrodirective phased array described in Section 1.1.5.3, powered by dc-rf klystron converters described in Section 1.1.5.3.2. DC power from the rotary joint is distributed in a manner to minimize I^2R losses to the klystrons, utilizing 85% unprocessed power with a maximum voltage of 42 kv. The transmitter design constraints are outlined in Figure 1.1.5-1. The high efficiency klystrons are described in Section 1.1.5.3.2 and are combined to provide a tapered (10 db quantized Gaussian) illumination of the array resulting in low sidelobe levels and high antenna efficiency (over 95%). The thermal loading in the center of the array (22 kw/m^2 rf) permits a design for a 1 km diameter array which provides roughly 5 GW of dc power on the ground per antenna. The phased distribution system is designed to minimize line lengths and cumulative phase errors in the distributing transmission lines by using a 3-node reference distribution system with line length compensation. The pilot reference signal from the ground utilizes 2-tone modulation with a suppressed carrier near the power beam frequency, to effect conjugation (i.e., electronic fine beam steering) in an efficient manner. Correction for some systematic propagation errors is provided through multiple pilot beam transmitting antennas.

Element Mass has been estimated at 12,749 metric tons and element cost at billions per antenna. Table 1.1.5-1 presents mass and cost summaries.

WBS 1.1.5.1 Support Subsystems

This element includes those subsystems not directly associated with conversion of electric power into rf beam power.

WBS 1.1.5.1.1 Primary Structure

WBS Dictionary

The Power Transmitter Primary Structure is the main structure that provides overall shape and form to the transmitter.

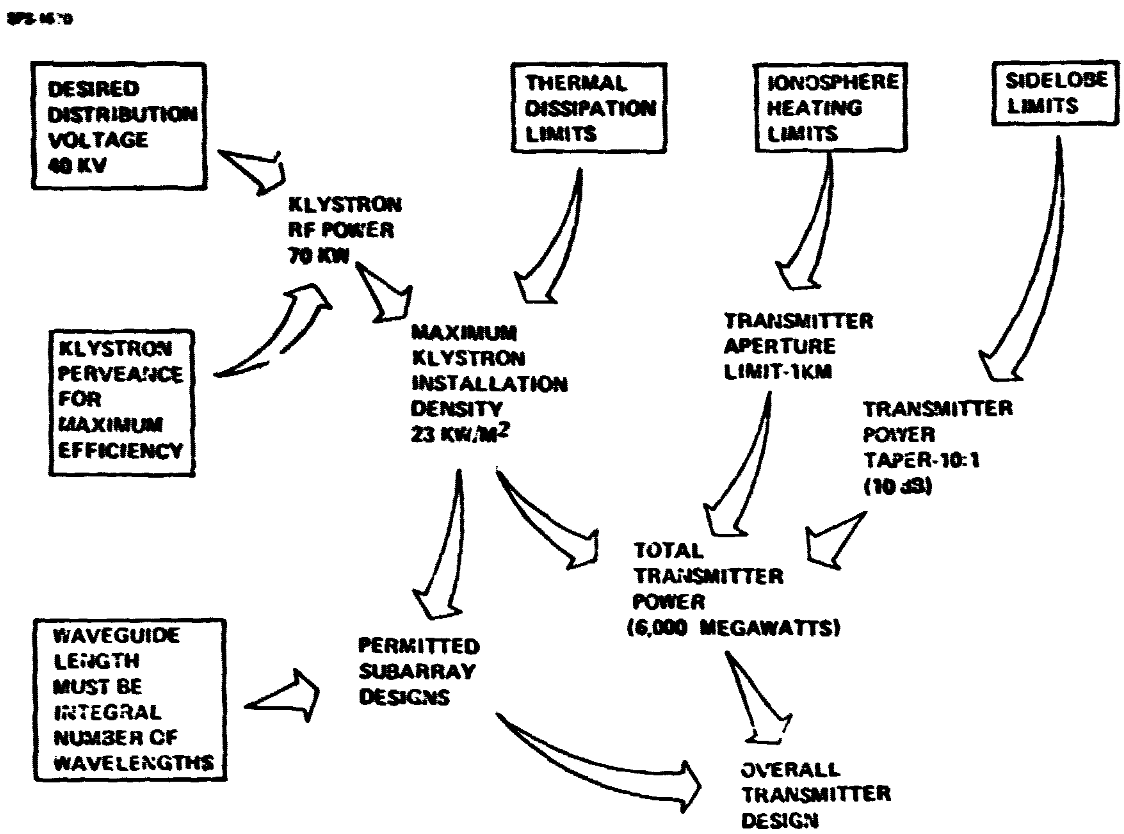

Figure 1.1.5-1 Constraints Dictate Power Transmitter Design

Table 1.1.5-1 Mass and Cost Summary

			MASS (MT)		COST (millions of 1977 $)
PRIMARY STRUCTURE	–		52.5		6.6
SECONDARY STRUCTURE	–		197.5		25.5
ATTITUDE CONTROL	–		127.9		101
COMM/DATA	–		20.7		102
POWER DISTRIBUTION	–		2993.5		401
DC–DC CONVERTERS & SWITCHGEAR –		1441.6		194	
THERMAL CONTROL –		222.1		73	
BUSSING –		397.9		48	
ENERGY STORAGE –		313.2		74	
SUPPORT –		118.7		12	
RF GENERATION & DISTRIBUTION	–		9880.9		794
KLYSTRONS –		4874.5		262	
THERMAL CONTROL –		2000.2		137	
WAVEGUIDE ASSYS –		1795.6		94	
HARNESSES AND CONTROL CKTRY –		543.6		231	
SUBARRAY STRUCTURE –		667.0		70	
TOTALS PER ANTENNA			12,773 MT		1430
TOTALS PER STATELLITE			25,546 MT		2860

NOTE: THIS BREAKDOWN COST DOES NOT INCLUDE ASSEMBLY AND CHECKOUT OR INITIAL SPARES.

Description

The Primary Structure is an A-frame open truss structure, 130 meters deep, with a quasi-octagonal shape in excess of 1,000 meters width and length. The Primary Structure and its relationship to the Secondary Structure and the rest of the power transmitter are shown in Figures 1.1.5-2 and 1.1.5-3. The A-frame elements of the Primary Structure are made up of 7-1/2 meter continuous chord beams composed of graphite polysulfone composite structure.

Mass

The mass of the Primary Structure is 52,500 kilograms per antenna for a total of 105,000 kilograms for the two antennas.

Cost

The cost of the Primary Structure was estimated at $125 per kilogram for a total cost of $13.2M for the two antennas.

WBS 1.1.5.1.2 Secondary Structure

WBS Dictionary

The Secondary Structure provides structural bridging over the Primary Structure with a sufficiently small repeating structure element interval to allow installation of the transmitter subarrays. The Secondary Structure does not include subarray structure.

Description

The Secondary Structure is a deployable cubic truss, with telescoping vertical members to minimize packaging volume. The members are made from graphite composite materials and the joints all include a rigidizing mechanism or device to provide complete rigidity of the structure after deployment. Diagonal cross-members are removable as necessary to allow for maintenance of the subarrays by the maintenance system described under WBS Section 1.3.4.

Mass

The Secondary Structure mass estimate was 197,500 kilograms for each antenna for a total of 395,000 kilograms.

Cost

The cost estimate for the Secondary Structure was estimated as $129/kilogram for a total $51 million (2 antennas).

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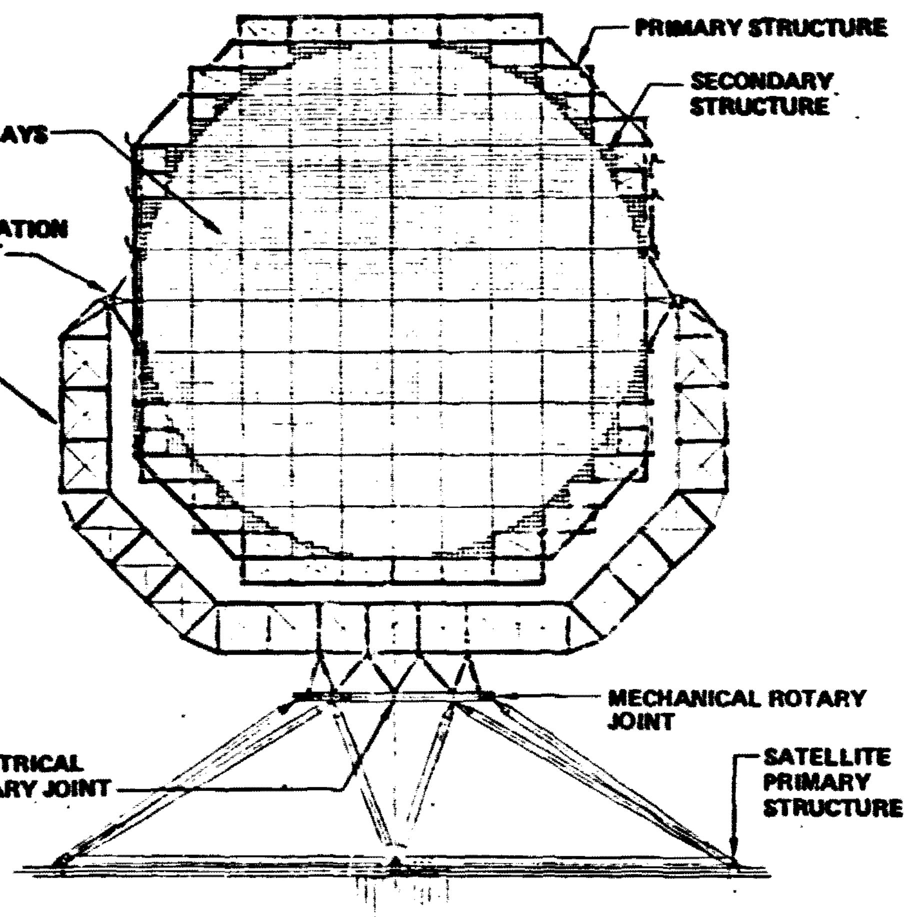


Figure 1.1.5-2 Reference MPTS Structural Approach

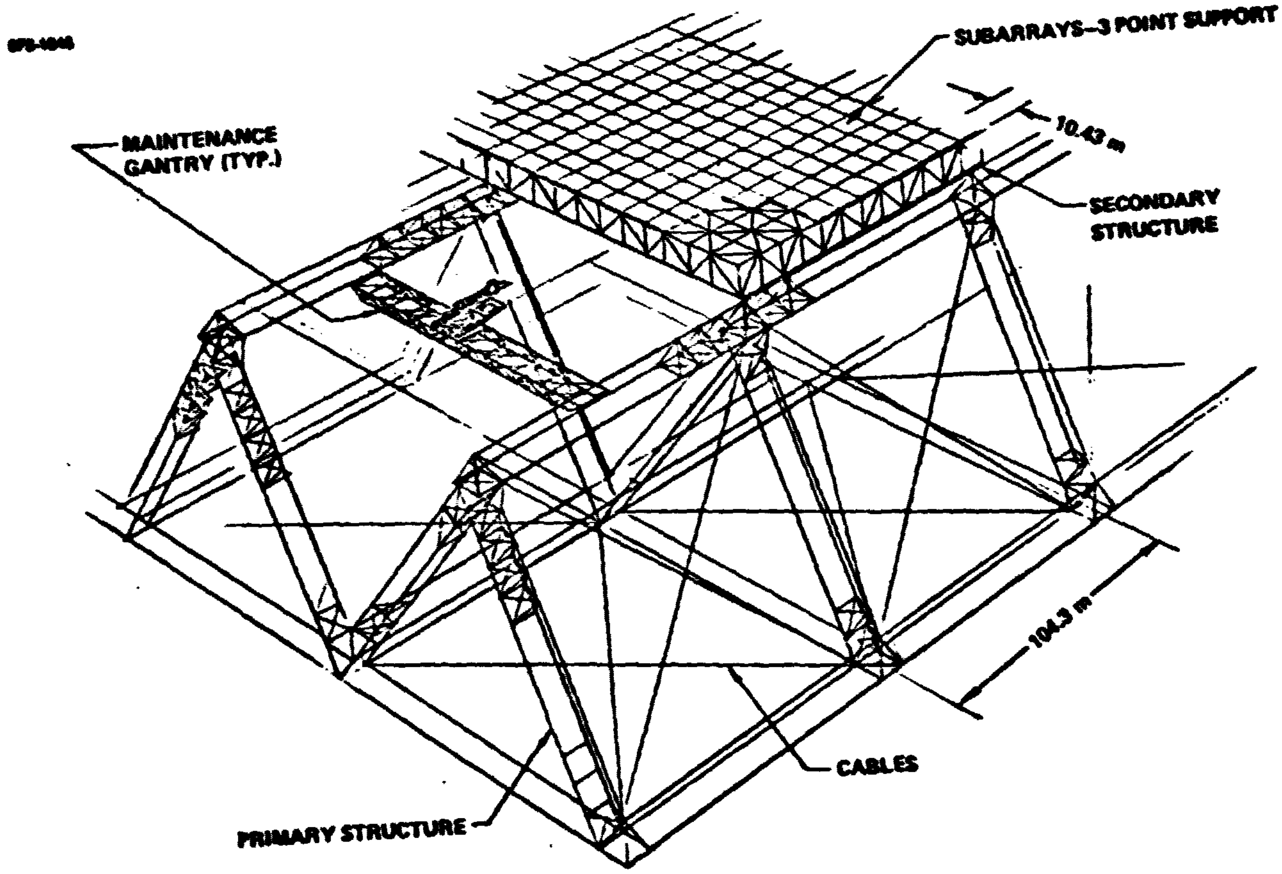


Figure 1.1.5-3 Reference MPTS Structure Interfaces

WBS 1.1.5.1.3 Attitude Control

WBS Dictionary

The Power Transmission System Attitude Control System provides fine control of antenna mechanical aiming. Control Moment Gyros (CMG's) are used to generate torques required for this fine control.

Description

The CMG's are located on the back side of the Primary Structure and are 12 in number for each transmitting antenna. A feedback loop from the Antenna Attitude Control System to the SPS mechanical rotary joint allows the rotary joint to apply torque to the antenna to continuously desaturate the antenna CMG's. This torque is supplied through a highly compliant mechanical joint so that the natural frequency of the antenna in its mechanical supports is below the control frequency bands for the CMG's controlling antenna attitude.

Mass

Each CMG was estimated to have a total mass of 10,660 kilograms for a total per antenna of 127,920 kg.

Cost

The total cost for the attitude control systems including the 24 CMG's for two antennas was estimated as $202 million based on a CER. This averages to $790/kilogram for the CMG hardware.

WBS 1.1.5.1.4 Computing and Data Processing

WBS Dictionary

This Computing and Data Processing system handles the computing and data processing load for the Power Transmission System. A data link is included for communication with the SPS Central Computing Complex. This antenna computing system also handles the computing load for antenna attitude control.

Description

For the reference design (the phase control is provided by a retrodirective system with phase compensation at each subarray), the computing load is mainly for condition monitoring, fault isolation and detection, and general antenna configuration management. Some of the potential phase control systems would add to this computing load (e.g., a command and control operation based on ground-measured phase information). The computing load for conditioning monitoring and associated functions requires a high capacity, high speed computer comparable in general capability to the current types of scientific or business large scale computers. Flight computers in this capacity range presently do not exist. It presumed that in the time frame of SPS interest such a computer could be developed using advanced LSI techniques. Each antenna was assumed to have three computers operating in a triply redundant fashion.

Mass

The estimated mass for each computer was 225 kilograms. This mass estimate includes radiation shielding and heat rejection.

Cost

The cost of the computer complex for one SPS was estimated as $56 million, including the six computers and their support subsystems.

WBS 1.1.5.1.5 Communications

The Antenna Communications System provides data, collection, processing, and command distribution onboard the antenna, and also provides a data link to ground separate from the main SPS data link in the event this is required. This communications system does not include the retrodirective phase control system, as such. That system is separately covered.

Description

The Communications Complex involves three primary data handing subsystems for redundancy and employs fiber optic data bussing to minimize mass of cable and problems with RFI on the transmitting antenna.

Mass

The total mass of the Communications and Data Complex was estimated as 20,000 kilograms per transmitting antenna for a total of 90,000 for the SPS.

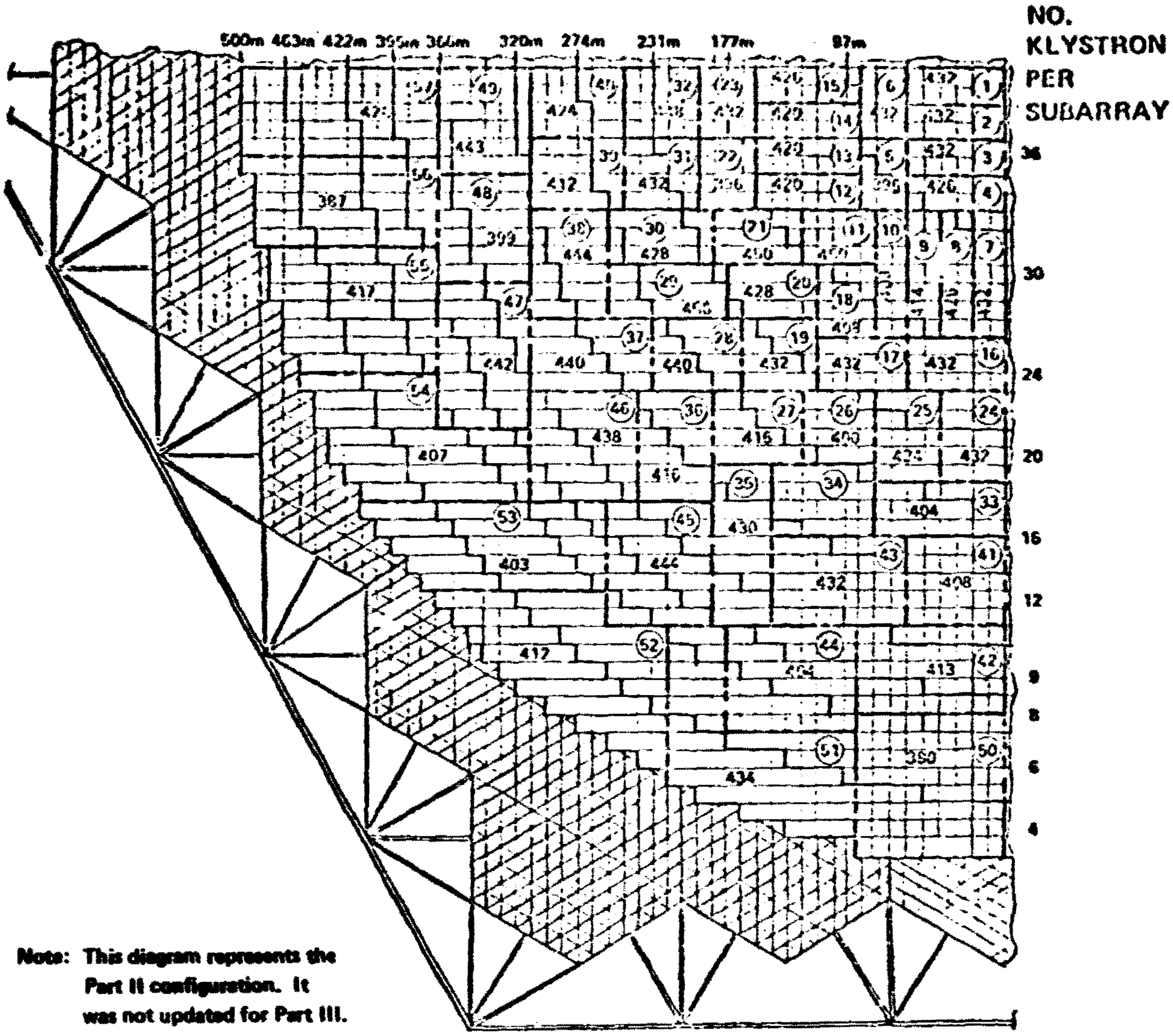
Cost

The total cost estimate for one SPS for the Communications and Data Complex was estimated as $147.5 million.

WBS 1.1.5.2 Power Distribution

The MPTS antenna power distribution system provides power transmission, conditioning, control, and storage for all MPTS elements. The antenna is divided into 228 power control sectors, each providing power to approximately 420 klystrons. Two of the klystrons' depressed collectors "A" and "B" which require the majority of supplied power are provided with power directly from the power generation system to avoid the dc/dc conversion losses. All other klystron element power requirements are provided by conditioned power from the dc/dc converter. System disconnects are provided for isolation of equipment for repair and maintenance.

Each dc/dc converter provides power to approximately 0.5% of the total number of antenna klystrons as shown in Figure 1.1.5-4. Its power requirements are given in Figure 1.1.5-5. The klystron with five depressed collectors has a calculated tube efficiency of 85%.



Note: This diagram represents the Part II configuration. It was not updated for Part III.

STEP	NO. SUBARRAYS	NO. KLYSTRONS
1 @ 36	272	9792
2 @ 30	580	17420
3 @ 24	612	14688
4 @ 20	612	12240
5 @ 16	756	12096
6 @ 12	864	10368
7 @ 9	628	5652
8 @ 8	576	4608
9 @ 6	1032	6192
10 @ 4	1000	4000
TOTALS	6932	97,056

POWER OUTPUT: (ANTENNA) 6.79 GW
(GROUND) 5.01 GW

Figure 1.1.5.4 MPTS Antenna Power Distribution Control Sectors

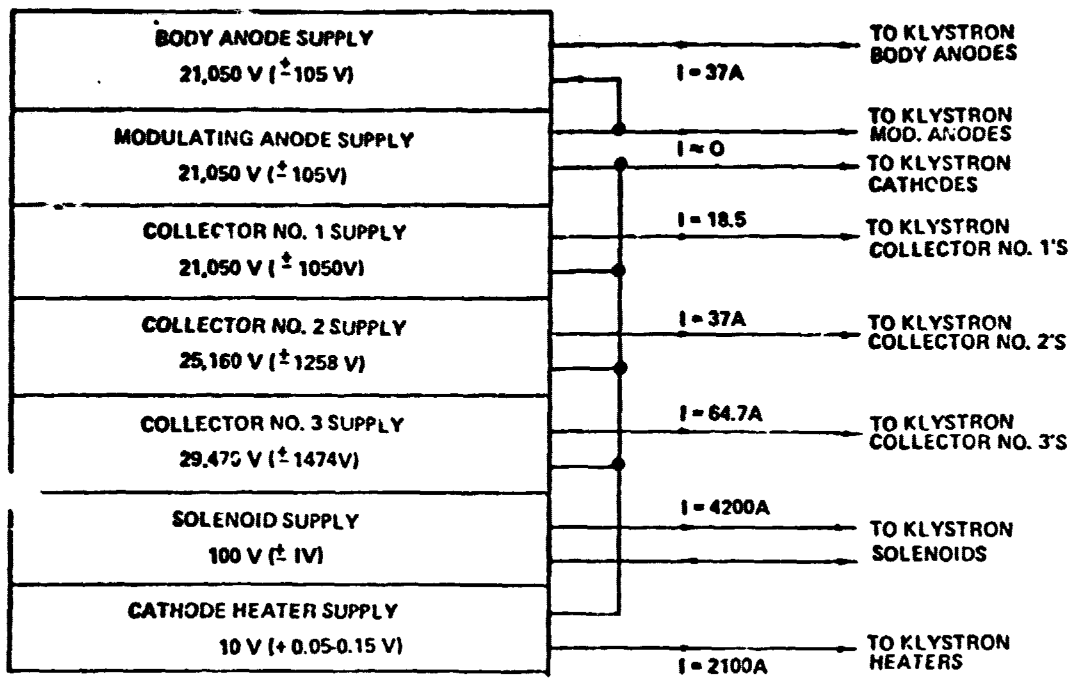


Figure 1.1.5-5 DC/DC Converter for Five Segment Depressed Collector Klystrons for MPTS

The MPTS antenna was divided into approximate equal power areas to define power control sectors. Figure 1.1.5-6 shows the location of the power sector control substation and the associated dc/dc converters. No substations are located on the center structural node, since this node is in the center of the highest waste heat flux region.

The reference antenna structural design concept consists of a relatively sparse primary structure, fairly dense secondary structure and ten different types of antenna subarray elements to achieve a ten step approximation of the desired illumination taper. Within the subarray element, one set of connections provides the interface between the external power distribution system and the subarray distribution system. Power is routed from the power sector substations to the antenna subarray elements. Disconnects are installed at the power sector substations to provide isolation for maintenance and repair. The power sector substation location was selected to be at the back of the primary structure. Aluminum sheet conductors are routed from the rotary joint to the power sector control substation located at the primary structure truss intersection nodes at the back of the structure.

The following is a list of the key antenna power distribution subsystem requirements which are satisfied by the reference configuration:

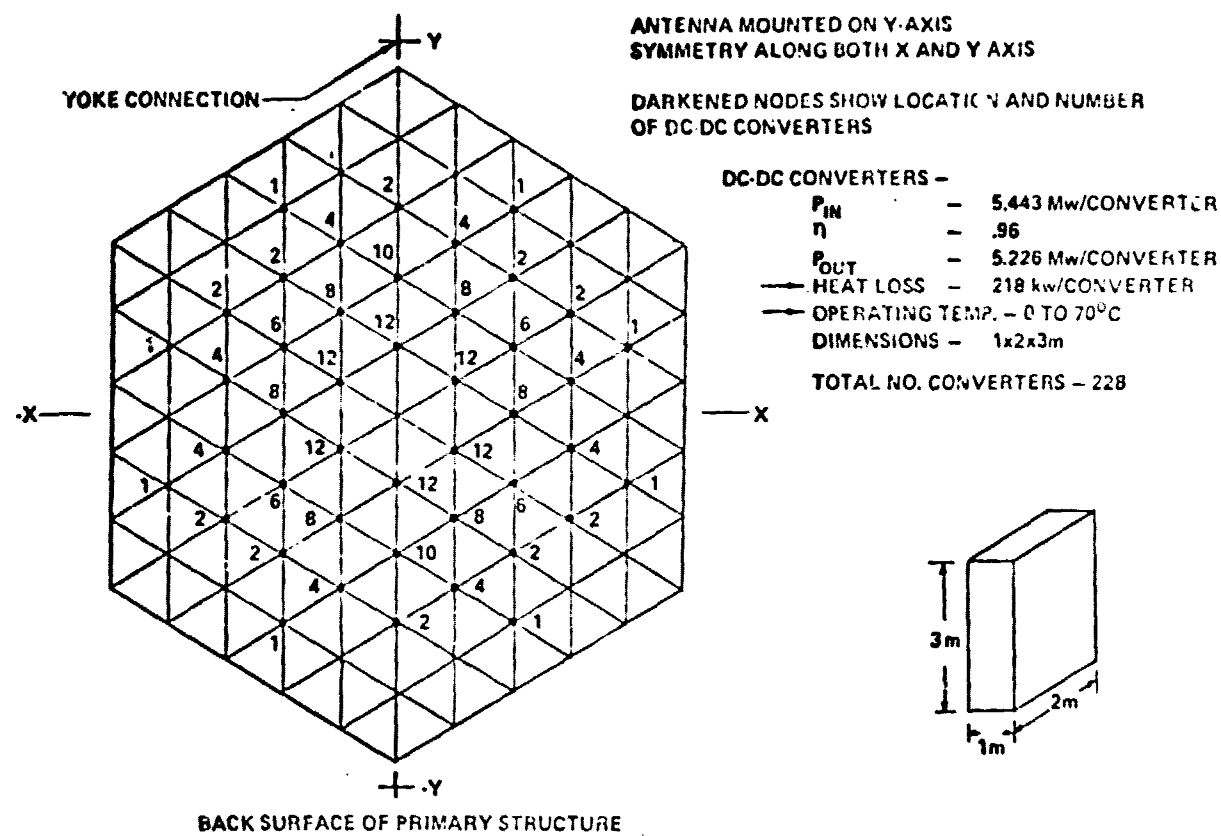
1. The power distribution system shall conduct dc electrical power from the energy conversion system interfaces to the klystron transmitter rotary joint interfaces. (It is assumed that there are two 5-GW ground output antennas and associated rotary joints per SPS.) The distribution system shall supply the following nominal voltages and currents to the rotary joint interface from the integrated klystron array module clusters:

   Bus A 40,800 volts at 138,600 amps (5.65GW)
   Bus B 38,700 volts at 59,400 amps (2.30GW)

   A common return for these two supplies shall be provided.

2. The antenna power distribution system shall employ dedicated aluminum conductors (not part of main structure) which are passively cooled by radiation to free space.

3. The antenna power distribution system shall have switching and control equipment as necessary to isolate the rotary joint and power transmission system from energy conversion system startup and shutdown transients. This requirement may be in part met by delayed activation of power distribution provided that the delay is not greater than five minutes.



Note: This diagram represents the Part II configuration. It was not updated for Part III.

Figure 1.1.5-6 MPTS Reference Antenna Power Conditioning Placement

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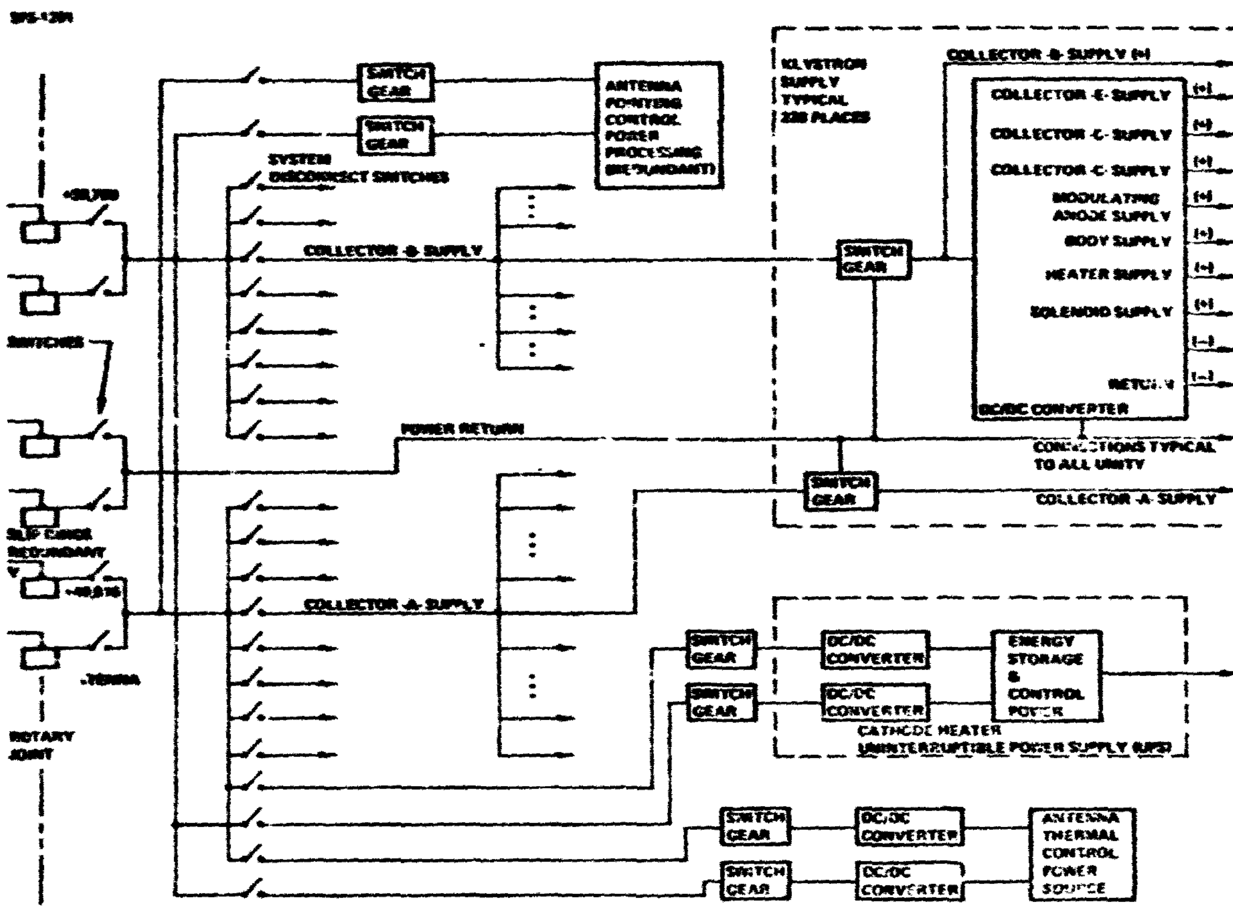

Figure 1.1.5-7 MPTS Power Conditioning Subsystem

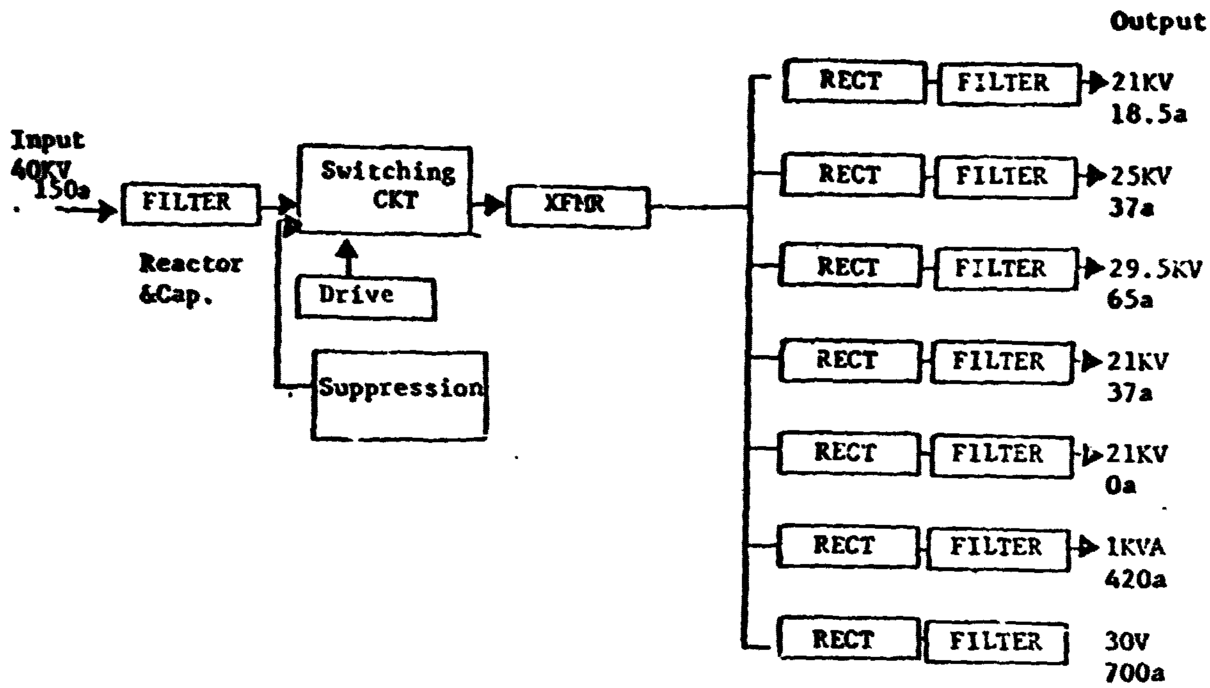

Figure 1.1.5-8 Simplified DC/DC Converter Block Diagram

Table 1.1.5-2 Calculated Power Distribution System Mass & Loss Summary

LOCATION	CONNECTION & COMPONENT	MASS (KG)	I^2R LOSS (WATTS)
"ANTENNA"	SECTOR CONTROL DC/DC CONVERTERS AND SWITCHGEAR	1,441,596	49,644,720
"ANTENNA"	SUBARRAY WIRING (INSULATION INCLUDED)	35,871	4,774,760
	TOTAL	1,877,034	249,776,890

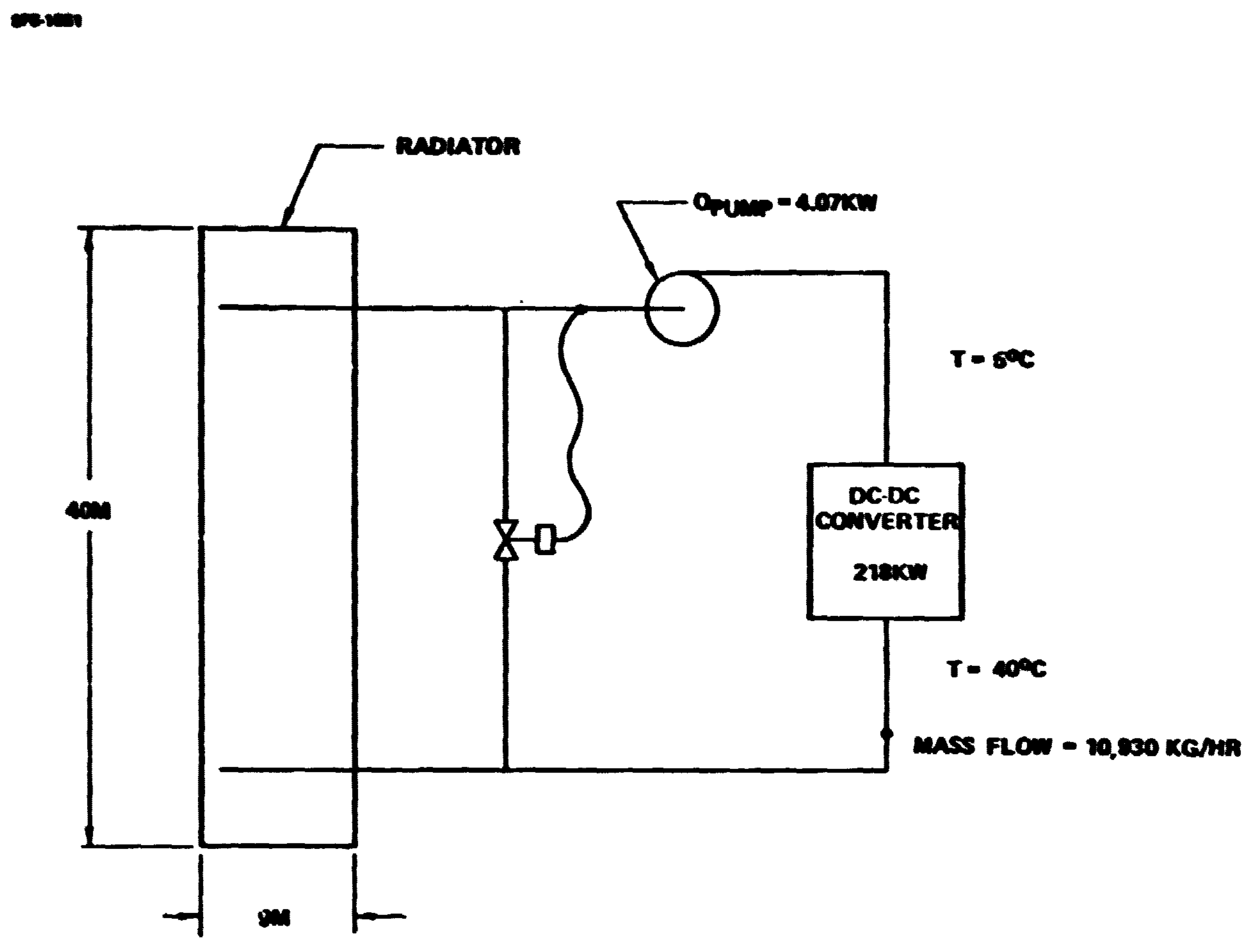

Figure 1.1.5-9 Power Processer Thermal Control

WBS 1.1.5.2.1 Power Processor

The MPTS power control and distribution subsystem provides conditioned power for all MPTS elements. The five depressed collector klystron requires conditioned power on all inputs except the two collectors which utilize power directly from the SPS Collector A supplies and Collector B solar panel supplies. The power conditioning subsystem block diagram is shown in Figure 1.1.5-7. The estimated input power to each dc/dc converter is about 5400KW.

Figure 1.1.5-8 shows a simplified more detailed diagram of the individual dc/dc converter modules employed. The selection of the particular switching circuit device has not yet been made but an analysis has shown that a switching speed of 20 KHz with SCR's or power transistors can yield a dc/dc conversion efficiency of about 95%.

Overall power distribution system mass and losses are summarized in Table 1.1.5-2.

WBS 1.1.5.2.2 Processor Thermal Control

WBS Dictionary
This element includes all production hardware required to collect and dissipate the waste heat flux from the power processing equipment on the MPTS system.

Element Description
The power processors (dc-dc converters) have a waste heat of approximately 218 Kw per unit. The thermal limitation of the power processors is 70°C (for high reliability) so it was necessary to baseline an active thermal control system for this equipment.

The active thermal control system (Figure 1.1.5-9) was sized, for the MPTS system, using a heat flow of 1000 watts per square centimeter. Redundancy was built into the system (pumps, valves, and control equipment) for higher reliability.

The basic system is composed of a heat exchanger, pump, thermal control/bypass valve, and thermal radiator. The heat exchanger uses finned heat pipes, with the condenser sections in contact with the working fluid of the active loop. The evaporator section is in the power converters, for better heat rejection from the more sensitive solid state components. The fluid pump was sized at 4.1 Kw. The power consumption of all the processors thermal control systems was estimated at 928 Kw.

Element Mass
The estimated mass of a typical power processor themal control system is 972 kg. Approximately 33 percent of this mass is for the thermal radiator with the remaining mass distributed between working fluid, piping, pumps, motors, control valves, and includes redundant components. The total processor thermal control systems mass is 222.1 MT

Element Cost

The cost estimating factor for this element was 414 $/kg as discussed in the Part 2 final report.

WBS 1.1.5.2.3 Switchgear/Energy Storage

Each MPTS antenna in the baseline design contains over 97,000 dc/rf converters and 228 power sector control substations. During the conceptual design of the klystron, an effort to minimize the mass of the individual tube elements resulted in an overall lightweight tube. However, removing mass from the tube imposes the requirement that the probability of internal arcing must be minimized and, in the event that arcing should occur, rapid removal of the power sources is required. Preliminary requirements placed on the MPTS switchgear were extremely stringent - 10 microseconds current interruption time. The development of switchgear to perform this task will require an improvement of two orders of magnitude in current interruption time over present switchgear capabilities (milliseconds to hundredths of milliseconds). Analyses are required of possible klystron design changes and possible uses of current limiting reactors to increase this time.

The antenna circuit breakers could be either solid state (present configuration) or vacuum switches (proposed configuration). The rating of the switchgear is 600A at 49KV. Table 1.1.5-3 summarizes the two circuit breakers.

An additional circuit breaker is required which clamps the anode to the cathode at the klystron. Microsecond switching is required at 40KV and no current. A solid state circuit breaker is proposed.

The antenna power distribution system fault protection scheme is shown in Table 1.1.5-4.

In addition to the fault protection required in the MPTS Power Distribution System, isolation of the switchgear for maintenance purposes is required. The use of isolation disconnects would enable isolation of a single power sector substation without powering down the main power busses. The disconnects are not designed for current interruption and are only operated when no current flow exists (i.e., the downstream breaker is open when the disconnect is operated).

In Figure 1.1.5-7, the need for an Uninterruptable Power Supply (UPS) is indicated which has suitable dc/dc converters which continuously charge an energy source (battery bank). Klystron life is impacted by cathode heater power on-off cycles. In order to increase the MTBF of the klystron, it is proposed that heater power be maintained during the period of time when occultation (caused either by the earth or other solar power satellites) is encountered.

It is anticipated that significant increase in the MTBF of klystrons can be achieved if thermal cycling of the klystron cathode heater can be minimized. There are 101,552 klystrons per antenna each requiring heater power of 50 watts at 30 VDC. Thus, a total of 5.08 megawatts of power is

Table 1.1.5-3 Summary of DC Circuit Breakers

GE VACUUM SWITCH (PRESENT TECHNOLOGY)

- RATING: 40 KV, 300 to 2000A continuous, 20,000 A interrupt
- MASS: 10 gm/KW
- COST: $100/KG
- SWITCHING TIME: 5 milliseconds range

SOLID STATE SWITCHES (FUTURE TECHNOLOGY)

- Rating: 40 KV, 300 to 2000A continuous, 10,000 A interrupt
- Mass: 18 gm/KW
- Cost: $260/KG
- Switching Time: 5 microseconds range

Table 1.1.5-4 Antenna Power Distribution Fault Protection

FAULT AREA	PROTECTION SCHEME
MAIN BUS	REMOVE ALL SATELLITE POWER SOURCES
ANTENNA SUB DISTRIBUTION BUS	OPEN APPROPRIATE MAIN ANTENNA CIRCUIT BREAKER
ANTENNA DC/DC CONVERTER	OPEN CONVERTER CIRCUIT BREAKER
KLYSTRON INTERNAL ARCING	TAKE KLYSTRON MODULATING ANODE TO CATHODE POTENTIAL
OUTPUT WAVEGUIDE ARCING	REMOVE KLYSTRON INPUT RF DRIVE

used for klystron heaters. If a distribution loss of 20% (because of the low voltage) and a period of 2 hours required for operation from stored energy are assumed, then 12.186 megawatt hours of stored energy are required for klystron heaters.

Gas electrode (i.e., nickel hydrogen) battery systems offer the advantage of numerous recharge cycles and high energy densities. A nickel hydrogen battery system is selected for the reference configuration and should provide at least four times the service life of conventional nickel cadmium battery systems. With an energy storage system of this size, an energy density of 57.3 watt-hours/kg (26 WHr/lb) including tankage was derived. With a depth of discharge of 0.7 during a normal 2 hour operation, a density of 40.1 WHR/kg is used to determine the mass of the required energy storage system. The estimated mass for the energy storage system is 313.2×10^3 kilograms (313.2 metric tons).

WBS 1.1.5.2.4 Bussing and Cabling

The conductors for the MPTS power distribution consist of aluminum sheet conductors from the rotary joint to the power sector control substation, circular aluminum conductors from the substations to the subarray interface, and circular conductors on the subarray.

The conductors on the individual MPTS antenna subarrays are included under "harnesses," WBS 1.1.5.3.5.

WBS 1.1.5.3 Transmitter Array

WBS Dictionary
This element includes all hardware required for the generation, distribution, phase control, and radiation of the microwave energy including thermal control.

Element Description
The retrodirective phase array configuration utilizes 7220-10.4 x 10.4 meter subarrays arranged in a quantized 10 db taper configuration conforming to dimensional requirements which will result in a maximum RSS error associated loss of 2%. The concepts of configuration for fine beam steering have been adequately defined to the block diagram stage but require further design refinement and laboratory verification. The array features a standing wave slotted waveguide approach with a maximum effective stick length of 5.2 meters and maximum power level of 3.5 kw per stick. A test program for a plated composite waveguide has been suggested to verify the potential advantages of this lightweight approach, currently in modest use on some communication satellites.

A modular concept integrates klystron power tubes with subarray radiators. One quarter of the transmitting array is shown in Figure 1.1.5-10. The square subarrays, complete with associated klystrons, tile the face of the antenna which is in turn supported by the secondary structure. A

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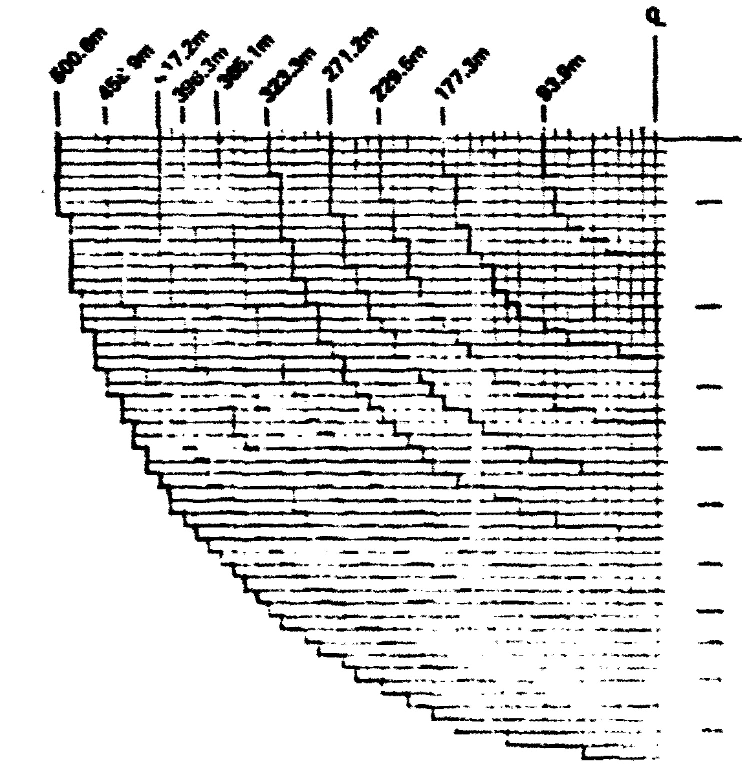

STEP	NUMBER SUBARRAYS	NUMBER KLYSTRONS/ SUBARRAYS	NUMBER KLYSTRONS
1	276	36	9,936
2	632	30	18,960
3	644	24	15,456
4	628	20	12,560
5	784	16	12,544
6	900	12	10,800
7	664	9	5,976
8	612	8	4,896
9	1,052	6	6,312
10	1,028	4	4,112
Totals	7,220		101,552

Figure 1.1.5-10 Transmitting Array

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taper of the microwave power density across the antenna aperture is achieved by varying the number of klystrons used per subarray. A section of a subarray called the integrated klystron module is shown in Figure 1.1.5-11. It shows the 70 kw klystron mounted on the back of the slotted waveguide antenna array. The passive cooling system can be seen. Not illustrated here is the phase control system required to insure that the radiation from the modules will be in phase at the rectenna. This system will tie the modules within a subarray together with waveguide and all the subarrays together with coaxial cable or an equivalent transmission link.

Element Mass

Detailed mass estimates for this element are given in Table 6-9 of Vol. IV of the Part 2 final document. The total is 9880.9 metric tons per antenna.

Element Cost

Cost estimates for this element are given in the summary table (1.1.5-1) as $1.43 billion per antenna for structure, waveguide, klystrons, thermal control, and control circuits (mature industry estimate at 1 SPS per year).

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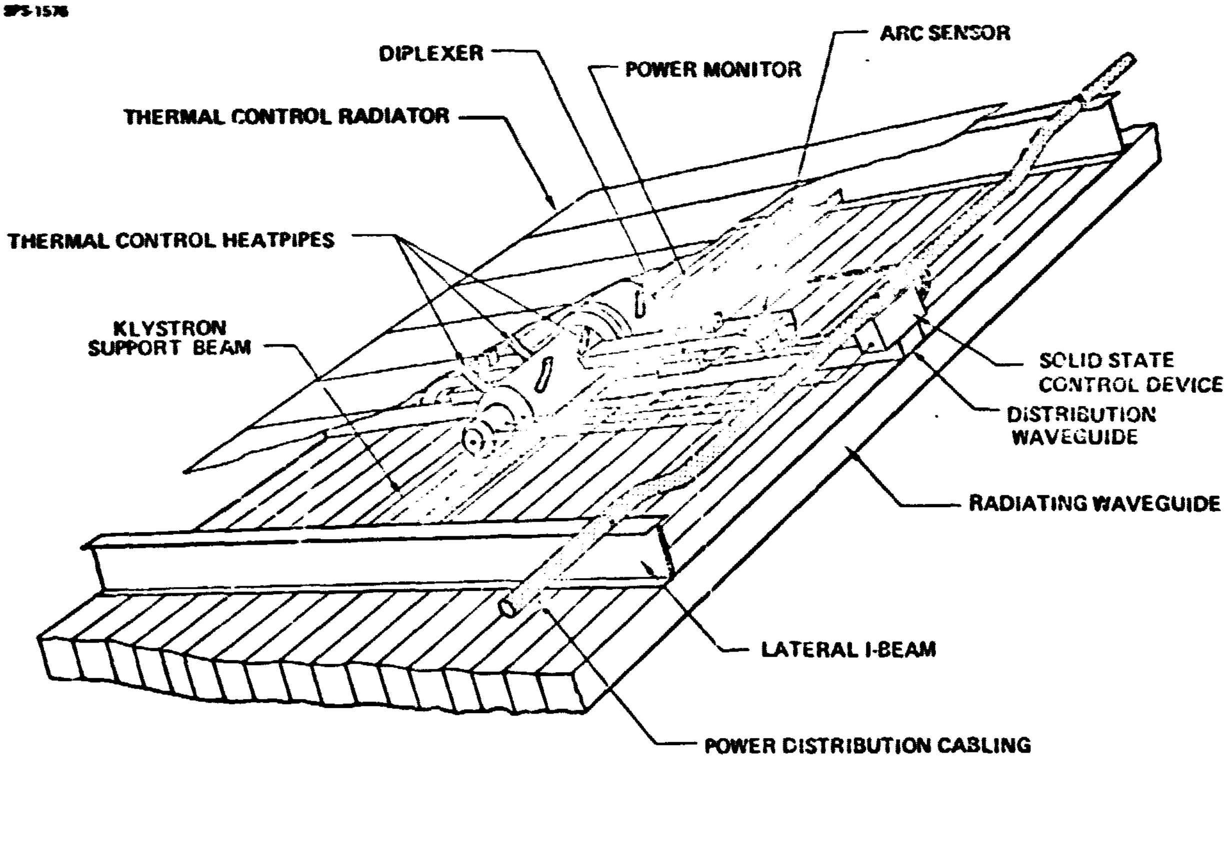

Figure 1.1.5-11 Integrated Klystron Module

WBS 1.1.5.3.1 Structure and Waveguide

WBS Dictionary

This element includes all production hardware required for the radiating waveguide, distribution waveguide, subarray support structure and attachment provisions for subarray components.

Element Description

A typical, four module, subarray is shown (Figure 1.1.5-12) with all pertinent systems installed. The elements to be discussed in this section are the radiating waveguide, distributin waveguide, subarray support structure, and the klystron support structure.

The radiating waveguide, at the subarray level, is composed of 120 waveguide sticks (Figure 1.1.5-13) that are 10.43 meters long. The method of attaining various numbers of module units per subarray is to install internal shorts, conducting elements, within the stick lengths and to distribute rf power with the distribution waveguide sticks to the desired number of waveguide sticks, for a single klystron. In this manner, it was possible to obtain ten types of subarrays, ranging from 36 to 4 klystrons per subarray (Table 1.1.5-5), to achieve the desired power taper. The integral radiating waveguide forms a subarray unit 10.43 meters square, which remains unchanged throughout the array, a[illegible] based on realizable mechanical tolerances and acceptable error plateau levels.

The distribution waveguides feed power from the klystron output waveguide to the radiating waveguide. The distribution waveguide sticks are arranged in pairs, each one supplying half of the rf power to a given klystron module. There is also an attachment point, at half of the distribution stick length, to connect/disconnect the klystron output waveguide.

The subarray support structure is composed of perimeter beams, lateral and longitudinal I-beams (Figure 2.2.5-12). These beams have a web of 12.0 cm and flanges of up to 6.0 cm and are bonded directly to the back of the radiating waveguide. The lateral and longitudinal I-beams form a matrix with a klystron module being framed within each box.

Attachment provisions are made on the subarray structure for the klystron support structure, power distribution harnesses, module power connectors, solid state control devices, and subarray support to the secondary structure. The klystron is supported, within the module, by a C-beam/saddle fixture that has a support block on each end for load transmittal into the radiating waveguide. Further support of the klystron is provided through the klystron output waveguide/distribution waveguide connection.

The power distribution harnesses are discussed in Section 1.1.5.3.5. The harnesses are supported, by the subarray support structure beams, with tiedown bands at half module lengths. At the point of departure of the cables, from the harness to the module, a connector support attachment is provided for the module power connector.

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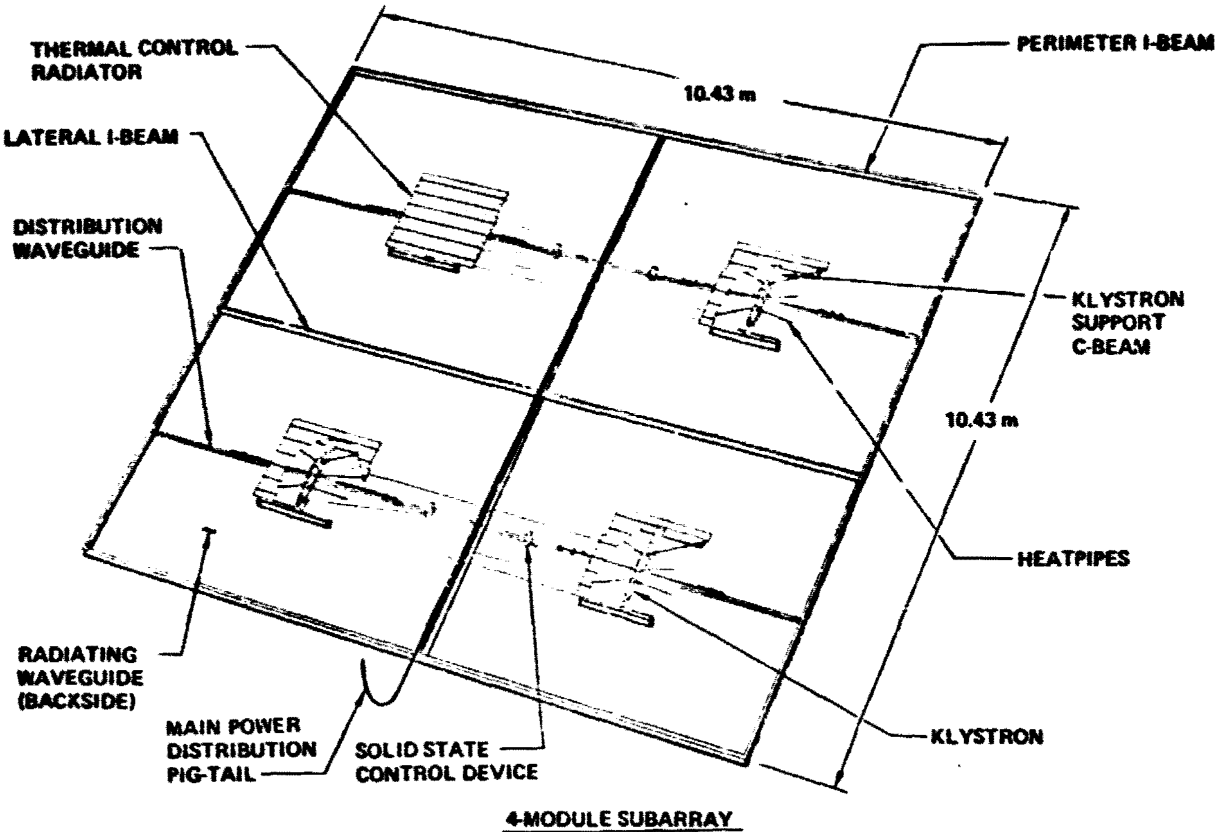

Figure 1.1.5-12 Reference MPTS—Integrated Subarray

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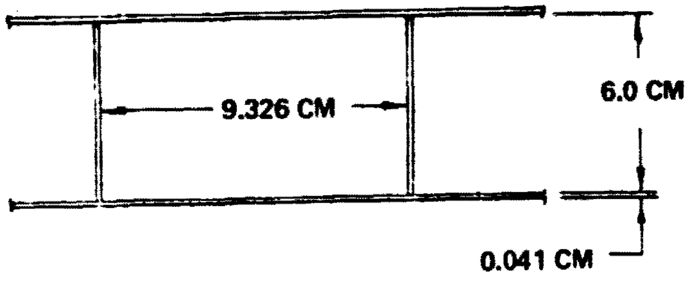

STRUCTURAL MAT'L: $G_R E_P$ -8PLY

CONDUCTING MAT'L: ALUMINUM (T = 6.67 μM)

Figure 1.1.5-13 Radiating Waveguide Stick Dimensions

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Table 1.1.5-5

SUBARRAY TYPE	NO. MODULES SUBARRAY	ARRANGEMENT OF MODULES (W x L)	MODULE DIMENSION W (m) x L (m)
1	36	6 x 6	1.738 x 1.738
2	30	6 x 5	1.738 x 2.086
3	24	6 x 4	1.738 x 2.608
4	20	5 x 4	2.086 x 2.608
5	16	4 x 4	2.608 x 2.608
6	12	5 x 4	2.608 x 3.477
7	9	3 x 3	3.477 x 3.477
8	8	4 x 2	2.608 x 5.215
9	6	3 x 2	3.477 x 5.215
10	4	2 x 2	5.215 x 5.215

Provisions must also be made on the perimeter beams, at three points, to attach the subarray to the secondary structure. This attachment will allow the adjusting mechanism, located on the secondary structure attachment points, to attach to the subarray structure to facilitate relative movement between the subarray and the MPTS structure.

Element Mass

The element masses for the element in this section are shown in Table 1.1.5-6. The structural mass includes attachment and support provision for the subarray. The mass per subarray for the distribution waveguide and subarray strucutre varies, between the limits shown, depending on the number of modules per subarray.

Element Cost

The cost estimating factor used for the elements in this section, was 66$/kg. This factor covers both waveguides and structure at the subarray level using a mature industry approach.

WBS 1.1.5.3.2 Power Amplifiers

WBS Dictionary

This element includes all the hardware and control circuits for the klystron rf transmitters, namely the cathode subassembly, the rf circuit (body), the collector, the output waveguide and window (if required) and the solenoid for beam focusing. External monitor circuits, both dc and rf are also included.

Element Description

An rf transmitter and configuration of 101,552 - 70 kw CW klystron amplifiers operating at 42 kv with 45-50 db gain using a compact efficient (82-85%) solenoid wound-on-body design approach with conservative design parameters (0.15 amps/cm^2 cathode loading) to achieve long life has been chosen. This 5 stage depressed collector design provides a complementary design to the amplitron alternative. Proposed multiple tube development programs and assessment of high voltage operation in space will provide the final answer to the transmitter selection. The layout of the basic klystron building block module is shown in Figure 1.1.5-14, with the various elements shown. The 6 cavity design, with a second harmonic bunching cavity for short length and high efficiency, features a dual output waveguide with 35 kw in each arm. Heat pipes at conservative ratings are used to cool the output gap, the depressed collector and the solenoid, with a design temperature of 300°C maximum on the body and 500°C on the collector. An MTBF improvement of 3 to 10 from the present value for several hundred spaceborne tubes of 2 years, and best tubes of small groundbased radar systems of 10 years will have to be realized through conservative design and proper burn-in procedures. The driver for the final klystron power amplifier will require an output of about 3 watts cw for a 45 db output amplifier saturated gain. This power level is available in several off-the-shelf reliable low power low noise TWT amplifiers which can be driven directly from phase

Table 1.1.5-6

ELEMENT	MASS/SUBARRAY (Kg)	MASS/ANTENNA (MT)
RADIATING WAVEGUIDES	214	1545
DISTRIBUTION WAVEGUIDES	22 – 63	289
SUBARRAY STRUCTURE	63 – 120	667

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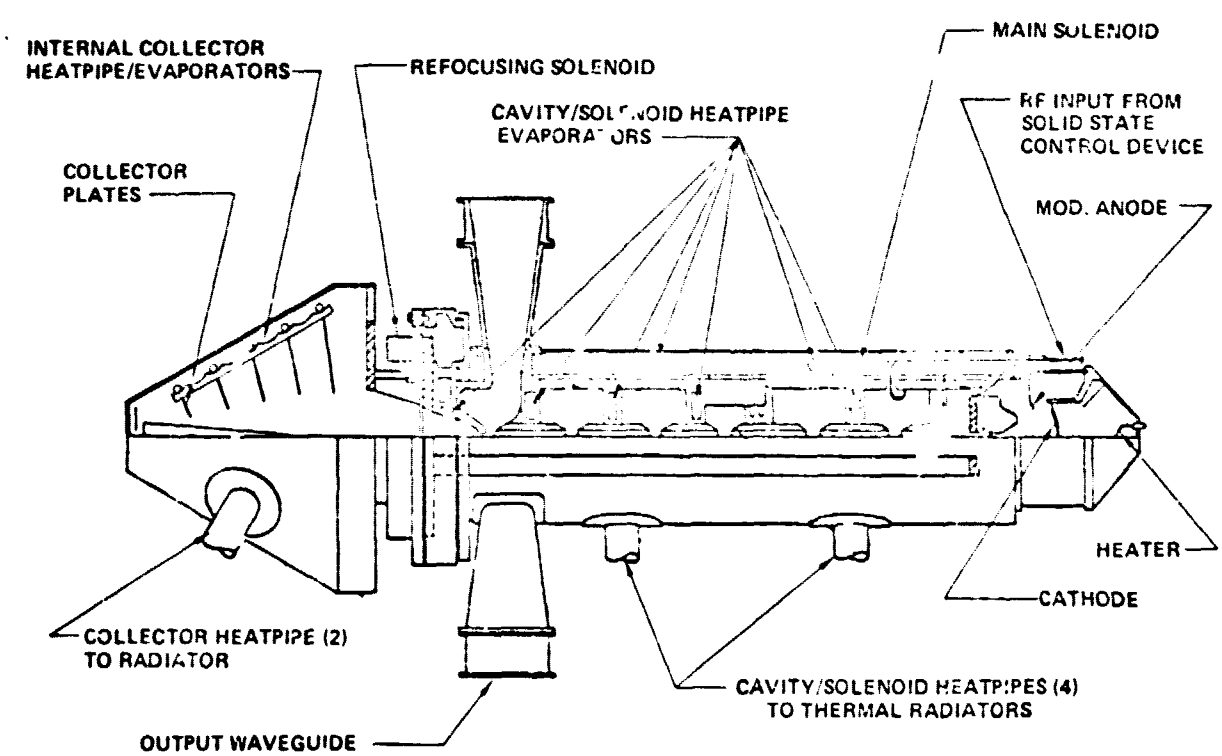

Figure 1.1.5-14 70 Kw Klystron

Table 1.1.5-7 Waste Heat Sources

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SOURCE	LEVEL	QUALITY
A. KLYSTRON:		
1) COLLECTOR	8.0 KW/UNIT	500°C
2) CAVITY LOSSES	3.8 KW/UNIT	300°C
3) SOLENOID	1.4 KW/UNIT	300°C
B. SOLID STATE CONTROL DEVICES	10 W/UNIT	0-70°C
C. RADIATING AND FEED WAVEGUIDE	1.9 TO 9.1 KW/SUBARRAY	0-125°C

Table 1.1.5-8 Thermal Limitation Assumptions

SPS-1062

KLYSTRON:	COLLECTOR	500°C
	SOLENOID AND CAVITIES	300°C
	SOLID STATE CONTROL CIRCUITS	70°C
STRUCTURES:	COMPOSITE MATERIALS	
	1. GRAPHITE–EPOXY	175°C
	2. GRAPHITE–POLYMIDE	260°C

regeneration circuitry at power levels well below a milliwatt. The driver tube could be either an off-the-shelf low-noise high-gain TWT or a multi-stage transistor amplifier with up to 10 db gain per stage at this frequency. All phase configuration functions will be performed at low drive levels.

Element Mass

The klystron mass per tube is estimated to be 48 kg, with an additional 18.9 kg for thermal control.

Element Cost

The mature indurtry mass production cost per klystron has been estimated between $1900 and $2500 per klystron (1977 dollars).

WBS 1.1.5.3.3 Thermal Control

WBS Dictionary

This element includes all production hardware required to remove and dissipate waste heat from the klystron modules at the subarray level. Such elements include the klystron heat pipe radiators, solid state control device thermal control, and thermal insulation within the subarray.

Element Description

The two major waste heat sources, at the subarray level, are the collector and cavity solenoid sections of the klystron. A small amount of waste heat must be dissipated from the solid state control device. Tables 1.1.5-7 and 1.1.5-8 list the waste heat sources and thermal limitation assumption for subarray components.

Heat pipes and radiators were designed to dissipate klystron waste heat losses. The heat pipe evaporators, an integral part of the klystron, pick up the waste heat for transfer to the thermal radiators (Figure 1.1.5-15). The thermal radiator has six sections, two sections for the collector and four for the cavities and solenoid. A cross-brace is used to retain the radiators along two edges. The collector section operates at 500°C and the cavity solenoid section at 300°C. A better description of the heat pipe radiators is given in Table 1.1.5-9.

Even though the thermal control system removes the heat released by the klystron, a high temperature still existed at module components such as solid state control, power distribution busses, and composite materials in the structure and waveguides. A lower temperature environment for these components was provided simply by isolating the high temperature sections of the klystron and the back side of its thermal radiator with thermal insulation (Table 1.1.5-10). The small amount of waste heat from the solid state control device is dissipated by its own radiator heat sink.

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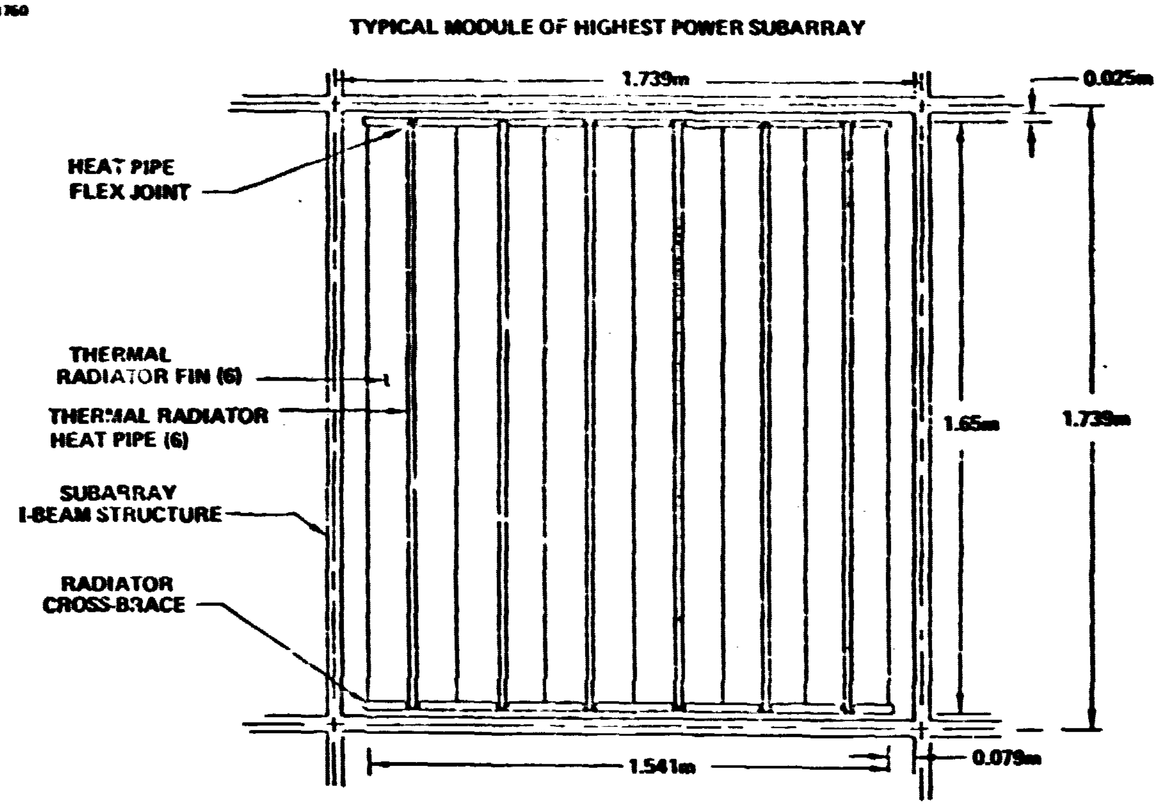

Figure 1.1.5-15 Top View of Klystron Module Thermal Radiator

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Table 1.1.5-9 Klystron Thermal Control

CAVITY AND SOLENOID SECTION:	300°C
	HEAT PIPE TYPE – 1.339 KG/M
	WORKING FLUID – H_g
	4 HEAT PIPES @ 1.30 KW EACH
	RADIATOR – ALUMINUM
	– THICKNESS = .081 CM
	– AREA = 0.432 M^2 EACH
	MASS (EACH) = 3.18 KG
COLLECTOR SECTION:	500°C
	HEAT PIPE TYPE – 1.339 KG/M
	WORKING FLUID – H_g
	2 HEAT PIPES @ 4.0 KW EACH
	RADIATOR – COPPER
	THICKNESS = 0.086 CM
	AREA = 0.406 M^2 EACH
	MASS (EACH) = 3.08 KG

MASS/KLYSTRON = 18.9 KG

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Table 1.1.5-10 Thermal Insulation

COMPONENTS:	TYPE:
500°C	
COLLECTOR SECTION (RADIATOR & KLYSTRON)	– 9 LAYER MULTIFOIL (ZrO SPACER) 6 LAYER KAPTON (QUARTZ NET SPACER)
300°C	
CAVITY & SOLENOID (RADIATOR & KLYSTRON)	– 15 LAYER KAPTON (QUARTZ NET SPACER)
WAVEGUIDES	– 10 LAYER KAPTON (QUARTZ NET SPACER)

MASS/MODULE = 2.80 KG

Element Mass

The major thermal control system element masses were listed in Tables 1.1.5-9 and 1.1.5-10. The total thermal control mass per subarray varies between 778 kg and 86 kg, depending on the subarray power density. The total mass of subarray thermal control systems is 00.2 MT.

Element Cost

The cost of thermal control elements was estimated as $1350 each.

WBS 1.1.5.3.4 Phase Control Circuit

The purpose of the phase control circuit for the space antenna of the microwave transmission system is to focus over 96% of the microwave power radiated from space to the rectenna located on the ground.

Figure 1.1.5-16 shows the simplified block diagram of the system consisting of a ground and a sapce segment.

On the ground, a transmitter and antenna complex generates a pilot signal which is radiated toward the space antenna. In space, the subarray elements of the overall space array antenna receive the pilot signal in a phase correspondig to their location relative to the ground antenna. By comparing these phases to the phase of one of the subarrays (typically the nominally closed, or center subarray) the phase differences at the individual subarrays are determined. Then the relative transmit phase at these subarrays is set to the conjugate of the received phases at each subarrays. This assures that the downlink signals from all the subarrays are launched in the proper direction to the pilot signal and arrive in phase at the pilot antenna. The correct operation of the system is monitored on the ground by a set of monitor stations. The output signals from these stations are used to calculate fine corrections which may be necessary to compensate second order systematic pointing errors due to the transmission medium.

A key function in the operation of the above described system is the determination and the conjugation of the relative phases of the pilot signals of the subarrays. This requires the generation and distribution of a reference phase for the conjugators. In the selected system, the reference phase is the phase of the A_0 subarray and this phase is distributed over a transmission line tree. The electrical length changes in these transmission lines are sent back to the next higher level node on the phase distributing network. This is equivalent to performing all conjugations at the A_0 subarray. In such an arrangement, the phase distributing lines are used bilaterally, thus their line length changes do not affect the conjugation process.

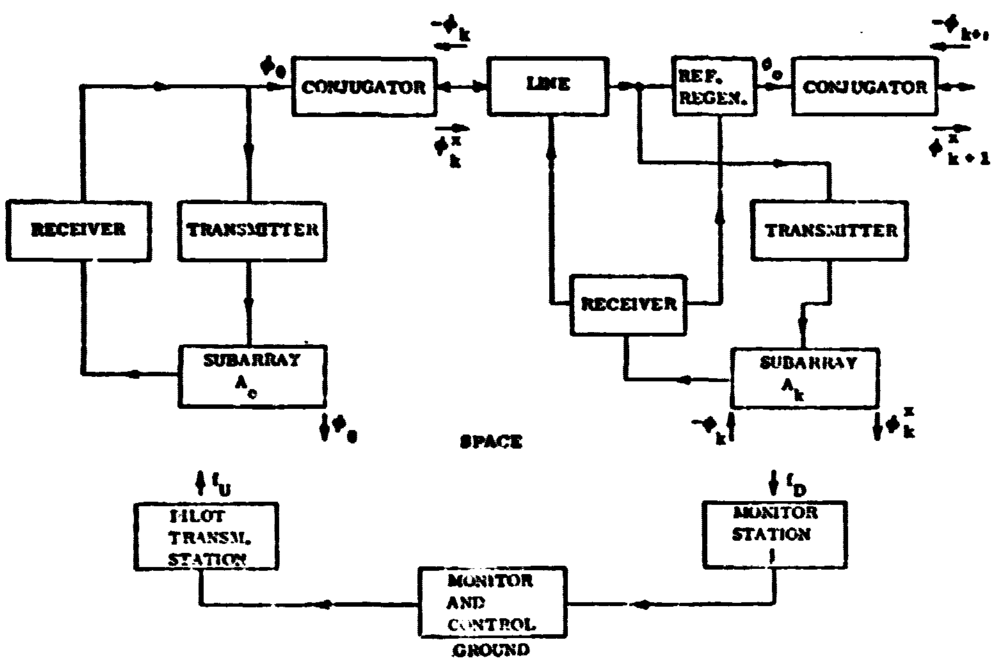

Figure 1.1.5-16 Retrodirective SPS Phase Control System

Figure 1.1.5-17 shows a more detailed block diagram of the system. The operation of the system can be explained by following a typical signal through the circuit.

On the ground (Figure 1.1.5-17a) a pilot generator at f_U = 2460 MHz is amplitude modulated by a nominal f_1 = 76.5625 MHz ~ 77 MHz. The carrier is suppressed and the remaining $f_- = f_U - f_1 \cong$ 2383 MHz and $f_+ = f_U + f_1 \cong$ 2537 MHz tones are distributed to the transmitters of three antennas. These antennas are 10 m diameter steerable paraboloids, which are located in the apexes of a triangle, approximately 1.3 km from each other and symmetrical relative to the center of the rectenna. These antennas are used for fine positioning of the beam and larger separation may be used when a wider pointing range is desirable.

At the pilot antennas a dual transmitter is located, capable of transmitting each of the uplink tones at 13 kw level. The actual level and phase of these transmitters can be adjusted in such a manner that the effective phase center of the three element array appears to be adjustable from the space craft antenna. This adjustment is achieved by the pilot location control subystem which is using input signals from the monitoring antennas of the downlink beam.

The frequency plan for the phasing circuits is outlined in Figure 1.1.5-17b and a detailed description of the retrodirective system is given in the MPTS Phase III Studies.

The operation of the above described system in real life is influenced by a number of practical limitations which degrade the power transfer efficiency from its ideal value.

Table 1.1.5-11 gives a summary of the considered errors. They can be divided into random and systematic categories. In each case phase and amplitude errors can be distinguished.

The results of this error analysis are summarized in Table 1.1.5-12.

WBS 1.1.5.3.5 Harnesses

WBS Dictionary

This element includes all production hardware to provide power distribution at the subarray level. The subelements in this category include the pigtail connector for the subarray, busing between this connector and the klystron module connector, and the klystron module connector.

Element Description

The conductors on the individual MPTS antenna subarrays are insulated circular aluminum conductors. The thermal environment for the conductors is relatively benign since the klystron radiator system is designed to radiate away from the waveguide surface. Each subarray conductor is routed from the interface connection at the subarray drop to the klystron. For reliability reasons no conductor taps are made on the subarray to provide for multiple klystron feeds from a single

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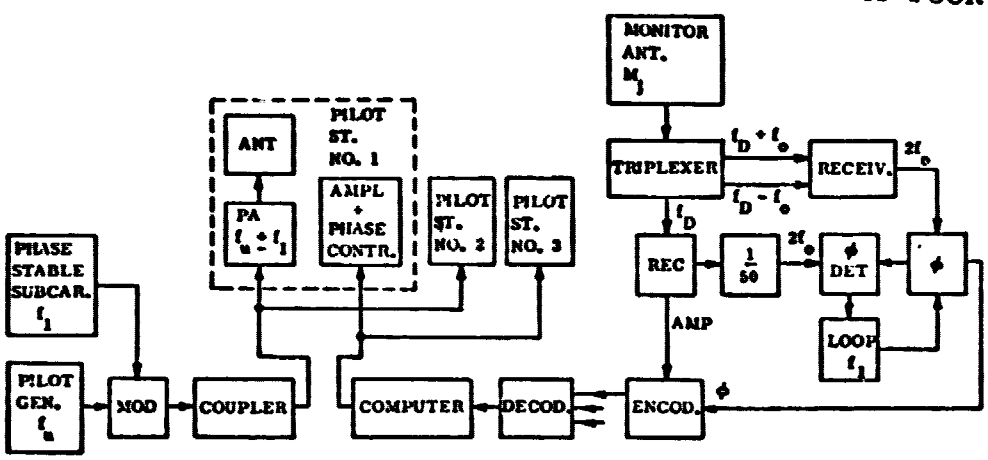


Figure 1.1.5-17a Three Pilot Antenna Control System

Glossary of Symbols

Frequencies (MHz)

f_D = 2450
f_U = 2460
f_L = 2486.25
$f_1 = f_D/32$ = 76.5625
f_- = 2383.4375
f_+ = 2536.5625
f_a = 50.3125
f_b = 102.8125
$f_A = f_L - f_D$ = 36.25
$f_B = f_D - f_1$ = 66.5625
$f_E = f_+ - f_D$ = 86.5625
$f_a - f_A$ = 14.0625
$f_B - f_a$ = 16.25
$f_B - f_C$ = 16.25
$2f_1$ = 153.125
$4f_1$ = 306.25
$8f_1$ = 612.5

Circuit Designations

r = receiver
R = regenerator
C = conjugator
d = i-f diplexer
t = transmitter
xq = multiplier

Indices

o = reference
k = first layer ($k = 1, 2, \ldots n_1 = 19$)
kℓ = second layer ($\ell = 1, 2, \ldots n_2 = 23$)
kℓm = third layer ($m = 1, 2, \ldots n_3 = 22$)

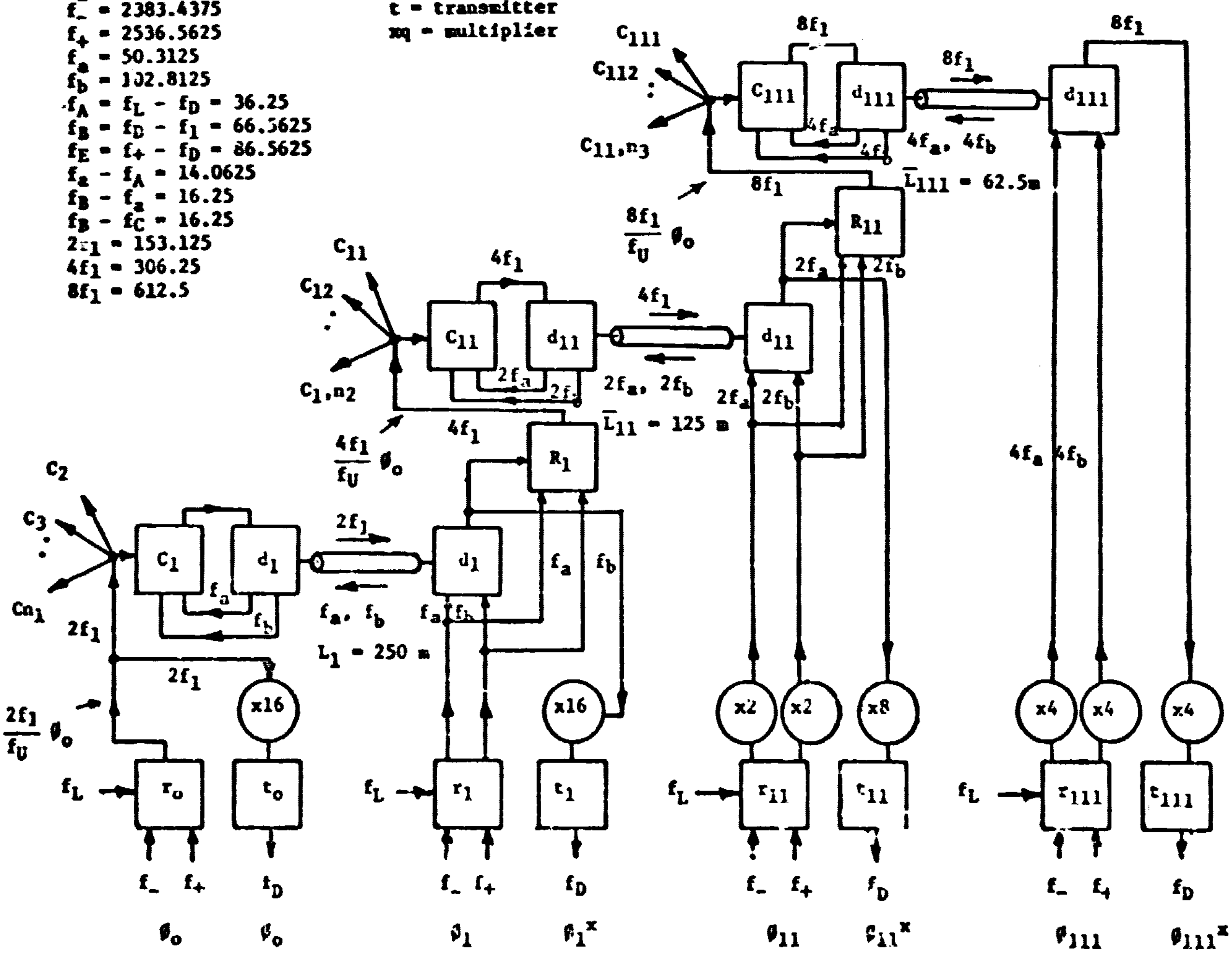


Figure 1.1.5-17b Block Diagram and Frequency Plan of Phasing Circuit for Space Antenna

Table 2.2.5-11 Illumination Errors Affecting Antenna Efficiency

RANDOM: PHASE	RANDOM: AMPLITUDE	SYSTEMATIC: POINTING	SYSTEMATIC: AMPLITUDE
PHASE JITTER (f_U, f_1)	TRANSMIT POWER	APPROXIMATE CONJUGATION	ILLUMINATION QUANTIZATION
TRANSMITTER NOISE	SUBARRAY ROTATION	DOPPLER FREQUENCY SHIFT	POLARIZATION ROTATION
CONJUGATOR (δ_c)		ABERRATION	
LINE MATCH DIFFERENTIALS (δ_{ℓ})		IONOSPHERIC DIFFERENTIAL	
DIPLEXER MATCH DIFFERENTIALS (δ_d)		ATMOSPHERIC DIFFERNTIAL	
TRANSMITTER PHASING (δ_p)			
DIFFERENTIAL DOPPLER			

Table 1.1.5-12 Summary of Losses

SOURCE	LOSS (%)
RANDOM PHASE	1.53
RANDOM AMPLITUDE ($\Delta\theta_s = .05^\circ$)	1.34
SYSTEMATIC POINTING (3 PILOT STATION)	.14
SYSTEMATIC AMPLITUDE (8 LEVELS)	.31
RESULTANT LOSS ASSOCIATED TO SPACECRAFT ARRAY	3.32, RMS
FARADAY ROTATION (Bonston, WORST YEAR)	.48% "AVERAGE" PEAK.

conductor. Connectors are provided at the interface connection, of the secondary structure and subarray, and also at the interface of the harness and the klystron module. This provides the capability to physically connect/disconnect either the module or subarray for maintenance options.

Figure 1.1.5-18 presents the conductor summary for the four klystron subarray. Also shown in this figure are per unit length tabulations of conductor mass and I^2R losses. All subarray conductor calculations for subarray distribution mass and losses were computed using these per unit length values. Figures 1.1.5-19 through 1.1.5-23 present the results for the other antenna subarray types. Total antenna subarray conductor mass and losses were computed by multiplying these quantities by the number of each subarray types.

Element Mass

The harness mass for each type of subarray was listed in the tables on Figures 1.1.5-18 through 1.1.5-23. The total mass of harnesses for an MPTS antenna is 35.9 MT.

Element Cost

The cost estimating factor for the harnesses is the same as that given in the Part 2 final documentation, 45 $/kg.

WBS 1.1.6 Assembly and Checkout

WBS Dictionary

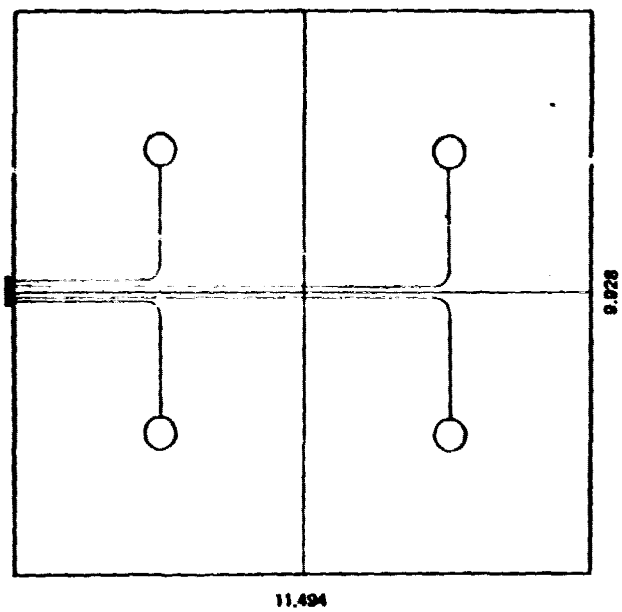
The Assembiy and Checkout functions include assembling and packaging of SPS hardware for a launch to low Earth orbit, installation of the individual payload packages into a payload pallet, and ground checkout prior to packaging and prior to launch as applicable. This function does not include the assembly and checkout of the SPS modules in space. That function is separately covered under the space construction work breakdown structure element.

Description

A description for assembly and checkout was not developed.

Mass

Mass of payload packages and pallets was estimated as 11% of the mass of contained useful payload on an average basis. This 11% estimate was included in calculations of numbers of flights for the transportation system. (The useful payload was considered to be 90% of the launch vehicle gross payload lift capability.) Payload pallets and payload packaging provisions are considered reusable: they are returnable to Earth by the launch vehicle, except for solar cell boxes which remain attached to the SPS to protect solar cells during the transit to geosynchronous orbit.



4 KLYSTRONS 2X2

VOLTAGE	CURRENT/TUBE	TOTAL CURRENT
21,050		
42,100	0.088	0.352
21,050	0.044	0.176
26,100	0.088	0.352
29,470	0.154	0.616
37,830	0.330	1.320
40,000	1.452	5.808
10 V	5.000	20.000
100V (2 EA)	10.000	40.000
COMMON	7.156	28.624

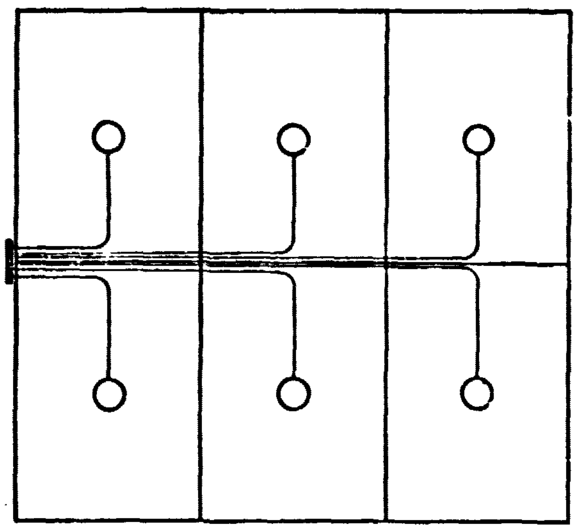
L_T = 32.916 + PIGTAIL

W_W = 241.06 I^2R = 241.06

WIRE		NO. REQ'D	WIRE SIZE AWG.	INSUL THICK (MIL)	WT/M KG.	I^2R/M WATTS
VOLTAGE (REF TO BODY ANODE)	CURRENT					
21,050		1	30	8.6	.0009	
	0.088	1	30	8.6	.0009	0.004
21,050	0.044	1	30	8.6	.0009	0.001
16,940	0.088	1	30	6.8	.0007	0.004
12,630	0.154	1	28	5.2	.0007	.008
4,210	0.330	1	27	2	.0004	0.030
2,100	1.452	1	22	1	.0010	0.184
42,100	5.000	1	18	16.8	.0068	0.861
42,100	7.156	1	16	16.8	.0090	1.107
42,100	10.000	2	15	16.4	.0103	1.709

Σ = 0.0419 5.617

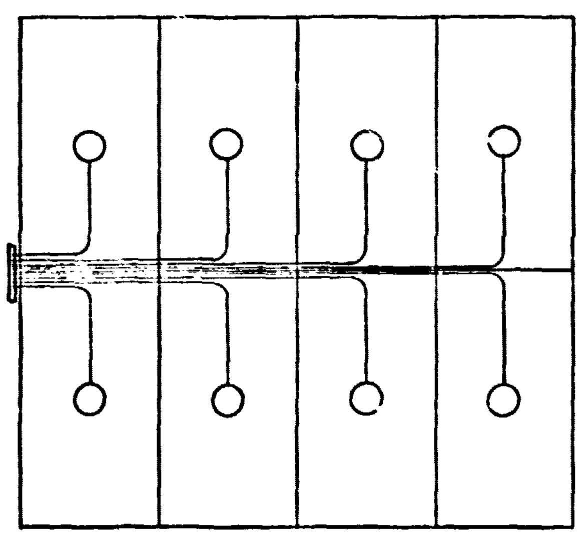
Figure 1.1.5-18 Four Klystron Subarray Conductor Summary



VOLTAGE	TOTAL CURRENT
21,050	—
42,100	0.528
21,050	0.264
25,160	0.528
29,470	0.924
37,890	1.980
40,000	8.712
10	30,000
100	60,000
COMMON	42.936

L_T = 49.374 M
W_W = 2.49 Kg
I^2R = 333.50

6 KLYSTRONS 2X3

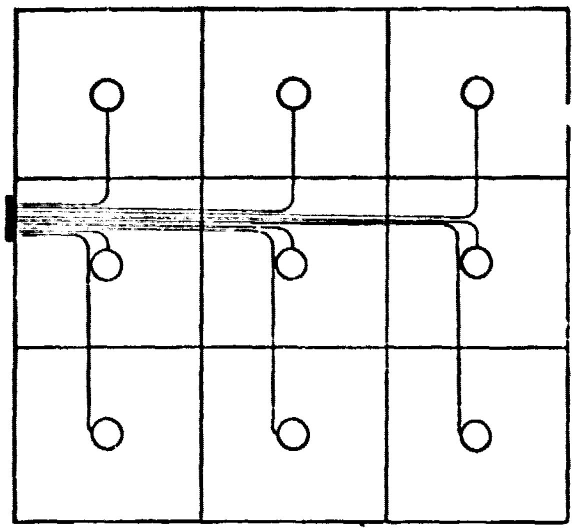


VOLTAGE	TOTAL CURRENT
21,050	—
42,100	0.724
21,050	0.352
25,160	0.724
29,470	1.232
37,890	2.640
40,000	11.616
10	40,000
100	80,000
COMMON	57.248

L_T = 65.832
W_W = 3.18 Kg
I^2R = 369.78

8 KLYSTRONS 2X4

Figure 1.1.5-19 Six and Eight Klystron Subarray Conductor Summary



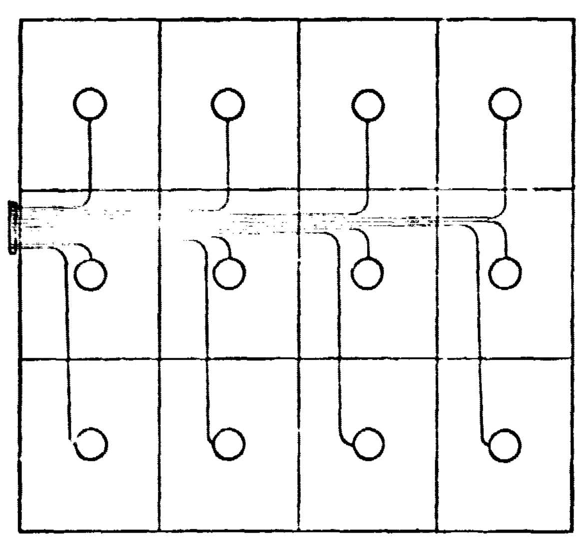
VOLTAGE	TOTAL CURRENT
21,050	——
42,100	0.792
21,050	0.396
25,160	0.792
29,470	1.386
37,890	2.970
40,000	13.068
10	45.000
100	90.000
COMMON	64.404

L_T = 71.579

W_W = 3.42 Kg

I^2R = 458.23

9 KLYSTRONS 3X3



VOLTAGE	TOTAL CURRENT
21,050	——
42,100	1.056
21,050	0.528
25,160	1.056
29,470	1.848
37,890	3.960
40,000	17.424
10	60.030
100	120.000
COMMON	85.872

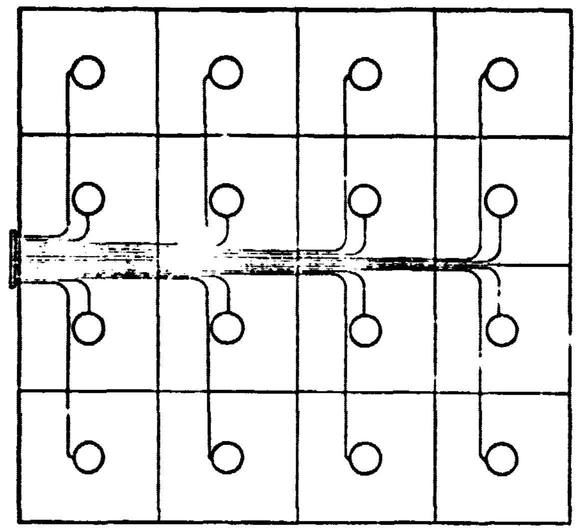
L_T = 95.439 M

W_W = 4.42 Kq

I^2R = 592.25

12 KLYSTRONS 3X4

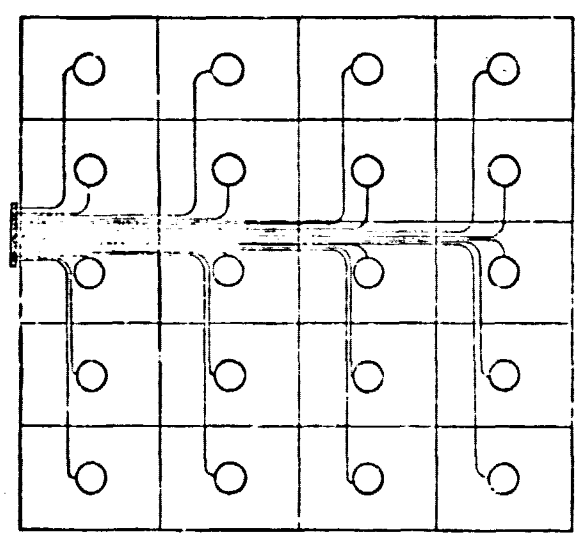
Figure 1.1.5-20 Nine and Twelve Klystron Subarray Conductor Summary



VOLTAGE	TOTAL CURRENT
21,050	—
42,100	1.408
21,050	0.704
25,160	1.408
29,470	2.464
37,890	5.280
40,000	23.232
10	80.000
100	160.000
COMMON	111.496

L_T = 131.664
W_W = 5.94 Kg
I^2R = 795.73

16 KLYSTRONS 4X4

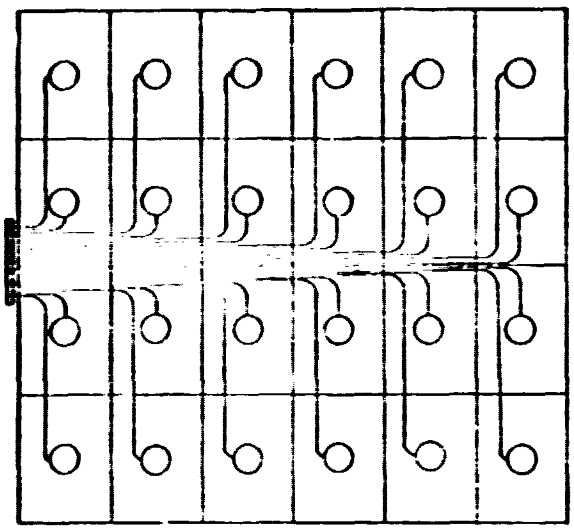


VOLTAGE	TOTAL CURRENT
21,050	—
42,100	1.760
21,050	0.880
25,160	1.760
29,470	3.080
37,890	6.600
40,000	29.040
1C	100.000
100	200.000
COMMON	143.120

L_T = 166.566 M
W_W = 7.40 Kg
I^2R = 991.77

20 KLYSTRONS 5X4

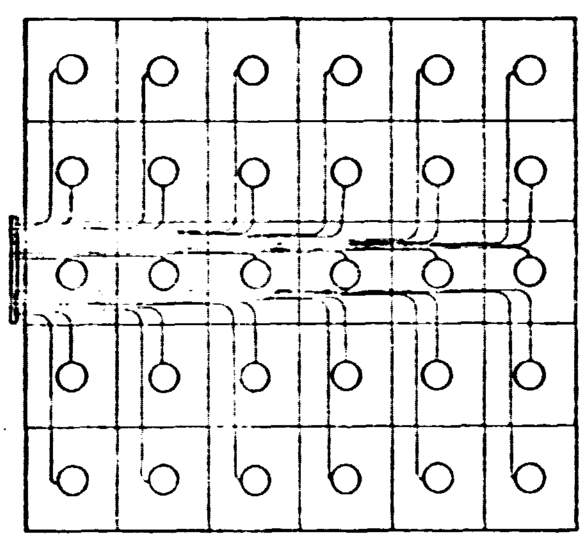
Figure 1.1.5-21 Sixteen and Twenty Klystron Subarray Conductor Summary



VOLTAGE	TOTAL CURRENT
21,050	—
42,100	2.112
21,050	1.056
25,160	2.112
29,470	3.696
37,890	7.920
40,000	34.848
10	120.000
100	240.000
COMMON	171.744

L_T = 197.486
W_W = 8.00 Kg
I^2R = 1,165.51

24 KLYSTRONS 4X6

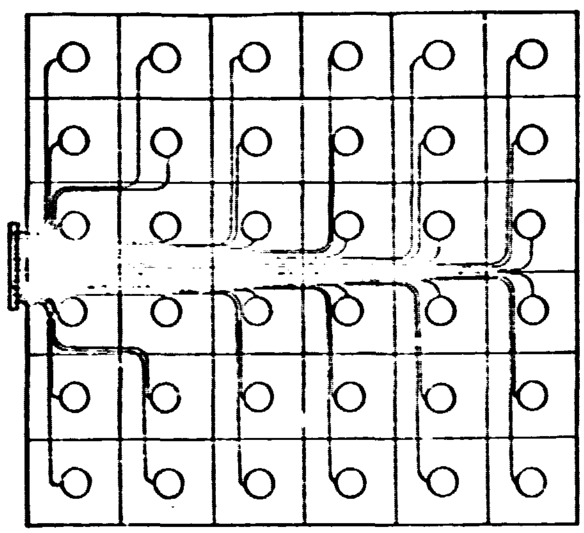


VOLTAGE	TOTAL CURRENT
21,050	—
42,100	2.640
41,050	1.320
25,160	2.640
29,470	4.620
37,890	9.900
40,000	43.560
10	150.000
100	300.000
COMMON	214.680

L_T = 231.677 M
W_W = 10.13 Kg
I^2R = 1,357.50

30 KLYSTRONS 5X6

Figure 1.1.5-22 Twenty-four and Thirty Klystron Subarray Conductor Summary



VOLTAGE	TOTAL CURRENT
21,050	—
42,100	3,168
21,050	1.584
25,160	3,168
29,470	5.544
37,890	11.880
40,000	52.272
10	180.000
100	360.000
COMMON	257,616

L_T = 296.244 M
W_W = 12.83 Kg
I^2R = 1,720.17

36 KLYSTRONS 6X6

Figure 1.1.5-23 Thirty-six Klystron Subarray Conductor Summary

Cost

A 5% blanket allowance was applied to applicable SPS items for packaging, assembly and checkout costs.

1.1.7 Initial Spares

WBS Dictionary

Initial spares are those spares supplied with the SPS as initially purchased to provide an adequate spares base to accomplish the construction and the initial checkout job. The quantity has been estimated as 2% and was costed as 2% without a specific breakout as to how many spares of what type.

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WBS 1.2 Ground Receiving Stations

WBS Dictionary

The SPS ground receiving stations include all functions required to receive the power beams, convert them to grid-compatible electric power, and provide ground control of beam formation, aiming, and power. Whether the ground receiving stations would be responsible for SPS flight control has not been determined.

Description

The design of the ground station is a combined effort by The Boeing Company, Raytheon (Walltham), and General Electric Space Division. Each receiving station includes the land area, rectenna (rectifying antenna), grid interface equipment, and control and communications systems. The land sites are 13.18 x 18.7 km (nominal, at 35° latitude) and each rectenna proper is 9.885 x 14 km. The output power of 5000 megawatts is delivered through five 1000-megawatt transformer stations. Several rectenna configuration options were evaluated. The tilted-panel configuration shown in Figure 1.2-1 was retained as preferred concept.

Mass

Mass estimates were not made.

Cost

Land and site preparation was estimated as $5000/acre based on Bovay estimates (contract NAS9-15280) of $1500–4000/acre, with additions for agriculture in the perimeter area not covered by rectenna.

Cost Summary

Rectenna costs were based on Bovay Engineers estimates for structure and installation, Raytheon estimates for the RF hardware and ground planes, Boeing and GE estimates for RF diodes, and GE estimates for power processing and grid interface.

The structure used Bovay #4 (see below, WBS 1.2.3), which is approximately $19.3/m^2 (of panel area). The panel area is 76.7 km^2.

Land was estimated at $5000/acre for acquisition and site preparation.

The RF assemblies were estimated at 3¢ each, with each dipole element receiving 70 cm^2 of beam area. A total of 10.96 billion elements and diodes are required.

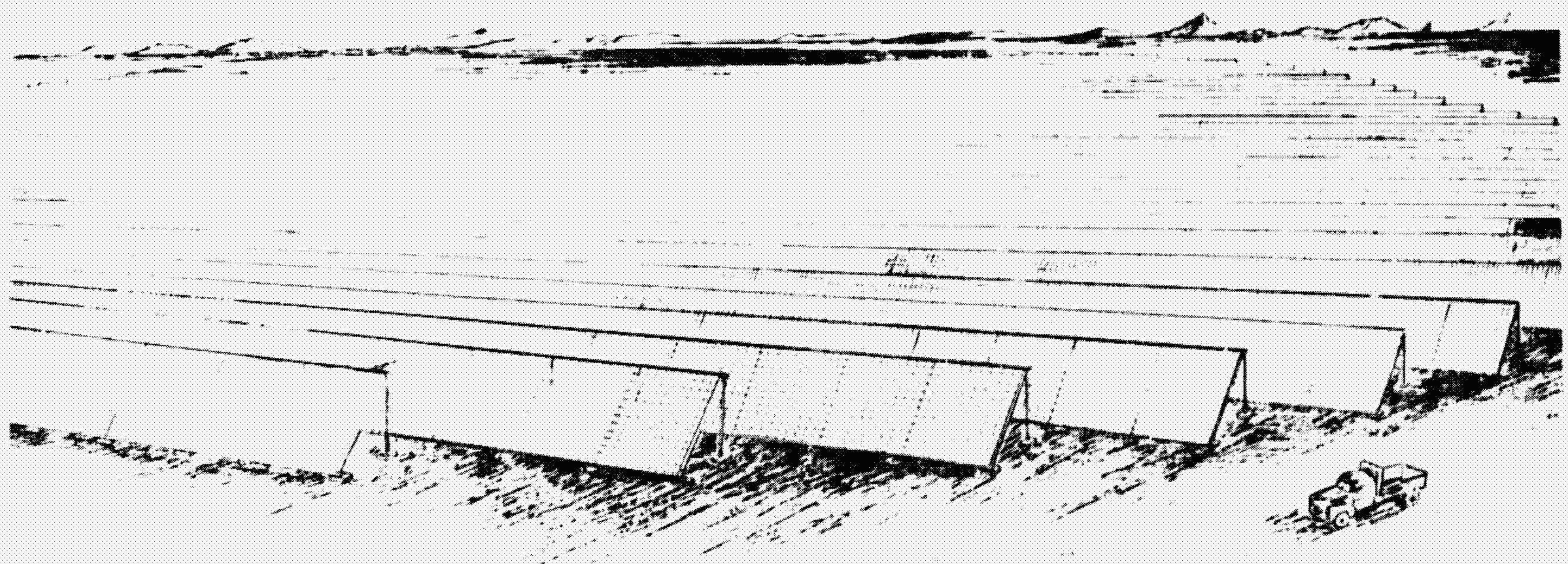

Figure 1.2-1. Tilted Panel Rectenna Configuration

Diodes were estimated from 1¢ to 2½¢ each by GE and Boeing. A figure of 2¢ was used. Distribution busses were estimated at $57 million. The command and control system was estimated at $55 million. Power processing and grid interface costs were estimated as $674 million.

A summary follows:

		Cost millions of $
Land	47,800 acres	120
Structures & Installation		1,480
RF Assemblies & Ground Plane		329
Diodes		219
Distribution Busses		57
Command & Control Center		55
"Bare" Rectenna Total		2,260
Power Processing & Grid Interface		674

These figures are for one receiving site. The 10,000 megawatt SPS requires two receiving sites.

WBS 1.2.1 Real Estate

WBS Dictionary

This element includes the land area for the ground receiving stations and all site preparation.

Description

The land area requirement was assumed to be equivalent to the SPS power beam footprint on the ground. The size is nominally 13.18 x 18.7 km, elliptical, but varies with latitude. That portion of the land area not used for active rectenna elements may be planted in grass or forest (as is appropriate to the climate) to minimize reflection of the outer fringes of the microwave beam. The beam intensity in this region will be less than 1 mw/cm^2. The entire receiving site will be fenced.

Mass

Not applicable.

WBS 1.2.2 Control and Communication

Electronic systems are provided which cause the spacetenna to generate the required coherent beam. The ground-based power of this system consists of beam monitoring systems and a pilot transmission system. Ground-based systems for control of satellite operations have not been investigated.

WBS 1.2.2.1 Phase Control System

On the ground the position of the received beam is monitored and the effective phase center of triangularly configured pilot antenna array is varied in such a way that the beam center is kept at the center of the rectenna. The uplink frequency is baselined as 2460 Mhz (to provide separation from the down link frequency of 2450 Mhz). Three pilot antennas would be spaced approximately two kilometers apart within the rectenna area. Four monitoring antennas would be provided, as a minimum.

WBS 1.2.2.2 SPS Operations

A detailed analysis of SPS operations has not been performed. However, on a preliminary basis it appears that all ground system operations can be performed automatically. This does not include system maintenance such as the replacement of rectenna panels. The modular configuration of the rectenna allows load following and facilitates maintenance. The power collection and distribution system is described in section 1.2.4.3 through 1.2.4.6.

WBS 1.2.3 Rectenna Primary Structure

WBS Dictionary

This element includes all support structure for the active rectenna.

Description

The structural design selected was Bovay #4. It is illustrated in Figure 1.2.3-1, excerpted from the Bovay report.

Mass and Cost

Mass and cost estimates were adapted from the Bovay Report, Contract NAS9-15280, summarized in Table 1.2.3-1

WBS 1.2.4 Energy Collection

WBS Dictionary

The rectenna energy collection system includes all active elements of the RF-DC conversion system dipoles, filters, diodes, environmental shields, ground planes, and any integral bussing. The energy collection system was defined by Raytheon under subcontract and is documented in the Phase III MPTS report (Book IV) in detail.

The rectenna size optimization was developed on the basis of an improved diode efficiency model and a rectenna revenus per m^2 parameter beyond which collection was marginal. The implementation of such a system will require further definition of how best to concentrate energy on the dipole, such as the use of the "hogline" antennas, or methods of efficiently paralleling dipoles to diodes.

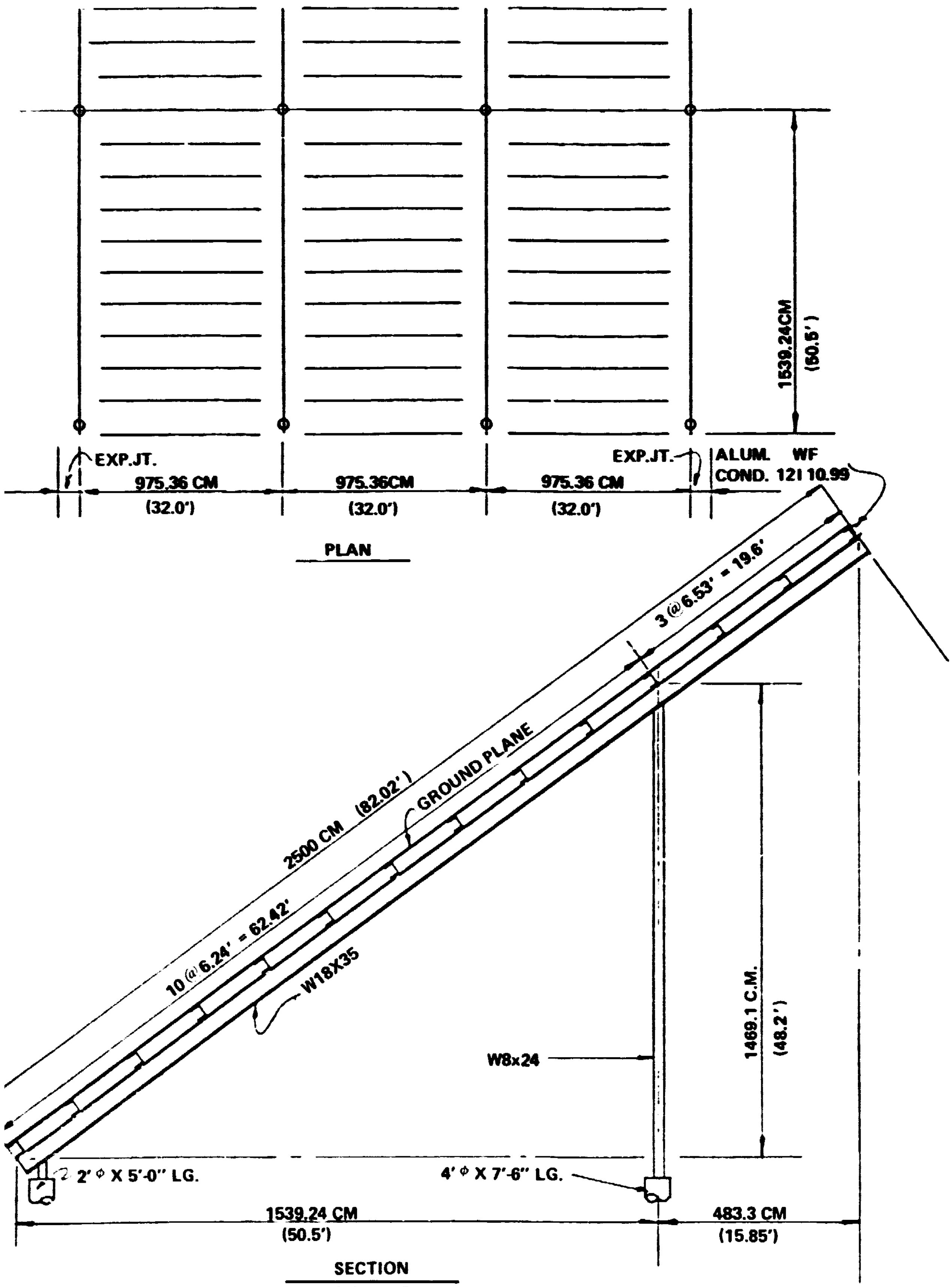

Figure 1.2.3-1. System No. 4

Table 1.2.3-1

SYSTEM NO. 4 STEEL FRAMES ON 32 FT. CENTERS, WITH 13 LIGHTGAGE STEEL PURLINS AND ONE ALUMINUM PURLIN AND SPANDREL FOR ELECTRICAL CONDUCTION QUANTITIES FOR ONE 96 FOOT SECTION.

1422 LBS. ALUMINUM SHAPES @ $1.50	$ 2,133
10377 LBS. LIGHTGAGE STEEL @ $.36	3,736
13277 LBS. STRUCTURAL STEEL @ $.42	5,576
2 EACH CONDUCTOR INSULATION MOUNT @ $5.00	10
1 EACH CONDUCTOR SLIDING MOUNT @ $8.00	8
3 EACH 2' 0 X 5' LG. FTG. @ $50.00	150
3 EACH 4' 0 X 7'–6" LG. FTG. @ $200.00	600
1 EACH JUMPER CABLE @ $30.00	30
	$12,243
5% CONT.	612
	12,855
10% PROFIT	1,286
	$14,140

COST/SQ. FT. = $\frac{14,140}{7,874}$ = \$1.80/SQ. FT. GROUNDPLANE = \$19.32/M^2

Description

The rectenna concept utilizes a weather proof matched dipole configuration shown in Figure 1.2.4-1, which is amendable to mass production. All materials required are readily available and of low cost. The mechanical design is amendable to highly automated production. Using the previously proven rectennas construction methods from the JPL/Raytheon tests, a more efficient two plane design format has been developed (Fig. 1.2.4-2). An actual complete section has been evaluated in r.f. tests and is shown in Figure 1.2.4-3. The metal shield is used to provide invironmental protection as well as prevent direct radiation of harmonic power. Also, the dc converting bus forms part of the filter and r.f. rectification circuit.

An Artists' concept of a moving rectenna factory is shown in Figure 1.2.4-4. Materials brought in at one end of the factory are basic ingredients to high speed automated manufacture and assembly of rectenna panels which flow continuously from the moving factory. The details of the manufacturing process are given in the MPTS Phase III study report, which also includes a discussion of the impact of structural loadings.

1.2.4.1 Ground Planes

The two plane design consists of the active receiving elements and a reflecting plane, or ground plane. The reflecting plane need only be a metallic mesh with suitable spacing relative to the wavelength. Refer to Figure 1.2.4-2 for the form and location of the ground plane.

Use of a mesh allows passage of the wind, rain, snow, etc., to reduce structural loading.

1.2.4.2 R. F. Assemblies

The foreplane contains the half-wave dipoles, the input wave filters, the rectification circuit, the smoothing capacitance, and the DC power collection and bussing function. Figure 1.2.4-5 shows the electrical format of the foreplane. Figure 1.2.4-3 showed a physical embodiment of a section of foreplane construction as defined in Figure 1.2.4-5 with the addition of a shield. The foreplane shown in Figure 1.2.4-3 has been thoroughly checked out electrically (Section 5.5 of Reference 1) l found to be equal in efficiency to that of the three plane construction. Figure 1.2.4-2 showed how the foreplane can be integrated with the reflecting screen to form the major portion of the rectenna structure. It is found that the metal shield placed over the active portion of the rectenna to shield it from the environment and to prevent direct radiation of harmonic power from the rectifier circuit can function very satisfactorily as the horizontal load bearing member of the rectenna.

1.2.4.2.1 Dipoles

The dipoles are formed of aluminum wire as shown in Figure 1.2.4-6.

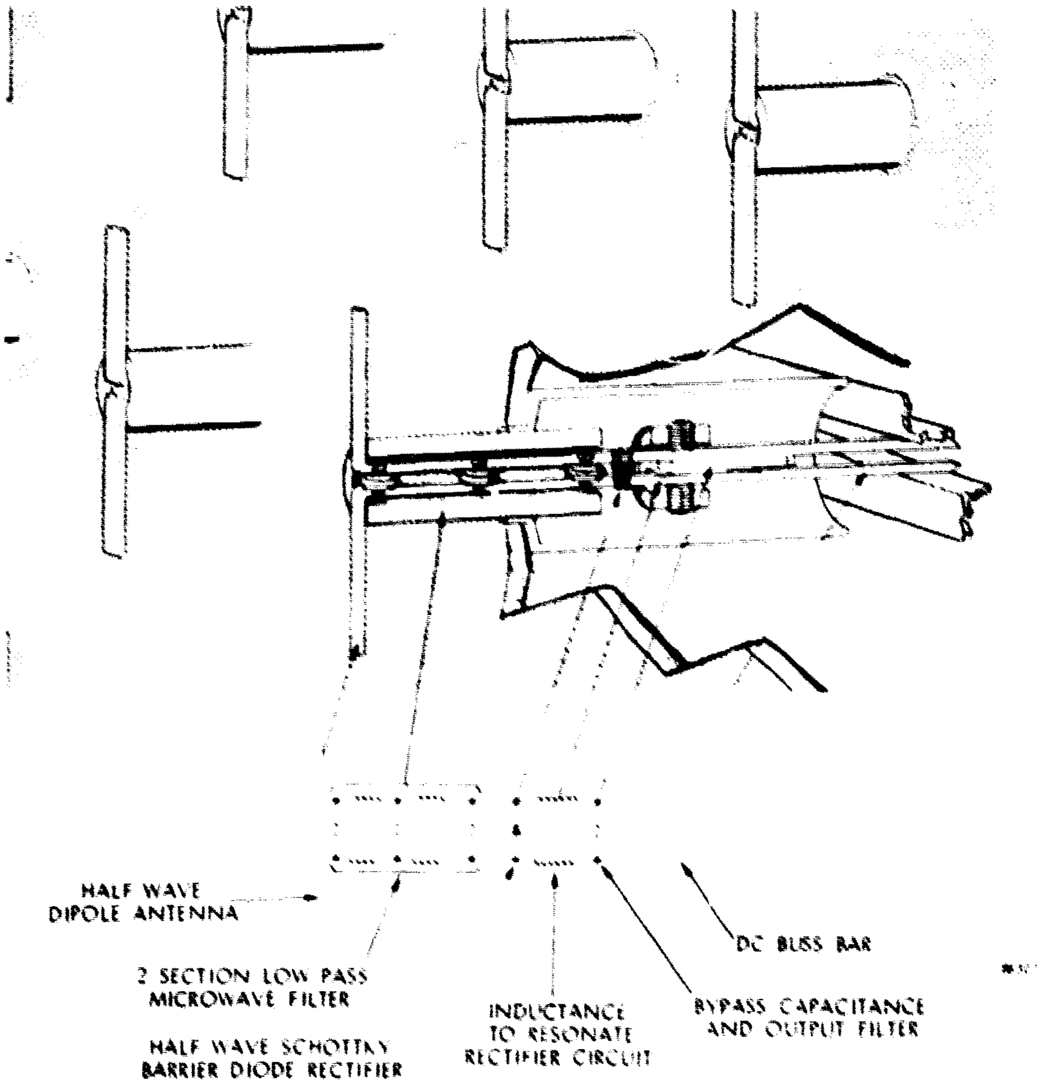

Figure 1.2.4-1. Cutaway section of the three-plane rectenna approach used in the RXCV at JPL's Goldstone facility showing how the rectenna elements plug into the array. Although this approach was satisfactory electrically, it is complicated from a fabrication point of view. A greatly simplified mechanical approach is the two-plane system which preserves all of the desirable electrical properties of the three-plane system.

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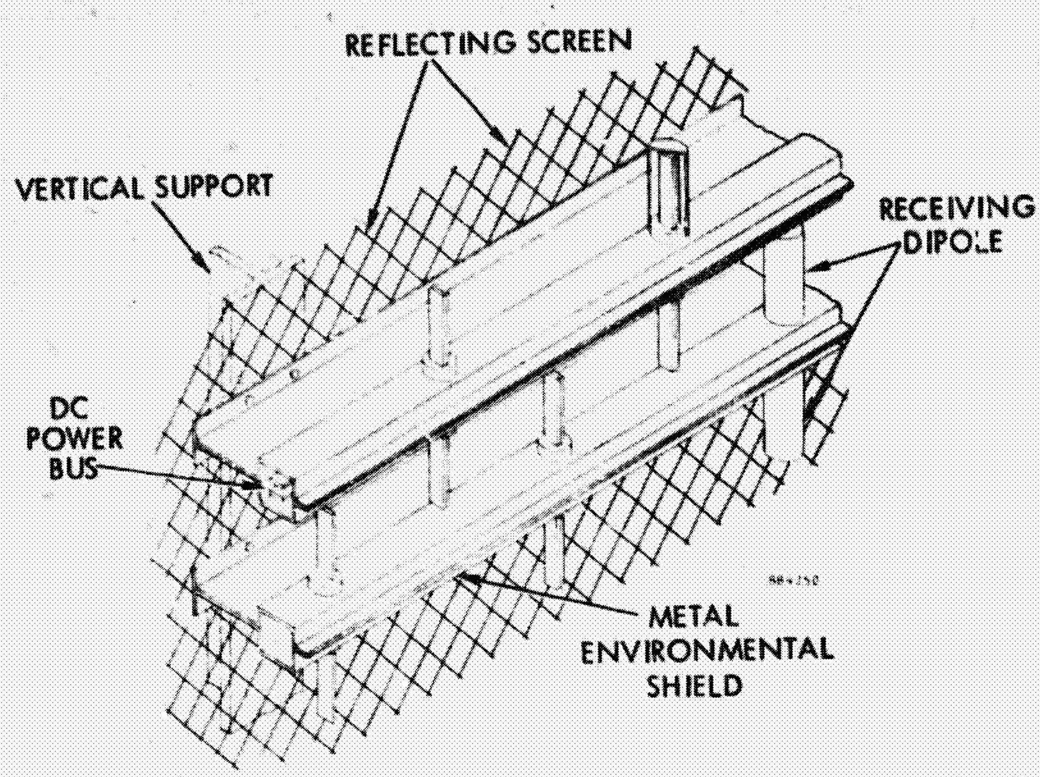

Figure 1.2.4-2. Drawing of the two-plane rectenna construction format consisting of a reflecting screen or ground plane and the foreplane which contains dipole antenna, wave filters, diode rectifiers, and bus bars - all protected from the enviornment by a metal shield.

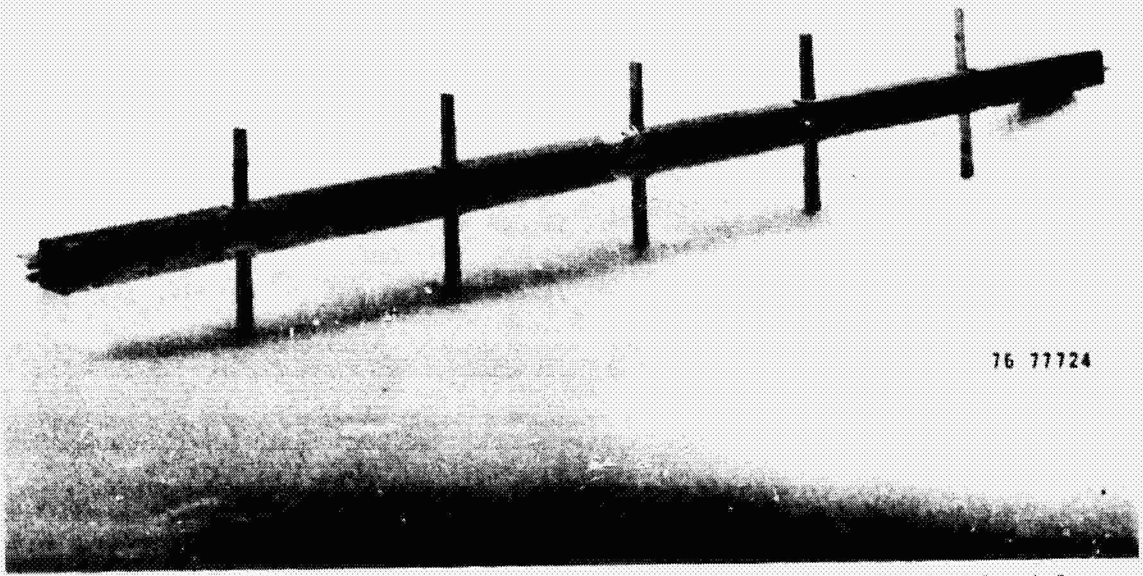

Figure 1.2.4-3. Completed rectenna foreplane assembly consisting of metallic shield and the core assembly of five rectenna elements. This section has been substituted for a section of the three level construction in a rectenna and found to perform as well.

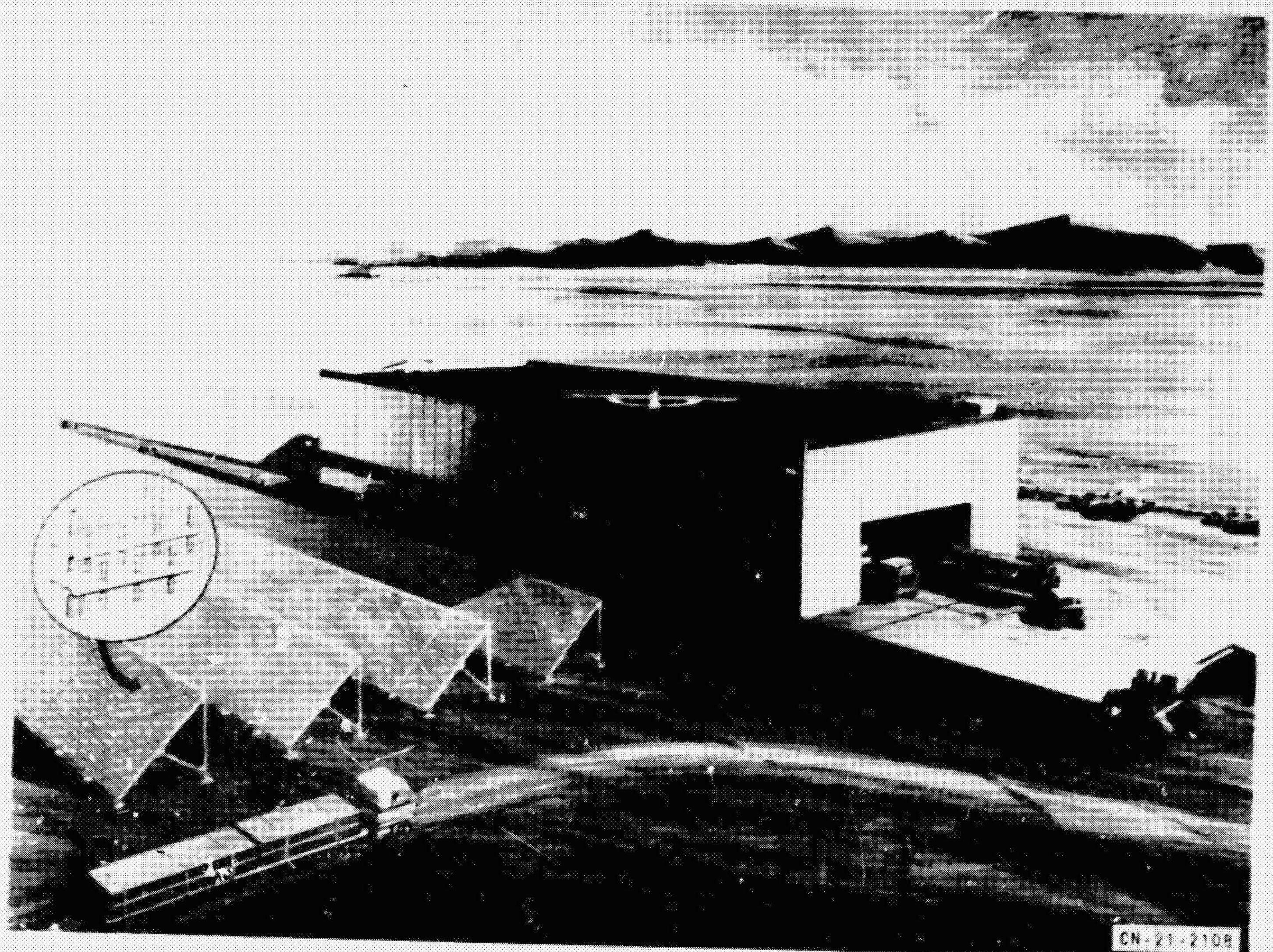

Figure 1.2.4-4. Artist's Concept of Moving Rectenna Factory

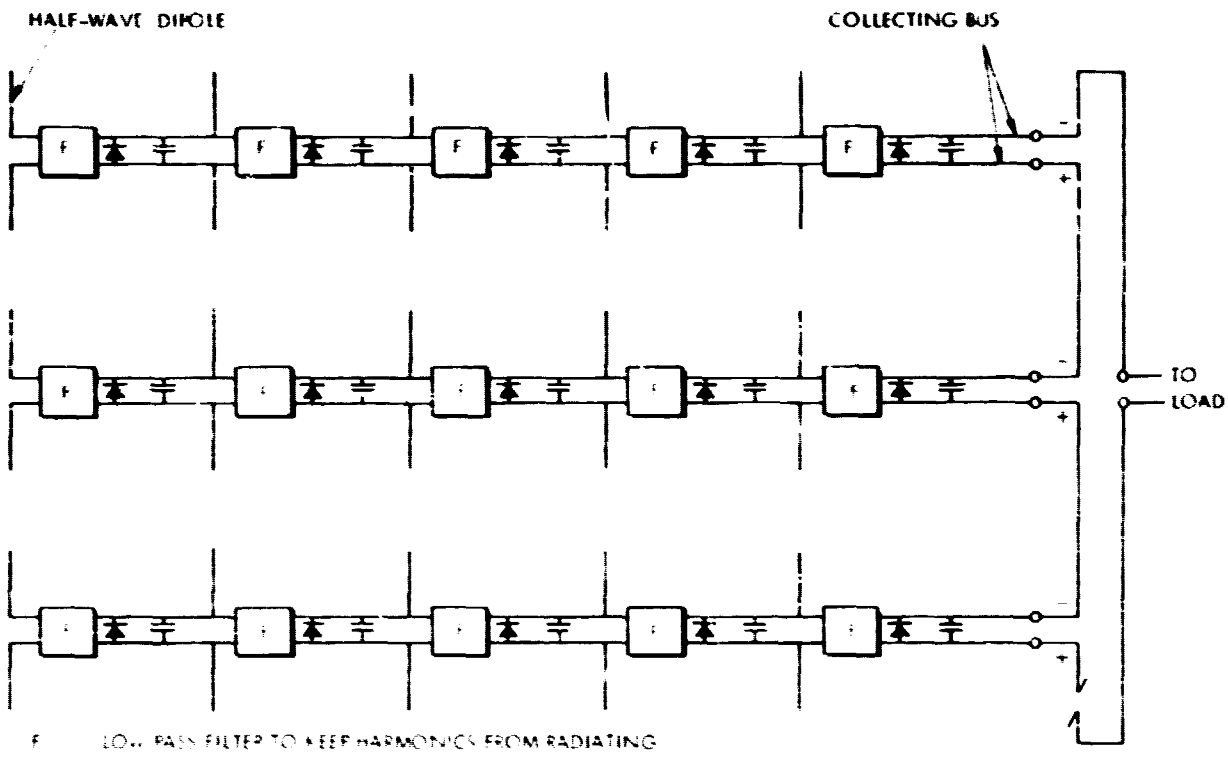

Figure 1.2.4-5a. Schematic of the foreplane of the two-plane rectenna showing the arrangement of half-wave dipoles, input filters, and Schottkybarrier rectifying diodes. Two-wire Transmission lines are used for both microwave circuits and carrying out the DC power collected by the array.

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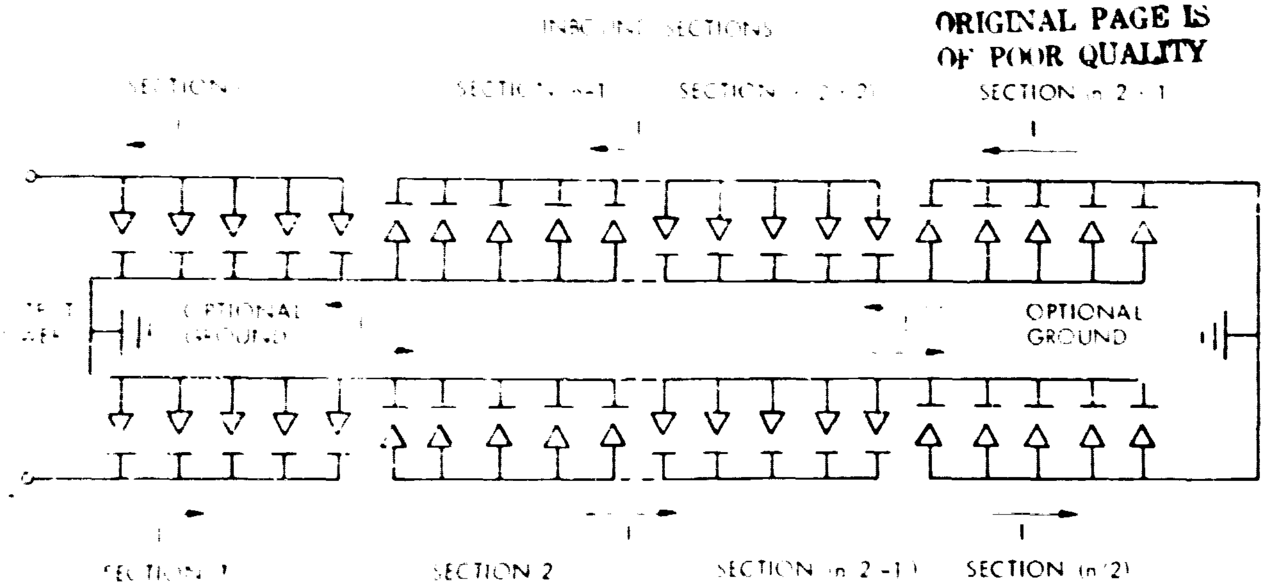

Figure 1.2.4-5b. Schematic electrical drawing showing how the sections of diodes representing the rectenna elements within a long length of foreplane are connected in parallel and series to build up to the desired output current and voltage levels.

1.2.4.2.2 Circuitry

Refer to Figure 1.2.4-5 for the electrical circuit of the rectenna panels. Panel interconnections are described in section 1.2.4.3.

1.2.4.2.3 Shields and Covers

The design shown in Figure 1.2.4-3 strongly suggests that the metal shield that is essential to the electrical and environmental design can also function as the principle load-bearing horizontal structural member in either a flat or serrated rectenna. It is the purpose of this section to make an analysis of this shield as the horizontal structural element and to determine the thickness of the sheet metal from which it is fabricated as a function of length of span between lateral support and the wind-loading or other loading impressed upon it. Of course the cost of the member is nearly proportional to the thickness of the material, so that the thickness parameter is an important one.

The shape and size of the shield shown in cross section in Figure 1.2.4-7 is determined by a number of factors. The depth of the beam is determined by the necessary distance of about one inch between the half wave dipole antennas and the reflecting screen and the method of assembling the shield to the screen. The assembly of the beam to the screen is important but the options on how to do it are severely limited. By making the shield deeper and inserting it into folds in the screen a secure, fast, and economical assembly can result while also providing the beam with greater strength because of the greater depth. The width of the shield is largely determined by the physical size of the core assembly and the requirement for operating the core assembly at some potential removed from ground. The thicker the assembly the more will be the wind resistance. The thickness of the member is made constant throughout its depth to provide it with high torsional resistance. If the top and bottom members of the shield are quite thin, they can be given resistance to buckling under stress by forming lateral grooves in the material.

Although the dimensions assigned to Figure 1.2.4-7 may be somewhat arbitrary, they are quite representative of what the design will probably be with this approach. With the assumed dimensions the neutral axis is found to be at 1.043 inch and the moment of inertia I_x is found to be 2.303 t, where t is the thickness of the material.

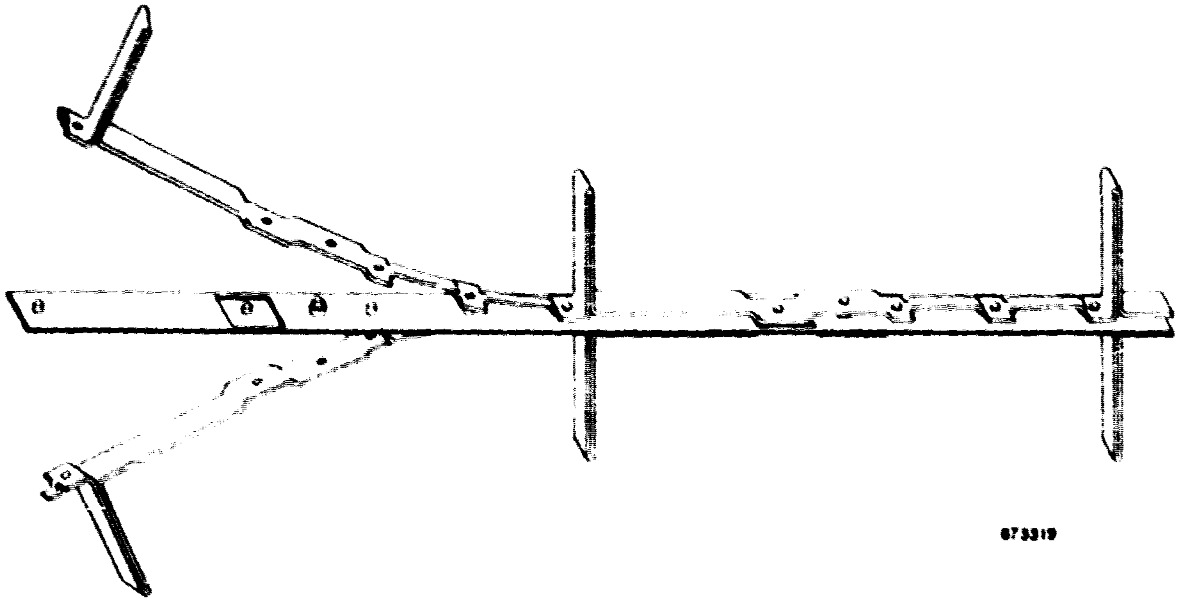

Figure 1.2.4-6. Proposed method of continuous fabrication of the core assembly of rectenna elements. Top and bottom members are continuously formed from two rolls of flat wire to the left of the assembly. Details of the above drawing have been superceded by a new design shown in Figure 1.2.4-2.

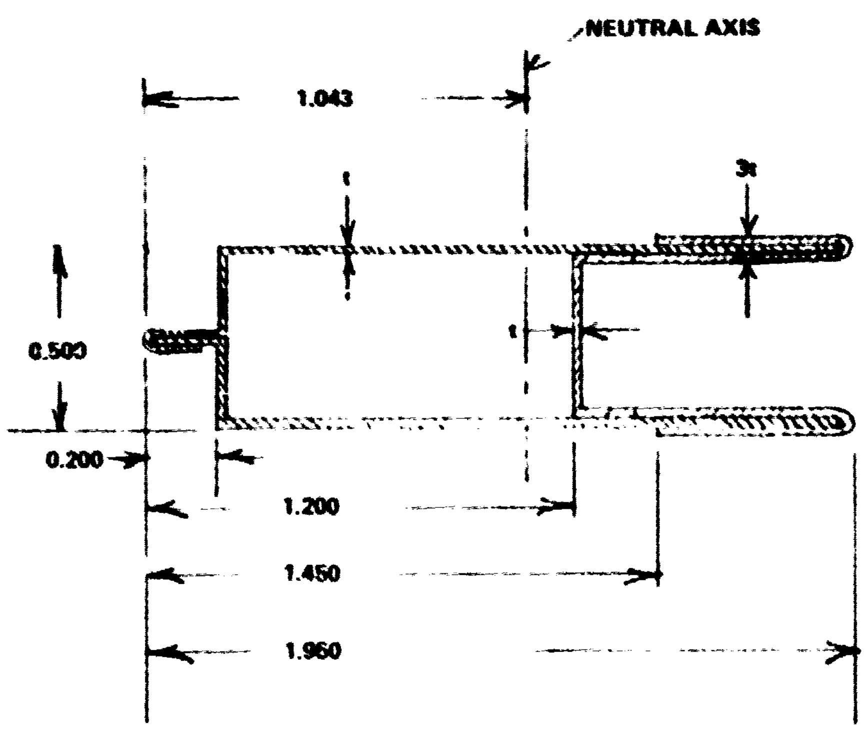

Figure 1.2.4-7. Proposed design of the shield for the foreplane assembly. Design consists of three parts. The parts are continuously assembled to each other by rolling over flanges left on top and side pieces, after the parts flow around and enclose the core of the foreplane.

1.2.4.3 Power Collection

The rectenna intercepts the RF radiation of the PSS and converts this RF power to useful utility power for public or industry consumption, nearby or far from the rectenna structure. The size and configuration of the rectenna is determined by the PSS radiated beam which is determined mainly from the amount of radiated power, the safe radiation densities (on earth and in the ionosphere) and the economy of power collection (as determined from the RF collection efficiency, the conversion efficiency of RF and the installation expenses). It appears at this time that the nominal size of 10 km for the rectenna radiatic beam is the most feasible dimension for collecting 5 GW of power at 2.45 GHz. Such a configuration complies with the previously mentioned constraints at maximum power density of 23 mw/cm^2 and with minimal atmospheric attenuation effects; especially at extreme weather conditions, with occasional rain, at the northern part of the globe.

The use of 5.8 GHz is attractive from the view point of smaller size for the rectenna structure. This advantage, however, is offset by the nearly six-fold increase in the on-axis RF field density, same degradation in the end-end efficiency, somewhat higher rain attenuation levels, and less total revenue. This analysis, as well as the atmospheric and ionospheric effects on the radiation beam are elaborated in the Phase III MPTS document.

Included within the rectenna structure is the ground segment of the retrodirective phase control link which includes separate RF trans-receive ground stations which are described in phase control section of the referenced document.

The rectenna is composed basically of 1 MW panels which are grouped together as shown in Fig. 1.2.4-8 (described in 1.2.4.4 below).

1.2.4.3.1 Layout of Rectenna Panels for RF Collection

The receiving rectenna elements locally absorb the RF radiation of their small aperture area and deliver its converted DC version to the local unit DC buss bars. In this way the accumulated DC power would be independent of the local phase front of the RF received power of the individual RF elements. The size of the panels which carry the RF elements is determined by the shadowing diffraction effects which modify the RF field levels incident on the consecutive panels.

The layout of the panel configurations is shown in Figure 1.2.4-9. At high latitudes, it is always structurally desirable to have large values for H, which translates to large values for K. On the other hand, the diffraction limitations restrict the values of H and makes it desirable to have flat rectenna structures which is easily achievable at low latitude locations of the rectenna. This limits, however, the width of the collecting panels at higher latitude locations.

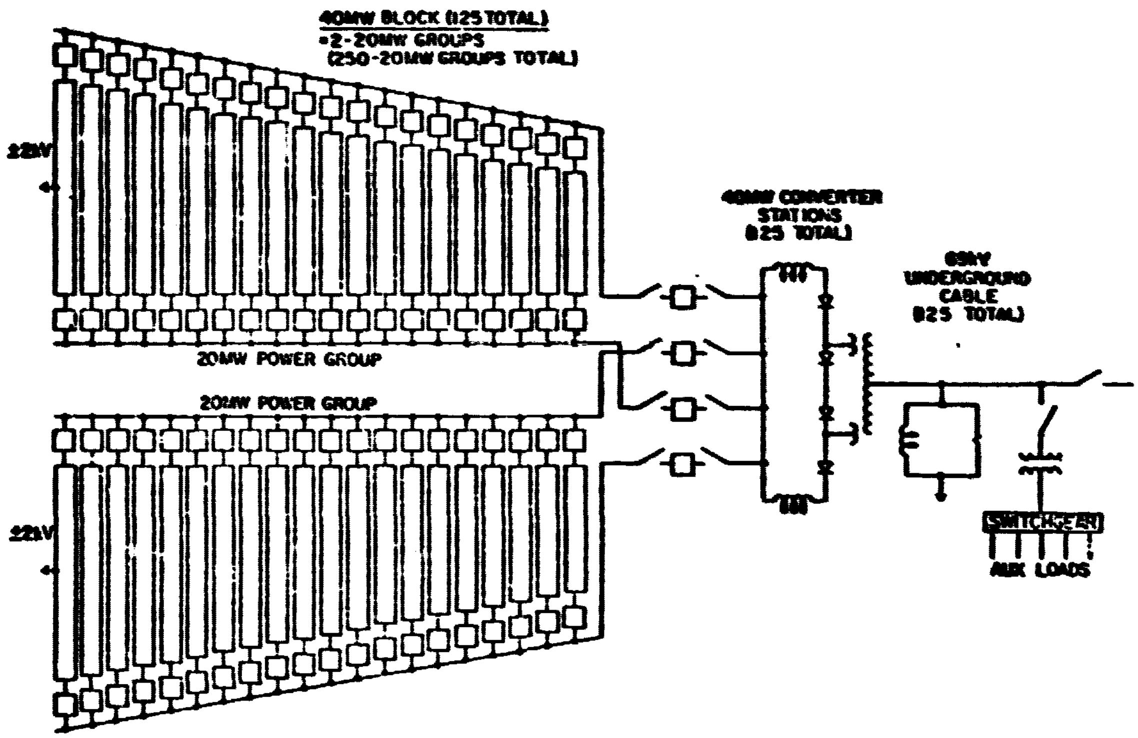

Figure 1.2.4-8. Ground Power Collection and Conversion System

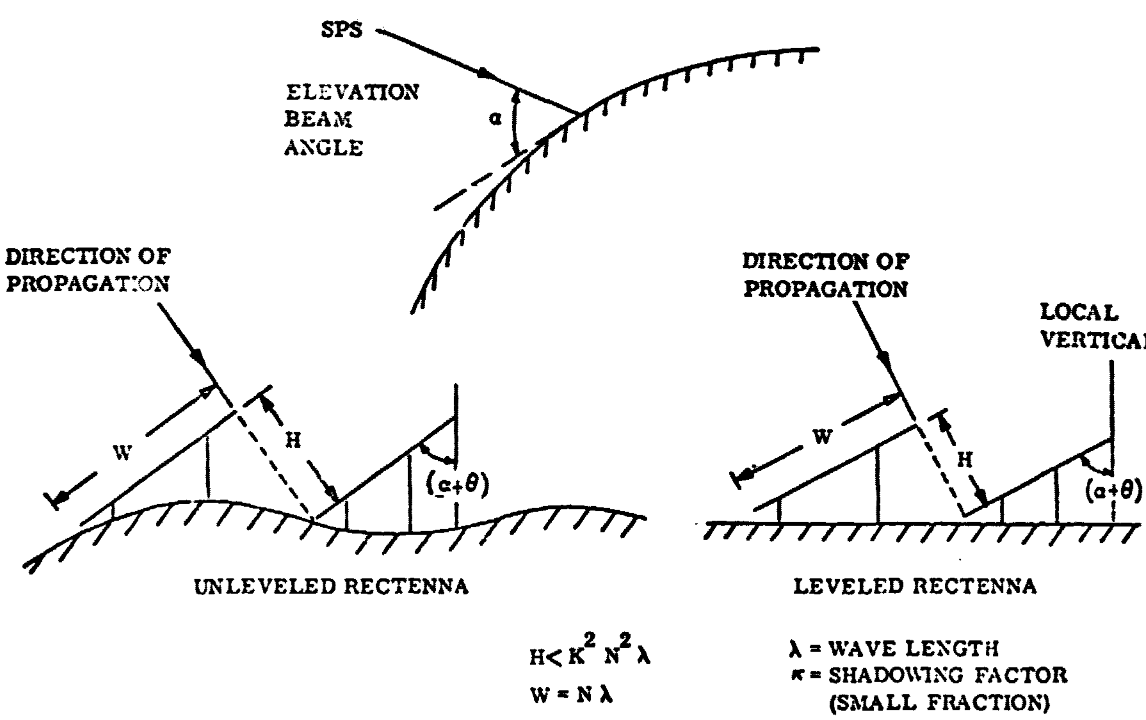

Figure 1.2.4-9. Layout of Rectenna Panels

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1.2.4.3.2 RF/DC Conversion

The RF/DC conversion occurs right behind the radiating elements using simple detection Schottky barrier diodes. These are back biased, by the buss bar generated DC voltage, which allows conduction of RF charging current pulses only in small portions of the RF oscillation cycles. Randomization of RF phase at each RF radiating element would randomize the charging pulses and avoid accumulation of RF ripples which can be wasted by radiation on the DC buss bars (which reduces the RF/DC detection efficiency). Fortunately this is the situation of the rectenna phase front after passing through the ionospheric and atmospheric layers which is also sequentially phased by the need for using a flat rectenna, where the radiating elements are arrayed in a plane tilted from the plane of the unperturbed phase front.

The optimum efficiency of the rectifying elements is attainable at specific RF density levels and at specific DC load levels. The matching DC load increases for low RF density levels, which makes it needful to use different elements at different locations of the rectenna. Higher impedance elements are needed at the rectenna edge locations which is concomitant with the need to array more parallel elements to reach specific power levels. The receiving aperture cross-section area of such an element is approximately 50 cm^2. The conversion efficiency of the element is averaged to be 89%, with 86% efficiency at the preiphery of the rectenna at power levels of approximately 1 mw/cm^2, and 94% at the center of the rectenna at power levels of 21 mw/cm^2.

The RF/DC converters are arrayed in units of 1 MW at a DC voltage of ±2 kV. These again are arrayed to form 2x20 MW primary units at the same DC voltage. The DC efficiency of arraying to the level of 40 MW units at ±2 kV is evaluated to be 97%, which leads to total RF/DC efficiency of approximately 85%.

All the primary units of 40 MW along a radial line of the rectenna are locally converted to utility power levels and the power flow is directed radially to or out of the center of the rectenna.

1.2.4.4 Local Busing

The collection of the outputs from the 1 MW primary units is done into blocks of 40 MW. This is shown in Figure 1.2.4-8. Two 20 MW power blocks each with ±2 kV is connected in parallel to one converter station. The DC cables will start closest to the periphery and run radially to the 20th primary unit in each block and then to the converter station located at the midpoint closest to the center of the rectenna for each 40 MW power block.

The 2 kV DC cables will be run in conduits and tapered to allow for the increasing current levels approaching the converter station.

1.2.4.5 Distributed Processing

Conversion to AC is performed in a total of 125 40 MW converter stations. The converter stations are shown on the diagram in Figure 1.2.4-8. The reactors shown are smoothing reactors for the purpose of reducing ripple currents.

The voltage-current characteristic of the rectenna, over the range to be considered, can be described as a constant power rectangular hyperbola. At high voltage and low current, an automatic short circuiting device or "crowbar" will be provided as an integral part of the rectenna. Likewise at the low voltage, high current end, the characteristics will be terminated by a short circuit. The only usable portion of the curve is the immediate vicinity of the rated voltage point as shown in Figure 1.2.4-10.

The inverter in the converter station is an electronic device capable of several modes of control. The line-commutated inverter is chosen for the SPS system and the inverter will operate in a constant voltage mode. It is not possible for the inverter to affect power throughout. It is therefore the goal of the control system and mode of operation to provide reliable operation at as optimum a power factor as possible.

In addition to the constant voltage portion of the converter characteristic, a constant extinction angle (γ) curve will be provided as a back-up during contingencies of low AC line voltage.

Figure 1.2.4-11 describes the converter control in block form. The "regulator" is seen feeding a transducer T which converts a voltage into an angle (or timing) for the firing pulses to the thyristors of the converter bridge circuit.

A DC voltage sensor provides a measure of the actual voltage which, when compared with the reference voltage (E_{ref}), provides the error signal for the regulator. This automatic voltage control loop is the primary control of the converter.

AC line current and AC line voltage are measured (as shown) and a relative timing signal is developed which results in measurement of extinction angle γ. This quantity is compared to the extinction angle reference and the resulting error signal passes to the regulator and holds the constant γ curve when conditions are such that constant voltage cannot be held.

A branch in the γ quantity is shown passing through a deadband controller and affecting the load tap changer on the primary of the transformer. This forces the converter to operate in the steady state at its optimum control point and compensates for variations in AC system voltage.

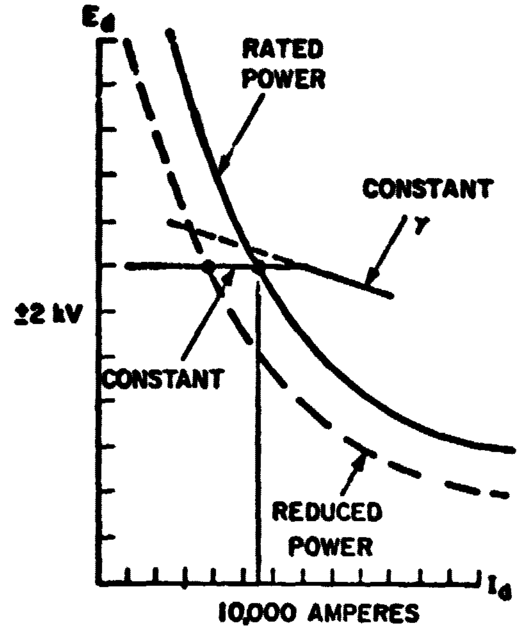

Figure 1.2.4-10 Converter Characteristic

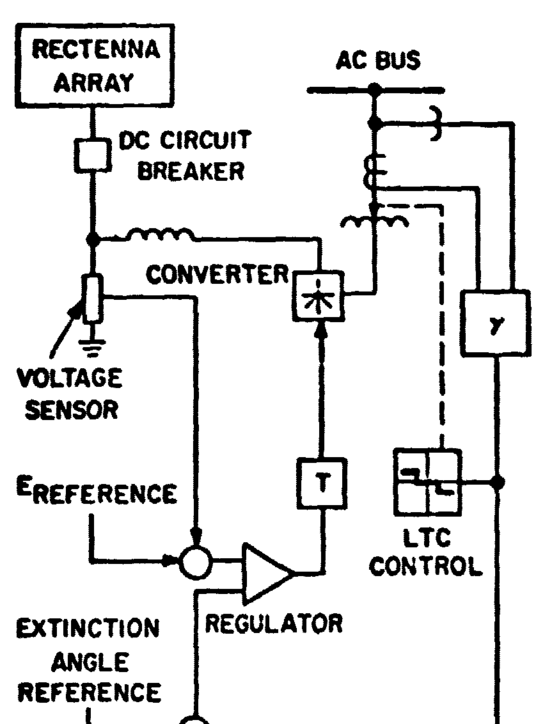

Figure 1.2.4-11 Converter Control Block Diagram

1.2.4.6 Grid Interface Provisions

The converter thyristor bridge circuit feeds alternating current to the converter transformer which steps the voltage up to 69 kV to 60 Hz.

Filters connected to the AC bus absorb current harmonics generated in the converter. The AC wave shape is thereby kept within acceptable harmonic content limits for the utility grid and associated plant equipment.

The converter station output, at 69 kV and a maximum current of 400 amperes is transmitted by underground cable to the transformer station as shown in Figure 1.2.4-12.

The converter station, once commissioned, operates automatically. All switching, startup and shutdown are directed and monitored by a small computer system in conjunction with other converter and station control equipment.

Since the rectennas are constant power devices and the DC/AC converter can in no way affect power flow, the control of power can be applied on the DC side. This means that either the RF level must be controlled at its source or the number of rectennas connected in parallel must be varied. Circuit breakers provided for rectenna protection can also be used to add or remove units in order to control power, but not on a continuous basis.

The collection/transformer station gathers the power output of 5 converter stations, connects these circuits into a reliable switching arrangement, and transforms the AC power from 69 kV up to 230 kV. This is done by physically and electrically arranging and connecting standard electrical equipment into the desired configuration. The electrical configuration provides reliability by a "breaker and a half" scheme 69 kV switchyard. A single contingency outage can be sustained in the 69 kV switchyard without loss of power output capability. To provide compensation for the inherent lagging power factor characteristics of the converter valve and trnasformer equipment one 100 MVAR synchronous condenser is connected to the 69 kV bus. The synchronous condenser rating is chosen to allow synchronous condenser maintenance on adjacent collection/transformer stations without curtailing power output.

The step-up switching station receives the output from five collection/transformer stations at 230 kV and transforms the voltage to 500 kV. The "breaker and a half" scheme employed can sustain any single contingency 230 kV switchyard fault without reduction in station output. The selection of the voltage level for the ultimate bulk power transmission interface with the utility grid as well as the possiblity of interconnecting two or more of the 1000 MW switching stations together should be optimized based on detailed information about the connecting utility system. The solution shown in Figure 1.2.4-12 is one of several possible.

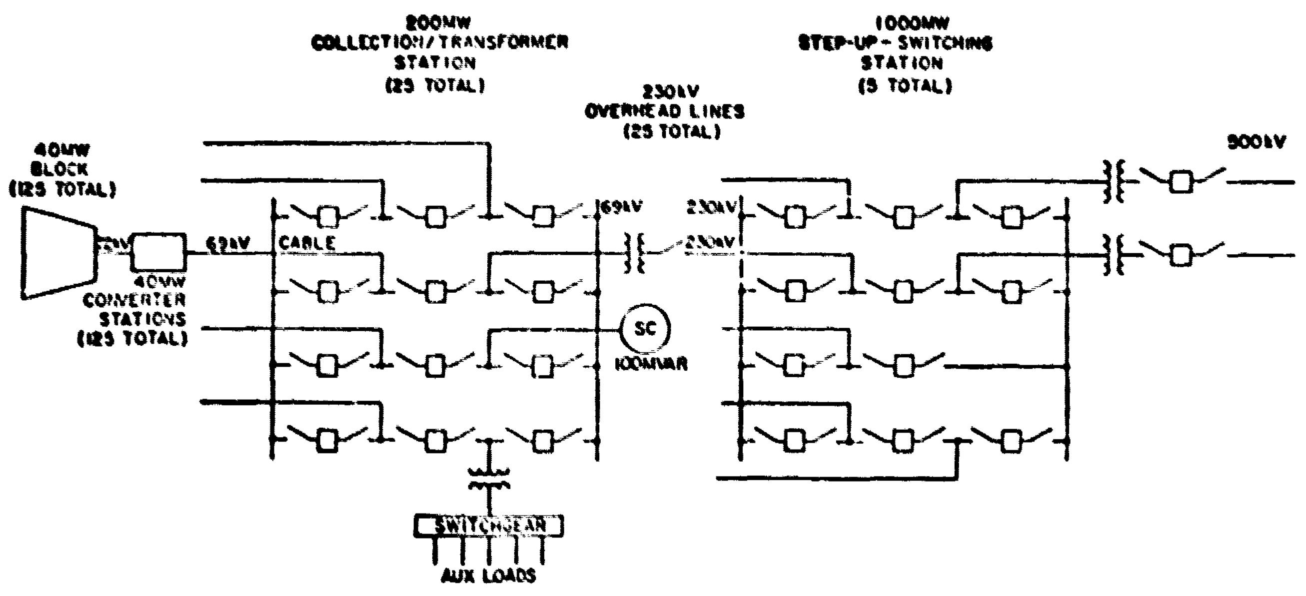

Figure 1.2.4-12. Ground Power Collection and Transmission System

WBS 1.3.0 SPS SPACE CONSTRUCTION AND MAINTENANCE

WBS Dictionary—This element includes all space facilities, construction and maintenance equipment, crew habitats, and the in-space crews.

Integrated Space Operations and Maintenance Concept Description

The integrated construction, maintenance and transportation operational concept for Low Earth Orbit (LEO) construction of the CR=1 photovoltaic satellite is shown in Figure 1.3.0-1. Space operations crews and all hardware and consumables required in space are delivered to LEO by launch vehicles. The crew launch vehicle was assumed to be an improved space shuttle with the solid rocket boosters replaced by a reusable liquid propellant booster. The cargo vehicle is a two-stage wing-wing vehicle capable of delivering approximately 400000 Kg of payload per flight. Crew flights occur every two weeks while three cargo vehicle flights are required every two days to each construction facility for the case of constructing one 10 GWe satellite per year.

The LEO construction base is nominally located in a 478 Km circular orbit at 31° inclination. This base houses a crew of 480 with overflow quarters for transients, e.g., those crew members awaiting transportation to some other location. The primary purpose of the LEO base is construction of eight SPS power generation modules and two antennas. The satellite construction timeline is shown in Figure 1.3.0-2. The base also serves as a staging depot for orbit transfer vehicles used to carry construction and maintenance crews, crew supplies and replacement parts to the GEO base. A construction crew OTV flight to the GEO base normally occurs once every three months. Maintenance crew and replacement components are also transferred to GEO every three months.

The satellite modules are equipped with electric propulsion systems and flight control systems for the self-powered trip to GEO. Figure 1.3.0-3 shows a typical module arrangement as configured for the transfer. Thruster installation are located at the module corners for maximum control authority. Propellant tanks are located at the center of the module. Although the propulsion system is primarily solar-electric, some chemical (LO_2/LH_2) thrust capability is also provided so that control authority can be maintained while flying through the Earth's shadow and during periods of high gravity gradient torque.

The GEO base is used for final assembly and maintenance operations. The final assembly operations include module berthing, antenna placement, and deployment of solar array. The maintenance operations include refurbishment of failed SPS hardware. The GEO base is also used as a staging area for the satellite maintenance crews, mobile habitats,spare parts (LRU's) and their orbit transfer vehicles. The GEO base houses 60 final assembly crew members and up to 240 SPS maintenance crew members.

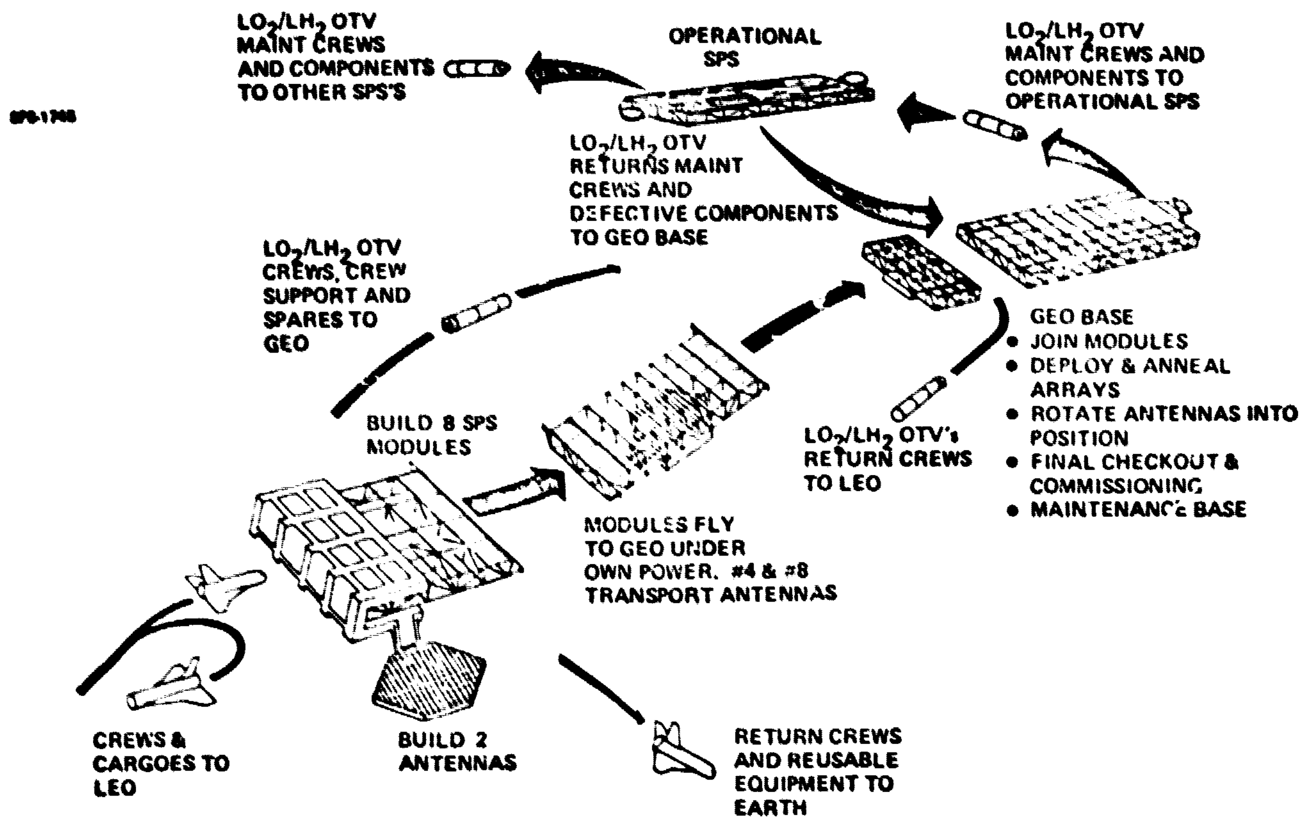

Figure 1.3.0-1 Integrated Space Operations

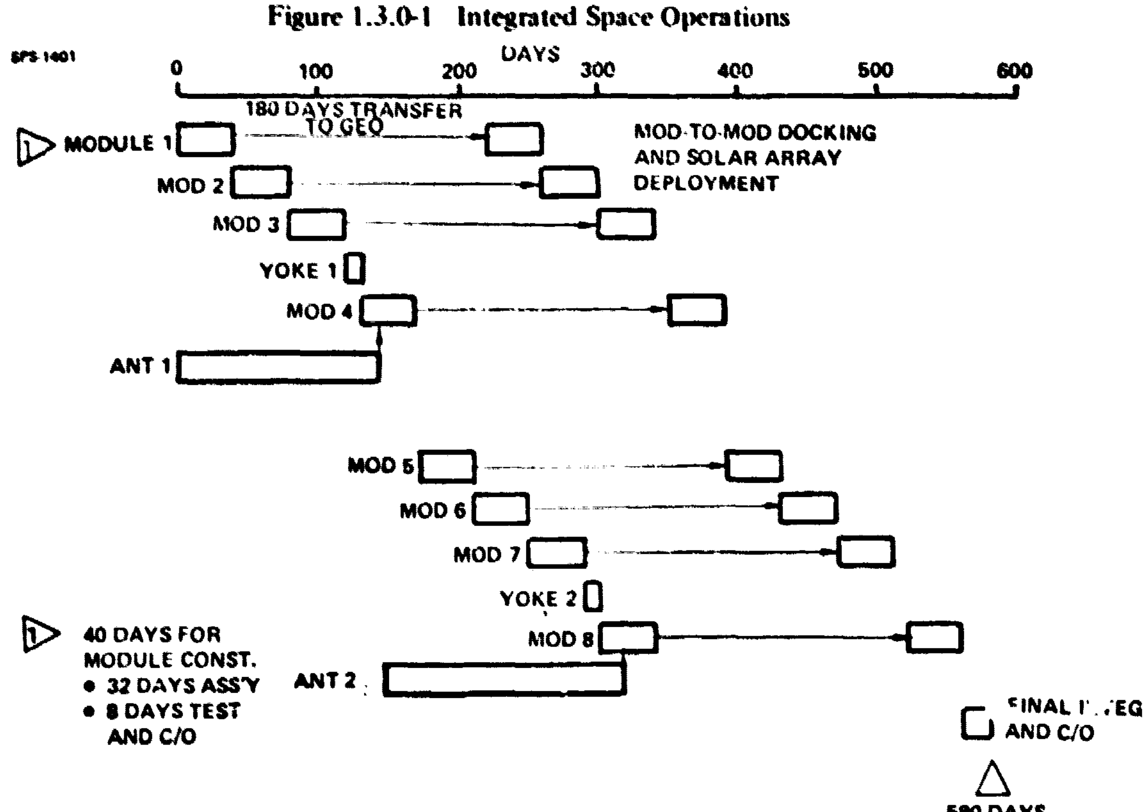

Figure 1.3.0-2 Photovoltaic Satellite LEO Construction Timeline

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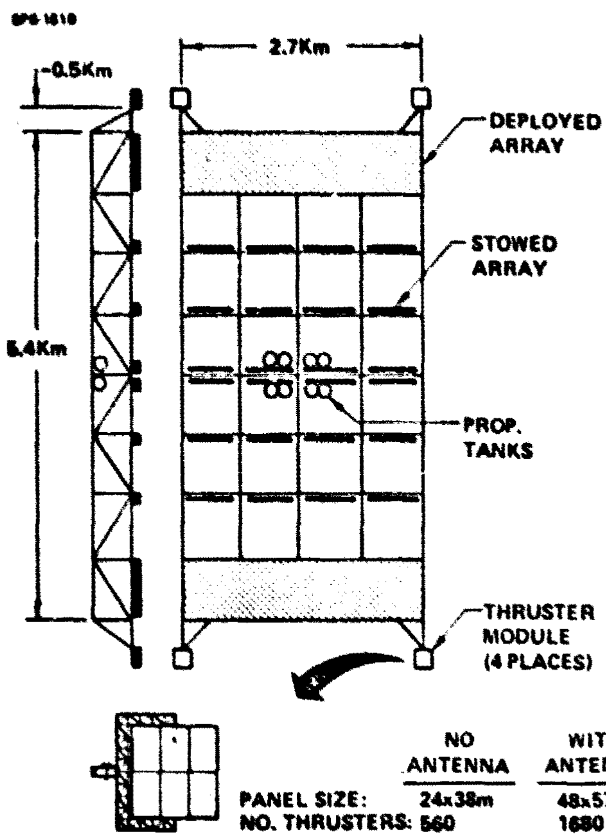

	NO ANTENNA	WITH ANTENNA
PANEL SIZE:	24x38m	48x57m
NO. THRUSTERS:	560	1680

GENERAL CHARACTERISTICS

- 5% OVERSIZING (RADIATION)
- TRIP TIME = 180 DAYS
- ISP = 7000 SEC

MODULE CHARACTERISTICS	NO ANTENNA	WITH ANTENNA
• NO. MODULES	6	2
• MODULE MASS (10^6KG)	8.7	23.7
• POWER REQ'D (10^6Kw)	0.3	0.81
• ARRAY %	13	36
• OTS DRY (10^6KG)	1.1	2.9
• ARGON (10^6KG)	2.0	5.6
• LO_2/LH_2 (10^6KG)	1.0	2.8
• ELEC THRUST (10^3N)	4.5	12.2
• CHEM THRUST (10^3N)	12.0	5.0

Figure 1.3.0-3 Self Power Configuration Photovoltaic Satellite

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The maintenance crews are dispatched from the GEO base in an OTV-propelled crew module along with an OTV-propelled replacement parts module destined for an operational SPS that is scheduled for regular maintenance. The maintenance crew will visit each SPS two times per year and will spend four days replacing defective components before returning to the GEO base or proceeding to the next SPS.

Construction Cost Summary

Construction costs include amortization of the facility and equipment and its transportation, crew operations and support, and construction crew transportation. Values shown were obtained from the Part II final report, Vol. 6, except for crew transportation cost.

	Cost in Millions
Construction Base Amortization	695
Crew Support and Operations	513
Total direct	1109
Crew & Supplies Transportation	(545)
Total Related to Construction	(1654)

NOTE: Crew and supplies transportation is reported as a space transportation cost in the overall cost summary.

WBS 1.3.1 Low Earth Orbit Construction Base and Operation

WBS Dictionary

This element includes the facility framework, crew modules, work modules, cargo handling distribution systems, base subsystems, construction equipment and maintenance provisions that comprise the low Earth orbit construction base.

Summary Description

LEO construction base for the photovoltaic satellite consists of two interconnecting facilities. of the facilities is used to construct the module and the other is used to construct the antennas shown in Figure 1.3.1 and 1.3.2.

The module construction facility is an open-ended structure which allows the 4-bay-wide module to be constructed with only longitudinal indexing. There are two sets of internal working bays. The aft bays are used for structural assembly using moving beam machines and crane manipulators attached to both the "A" level and "D" level surfaces of the facility. Solar array and power distribution components are installed from equipment located on the "A" level in the forward bays. (In

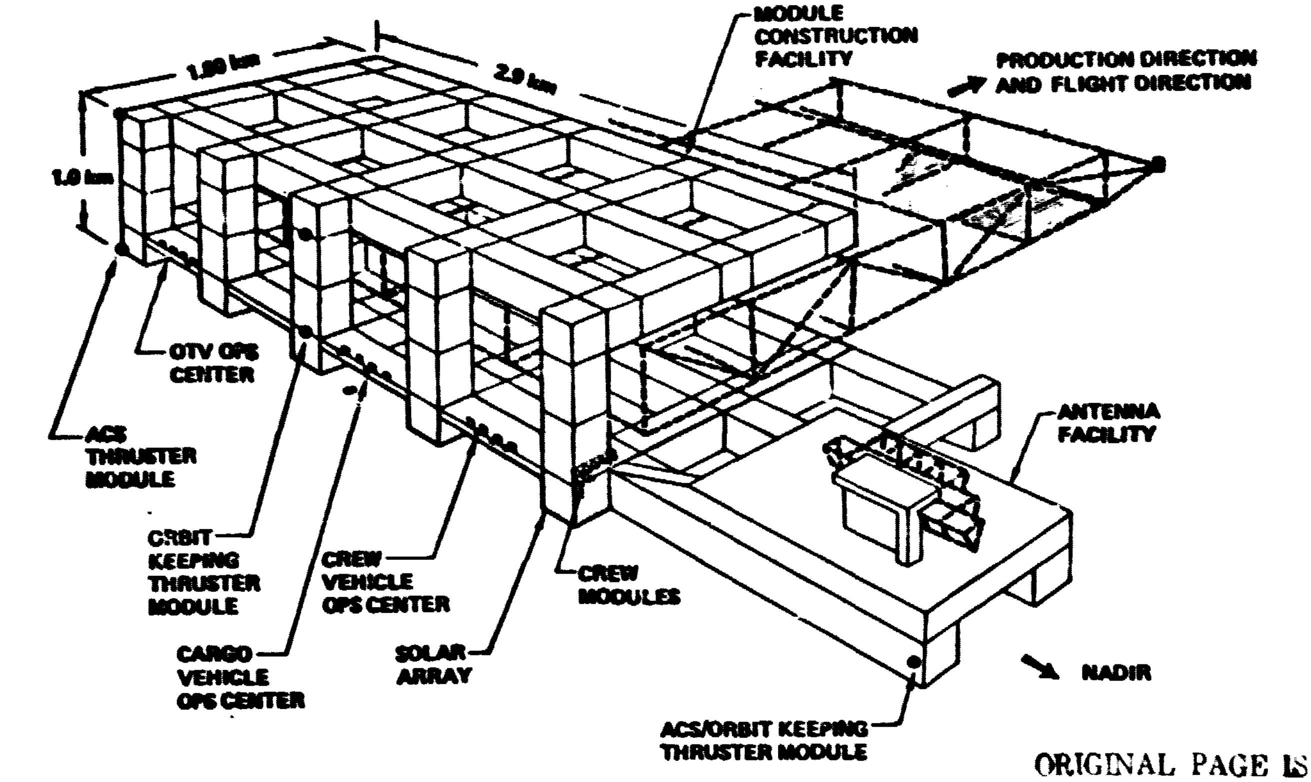


Figure 1.3.1-1 LEO Construction Base Photovoltaic Satellite

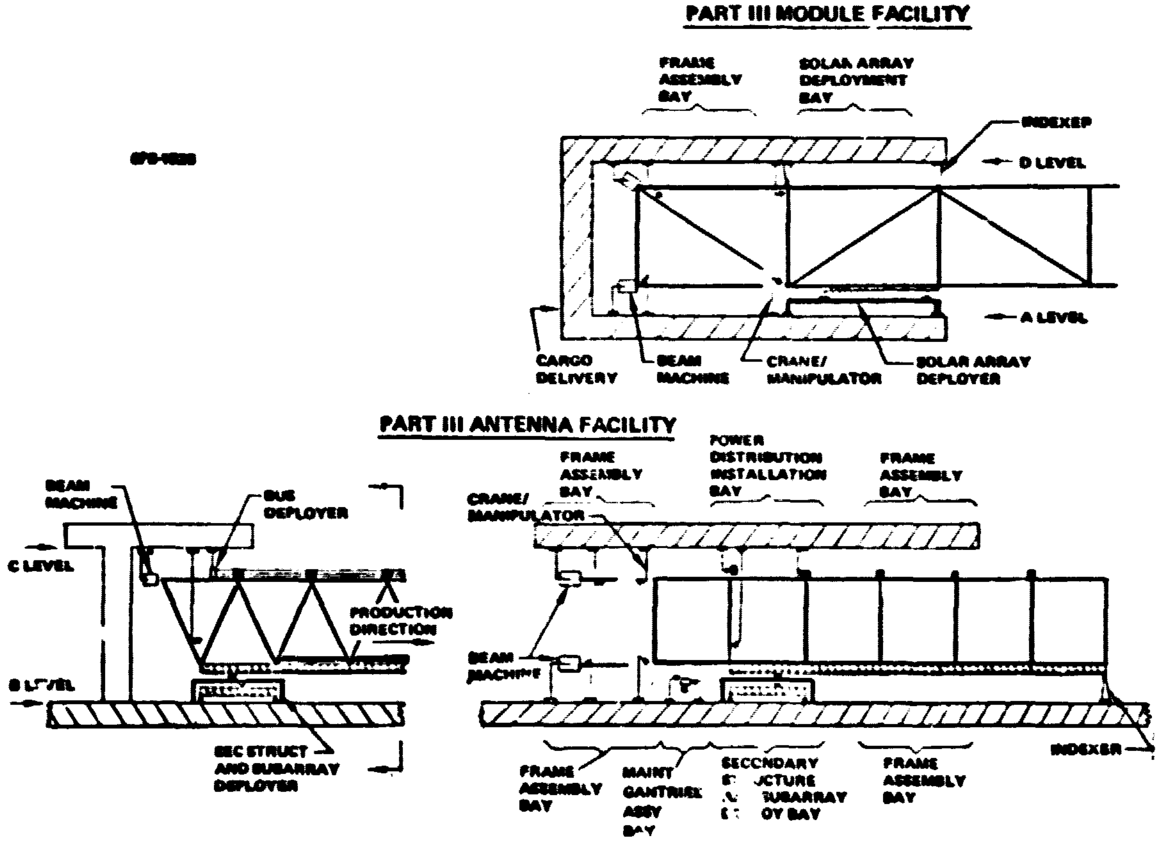


Figure 1.3.1-2 Construction Base Equipment/Operations

Part II, the solar arrays were deployed from the "D" level of the facility. Cargo movement considerations led to relocating this operation to the "D" level). The satellite module is supported and indexed by movable towers located on the "D" level of the facility.

The antenna facility is located with respect to the module facility in such a way that the antenna is constructed at a location where the completed antenna can be mated to the yoke without any vertical movement. The antenna construction facility (also shown in Figure 1.3.1-2) is configured in an open-ended structure that is five antenna bays wide which allows the antenna to be constructed using both lateral and longitudinal indexing. The two end bays are used to assemble the primary structure and the inner bays are used to deploy the secondary structure and subarrays, and to install the power distribution system and maintenance gantries. Construction equipment operates from both the "B" and "C" levels of the antenna facility.

The antenna facility concept has been changed from that shown in Part II to reflect the "A" frame (Vee Ridge) primary structure of the antenna described in Section 1.1.5.1.1. This new antenna configuration was chosen as a result of the maintenance analysis which shows that this primary structure provides better access for maintenance than other alternative structures.

The module construction sequence for the structure, solar array and power buses begins with building the first end frame of the structure. This completed end frame is indexed forward one structural bay length. Machines can then form the remainder of the structure in each of the bays. Figures 1.3.2-3 and -4 show how the beams are assembled. The first row of four bays is then indexed forward to allow construction of the second row of structural bays in parallel with installation of solar arrays in bay 1 through 4. This sequence is shown in Figure 1.3.1-5. Solar array installation and construction of structure occurs simultaneously across the width of the module, although neither operation depends on the other. At the completion of the 16 bays (four rows of bays in length), the power buses and propellant tanks are installed. Construction of the structure and installation of solar arrays of the remaining four bay lengths of the module are done in a similar manner to that previously described. Thruster modules for the self-power system are attached to each of the four corners of the module. An annealing device gantry is installed on each module. The module construction timeline is shown in Figure 1.3.1-6.

Construction of the antenna takes place in parallel with module construction. The first antenna is completed during construction of the fourth satellite module; the second antenna is completed with the eighth module. The antenna construction sequence is shown in Figure 1.3.1-7. The antenna is indexed laterally through the facility one bay at a time. When a full width of bays is constructed the antenna is indexed longitudinally out of the facility so that the next strip of bays can be assembled. When the antenna is completed, it will be located at the proper position so that it can be mated to the yoke. (see Figure 1.3.1-9 in Section WBS 1.3.1.1)

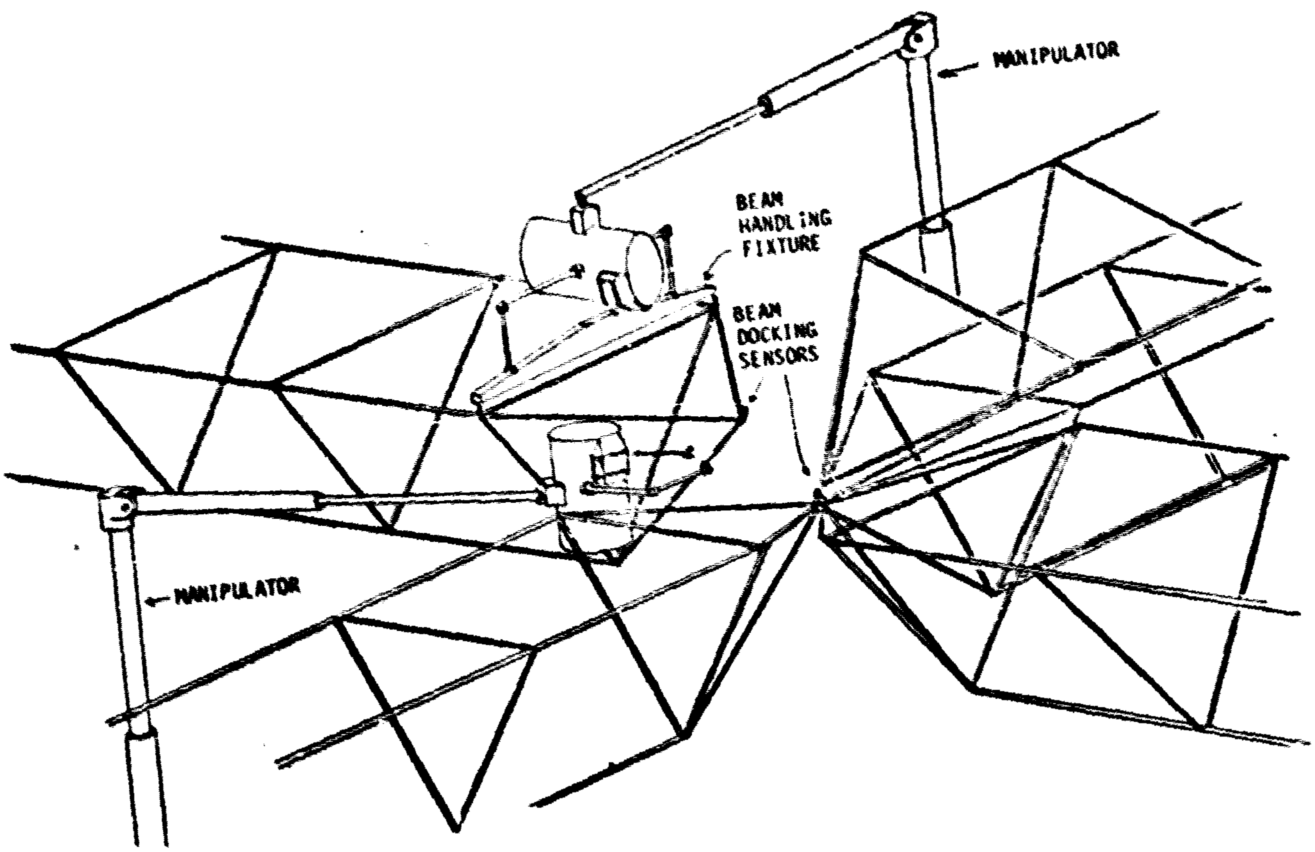
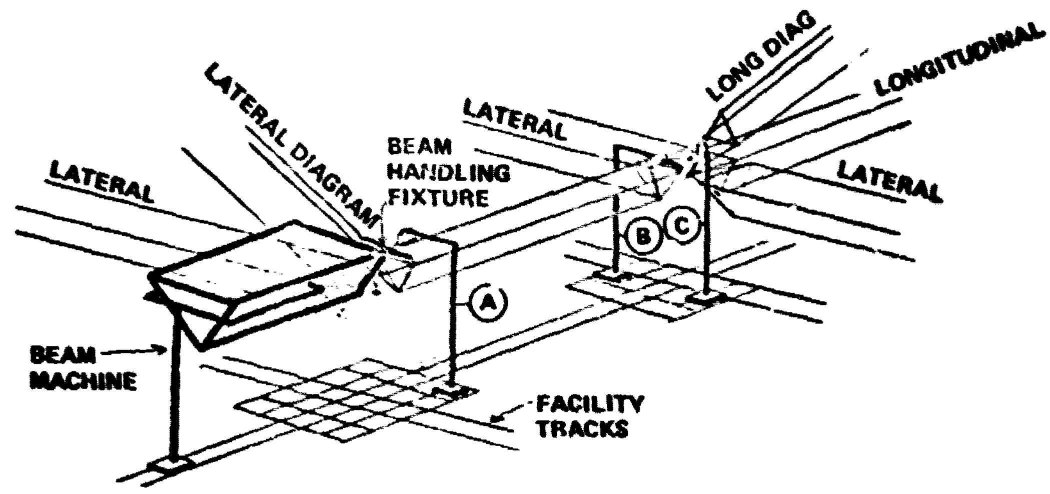


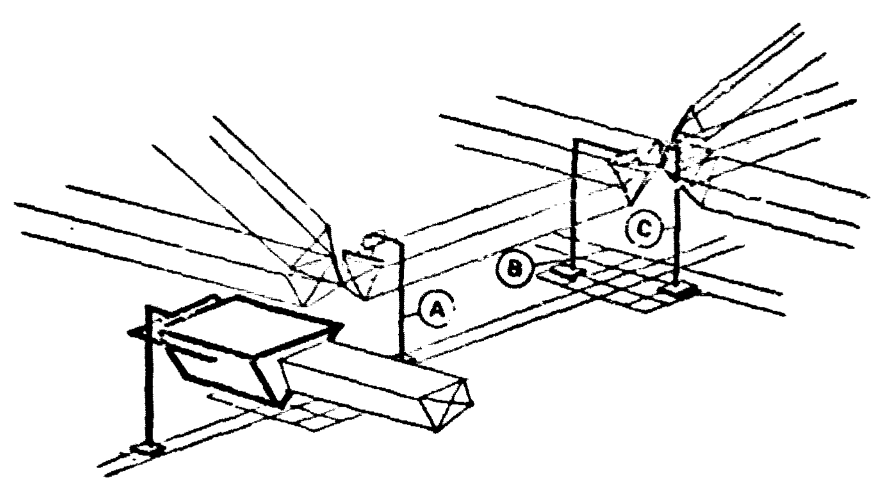
Figure 1.3.1-3 Frame Assembly

①



- BEAM MACHINE COMPLETES NEW LONGITUDINAL BEAM
- MANIPULATORS (A) AND (B) ATTACH TO BEAM AND REMOVE IT FROM THE BEAM MACHINE
- MANIPULATOR (C) ATTACHES BEAM DOCKING SENSOR

②



- BEAM MACHINE RELOCATES, ROTATES 90°, AND INITIATE FABRICATION OF LATERAL BEAM
- MANIPULATORS (A) AND (B) ATTACH LONGITUDINAL BEAM AT EACH END

Figure 1.3.1-4 Frame Assembly Operations

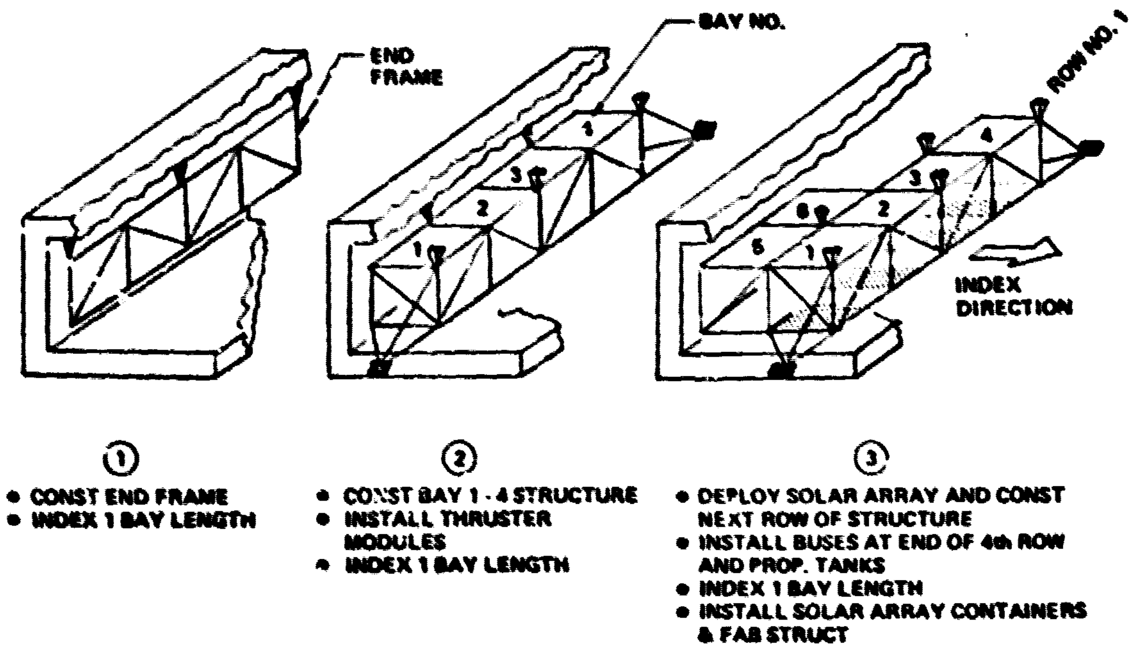


Figure 1.3.1-5 Module Construction Sequence

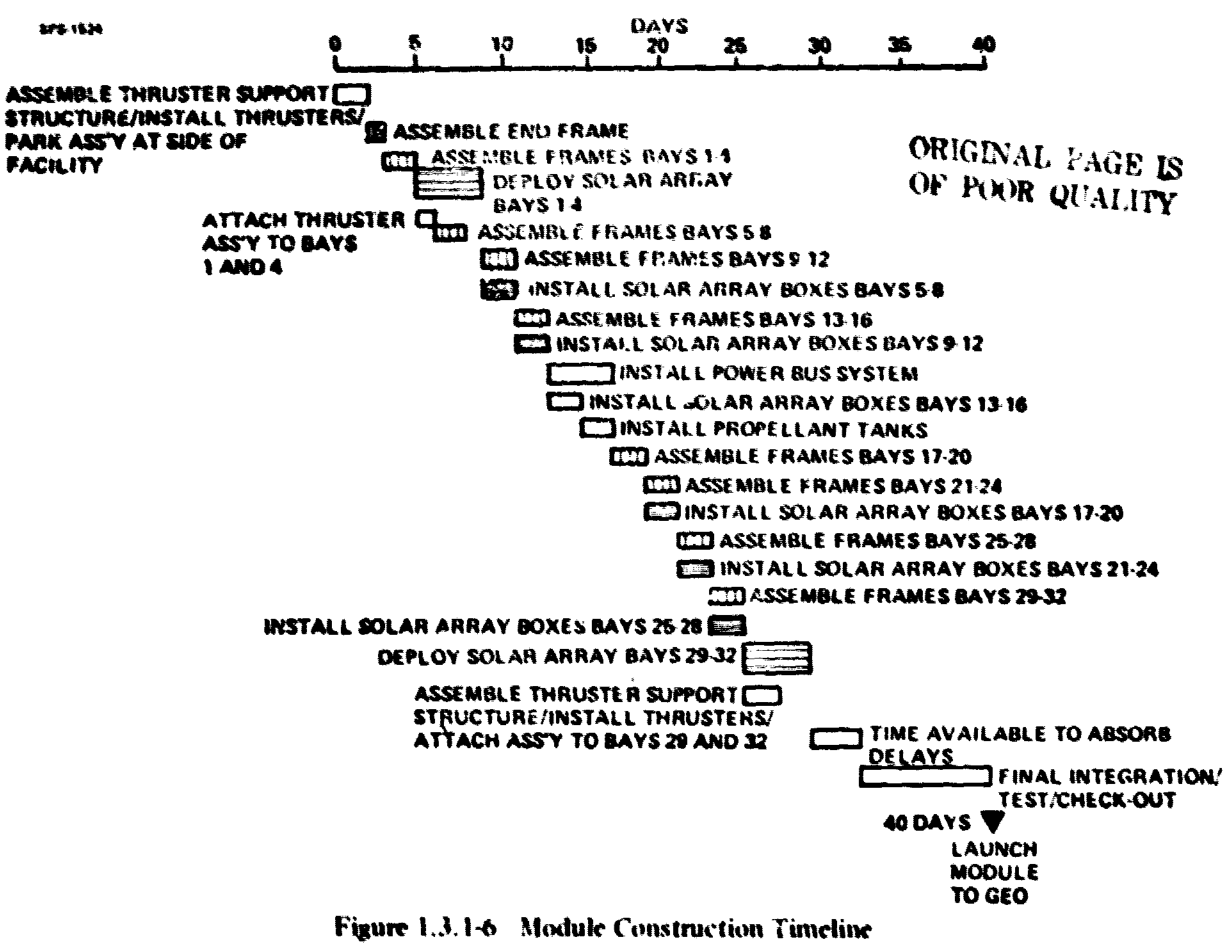


Figure 1.3.1-6 Module Construction Timeline

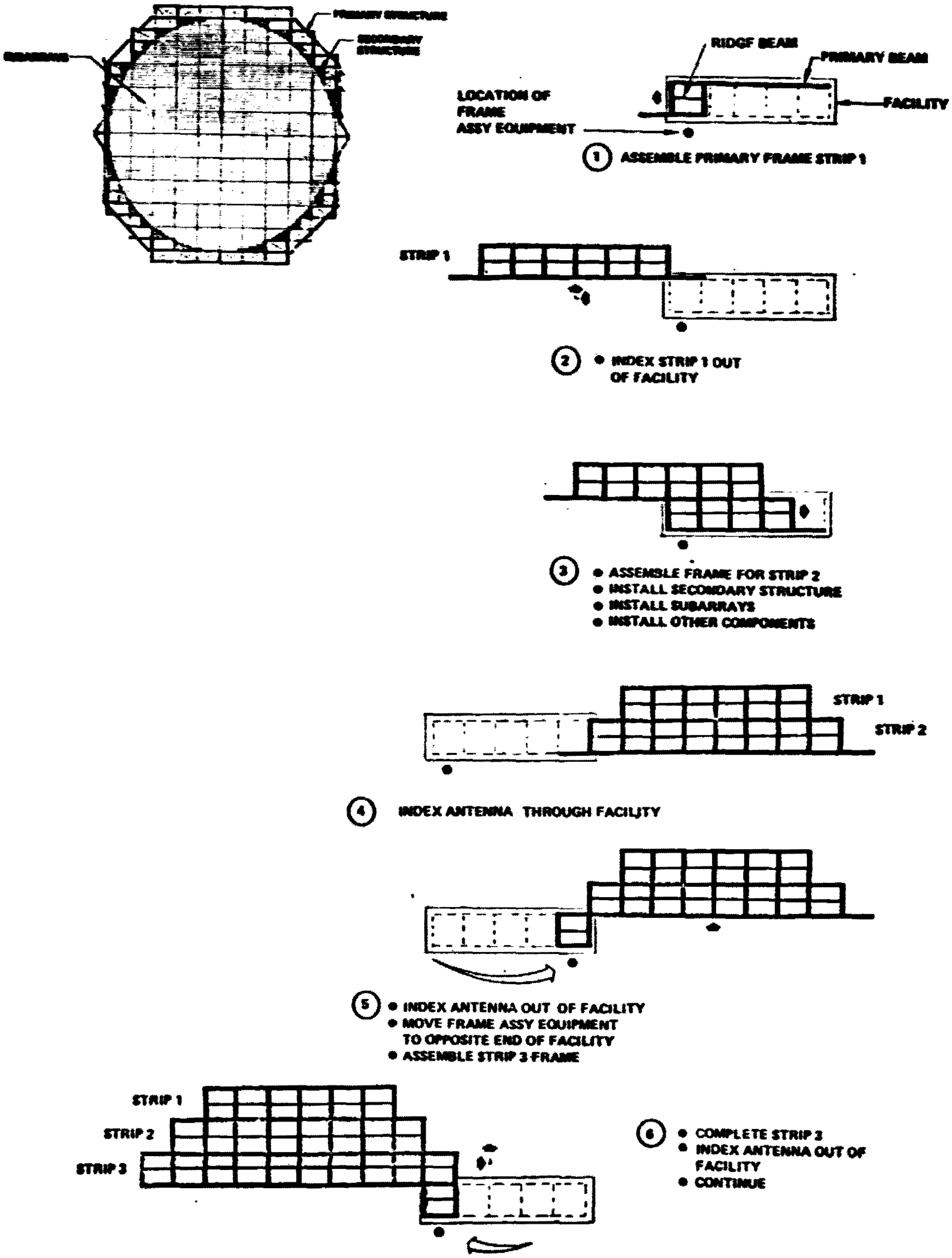


Figure 1.3.1-7 Antenna Assembly Sequence

As shown in Figure 1.3.1-8 the yoke for the antenna is constructed in the module construction facility because of its large dimensions. This requires the yoke to be made between the third and fourth module and between the seventh and eighth modules. Following yoke construction, it is moved to the side of the module facility. At that time, either the fourth or the eighth module will be constructed. During the construction of these modules, the antenna is completed so that it can then be attached to the yoke. After five bays of either the fourth or eighth module have been completed, the antenna/yoke combination can then be attached to the module in its required location. Construction of two more rows of bays pushes the antenna outside the facility where it then can be hinged over the module for its transfer to GEO.

Mass Summary

The mass of the LEO construction base is summarized in Table 1.3.1-1.

Cost Summary

The cost of the LEO construction base is summarized in Table 1.3.1-2.

Crew Summary

The crew size at the LEO construction base is summarized in Table 1.3.1-3. The crew scheduling concept that was used was as follows:

- 90 day staytime
- 6 days on/1 day off per week
- 10 hours work shift per day (5/1/5/13 work-rest cycle)
- 2 shifts per day (2 crews)
- .75 operator productivity factor

WBS 1.3.1.1 Facility

WBS Dictionary

This element includes the LEO base facility framework, crew modules, work modules, cargo handling/distribution system, and base subsystem.

Element Dictionary

The general arrangement of the construction base has been described in Section 1.3.1. In summary, the base is divided into two major facilities with one used to construct the satellite and the other to construct the antennas.

The overall construction base is shown in greater detail in Figure 1.3.1-9. The principal elements of the base include the structural framework, cargo handling and distribution system, crew modules and base subsystems.

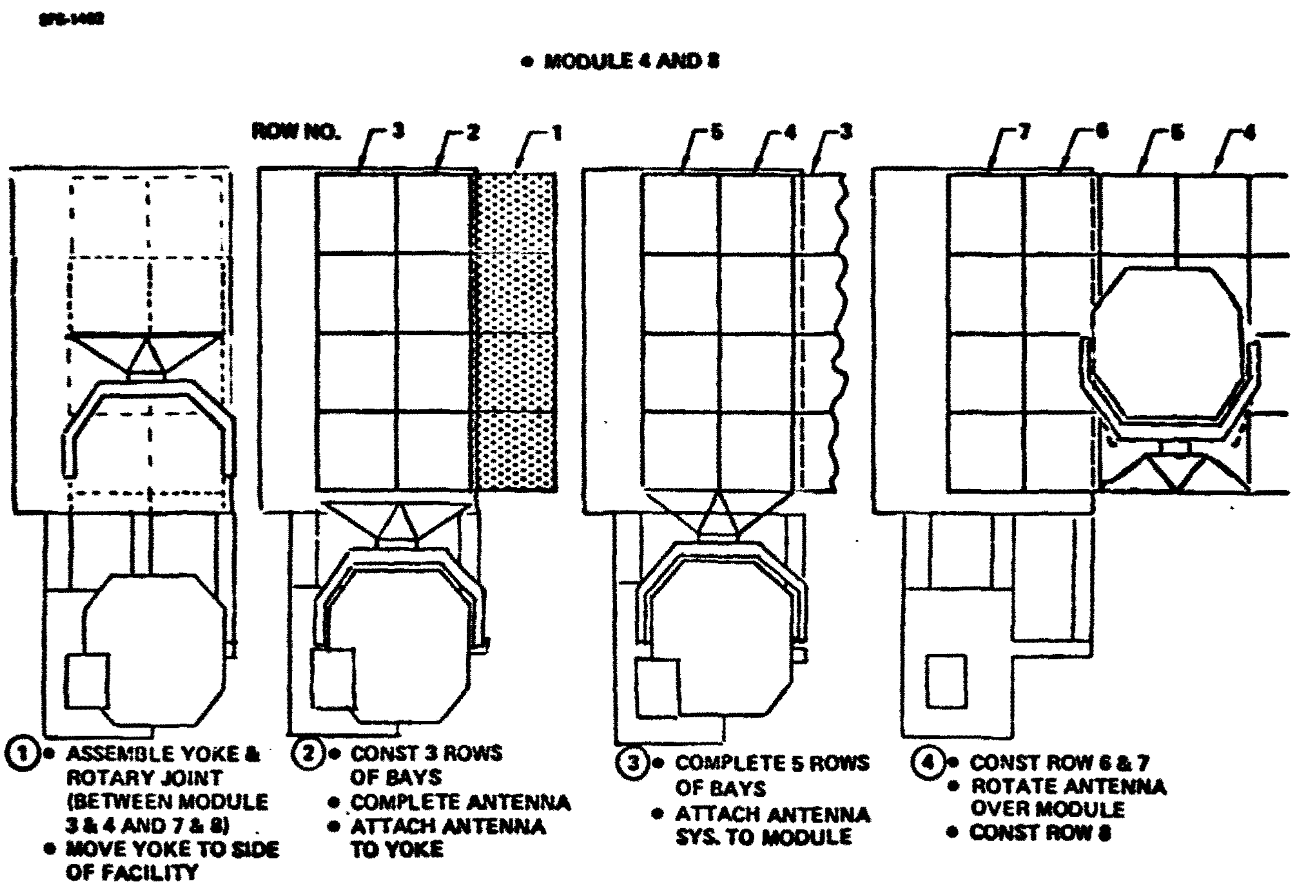


Figure 1.3.1-8 Antenna/Yoke/Module Assembly Photovoltaic Satellite

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Table 1.3.1-1 LEO Construction Base ROM Mass

	10^3kg	
FACILITY		
FRAMEWORK	(5200)	
CREW MODULES	2500	
CARGO HANDLING/DISTRIBUTION	2000	▷1
BASE SUBSYSTEMS	400	
MAINTENANCE PROVISIONS	200	
	100	
CONSTRUCTION AND SUPPORT EQUIPMENT		
STRUCTURAL ASSEMBLY	(400)	
ENERGY COLLECTION/CONVERSION INSTALL.	80	
POWER DISTRIBUTION INSTALL.	60	
ANTENNA SUBARRAY/SEC. STRUCT INSTALL.	20	
CRANES/MANIPULATORS	30	
INDEXERS	180	
	30	
DRY TOTAL	(5600	
CONSUMABLES (90 DAYS)	(270)	
TOTAL	(5870)	

▷1 INCLUDES 33% GROWTH ALLOWANCE.
OTHER ITEMS DO NOT INCL. GROWTH.

Table 1.3.1-2 LEO Construction Base ROM Cost

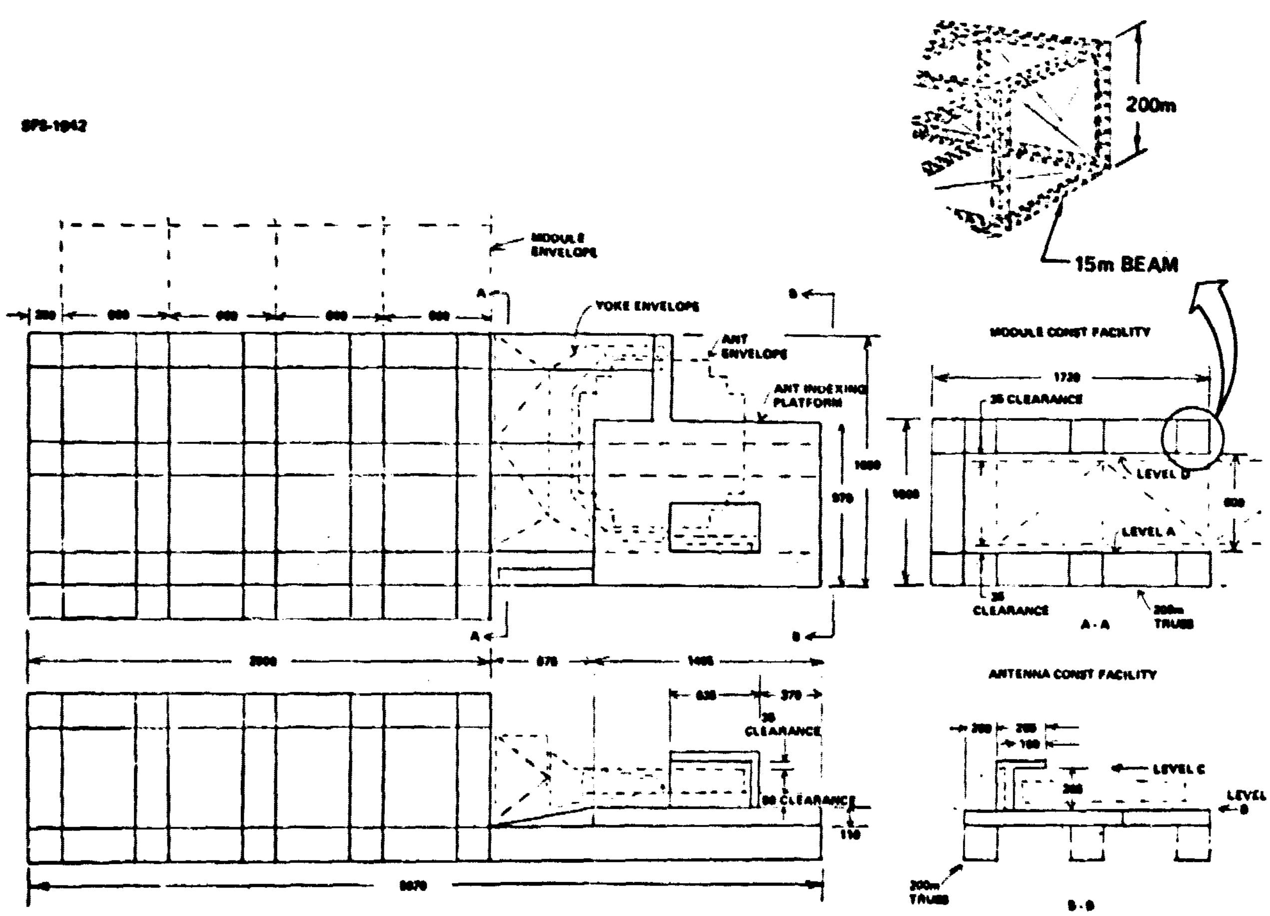
	$\$10^6$	
FACILITY		(3465)
FRAMEWORK	350	
CREW MODULES	2870	
CARGO HANDLING/DISTRIBUTION	330	
BASE SUBSYSTEM	15	
MAINTENANCE PROVISIONS	–	
CONSTRUCTION AND SUPPORT EQUIPMENT		(1310)
STRUCTURAL ASSEMBLY	350	
ENERGY COLLECTION CONVERSION INSTALL.	165	
POWER DISTRIBUTION	75	
SUBARARY INSTALL.	80	
CRANES/MANIPULATORS	560	
INDEXERS	80	
	BASIC HARDWARE	(4775)
SPARES (15%) [1]		715
INSTALL, ASSY, C/O (16%)		765
SE & I (7%)		335
PROJ MGT (2%)		95
SYS TEST (3%)		145
GSE (4%)		190
	TOTAL	(7020)

[1] % OF BASIC HARDWARE

Table 1.3.1-3 LEO Construction Base Crew Size Estimate

SPS 1455

BASE MGMT	(10)
CONSTRUCTION	(352)
MGMT	22
MODULE CONST	68
ANTENNA CONST	82
SUBASSEMBLY	49
MAINT	49
LOGISTICS	42
TEST/QC	40
BASE OPS	(39)
MGMT	7
TRANSPORTATION	18
COMM	8
DATA PROCESSING	6
BASE SUPPORT	(77)
MGMT	8
BASE UTILITIES	14
HOTEL	38
MEDICAL	13
FLT CONT	4
BASE TOTAL	478



NOTE: ALL DIMENSIONS IN METERS

Figure 1.3.1-9 LEO Construction Base

The framework for both the module and antenna facilities include upper and lower surfaces to which construction equipment is attached, the satellite is supported and other base elements are attached.

Ten primary crew modules are located in an area where the greatest concentration of personnel are involved while performing their daily duties. Six of the modules serve as crew quarters and four as work centers. Other pressurized shirt sleeve work modules are also present but serve only as small work quarters sometimes referred to as remote work stations or control cabs.

Docking provisions for all transportation vehicles are located along the back edge of the module facility. The orbit transfer vehicle operations center is located at the opposite end of the base from the crew modules due to the required proprellant transfer operations.

Each of the base elements is described in additional detail in subsequent paragraphs.

WBS 1.3.1.1.1 Framework

WBS Dictionary
This element includes all of the structural elements that comprise the framework of the LEO base.

Element Description
The structural framework of the construction base must provide a mounting/attachment surface for all construction equipment as well as mounting provision for other base elements such as crew modules, cargo handling and distribution systems and base subsystems.

The structure of the module facility consists of five 200m trusses formed in the shape of a "C" that are connected together with three 200m lateral trusses in both the upper and lower surfaces of the facility as was shown previously in Figure 1.3.1-9. Each truss consists of four 15m beams running its entire length. The truss also includes perpendicular and diagonal members which are also 15m beams. The 15m beams are the same type as used in the satellite with all individual struts having a wall thickness of 0.05 cm (0.020 in.) resulting in a mass of 5 kg per meter. This sizing appears to be rather conservative but seems justified at this point in the analyses. The module construction facility was found to have approximately 435000m of 15m beam.

The antenna construction facility was assumed to have truss depths of 50m in its upper and lower surfaces. As a result, a total length of 53,000m of 15m beam was estimated. Again, the 15m beam was assumed to have a mass of 5 kg meters.

WBS 1.3.1.1.2 Crew Modules

WBS Dictionary

This element includes the crew modules designated as crew living quarters. The crew module structure, electrical power, environmental control, life support, crew accommodations, and information systems are described. Excluded from this category of modules are the crew work modules, the crew buses used to transfer personnel around the base and the small two-man control cabins used in conjunction with the construction equipment and cargo handling and distribution equipment.

Element Description

A total of five primary crew modules have been included in the LEO construction base. The modules have an Earth atmosphere environment and have been sized to accommodate crew sizes between 50 and 100. Accordingly, the modules have dimensions of 17m diameter and up to 23m length.

A summary listing of these modules and their functions are presented in Table 1.3.1-4. All modules are self-sufficient in terms of environmental control provisions and emergency power. Primary power is obtained through a common power supply provided by the base. Five crew quarter modules have been provided with each sized for a crew of 100. These modules provide all of the off-work functions associated with living. Further information concerning the sizing of each module is presented in subsequent paragraphs.

As indicated, a transient crew quarters has been provided. The logic associated with this module relates to crew rotation periods where the overlapping of the crews could occur without causing inconvenience in terms of quartering etc., and also allows for time to clean up the rooms or modules of the departing crew. An additional feature of this module concerns itself with an emergency situation where one of the primary crew quarters has a failure or in the event a crew scheduled to move from the LEO base up to GEO or back to Earth are unable to do so due to weather, vehicle trouble, etc.

Floor area requirements associated with a 100 person module and the division of functions among the decks of the module are shown in Figure 1.3.1-10. The indicated area allocations are based to a large degree on the Rockwell Integral Space Station Study (NAS9-9953). It should also be pointed out that the indicated areas reflect having all 100 people present which is a case which occurs one day per week when both shifts are off-duty.

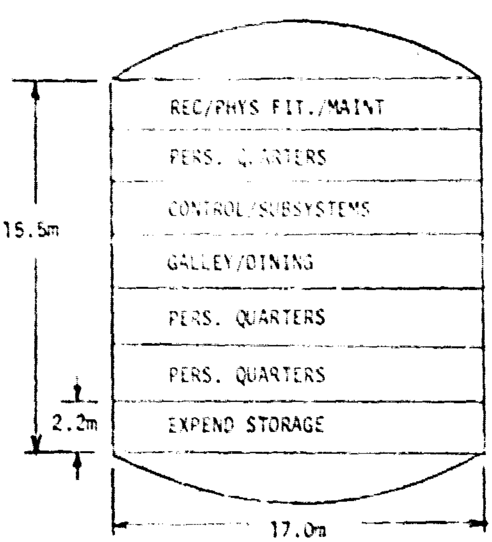
The size of the module to contain the required floor space is 17m in diameter and approximately 20m in length including the spherical end domes. The module is divided into seven decks with the indicated functions performed on each deck. General arrangement within each deck was not performed at this time.

Table 1.3.1-4 Construction Base Crew Modules

MODULE	QUANTITY	FUNCTION (PROVISIONS)
• CREW QUARTERS	5	• PERSONAL QUARTERS/HYGIENE • PHYSICAL FITNESS/RECREATION • DINING
• TRANSIENT CREW QUARTERS	1	• USED DURING CREW ROTATION PERIODS • HOUSE VIP'S • EMERGENCY QUARTERS

NOTE: ALL MODULES SELF SUFFICIENT EXCEPT PRIMARY POWER AND FLIGHT CONTROL.

- o SIZED FOR 100
- o FLOOR AREAS SCALED FROM 12 MAN UNITARY SPACE STATION (BASED ON ROCKWELL 1970 STUDY - NAS 9-9953)
- o AREAS BASED ON ENTIRE CREW BEING PRESENT



- o GEO MODULE MODIF
  - o ADD 1 DECK FOR RADIATION SHELTER

ALLOCATIONS PER MODULE

FUNCTION	FLOOR AREA M^2	(FT^2)
o PERSONAL QTRS	512	(5500)
o PHYSICAL HYGIENE	89	(960)
o RECREATION	107	(1150)
o PHYSICAL FITNESS	53	(570)
o GALLEY	53	(570)
o DINING	116	(1250)
o CONTROL CENTER	37	(400)
o SUBSYSTEMS	149	(1600)
o MAINTENANCE SHOP	9	(100)
o EXPENDABLE STORAGE (90 DAYS)	193	(2080)
o TUNNELS/AISLES	163	(1750)
TOTAL	1480	15930
MARGIN	71	760

Figure 1.3.1-10 Crew Quarters Sizing

Crew Module Subsystem Definition—The design approach used for each subsystem was generally the same as defined by Rockwell in their solar powered integral Earth orbit space station study (NAS9-9953) for JSC in 1970. A summary of these subsystems is provided in Table 1.3.1-5 and described below.

Structure—Crew module structure primarily consists of aluminum alloy. The pressure compartment is designed for an operating pressure 10100n/m^2 (14.7 psia). The outer shell of each module consists of a double bumper micrometeoroid protection system that was designed to give a 0.9 probability of no penetration in 10 years. Also included in the outer bumper system is the thermal radiator for internal heat rejection. An aerothermal shroud for the crew modules is not required since they will be launched within the payload shroud of the launch vehicle.

Electrical Power—The primary electrical power system is discussed under the Base Subsystem Section 1.3.1.1.5. Each crew module however incorporates an emergency power system consisting of fuel cells. Distribution, wiring and special power conditioning equipment is also included in each module.

Environmental Control—All modules have an independent ECS. The system provides an Earth atmosphere environment. Oxygen makeup for leakage and usage is provided through electrolysis of water which is obtained by reduction of CO^2 using a Sabatier reactor while CO^2 itself is removed using molecular sieves.

Nitrogen to supply leakage and repressurization is stored as a cryogenic. Oxygen for repressurization is stored as a cryogenic while the emergency oxygen system uses high pressure storage. Thermal control of the modules makes use of water and freon loops.

Life Support—Both urine and wash water are recovered. The urine is reprocessed using vapor compression while wash water recovery utilizes reverse osmosis. Dried and frozen food was used. Also included under life support are the waste management and personal hygiene systems.

Crew Accommodations—Included under this category are the personal equipment, furnishings, recreation and physical fitness equipment. Again these systems are located only in the crew quarters.

Table 1.3.1-5 Subsystem Summary

CREW MODULES

• STRUCTURE	• ALUMINUM ALLOY
	• METEOROID PROTECTION
	• $P_{(O)} \sim 0$ FOR 10 YRS.
	• DOUBLE BUMPER
	• PRESSURE COMPARTMENT
	• 101000 n/m^2 (14.7 psia)
• ELECTRICAL POWER	• EMERGENCY - FUEL CELLS
• ENVIRONMENTAL CONTROL	• EACH INDEPENDENT
	• LEAKAGE
	• OXYGEN - WATER ELECTROLYSIS
	• NITROGEN - CRYOGENIC
	• REPRESSURIZATION
	• OXYGEN - HIGH PRESS
	• NITROGEN - CRYOGENIC
	• WATER - SABATIER REACTOR
	• CO_2 REMOVAL - MOLECULAR SIEVES
	• THERMAL - WATER AND FREON LOOPS
• LIFE SUPPORT	• URINE AND WASH WATER RECOVERY
	• DRIED AND FROZEN FOOD
	• WASTE MANAGEMENT
	• PERSONAL HYGIENE
• CREW ACCOMMODATIONS	• PERSONAL EQUIPMENT
	• FURNISHINGS
	• RECREATION
	• PHYSICAL FITNESS
• INFORMATION SYSTEM	• COMMUNICATIONS - S BAND
	• DATA PROCESSING
	• DISPLAYS AND CONTROLS

Information System—The principal systems included are communications, data processing and displays and controls. Each module will have its own internal communication system as well as contact with the main communication center located in the operations module. The principal link between the base and Earth or transportation vehicles is S-band. Each module has data processing capability suitable for its needs. However, again the principal data processing center is located in the Operations module. Each module also has the appropriate set of displays and controls although the Operations module contains all displays and controls associated with overall base operation.

Guidance and Control—Displays and controls for these systems are located in the Operations module although the equipment itself is located throughout the base and consequently are discussed under Base Subsystems.

Reaction Control—Again, this is a base level subsystem and is discussed under Section 1.3.1.1.5.

Special Equipment—This is equipment that is peculiar to the maintenance/test/checkout and training/simulation modules.

Element Mass
The mass of the crew modules are summarized in Table 1.3.1.6.

WBS 1.3.1.1.3 Work Modules

WBS Definition
This element includes the crew modules used for operations, maintenance and training.

Element Description
The work modules have the same general configuration and subsystems described for the crew modules. A summary listing of the work modules is shown in Table 1.3.1-7.

The operations module serves as the control center for all base operations and construction operations. Typical base operations to be controlled from this module include that associated with the primary power supply and flight control system (attitude and station keeping), communication system within the base as well as that with Earth, other bases and transportation vehicles in transit.

Overall crew scheduling and consumables management functions are also included under base operations. Construction operations controlled from the module include those functions associated with scheduling, briefings, troubleshooting or identifying workarounds, monitoring of the actual construction operations being conducted and the operations associated with cargo handling and distribution. Another function provided by the operations module is that of housing the central data management and processing center.

Table 1.3.1-6 Crew Module Mass Summary
o Mass In 10^3kg

SYSTEM	CREW QUARTERS (EA)
STRUCTURE	80
ELEC. POWER	5
ENVIRON. CONT./ LIFE SUPPORT	60
CREW ACCOMMODATIONS	11
INFORMATION	6
GUID & CONT	0
REACTION CONT	0
SPECIAL EQUIPMENT	0
SUBTOTAL	162
GROWTH/ CONTINGENCY	53
TOTAL DRY	215
CONSUMABLES (90 DAYS)	45
TOTAL	260

Table 1.3.1-7 Construction Base Work Modules

MODULE	QUANTITY	FUNCTION (PROVISIONS)
• OPERATIONS CENTER	1	• BASE OPERATIONS • CONSTRUCTION OPERATIONS
• MAINTENANCE, TEST AND CHECKOUT	1	• CONSTRUCTION EQUIPMENT • SATELLITE COMPONENTS
• TRAINING & SIMULATION	1	• NEW PERSONNEL • NEW CONSTRUCTION OPERATIONS
• UNDEFINED	1	• CLINIC

NOTE. ALL MODULES SELF SUFFICIENT EXCEPT PRIMARY POWER AND FLIGHT CONTROL.

The maintenance, test and checkout module provides the capability to work on large pieces of construction or base equipment or satellite components while in an Earth atmosphere environment.

A training and simulation module has been included with its primary purpose being to train new personnel and to establish and/or demonstrate certain construction tasks while in a controlled environment.

An unspecified module has been included primarily to cover the volume requirements of functions not included in other modules at this time. Examples of such functions include clinic type provisions in terms of medical, dental and sickbay provisions as well as for the temporary containment of personnel who have died while on duty. Isolation of the sickbay from the other base crew quarters seems to be particularly important due to relatively confined volume that is available.

Element Mass

The mass of the work modules are summarized in Table 1.3.1-8.

WBS 1.3.1.1.4 Cargo Handling/Distribution

WBS Dictionary

This element includes all of the LEO base logistics track system, transporter vehicles, and cargo handling equipment.

Element Description

Each level of the base has a logistics track network that provides the capability for moving materials and crews from the transportation centers to the warehousing, subassembly, crew habitats, and assembly areas via transporter vehicles. Figure 1.3.1-11 shows a typical track network. This particular one is for the lower level of the module construction facility. In addition to providing the pathways for moving the materials and crew, the track system is also used by all of the construction equipment. These tracks also serve as the indexing paths for the module and antenna support indexing towers.

These are cargo handling equipment items that are used to dock cargo vehicles, off load cargos, and sort cargos.

Table 1.3.1-9 lists the cargo handling and distribution equipment required at the LEO base.

Table 1.3.1-8 Work Module Mass Summary
o Mass In 10^3kg

SYSTEM	CREW QUARTERS (EA)	OPERATIONS CENTER	MAINTENANCE TEST & C/O	TRAINING & SIMUL	MISC.
STRUCTURE	80	80	80	80	
ELEC. POWER	5	7	3	7	
ENVIRON. CONT./ LIFE SUPPORT	60	42	24	11	
CREW ACCOMMODATIONS	11	4	3	3	
INFORMATION	6	30	5	0	
GUID & CONT	0	1	0	0	
REACTION CONT	0	0	0	0	
SPECIAL EQUIPMENT	0	0	5	0	
SUBTOTAL	162	164	120	108	110
GROWTH/ CONTINGENCY	53	54	40	35	36
TOTAL DRY	215	218	164	143	146
CONSUMABLES (90 DAYS)	45	0	0	0	0
TOTAL	260	218	164	143	146

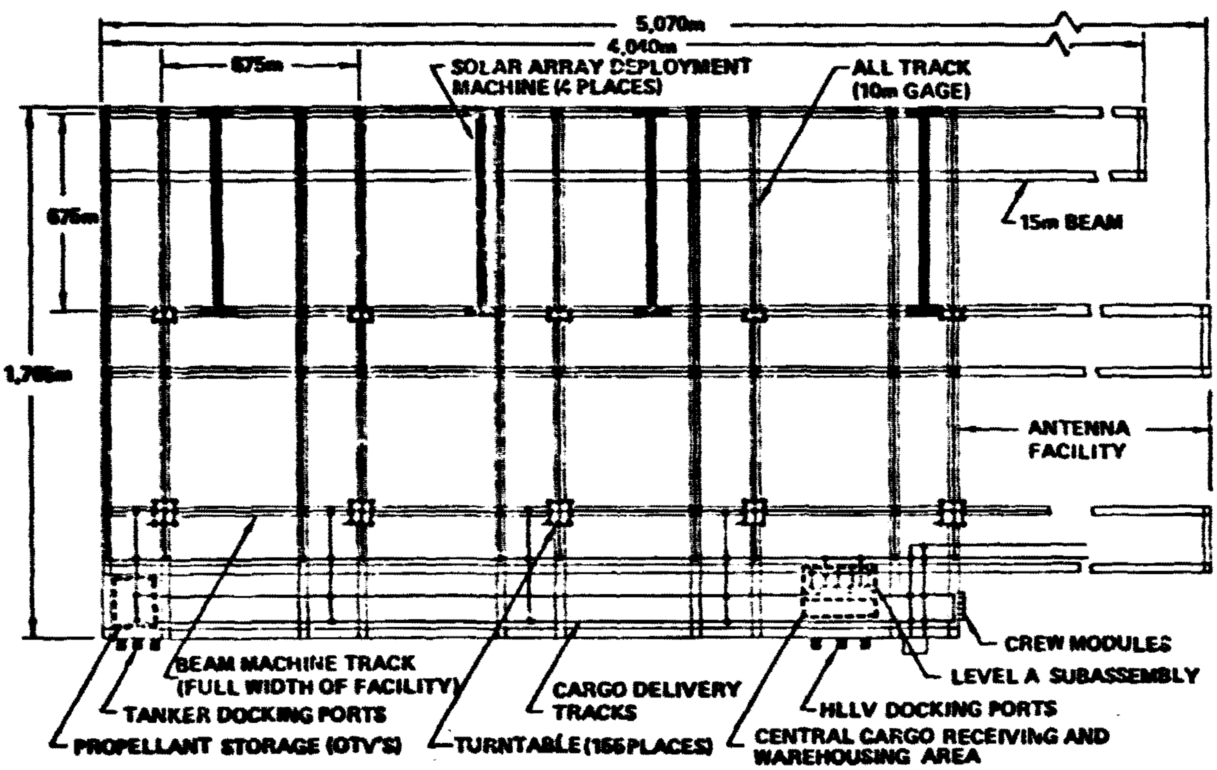


Figure 1.3.1-11 Logistic Network Level A LEO Construction Base

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Table 1.3.1-9 LEO Base Cargo Handling & Distribution Equipment Photovoltaic Satellite

EQUIPMENT ITEM	NO REQ'D	MASS (EA) 10^3 Kg	COST (EA) $\$10^6$
• HLLV CARGO DOCKING PORT	4	4	10
• HLLV CARGO EXTRACTION SYS	4		6
• HLLV TANKER DOCKING PORT	3	4	10
• HLLV TANKER CARGO EXTRACTION SYS	3		6
• OTV TANKER DOCKING PORT	2		
• OTV TANKER LOADING SYS	2		
• SHUTTLE DOCKING PORT	3		
• GROWTH SHUTTLE DOCKING PORT	2		
• PERSONNEL TRANSFER AIRLOCK SYS	6		
• GANTRY CRANE	2		
• CARGO SORTING MANIPULATOR/TRANSPORTER	2		6
• 24 MAN CREW BUS	2	12	7
• 10 MAN CREW BUS	2	5	4
• TURNTABLES	483	0.2	0.97
• CONTROL CABS FOR LOGISTICS EQUIP	7		
• HLLV CARGO	1		
• HLLV/OTV TANKER	1		
• SHUTTLE/SHUT GROWTH	1		
• GANTRY CRANES	2		
• CARGO SORTER	2		
• TRANSPORTERS	20		

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WBS 1.3.1.1.5 Base Subsystems

WBS Dictionary
This element includes the base electrical power and flight control systems.

Element Description
As indicated previously, several subsystems do not relate specifically to anyone of the crew modules, but instead are associated with operating the base as a total entity. Such subsystems include primary power and flight control.

Electrical Power—Basic operating power requirements have been grouped into the categories associated with crew modules, construction equipment and external lighting as shown in Table 1.3.1-10. The average operating power level required is estimated at over 1600 KW. This load does not include recharging of the secondary power supply or losses.

Under the category of crew module, considerable use was made of the estimates identified for a 12 man space station as defined by Rockwell. These estimates were then scaled up both to account for the difference in crew size and the number of modules involved.

Construction equipment power estimates were made using both Boeing generated data and data from recent space station studies. Typical examples per machine include the 15m beam machine at 5 KW, solar array deployer at 5 KW, crane/manipulator at 3 KW. All of these estimates include the power for a two man control cabin.

External lighting estimates are based on providing 216 lumens/m^2 as specified by McDonnell Douglas in the Space Station Systems study (NAS9-14958). Typical construction areas in this study covered 2000 m^2 and required 10 KW to provide the specified illumination. A total of 32 areas of this size have been estimated for the SPS construction base.

The total power requirement to be used in sizing the primary power supply is 3725 KW as shown in Table 1.3.1-11. The secondary power recharging load is for a nickel hydrogen system that produces the operating loads during 37% of the orbit. The allowance for oversizing is that associated with 50 μm cells and 75 μm cover slips. No thermal annealing is assumed.

The primary power generation system is solar arrays similar to those used in the satellite, with a nickel hydrogen battery system used for occultation periods. An array voltage of 1500 volts has been selected and appears to be the highest practical when considering plasma losses.

Table 1.3.1-10 Base Operating Power Requirements Photovoltaic Satellite

OPERATING POWER		KW
CREW MODULES		(1175)
ENVIRONMENT CONT/LIFE SUPPORT	750	
INTERNAL LIGHTING	350	
INFORMATION SYSTEM	70	
GUID. & CONT.	5	
CONSTRUCTION EQUIPMENT		(150)
SATELLITE EQUIPMENT	50	
ANTENNA EQUIPMENT	50	
SUBASSEMBLY	50	
EXTERNAL LIGHTING		(320)
SATELLITE CONST.	120	
ANTENNA CONST.	120	
SUBASSY/WAREHOUSE	80	
	TOTAL	1645

Table 1.3.1-11 Solar Array Sizing

- REQUIREMENTS (KW) (3645)
  - OPERATING LOAD 1645
  - SECONDARY POWER SUPPLY RECHARGING 960
  - POWER CONDITIONING 330
  - POWER DISTRIBUTION 540
  - RADIATION DEGRADATION (5%) 170
- SIZING
  - CONTINUOUSLY SUN ORIENTED ARRAY: (SATELLITE TYPE CELLS, 140 w/m^2) 26000 m^2
  - FIXED BODY MOUNTED ARRAY WITH EARTH ORIENTED CONST. BASE
    - ARRAYS ON 3 SIDES OF BASE
    - MAX SUN INCIDENCE ANGLE OF 54.5 DEG
    - TOTAL ARRAY SIZE: ≈130000 m^2
      205m x 205m FOR EACH OF (3) ARRAYS

The selected installation approach for the array is a fixed body mounted concept, with an array located on three sides of the construction base so that the necessary power can be generated by any one array with the base at any location in orbit. Figure 1.3.1-1, shown previously, illustrates the location of two of these arrays. Each array also has been sized to account for sun incidence angle penalties so the combined net affect is a total array that is approximately five times as large as an array that was always PEP. By past space system standards, this excess would be prohibitive. However, in the era of power satellite with low mass and lost cost cells, the penalty is quite small.

Flight Control—Included under the category of flight control are the guidance/navigation/attitude type sensors such as IRU, star trackers and horizon sensors and the propulsion system to perform attitude and orbit maintenance maneuvers.

A key factor in establishing the flight attitude of the base and the location of attitude control and orbit keeping thrusters is the c.g. location at various stages of the construction. Figure 1.3.1-12 shows the c.g. location for several key phases of the construction.

The selected construction base attitude has the long axis of the base pointed toward the center of the Earth and the satellite module constructed parallel with the velocity vector and out in front of the base. The location of the orbit keeping thrusters is shown in Figure 1.3.1-13 while the attitude control thrusters are shown in Figure 1.3.1-14. It should be noted, the orbit keeping and attitude control thrusters located on the antenna facility may be placed at the same location. In all cases the thrusters are fixed (no gimballing) and use LO_2/LH_2 propellant. The average propellant requirement is approximately 1200 kg/day. Should a constant acceleration of 10^{-4} g's be used, the worst case configuration (picture V and VI of Figure 1.3.1-12) would require approximately 40,000 N of thrust. Should the thrust level be restricted to that which provides 10^{-4} g (5700 N) when only the base is present, a burn time of approximately 17 minutes would be required for an altitude correction of 1 Km.

WBS 1.3.1.2 Construction Equipment

WBS Dictionary

This element includes all equipment items directly associated with the fabrication and assembly of the satellite. Excluded from this element are machine items associated with cargo handling and distribution.

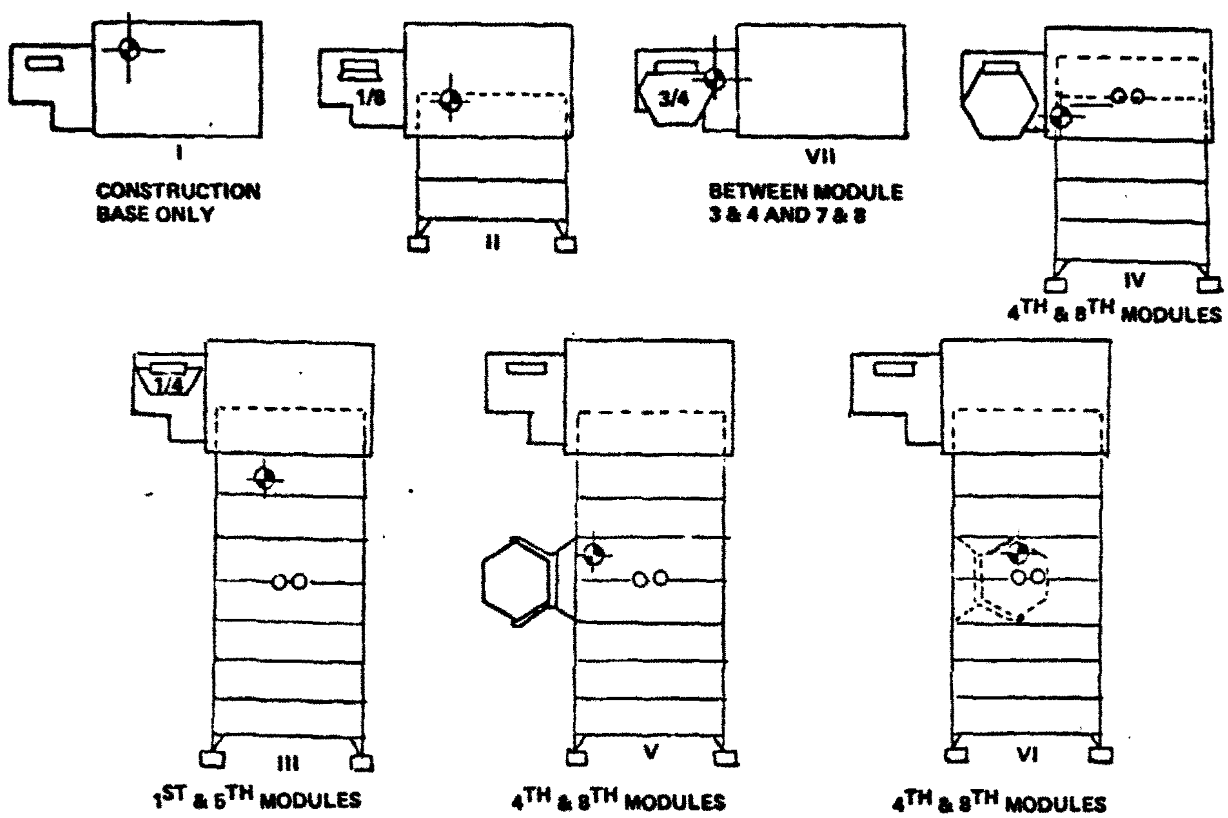

Figure 1.3.1-12 Construction Phase Configurations

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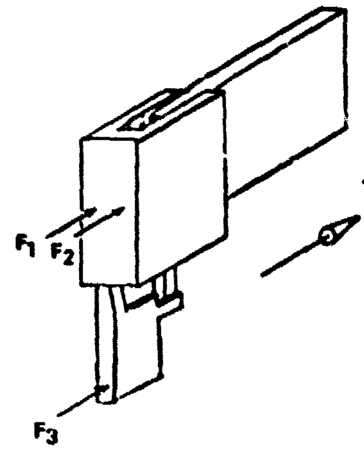


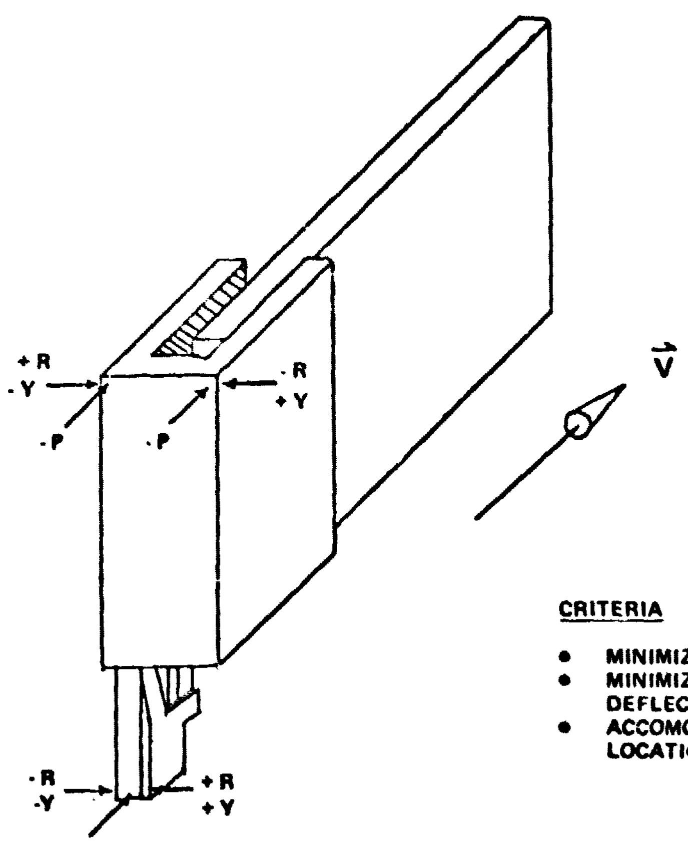
NOTES:

- LATERAL LOCATION OF F_1 & F_2 SELECTED TO MINIMIZE BASE STRUCTURAL DEFLECTIONS
- VERTICAL POSITION AND/OR THRUST MAGNITUDE BASED ON PREDICTED CG LOCATIONS

ADVANTAGES OF SELECTED DESIGN

- 100% EFFICIENT ΔV THRUSTING
- NO THRUST GIMBALING REQUIRED
- GRAVITY – GRADIENT STABILITY:
  - UNCONDITIONALLY STABLE ≈ 2/3 OF TIME
  - UNSTABLE EQUILIBRIUM ≈ 1/3 OF TIME
- LOWEST DRAG FOR HEAVY CONFIGURATIONS
- POSSIBLE COMMON LOCATION FOR ATTITUDE CONTROL AND ΔV THRUSTERS
- ATTITUDE CONTROL PROPELLANT CONTRIBUTES TO POSITIVE ΔV
- ORBIT MECHANICS FORCES BETWEEN BODIES MINIMIZED
- "VELOCITY VECTOR" APPROACH CAN BE USED FOR DOCKING OF SUPPLY VEHICLES

Figure 1.3.1-13 Selected Orbit-Keeping Control Concept



CRITERIA

- MINIMIZE IMPINGEMENT
- MINIMIZE STRUCTURAL DEFLECTIONS
- ACCOMODATE ALL C.G. LOCATIONS

Figure 1.3.1-14 Typical Reaction Control Thruster Arrangement

Element Description

The major construction equipment items associated with the photovoltaic satellite are illustrated in Figure 1.3.1-15, along with key characteristics such as quantity, mass and dimensions.

The beam machine shown is configured to allow two beam machines to form all the main module structure (actual assembly machines within framework not shown). Accordingly it has both translation and rotational capability. The dimensions and mass indicated are for the 15m segmented beam approach although machines fabricating thermally formed continuous chord structure could be attached to the same frame and used in a similar manner. Two 10m beam machines are used to fabricate the antenna primary structure. A two-man control cab is attached to each beam machine.

Crane/manipulator systems are primarily used to form the structural joints of the satellite frame. Although the size shown is most common, two 250 meter units are also required in the construction of the antenna yoke as well as several 20 meter cranes. Two-man control cabins with manipulators are located at the end of the crane which is itself attached to a moving platform.

Four of the solar array deployment machines will be located on the "A" level of the module construction facility. This machine will deploy the solar array required for self-powered transit to GEO. The non-deployed array will be installed on the structure in radiation-protective containers by this machine.

Power bus deployment machines are used to roll out sheet metal bus strips and weld these strips to supporting structures. These machines are used on the "A" level of the module facility and on the "C" level of the antenna facility.

The antenna deployable secondary structures and the subarrays are installed by the deployment platform shown in Figure 1.3.1-16. The most significant unique piece of equipment on this deployment platform is the subarray installer shown in Figure 1.3.1-17. This machine lowers subarrays onto the structure and makes the structural and electrical interfaces.

The construction equipment types and quantities are summarized in Table 1.3.1-12. Additional details about each of the equipment items is found in the Part II Final Report, Vol. V.

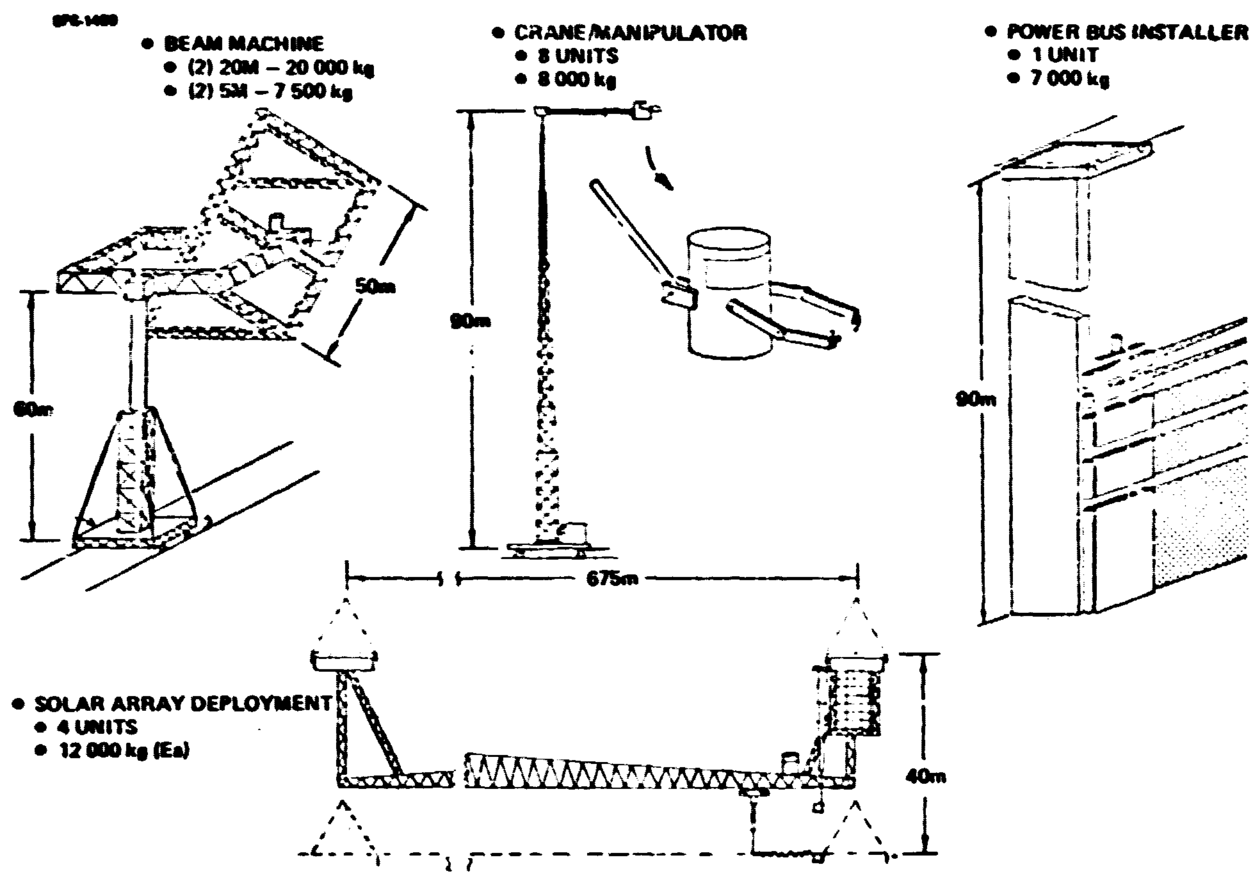


Figure 1.3.1-15 Major Construction Equipment Photovoltaic Satellite

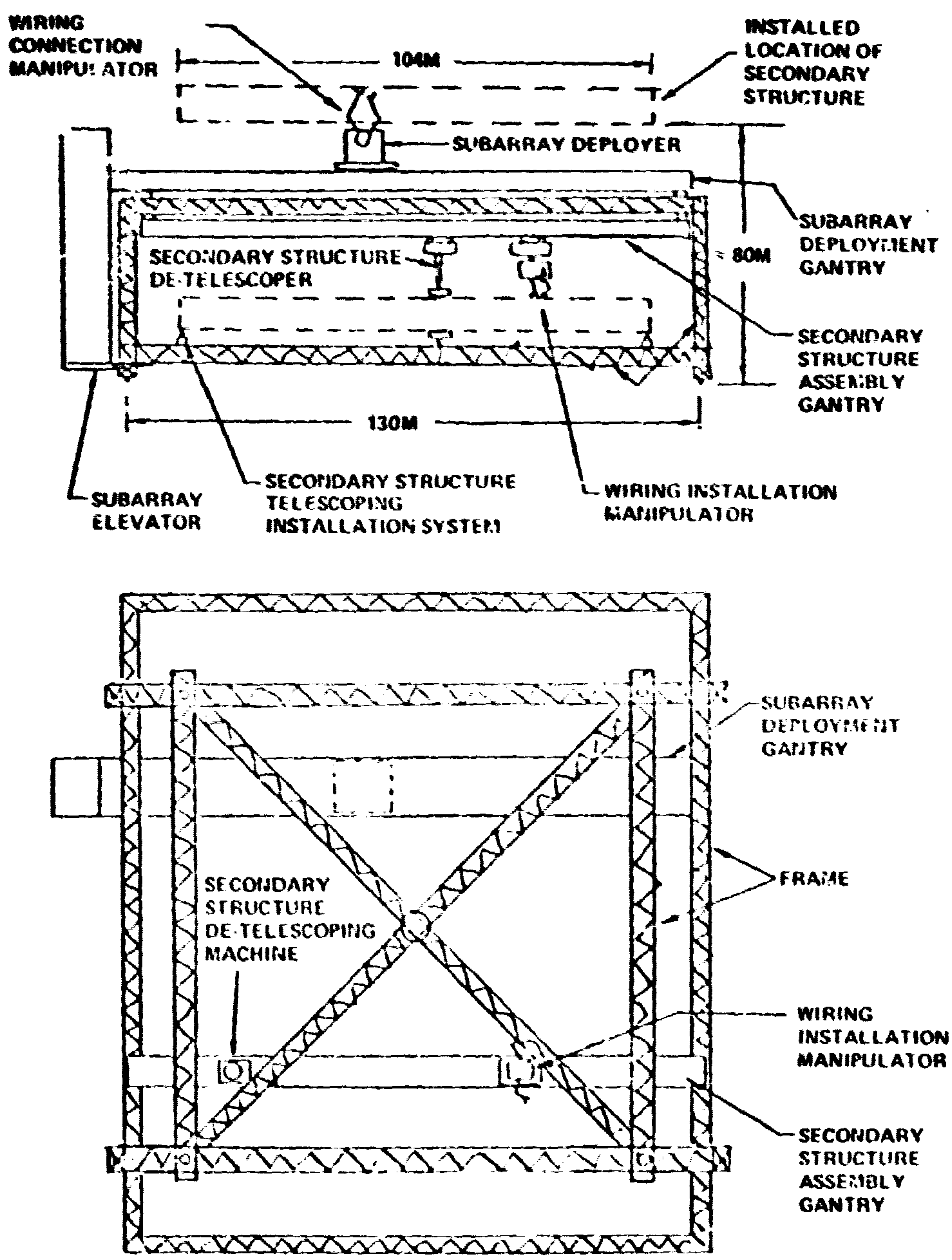


Figure 1.3.1-16 Deployment Platform

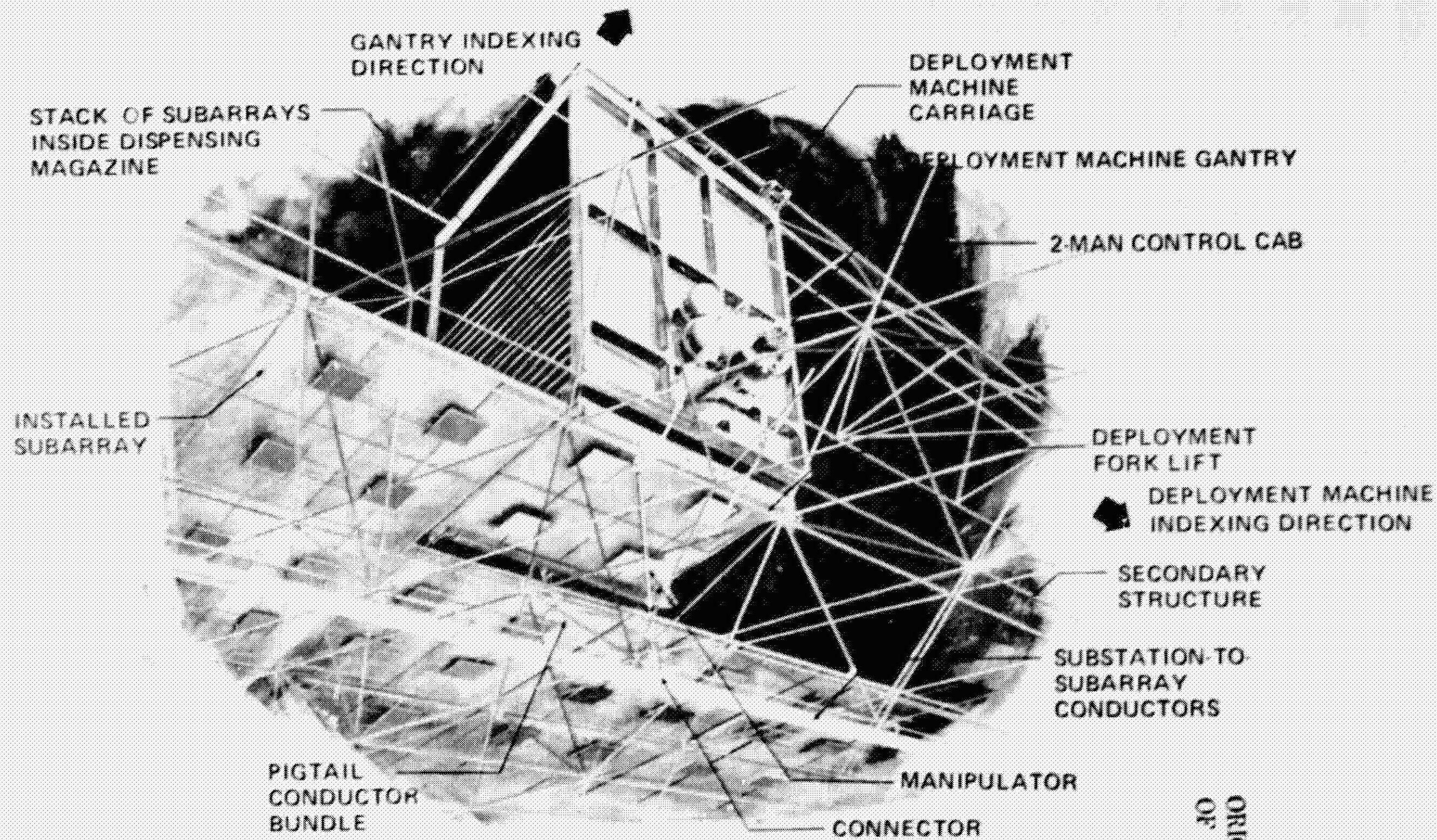


Figure 1.3.1-17 Subarray Deployment Machine Details

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Table 1.3.1-12 LEO Base Construction Equipment–Photovoltaic Satellite

EQUIPMENT ITEM	NUMBER REQ'D MOD	ANT	YOKE	SUBASSY	EQUIPMENT ITEM MAJOR ELEMENT	NO. REQ'D ITEM
• 15M BEAM MACHINE (1) ALSO USED TO MAKE MODULE-TO-VOICE INTERFACE STRUCTURE (MASS 20^K Kg) (COST $100M) (A)	2 (1)				• CARRIAGE • YOKE ASSY • STRUT ASSY MACHINE • JOINT FITTING FEED MECH • INDEXING CARRIAGES • STRUT MAGAZINES • JOINT FITTING CARROUSEL • CONTROL CAB (2 MAN)	1 1 [illegible] 3 6 13 3 1
• 10M BEAM MACHINE (MASS 7^K Kg) (COST $35M)		2	2			
• 10M TURNTABLE BEAM MACHINE (MASS 8^K Kg) (COST $40M)			1			
• 20M MANIPULATOR/CRANES (2) THRUSTERS 2 SW GEAR 4 STRUCTURES 4 CABLE ASSY 1 (MASS 3^K Kg) (COST $[illegible]M)		2		11 (2)	• CARRIAGE • ELEVATOR BOOM • TRANSVERSE BOOM • CONTROL CAB (1 MAN) • MANIPULATOR ARM	1 1 1 1 2
• 90M MANIPULATOR/CRANE (MASS 8^K Kg) (COST $19M)	8	8				
• 250M MANIPULATOR/CRANES (MASS 12^K Kg) (COST $26M)			2			

(A) ALL COST REFLECT AVG UNIT COST AFTER APPLYING LEARNING FACTOR OF 0.9.

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Table 1.3.1-12 (Continued)

EQUIPMENT ITEM	NUMBER REQ'D MOD	ANT	YOKE	SUBASSY	EQUIPMENT ITEM MAJOR ELEMENT	NO. REQ'D ITEM
• 45M INDEXING/SUPPORT MACHINE (MASS 1.3^K Kg) (COST $3.8M)	6	6	2		• CARRIAGE • BOOM	1 1
• 200M INDEXING/SUPPORT MACHINE (MASS 5^K Kg) (COST $10M)			2		• CARRIAGE • BOOM	1 1
• BUS DEPLOYMENT MACHINE • 90M BOOM • 50M BOOM • 110M ARTICULATING BOOM (2) NOT REQ'D ON YOKE AND ANTENNA MACHINES (MASS 8^K Kg) (COST $25M) { AVG FOR THE 3 SIZES	1 (90M BOOM)	1 (50M BOOM)	1 (110M ARTICULATING BOOM)		• CARRIAGE • BOOM • BUS DEPLOYMENT MACHINES • • A BUS • B BUS • C BUS • COLLECTOR BUS • CONTROL CAB (2 MAN)	1 1 1 1 1 (2) 1
• SOLAR ARRAY DEPLOYMENT MACHINE (MASS 12^K Kg) (COST $45M)	4				• CARRIAGE/GANTRY • BLANKET MAGAZINE • BLANKET FEED MECH • BLANKET PACKAGE INST MACH • BLANKET DEPLOYER • CARRIAGE • BLANKET END HANDLER MECH • EDGE CLAMPER • CONTROL CAB (2 MAN)	1 1 1 1 1 1 1 1

Table 1.3.1-12 (Continued)

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EQUIPMENT ITEM	NUMBER REQ'D				EQUIPMENT ITEM MAJOR ELEMENT	NO. REQ'D ITEM
	MOD	ANT	YOKE	SUBASSY		
• DEPLOYMENT PLATFORM 3 INCLUDED IN 20M MANIP/CRANE COUNT (MASS 20K Kg) (COST $80M)					• CARRIAGE/FRAME ASSY • SECONDARY STRUCTURE INST TELESCOPES • SECONDARY STRUCTURE DEPLOYMENT GANTRY • GANTRY/CARRIAGE • DETELESCOPING MACH • 20M MANIPULATOR/CRANE • SUBARRAY DEPLOYMENT GANTRY • GANTRY/CARRIAGE • ELEVATOR • SUBARRAY DEPLOYER • CARRIAGE • MAGAZINE • DEPLOYMENT MECH • 20M MANIP/CRANE • CONTROL CAB (2 MAN)	1 3 1 1 1 3 1 1 1 1 1 1 3 1
BUS BAR ROD BENDER				1		
BUS BAR WELDER				2		
RADIATOR PIPE WELDER				1		
CABLE FITTING MACH				1		
STRUT ASSY MACH (4 SIZES)				11		
SUBARRAY TESTING MACH				1		

WBS 1.3.1.3 Maintenance Provisions

WBS Dictionary

This element includes all information systems, structures, and machinery items devoted to maintenance of the LEO base.

Element Description

No unique base maintenance provisions have been identified at this time. The base logistics net work and the available construction crane/manipulators appear to be sufficient to accomplish any necessary base maintenance tasks.

WBS 1.3.2 Geosyncronous Earth Orbit Base and Operations

WBS Dictionary

This element includes the GEO-based operations, facility, construction equipment, and maintenance provisions.

Summary Description

The GEO base is a 2 x 2 bay-wide platform that is attached to and indexed across the solar array side of the modules, as shown in Figure 1.3.2-1. This platform has four solar array deployment machines that are used to deploy the undeployed solar arrays. There are also a variety of crane/manipulators, logistics and SPS maintenance equipment aboard.

The first operation to occur once the modules reach GEO is that of the berthing (or docking) of the modules. The modules are berthed along a single edge as indicated in Figure 1.3.2-2. The major equipment used to perform these berthing operations are shown. The concept employs the use of four docking systems with each involving a crane and three control cables. Variations in the applied tension to the cables allows the modules to be pulled in, provide stopping control and provides attitude control system involving thrusters which are not shown. This berthing concept is described in detail in Vol. V of the Part II Final Report.

During the transfer from LEO to GEO, the antenna is attached below the module with a single hinge line. Once GEO is reached, the antenna is rotated into position followed by the final structural and electrical connections, as indicated by Figure 1.3.2-3.

Mass Summary

The mass of the GEO base is summarized in Table 1.3.2-1.

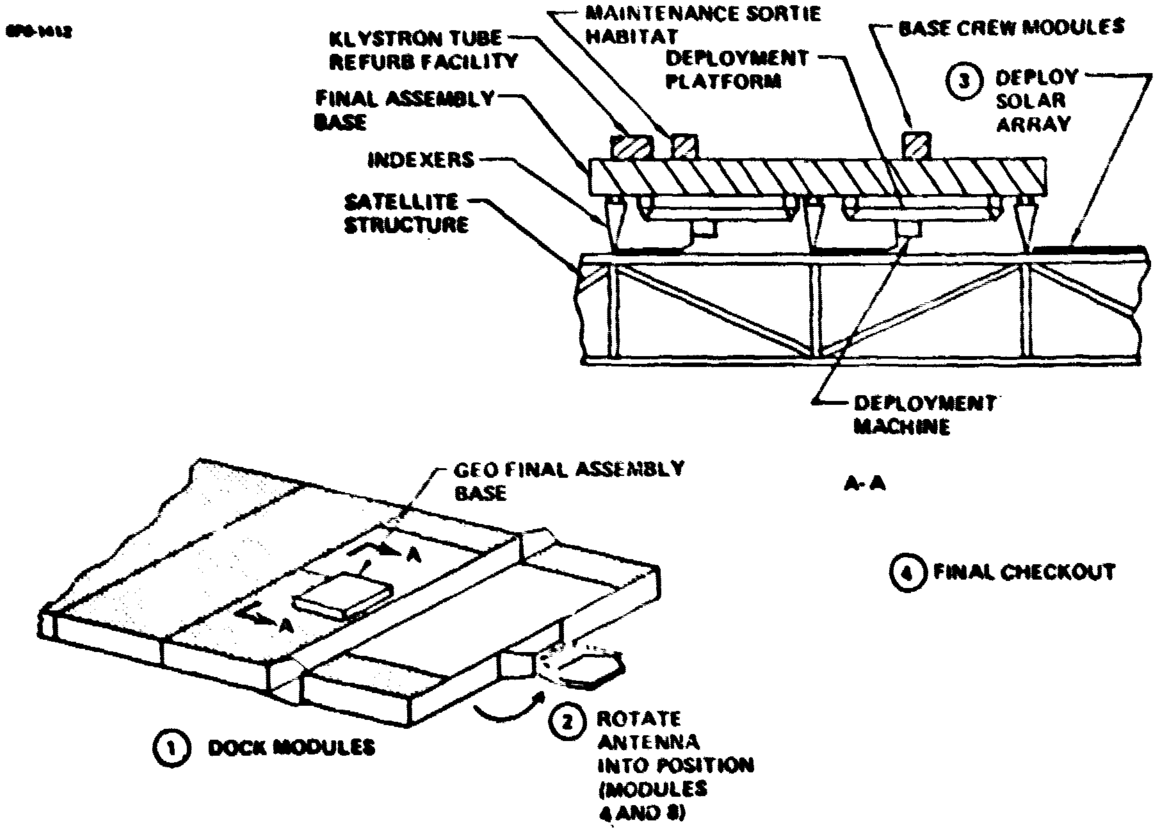

Figure 1.3.2-1 GEO Final Assembly Base/Operations

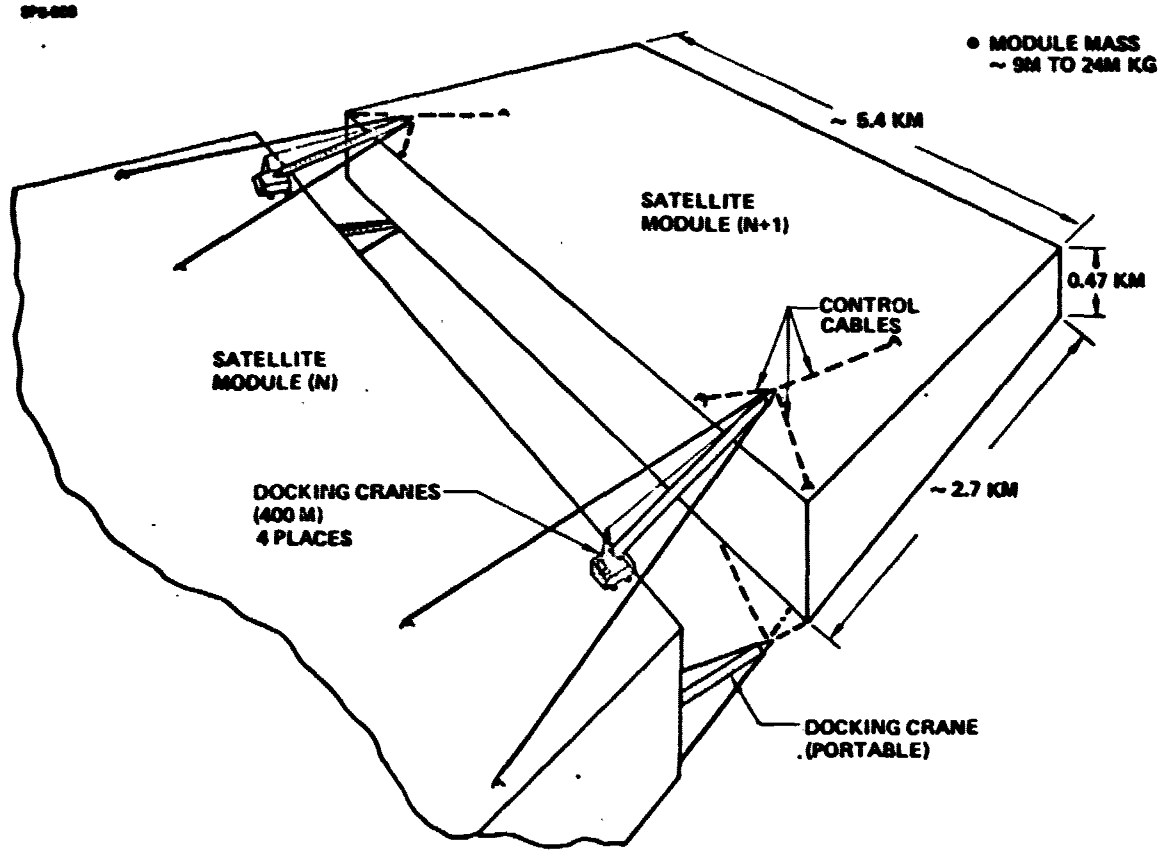

Figure 1.3.2-2 GEO Berthing Concept Photovoltaic Satellite

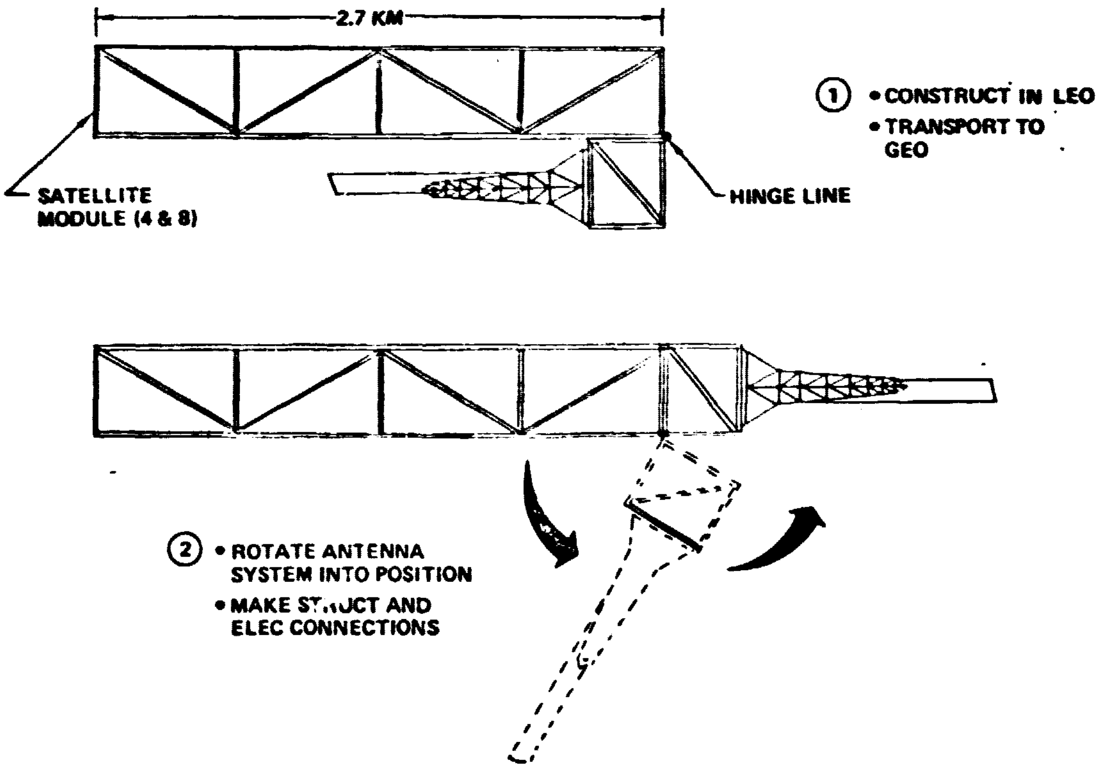

Figure 1.3.2-2 Antenna Final Installation Photovoltaic Satellite

Cost Summary

The cost of the GEO base is summarized in Table 1.3.2-2.

Crew Summary

The GEO base construction crew size is summarized in Table 1.3.2-3.

WBS 1.3.2.1 Facility

WBS Dictionary

This element includes the GEO base framework, crew modules, work modules, cargo handling/distribution systems and base subsystems.

Element Description

The overall configuration of the GEO final assembly base is shown in Figure 1.3.2-4. The base has overall dimensions of 1400m x 1600m x 100m with two decks of operation. The upper deck supports the crew and maintenance modules and docking facilities for transportation systems and payloads. The lower surface of the facility supports the four solar array deployment machines. Docking cranes used in berthing the modules are also attached to the base when not in use or when the GEO base is transferred to another longitudinal location.

WBS 1.3.2.1.1 Framework

WBS Dictionary

This element includes all of the structural elements that comprise the framework of the GEO base.

Element Description

The structure framework of the base has been sized to provide a natural frequency of 50 cphr which is greater than that of a single satellite module. The primary structure consists of 15m beams forming a grid pattern for both the upper and lower surfaces of the base. A total beam length of 55,000m has been estimated.

WBS 1.3.2.1.2 Crew Modules

WBS Dictionary

This element includes the construction crew module structure, electrical power, environmental control, life support, crew accommodations, and information systems. Excluded from this element are the crew modules associated with the maintenance activities.

Table 2.3.2-1 GEO Final Assembly Base ROM Mass

	10^3Kg	
FACILITY		(680)
FOUNDATION	280	
CREW MODULE	335 [1]	
CARGO HANDLING/DISTRIBUTION	55	
BASE SUBSYSTEMS	10	
CONSTRUCTION & SUPPORT EQUIPMENT		(175)
SOLAR ARRAY INST	50	
CRANE/MANIPULATOR	15	
INDEXERS	6	
DOCKING CRANES	104	
DRY TOTAL		(855)
CONSUMABLES (90 DAYS)		(35)
TOTAL		(880)

[1] INCLUDES RADIATION SHELTER

Table 1.3.2-2 GEO Final Assembly Base ROM Cost

		$\$10^6$
FACILITY		(382)
FOUNDATION	30	
CREW MODULES	300	
CARGO HANDLING/DISTRIBUTION	50	
BASE SUBSYSTEMS	2	
CONSTRUCTION EQUIPMENT		(425)
SOLAR ARRAY INSTALLATION	165	
CRANE/MANIPULATOR	35	
INDEXERS	15	
BERTHING CRANES	210	
BASIC HARDWARE		(807)
SPARES		120
INSTALL, ASSEMBLE, C/O		128
SE&I		55
PROJECT MANAGEMENT		15
SYSTEM TEST		17
GSE		30
TOTAL		(1172)

Table 1.3.2-3 GEO Base Construction Manpower Estimate

SPS 1455

BASE MGMT	(5)
CONSTRUCTION	(20)
MGMT	4
MODULE CONST	8
ANTENNA CONST	
SUBASSEMBLY	
MAINT	6
LOGISTICS	
TEST/QC	2
BASE OPS	(16)
MGMT	4
TRANSPORTATION	4
COMM	6
DATA PROCESSING	2
BASE SUPPORT	(26)
MGMT	4
BASE UTILITIES	6
HOTEL	8
MEDICAL	4
FLT CONT	4
BASE TOTAL	67

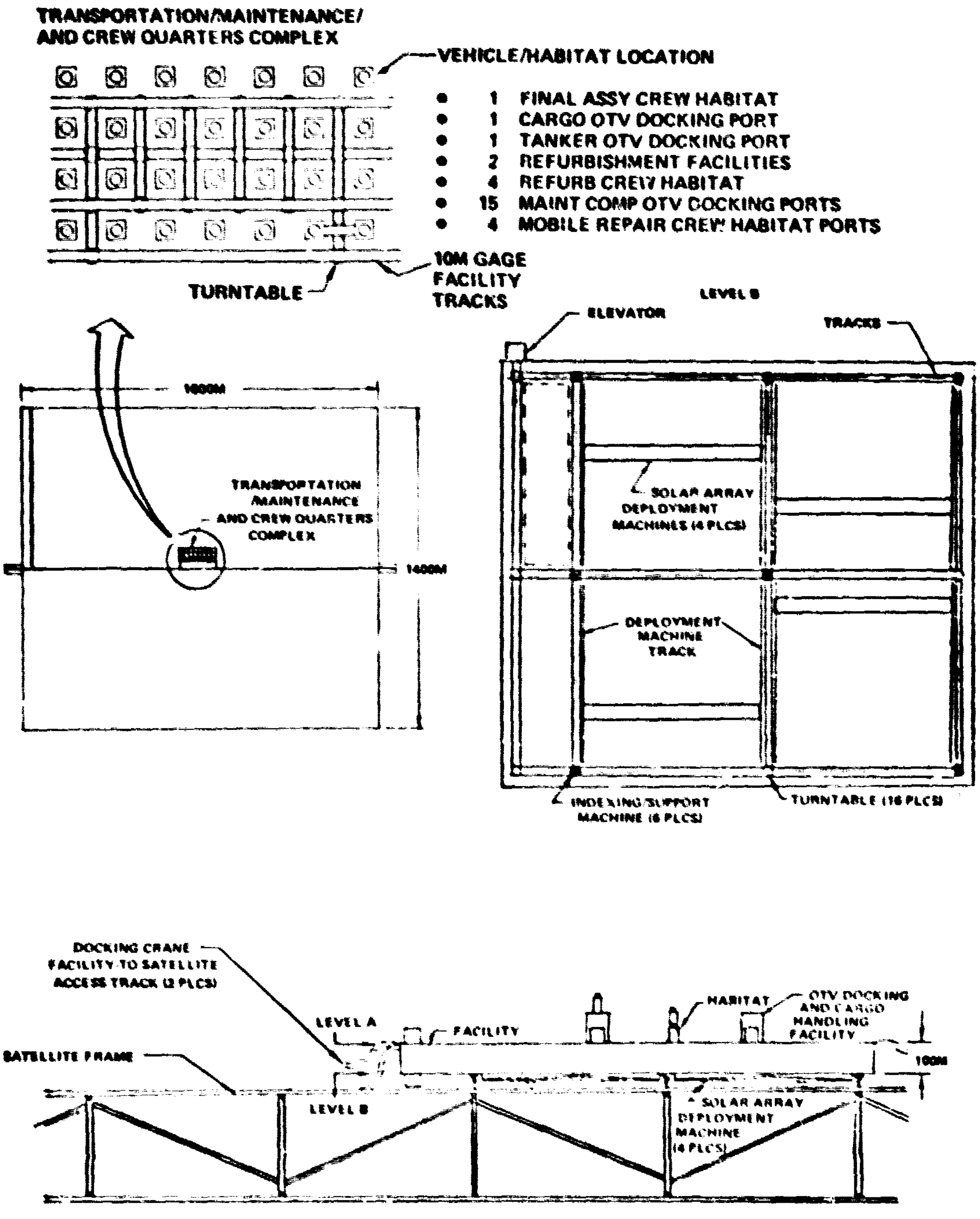

Figure 1.3.2-4 GEO Final Assembly Base

Element Description

The GEO base has a construction crew size of 65 and only a minimum of construction operations so, consequently, all functions can be incorporated into a single crew module. Transportable maintenance crew modules are also based at the GEO facility. These modules are discussed in section 1.3.3.3.

The crew modules of the GEO base are similar in design to the crew quarters modules used at the LEO construction base. The major modifications to the LEO modules are as follows: 1) incorporation of an operations deck in place of one of the three personnel decks since only 65 rather than 100 people are housed in the module, and 2) add an eighth deck which serves as a solar flare radiation shelter. Assuming a shielding requirement of 20 to 25 gm/cm^2, the shelter will add an additional 115,000 Kg to the basic module mass. Within the shelter will be provisions for up to five days and controls to operate the complete base on standby status. Subsystems used within the modules are the same as for the LEO base modules described previously.

WBS 1.3.2.1.3 Work Modules

WBS Dictionary

There are no work modules at the GEO base other than the refurbishment modules that are addressed in Section 1.3.3.

WBS 1.3.2.1.4 Cargo Handling/Distribution

WBS Dictionary

This element includes all of the facility track system, transportation vehicles, and cargo handling equipment.

Element Description

The logistics track network was previously shown in Figure 1.3.2-4. The logistics equipment is summarized in Table 1.3.2-4.

WBS 1.3.2.1.5 Base Subsystems

WBS Dictionary

This element includes the base electrical power and flight control systems.

Element Description

An operating electrical load of 260 Kw has been estimated. Use of satellite type solar arrays results in an array size of 1700 square meters. Flight control in terms of attitude control, station keeping and transfer of the base to the longitude location of the next satellite will make use of a LO_2/LH_2 propulsion system.

Table 1.3.2-4 Cargo Handling and Distribution Equipment
GEO Final Assembly Base

SPS 1482

EQUIPMENT ITEM	NO. REQ'D	MASS (EA) 10^3 Kg	COST (EA) $\$10^6$
• OTV CARGO DOCKING PORT	14	1	4
• OTV CARGO EXTRACTION SYS	14		
• OTV TANKER PORT	1	1	4
• OTV TANKER CARGO EXT SYS	1		
• OTV PERSONNEL DOCKING PORT	13		
• PERSONNEL AIRLOCK SYS	13		
• CARGO SORTING MANIP/CRANE	4	3	6
• CARGO TRANSPORTER	2	0.5	2
• 10 MAN CREW BUS	2	5	4
• TURNTABLES	34		
• CONTROL CABS FOR LOGISTICS EQUIP	4		

WBS 1.3.2.2 Construction Equipment

WBS Dictionary
This element includes all equipment items directly associated with the fabrication and assembly of the satellite. Excluded from this element are the equipment items associated with cargo handling and distribution and refurbishment equipment.

Element Description
The only piece of GEO base construction equipment that is different from that described for the LEO base are the four module docking cranes with characteristics shown in Figure 1.3.2-5.

The construction equipment located at the GEO base are summarized in Table 1.3.2-5.

WBS 1.3.2.3 Maintenance Provisions

WBS Dictionary
This element includes all information systems, structures, and machinery items devoted to maintenance of the GEO base.

Element Description
No unique GEO base maintenance provisions have been identified at this time. The logistics network and available construction crane/manipulation seem to be sufficient to attend to any necessary GEO base maintenance tasks.

WBS 1.3.3 Satellite Maintenance Systems and Operations

WBS Dictionary
This element describes the satellite maintenance mission concept.

Mission Concept Description
The reference satellite maintenance mission includes semi-annual visits to each satellite by four repair crews that work continuously on the satellite until finished. The maintenance operations associated with the first visit to the satellites occurs from the beginning of one equinox (e.g. spring) to the beginning of the next (e.g., autumn). The second visit to the satellites begins at the start of the autumn equinox and lasts until the beginning of the next spring equinox.

Typical flight operations associated with one GEO final assembly base and the operations associated with one repair group and one refurbishment group assigned to the base are described. Other final assembly bases would have comparable operations.

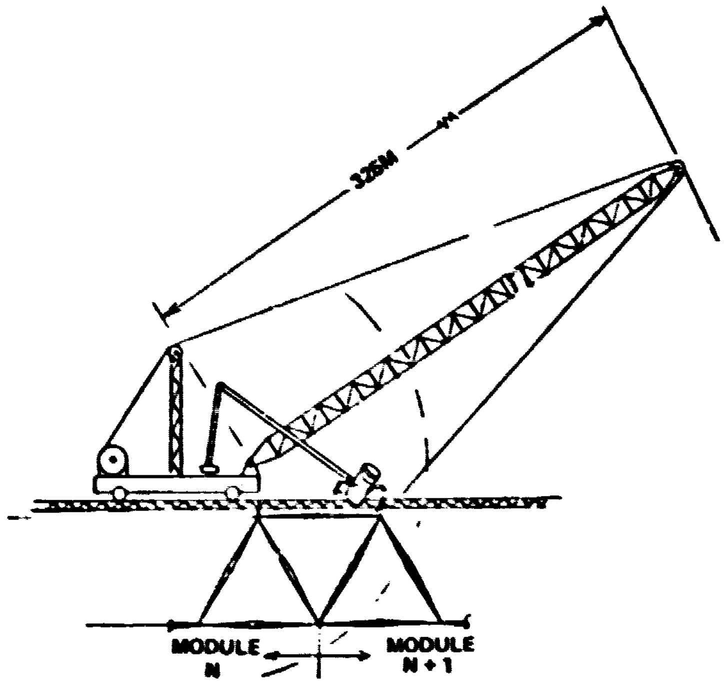

Figure 1.3.2-5 Docking Crane

Table 1.3.2-5 GEO Base Contruction Equipment Photovoltaic Satellite

SPS 1481

EQUIPMENT ITEM	NUMBER REQ'D	EQUIPMENT ITEM MAJOR ELEMENTS	NO. REQ'D ITEM
• DOCKING CRANES (MASS 26K Kg) (COST $52M) A	4	• CARRIAGE • BOOM • WINCH SYSTEM • DOCKING PROBES • CONTROL CAB (2 MAN)	
• 25M INDEXING/SUPPORT MACHINES (MASS 1K Kg) (COST $3M)	6	• CARRIAGE • BOOM	
• 60M MANIPULATOR/CRANES (MASS 7K Kg) (COST $18M)	4	• CARRIAGE • ELEVATOR BOOM • TRANSVERSE BOOM • CONTROL CAB (1 MAN) • MANIPULATOR ARMS	
• SOLAR ARRAY DEPLOYMENT MACHINE (MASS 12K Kg) (COST $45M)	4	• GANTRY/CARRIAGE • DEPLOYMENT CARRIAGE • BLANKET END HANDLER MECH • EDGE ATTACHMENT MECH • CONTROL CAB (2 MAN)	
• SOLAR ARRAY ANNEALING MACHINE	(TBD)	(TBD)	

A ALL COST REFLECT AVG UNIT COST AFTER APPLYING LEARNING FACTOR OF 0.9.

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Once maintenance operations are begun, the GEO construction base serves as a major staging depot for the maintenance crews and their hardware in addition to its role of constructing the satellites. The initial operations associated with a typical 90 day period are shown in figure 1.3.3-1. Four repair crews and four refurb crews are transported to the GEO final assembly base. Each crew is provided with its own orbit transfer vehicle. At approximately the same time another orbit transfer vehicle delivers klystron tube module components to be used in the refurbishment of failed tubes. This vehicle would also transfer other replacement components.

Refurbishment crews remain at the GEO final assembly base, repairing failed klystron tube modules that have previously been delivered by other repair crews. Repair crews transfer to the satellite designated for repair taking with them their habitat. The second stage of the orbit transfer vehicle which brought the crew to GEO is used for the transfer to the satellite. The second stage of the orbit transfer vehicle used to deliver the klystron tube components to the GEO final assembly base is then loaded with refurbished klystron tube modules and transferred to the first satellite to be repaired.

At the completion of repairs on the first satellite, the crew and habitat transfer to the next satellite to be repaired. The other orbit transfer vehicle returns the failed klystron tube modules back to the GEO final assembly base where they will be refurbished. The OTV then returns back to the LEO construction base. Prior to this time, however, another orbit transfer vehicle has come from LEO construction base to the GEO final assembly base delivering additional klystron tube components and is then dispatched with completely refurbished klystron tube modules to the second satellite that is to be repaired.

This cycle is repeated for each satellite to be repaired.

The final operations associated with a typical 90-day period are illustrated in figure 1.3.3-2. After the 20th satelllite has been repaired, the crew and habitat return to the GEO final assembly base where the habitat is left for the next repair crew. The initial crew then returns back to the LEO construction base and eventually back to Earth. The refurbishment crew has also completed their 90 day stay time and also returns back to Earth.

Four new crews and four new refurbishment crews are then transferred to the GEO final assembly base. The complete cycle is repeated again. The crew size at the GEO final assembly base will have a maximum operating size of 310 (240 associated with refurbishment and 70 with satellite assembly) and at the time the four repair crews return at the end of their tour of duty the crew size will be 550.

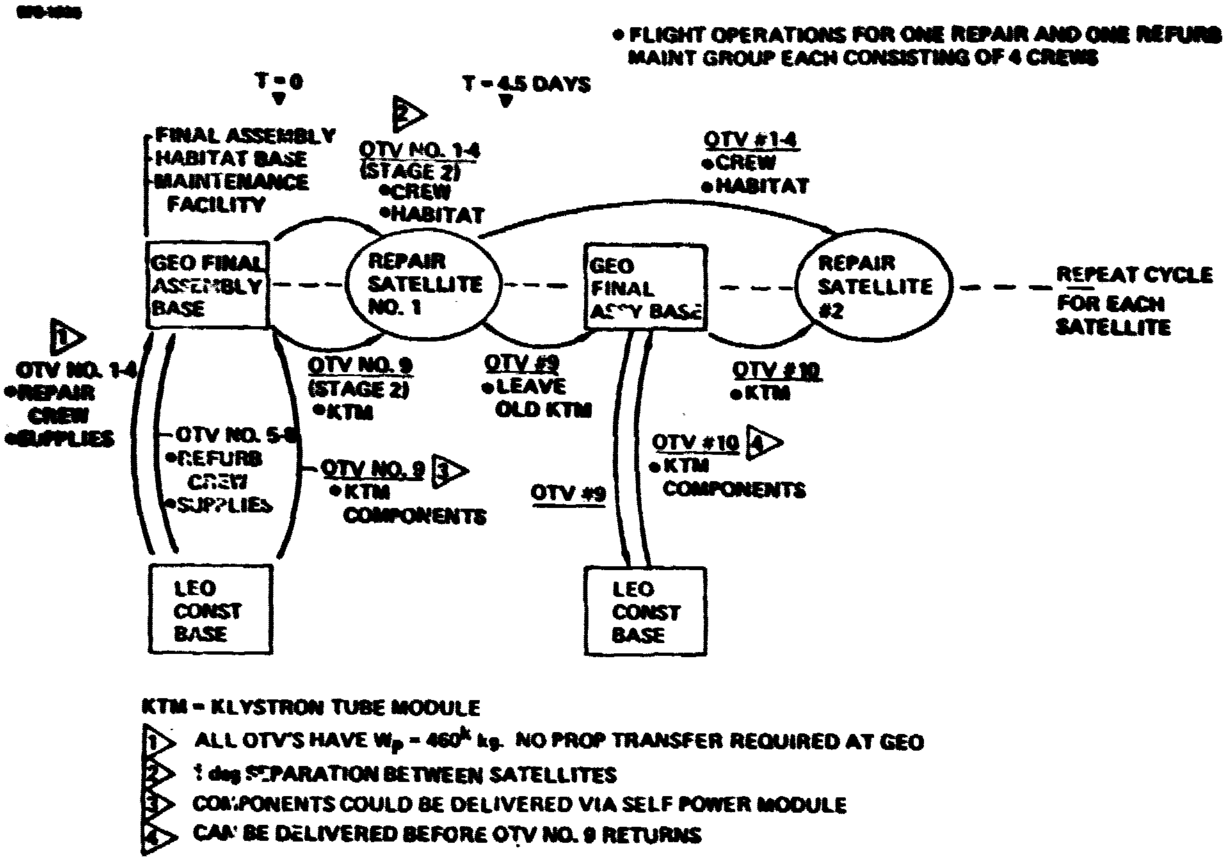

Figure 1.3.3-1 Selected Maintenance Mission Concept

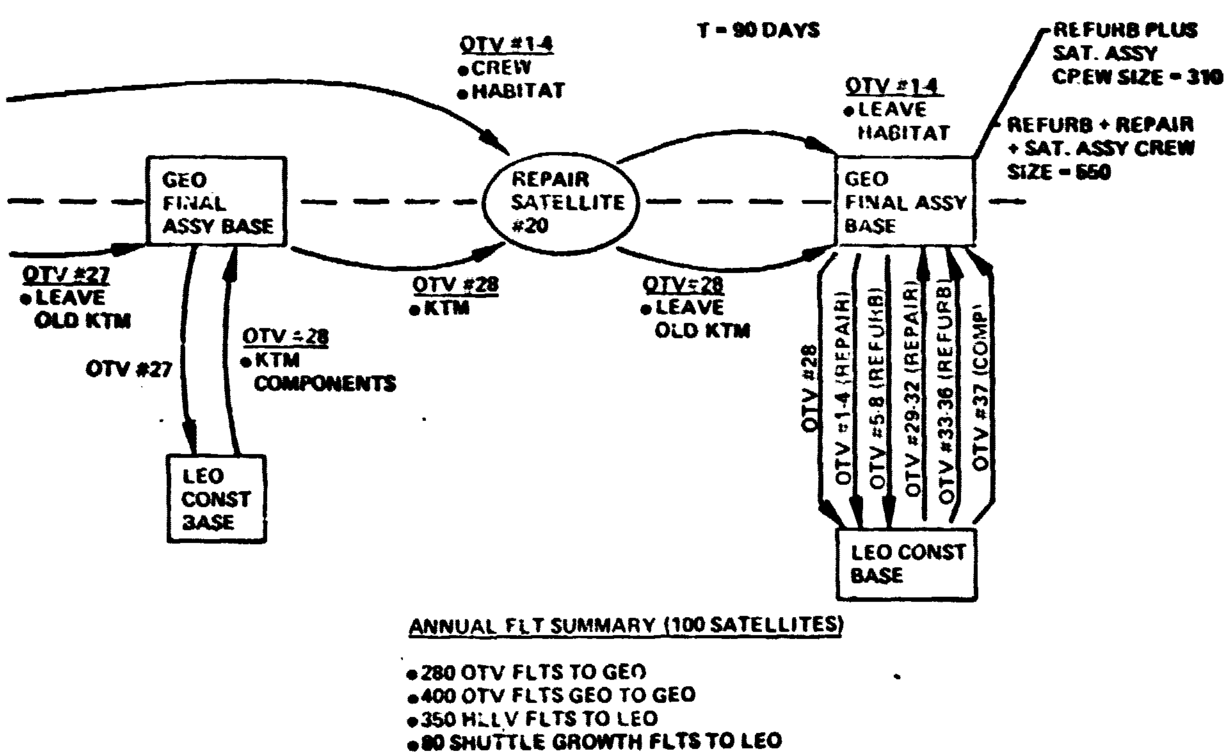

Figure 1.3.3-2 Selected Maintenance Mission Concept

The annual number of orbit transfer vehicles and launch vehicles flights which occur in the maintenance of 100 satellites are also indicated. During this time period, maintenance operations will completely dominate the GEO transportation operations rather than assembly of satellites at GEO.

Crew Summary

The maintenance crew size estimate is summarized in table 1.3.3-1.

Table 1.3.3-1 Maintenance Crew Size Estimate [1]

Repair Crews [2]	
Direct	160
Indirect	80
Refurbishment Crews [3]	
Direct	160
Indirect	80
	480

[1] Maintenance crew assigned to a typical GEO base. This size can repair and refurb the equivalent of 40 SPS's per year. Other GEO bases would have same crew size.

[2] These repair crews would be at operational SPS's except when at the GEO base at the time of crew rotation.

[3] These crew members would be stationed at each GEO base.

WBS 1.3.3.1 Satellite-Based Maintenance Equipment and Operations

WBS Dictionary

This element includes all of the structures, information systems, and equipment items built into the satellite to facilitate maintenance work.

Element Description

A number of major components of the satellite have been analyzed for their nature of failures, mean time between failure, power loss per failure, and finally the power loss per year. The component having the greatest impact in terms of power loss and in the time required to fix the failures is the klystron tube modules as indicated in figure 1.3.3-3. A total of 7600 tubes are estimated to fail per year resulting in an annual power output loss of 800,000 Kw. Antenna maintenance was therefore focused only on the klystron tube module and is described in Section 1.3.3.1.1.

The equipment used for annealing of solar arrays is included in the satellite-based maintenance equipment and operations. This system is described in Section 1.3.3.1.2.

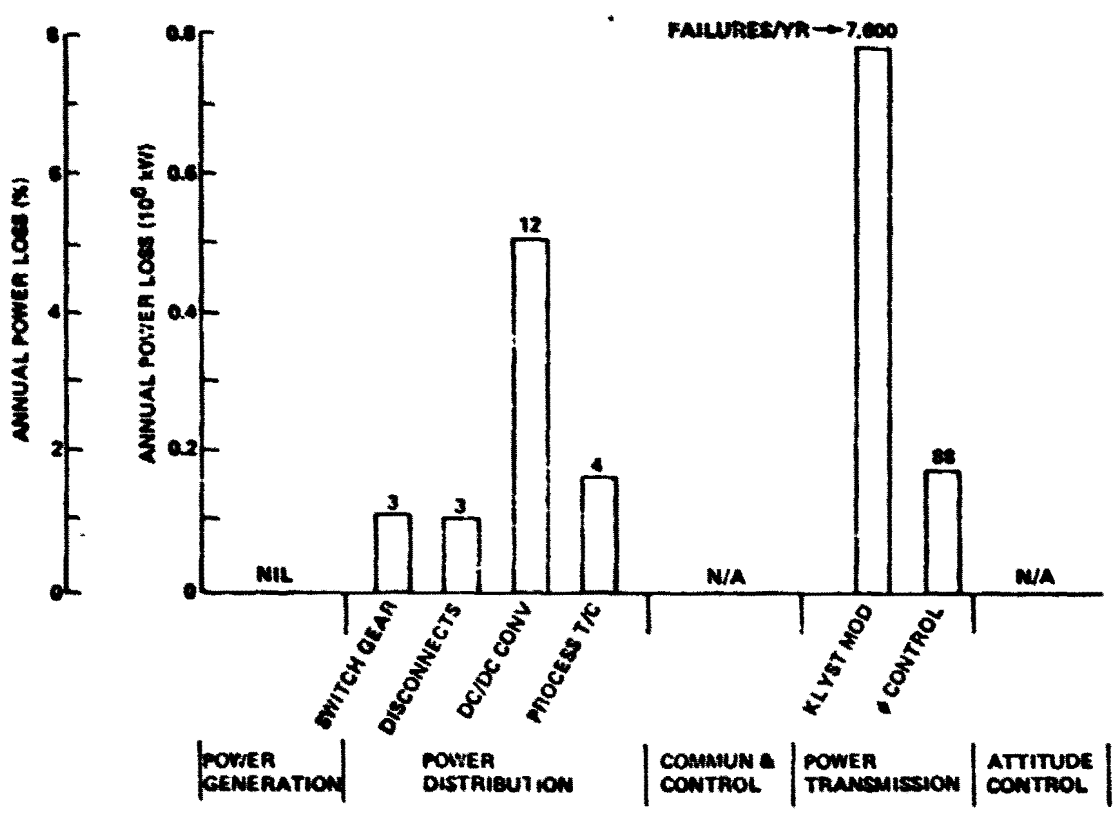

Figure 1.3.3-3 Items Requiring Maintenance

WBS 1.3.3.1.1 Antenna Maintenance Equipment and Operations

WBS Dictionary
This element includes the description of the antenna items requiring maintenance, the level of replacement, the replacement concept, logistics provisions, and the maintenance equipment.

Level of Replacement–The level of replacement selected is that of the klystron tube module plus its thermal control system as shown in Figure 1.3.3-4. Actual removal of the tube module involves access through holes in the radiator to reach the distribution wave guide attachment bracket which secures the module to the distribution wave guide. Once this attachment is released the module is free to be removed.

Concept
The selected klystron tube module replacement concept uses vertical access through the cubic secondary structure which is attached to the A-frame primary structure.

The overall concept is illustrated in Figure 1.3.3-5. The primary structure is an A-frame design forming ridges that allows free unobstructed movement of the maintenance gantry moving horizontally across the antenna.

The antenna will have a total of 10 channels in which maintenance gantries can be mounted. Attached to each of the gantries are the maintenance vehicles which reach up through the secondary structure to reach the failed klystron tubes as shown in Figure 1.3.3-6.

Additional detail of the cubic secondary structure and the maintenance vehicle is presented in Figure 1.3.3-7 with a maintenance vehicle shown moving along in the direction of the channel. The gantry itself is designed to transport all of the spare klystron tubes necessary for a given shift. The maintenance vehicle consists of a hinged boom and a two-man crew cabin with manipulators. A small klystron rack is also attached to the boom to eliminate the need for the manipulators to reach back down to the gantry for each tube that must be repaired. In the case of a 36 tube subarray as many as three tubes may require replacement.

Using this concept a tube replacement time of 45 minutes is expected, which includes removal and replacement of two diagonals (in lower and upper surface of secondary structure), removal and replacement of one klystron tube module, and movement to the next fialed klystron tube estimated at a distance of 2 subarrays away or 20 meters.

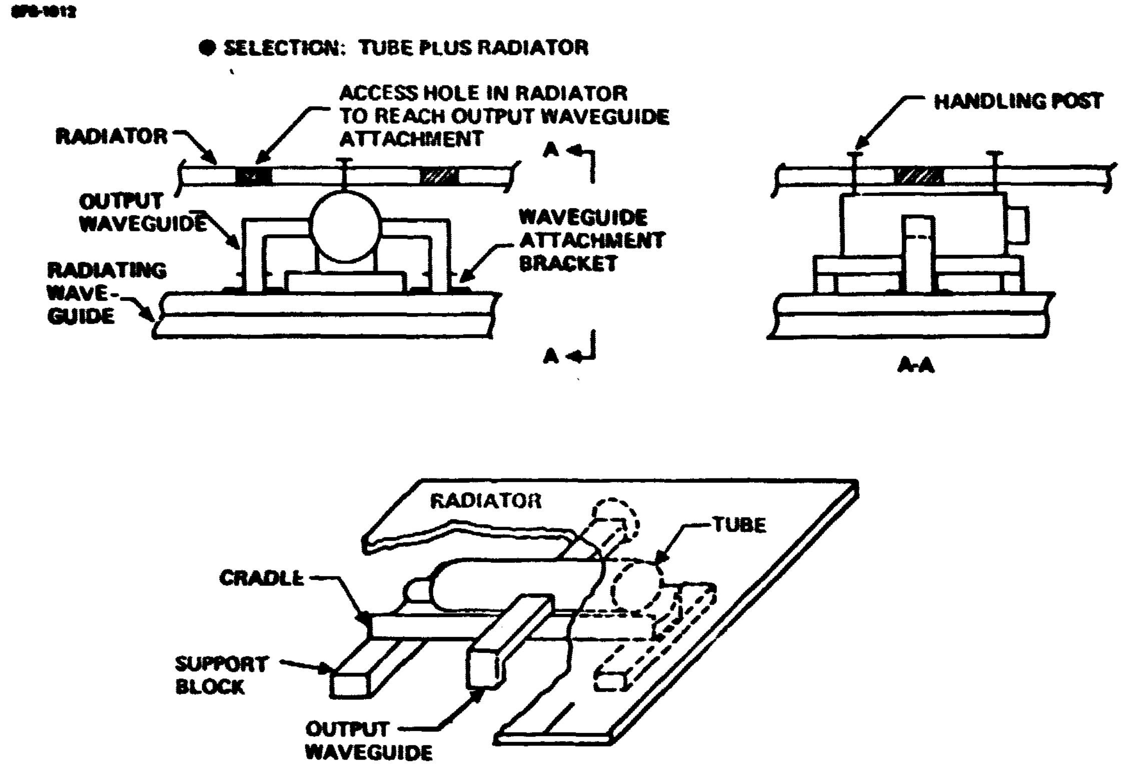

Figure 1.3.3-4 Level of Replacement Selection

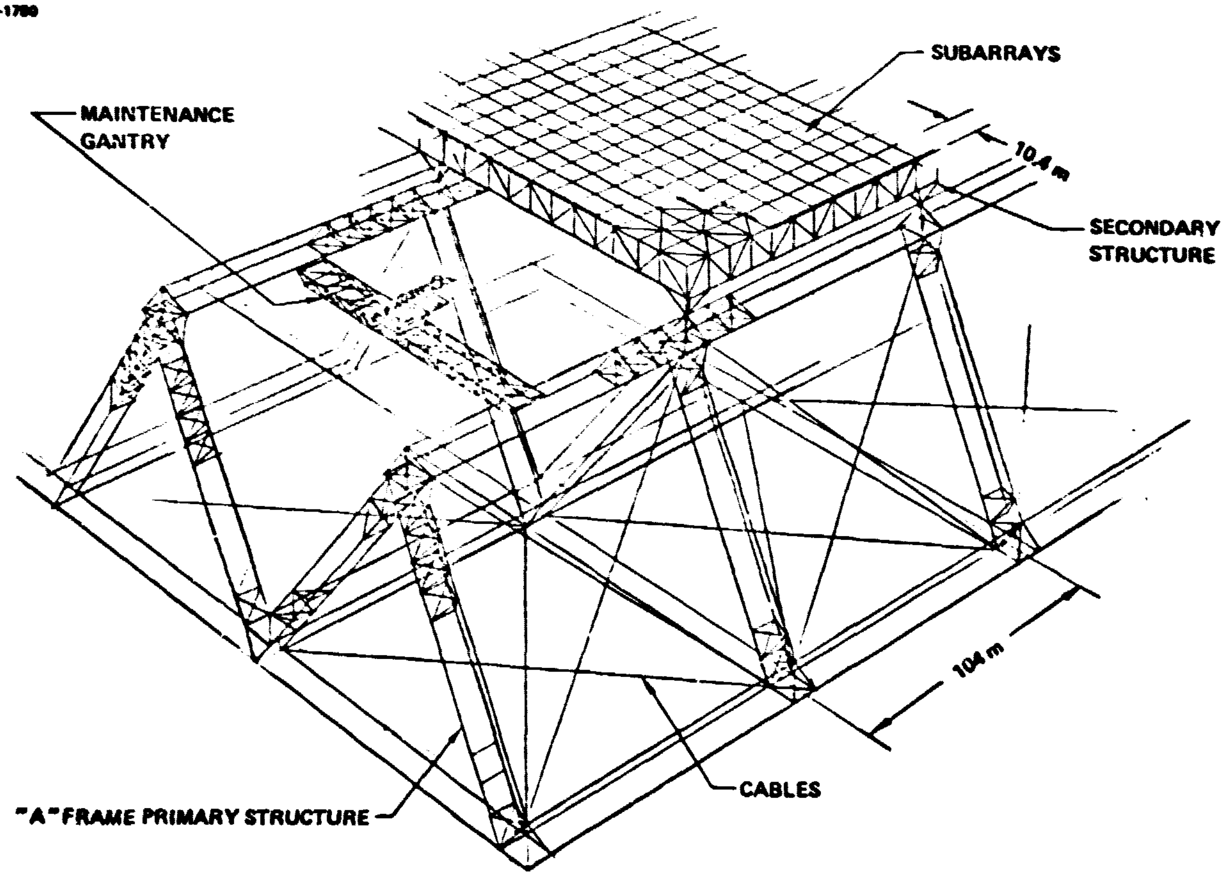

Figure 1.3.3-5 Vertical Access For Tube Maintenance

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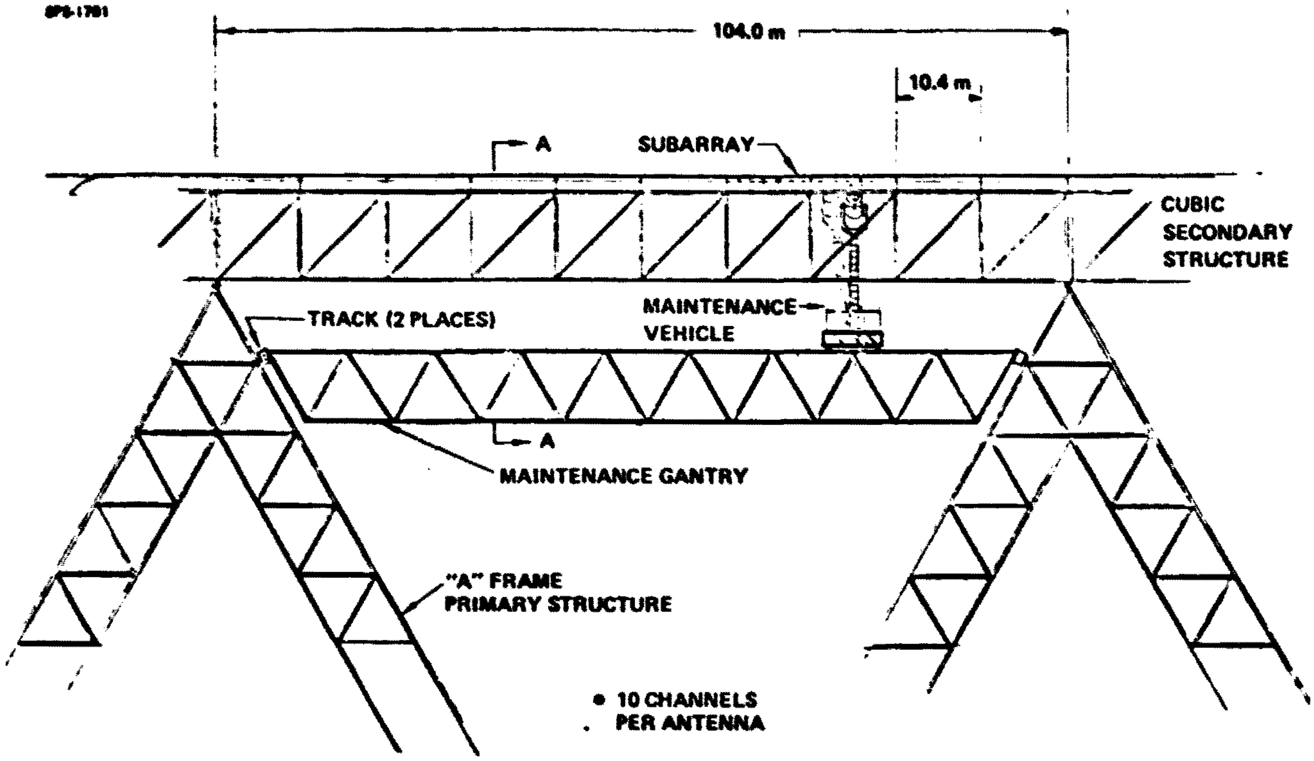


Figure 2.3.3-6 Vertical Access For Tube Maintenance

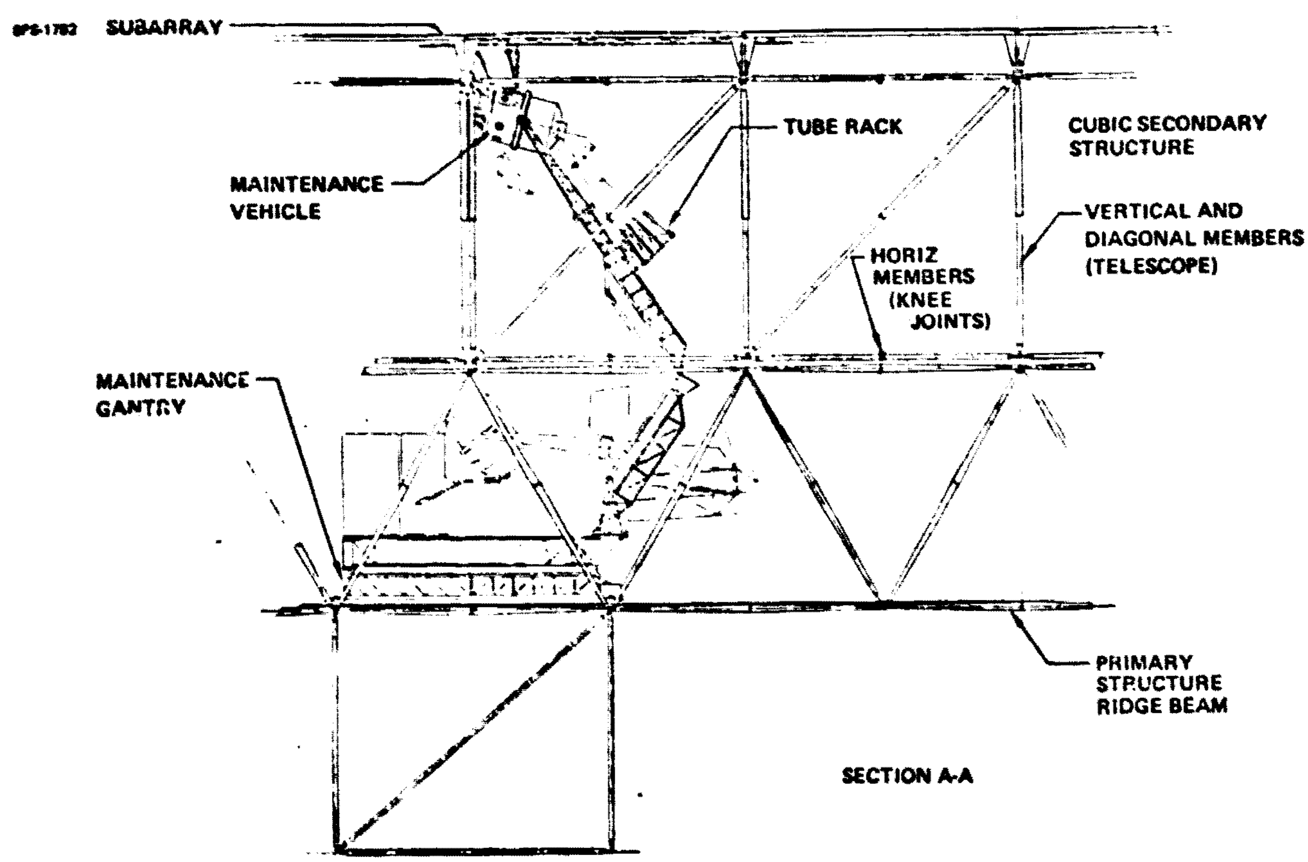


Figure 1.3.3-7 Vertical Access Maintenance Vehicle

The Satellite based maintenance systems will be installed during construction of the LEO construction base. The systems are shown as they relate to one side of one antenna in Figure 1.3.3-8 and 1.3.3-9. Since four crews work on each satellite, these same systems are present on both sides of both antennas.

To enable the docking of the various maintenance system elements and to transfer cargo around the antenna, the antenna structure has been designed to incorporate a cargo distribution system and has structural additions to allow maintenance gantries to be positioned so they can be maintained and supplied with new klystron tube modules.

The 60 person crew is delivered to the satellite in the crew habitat using the second stage of the OTV that initially brought the crew from the LEO construction base to the GEO final assembly base. Once at the satellite (antenna), a crew bus is used to transfer persons between the habitat and the maintenance repair vehicles.

Cargo, primarily in the form of klystron tube modules is also delivered to the satellite using a dedicated OTV (stage 2) that had initially brought klystron components to the GEO final assembly base for refurbishment of "failed" klystron tubes. The operations associated with an OTV include docking and release of one klystron tube pallet on one side of the antenna and then free-flying to the other side of the antenna leaving another pallet followed by flying to the other antenna and leaving two pallets in a similar manner. At the completion of the repair operation, the pallets are loaded with "failed" klystron tubes. The OTV then moves to the four docking locations collecting the pallets with failed tube modules and then returns them back to the GEO final assembly base where they will be refurbished. Following the release of the pallets, the OTV returns to the LEO construction base where it is made ready to deliver another load of klystron components.

The actual distribution of the cargo around the antenna is accomplished through use of cargo transporters operating on the track system on two sides of each antenna. The cargo transporter system consists of three separate units attached together to form a "train". The middle unit is a control unit that has a crew cabin, power systems and crane manipulator that moves the cargo between the train and the maintenance gantries. Units on either side of the control unit are essentially trailers that carry either new klystron tube modules or those that have failed and have been removed. The train system moves down to each gantry and delivers to it the number of klystron tubes required in that particular antenna channel during one shift or one day of operation depending on the channel.

The installation location of the maintenance equipment on an antenna being repaired by two crews is shown in Figure 1.3.3-10.

The number of maintenance vehicles (machines) installed in each channel of the antenna is a function of the estimated number of tube failures. This value is larger in the middle channels of the antenna since the center of the antenna has subarrays containing 36 and 30 klystron tube modules

SPS-1040

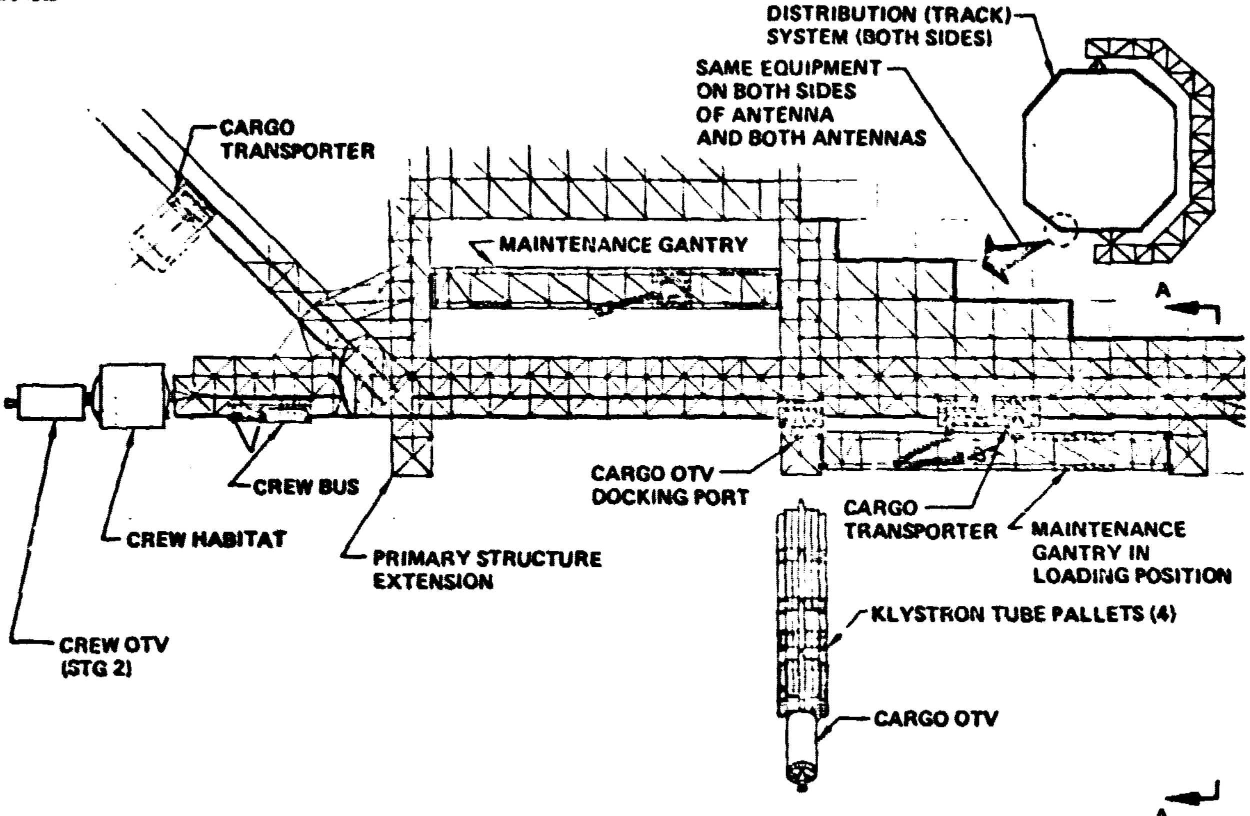


Figure 1.3.3-8 Satellite Maintenance Systems

SPS-1041

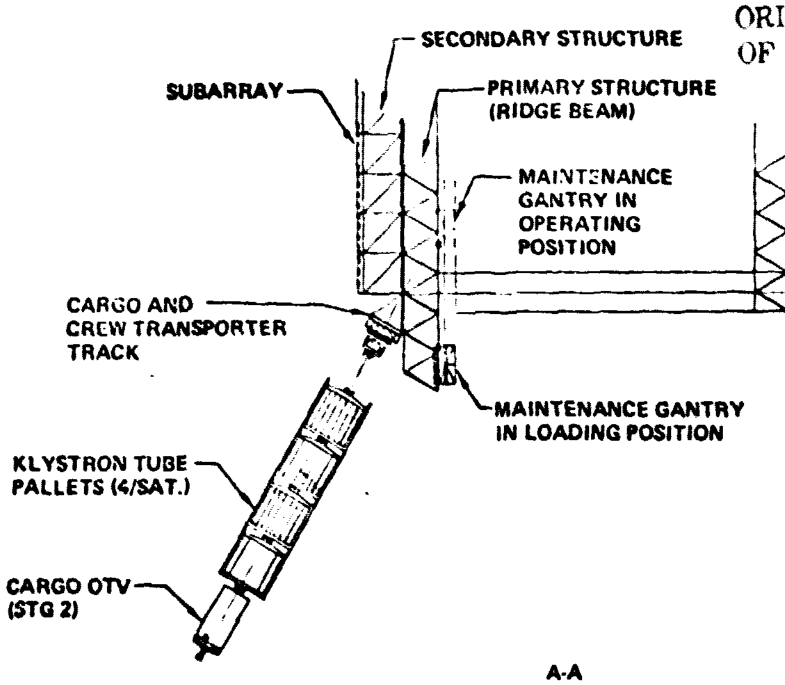


Figure 1.3.3-9 Satellite Maintenance Systems

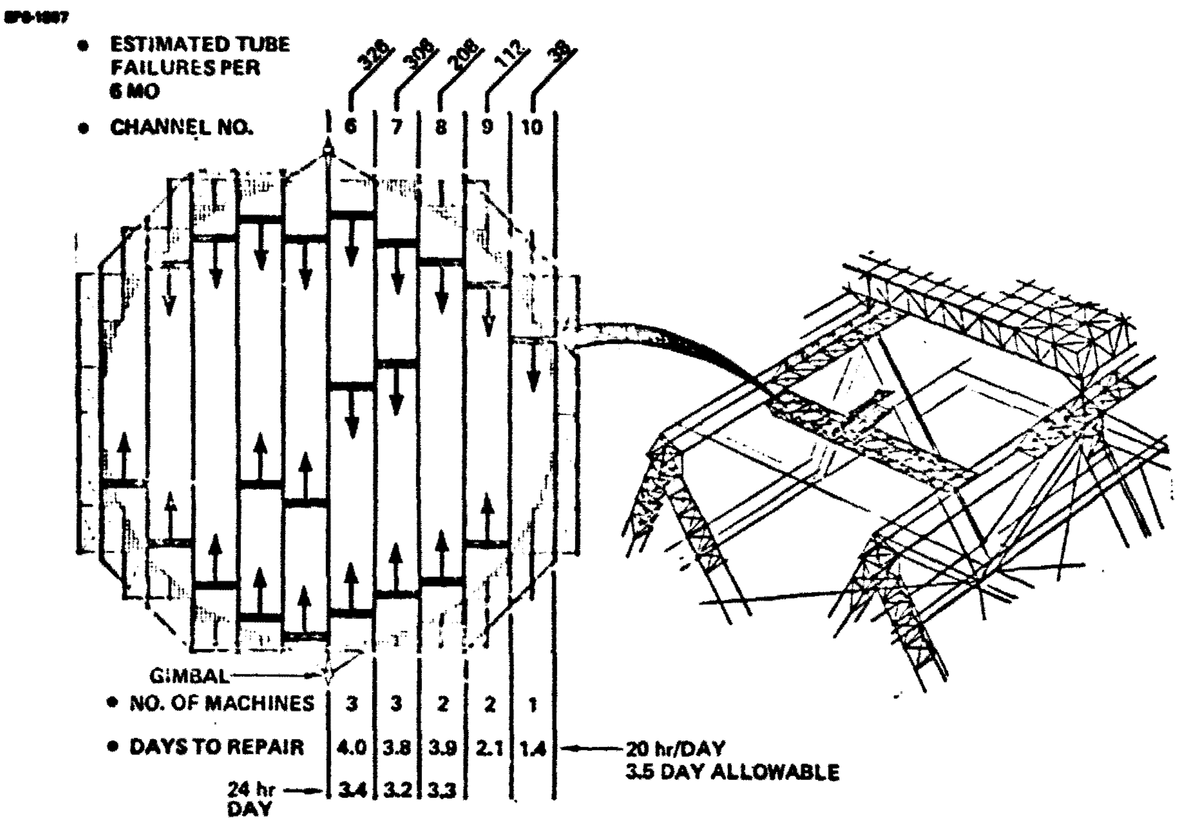


Figure 1.3.3-10 Antenna Maintenance System Installation

while near the edge of the antenna, the subarrays have 4 or 6 tubes per subarray. Consequently it will be noted that the middle channel has three maintenance systems consisting of a gantry and repair vehicle.

With this equipment distribution and working 20 hours per day, the middle channels require slightly more time than previously identified for repair—3 1/2 days per satellite. The addition of 1/2 day to the schedule, however, will not appreciably alter the prior analysis.

It should also be noted, the outside channels require far less time to repair and less equipment due to fewer failed tubes. Consequently when the crews assigned to this particular equipment are finished, they can then be used to repair other components on the satellite such as the dc-dc converters mentioned earlier in the discussion.

Mass and Cost
Mass and cost characteristics for the permanently installed antenna maintenance equipment is shown in Table 1.3.3-2.

WBS 1.3.3.1.2 Solar Array Annealing Equipment and Operations

WBS Dictionary
This element includes all hardware required to provide the capability of annealing radiation degradation from the solar cells. Subelements include the annealing device, support structure, and auxilliary equipment.

Element Description
Laser annealing was chosen as the reference approach to recover radiation induced performance degradation of the energy conversion system. Simulation Physics, Inc., under Boeing subcontract, has successfully demonstrated laser annealing in the laboratory. Table 1.3.3-3 lists the basic annealing parameters used in the laboratory tests.

The design assumptions for the laser device that was used in our analysis is given in Table 1.3.3-4. With these assumptions, several options were investigated for the number of annealing devices, method of annealing, and effect on system operation.

The option chosen for this study was to use one annealing device gantry per satellite module (Figure 1.3.3-11). A typical annealing device gantry is also shown using forty-four laser annealers. The gantry would index to its first position, at the edge of the satellite, anneal that section (15 meter width x 660 m length) and then move on to the next section. In this manner, it would traverse the width of the satellite annealing one bay wide sections of the module. When one row of bays (8) has been annealed, the gantry will index to the next row of bays and perform the annealing operation. These same operations are repeated until the complete module has been annealed.

Table 1.3.3-2 Antenna Built-In Maintenance Equipment

EQUIPMENT ITEM	NO. REQUIRED [1]	PER UNIT MASS (KG)	PER UNIT COST ($$10^6$)
o Maintenance Gantry & Manipulation	22	5000	20
o Crew Module Docking Port	2		
o Crew Bus	2	12000	7
o Crane/Manipulator	2	3000	8
o Component Transporter	4	1000	1
o Turntable	4		

[1] Items required on each antenna. Multiply by 2 for total per satellite.

Table 1.3.3-3 Laser Annealing (Spire Data)

Laser Type - CO_2

Pulse Power - 50 watts

Beam Diameter - 0.5 cm

Pulse Length - 2 sec

Tmax Cell ~550°C

Power Density 63.7 w/cm^2 (pulsed)

Table 1.3.3-4 Design Assumptions for Laser Annealer

Annealing Energy Density – 127 $\frac{\text{w-sec}}{\text{cm}^2}$

Power Density – 63.7 w/cm^2

Pulse Length – 2 sec

Beam Area - 500 cm^2

Tmax (Active Region) – 550°C

Laser Efficiency – 0.15

Laser Energy Consumption – 0.2355 $\frac{\text{w-hr}}{\text{cm}^2}$

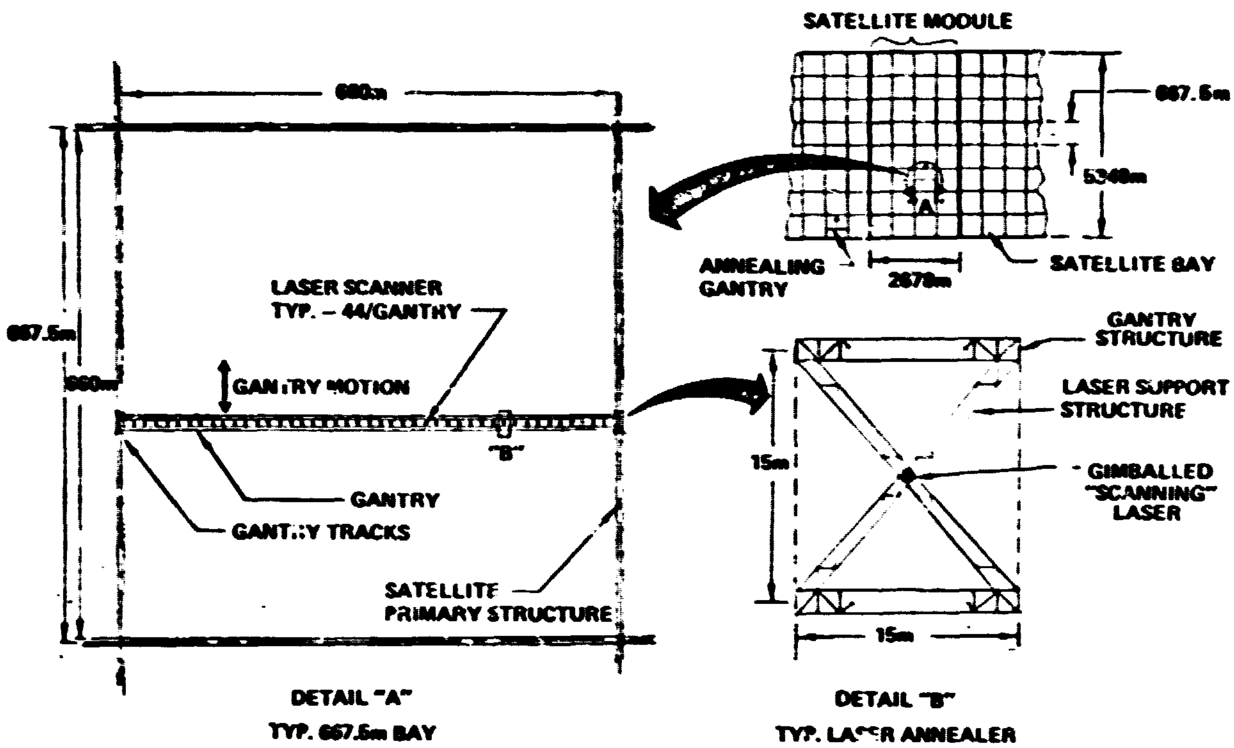


Figure 1.3.3-11 Laser Annealing Concept

The gantry system travels on tracks provided on the satellite primary structural members, in the upper surface beams, running across the satellite width.

Within the gantry, there are 44 laser systems. Each laser system is gimballed to allow the laser to scan a 15 meter square section. The 15 meter section was chosen to be consistent with the array blanket segment widths. With all of the laser systems on a single gantry operating, it will take approximately 2.5 hours to anneal a 15 meter section one bay wide. This results in a time of 110 hours to anneal one bay of solar array.

Table 1.3.3-5 lists the power requirement and time allocation of annealing the reference photovoltaic SPS.

WBS 1.3.3.2 Mobile Maintenance System

WBS Dictionary

This element includes the maintenance crew modules and component pallet modules that are transported to operational SPS's from the GEO base. The fleet of OTV's used to transport these modules are included in Section 1.4.

Element Description

The maintenance crew module and its characteristics are shown in Figure 1.3.3-12. Four of these modules are transported to each SPS when the semi-annual maintenance is to be performed.

The component pallet module and its characteristics are shown in Figure 1.3.3-13. Four of these modules are transported as a set by one OTV to each SPS when the maintenance is to be performed.

WBS 1.3.3.3 GEO Base Maintenance Support Systems

WBS Dictionary

This element includes the habitats for the refurbishment crew stationed at the GEO final assembly base and the facility and equipment required to perform the refurbishment operations.

Element Description

The habitat for the refurb crew is generally the same as that used by the repair crew on maintenance sorties to the satellites. The module is a five deck system including radiation shelter.

The refurb facility and its provisions have not been defined at this time.

Table 1.3.3-5 Reference Annealing Requirements

Power Required/Laser = 212 Kw

Power Required/Gantry = 9.35 Mw

Number of Gantry/Annealers = 8 (one/satellite module)

Total Power Requirement = 75 Mw

Time to Anneal Solar Array = 147 days
(assumes concurrent operation of all eight gantry-annealers)

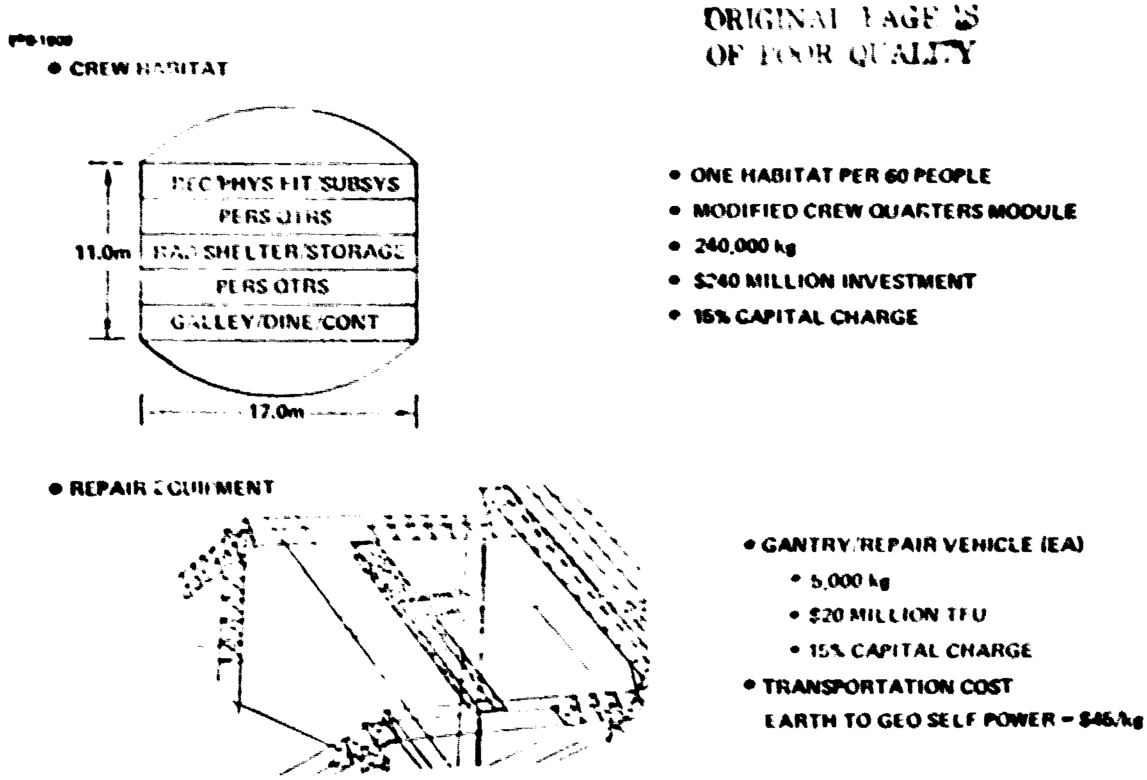


Figure 1.3.3-12 Maintenance Provisions

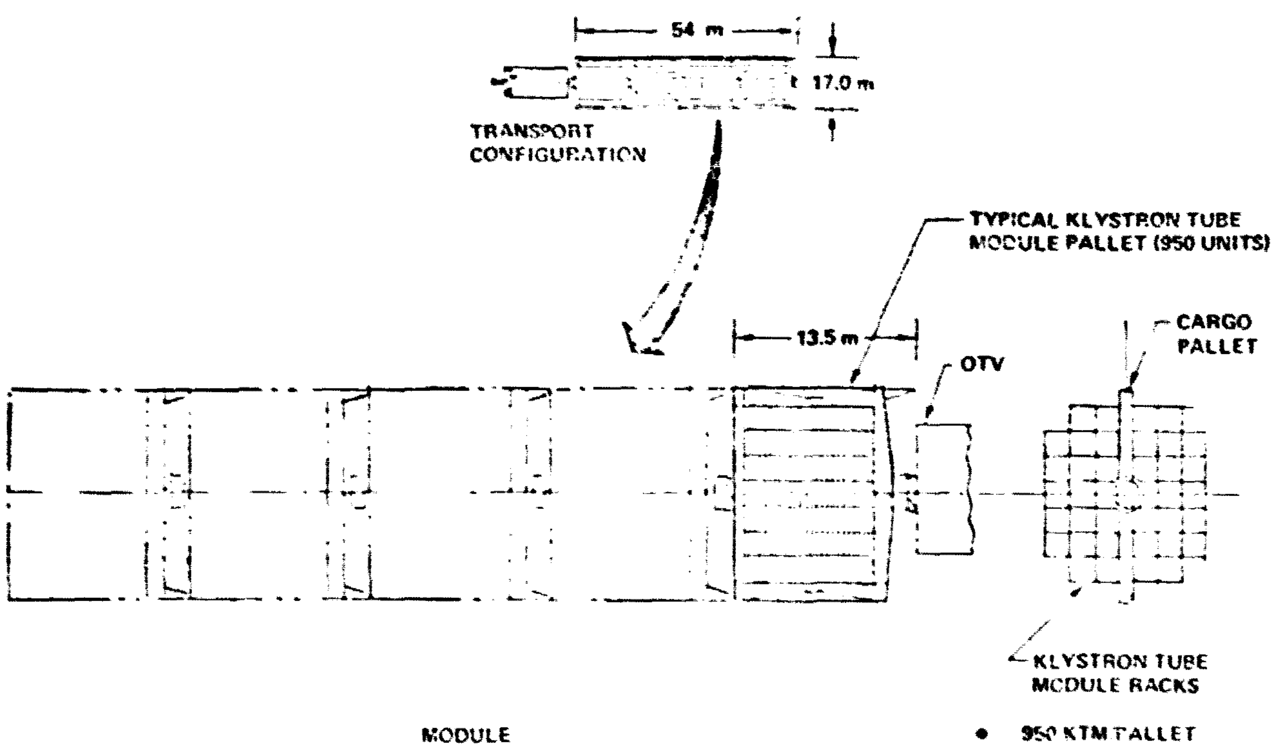


Figure 1.3.3-13

WBS 1.4.0 Space Transportation

This section of the document addresses the description of the space transportation system. Both launch and orbit transfer vehicles for cargo and personnel are included. In addition, launch facility requirements, propellant production and delivery systems, and operations/support are discussed in the following sub-sections.

Transportation Summary

The space transportation system includes a heavy lift launch vehicle (HLLV), a modified shuttle personnel launch vehicle (PLV), a personnel and supplies high-thrust orbit transfer vehicle (OTV), and low-thrust orbit transfer system (OTS) installed on the SPS modules constructed at LEO. The low-thrust OTS modules are reusable and are returned to LEO by a vehicle similar to the personnel OTV. A vehicle flight utilization and cost summary is presented in Table 1.4.0-1.

WBS 1.4.1 Cargo Launch Vehicle

The launch configuration of the SPS cargo vehicle is shown in Figure 1.4.1-1 with the overall geometry noted. This series burn concept uses 16 LCH_4/LO_2 engines on the booster and 14 standard SSME's on the orbiter. The LCH_4/LO_2 booster engines employ a gas generator cycle and provide a vacuum thrust of 9.79×10^6 newtons each. The SSME's on the orbiter provide a vacuum thrust of 2.09×10^6 newtons (100% power level). The nominal 100% power level for the SSME's was selected based on engine life considerations which indicated about a 3 factor reduction in life if the 109% power level is used.

An airbreather propulsion system has been provided on the booster for flyback capability to simplify the booster operational mode. The reference wing area for both stages is:

$$S_W \text{ (Orbiter)} = 1446 m^2 \ (15,560 \ ft^2)$$
$$S_W \text{ (Orbiter)} = 2330 m^2 \ (\ \_,080 \ ft^2)$$

Heat sink thermal protection system is provided on the booster and the Shuttle's Reusable Surface Insulation (RSI) is used on the orbiter.

WBS 1.4.1.1 Launch Vehicle Characteristics

WBS 1.4.1.1.1 Vehicle Design Characteristics

The vehicle design characteristics are noted in Table 1.4.1-1. The net delivered payload is 424,000 kg. A return payload of 15 [illegible] (63,500 kg) of the delivered payload was assumed for the orbiter entry and landing conditions. The resulting mass fraction is 0.875 for the booster and 0.841 for the orbiter.

Table 1.4.0-1 Vehicle Flight Utilization Summary

VEHICLE	PAYLOAD DELIVERED AND DESTINATION	MASS METRIC TONS	NO. OF FLIGHTS	COST, MILLIONS
HLLV	SPS HARDWARE TO LEO	99568	261	3486
HLLV	SPS SPARES	1591	4	53
HLLV	ORBIT TRANSFER SYSTEM SPARES	2432	7	93
HLLV	OTS PROPELLANT (ASCENT AND RETURN)	51602	135	1803
HLLV*	LEO AND GEO BASE SUPPLIES TO LEO EVERY 90 DAYS	375	4	53
HLLV*	PROPELLANT FOR GEO PERSONNEL/SUPPLIES DELIVERY	1960	6	80
TOTAL HLLV	FLIGHTS AND COST		417	5568
PLV*	CREWS TO LEO		32	400
POTV*	CREWS TO GEO AND RETURN		4	12
OTS	SPARES AND REFURBISHMENT		8	407
	TOTAL TRANSPORTATION			6387

*CAN BE CHARGED AS A CONSTRUCTION COST

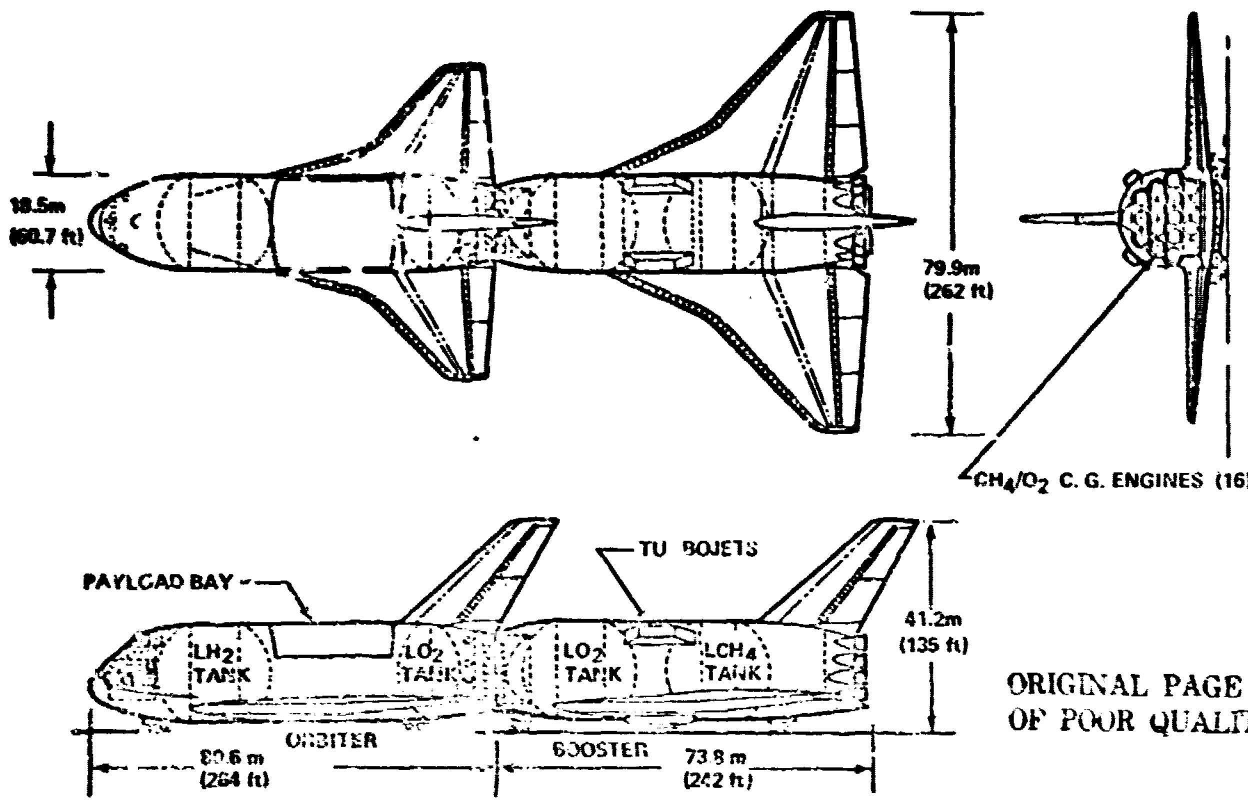


Figure 1.4.1-1 Two-Stage Winged SPS Launch Vehicle (Fully Reusable Cargo Carrier)

SPS-1052

Table 1.4.1-1 Two-Stage Winged Vehicle Design Characteristics

	ORBITER		BOOSTER
GLOW		10,978,400	
BLOW	—		7,813,700
BOOSTER FUEL (LCH4)	–		1,708,900
BOOSTER OXIDIZER (LO2)	—		6,126,700
BOOSTER INERTS	– –		978,100
OLOW–LESS PAYLOAD	2,740,700		—
ORBITER FUEL (LH2)	329,400 *		—
ORBITER OXIDIZER (LO2)	1,976,200 *		—
ORBITER INERTS	435,100		—
ASCENT PAYLOAD	424,000		—
RETURN PAYLOAD ~ 15%	63,500		—
MASS FRACTION	0.841		0.875
ENTRY WEIGHT–NO PAYLOAD	395,200		936,600
–WITH RETURN P/L	456,600		– –
START CRUISE WEIGHT–NO P/L	—		932,000
–WITH RETURN P/L	—		—
LANDING WEIGHT–NO PAYLOAD	391,800		846,700
–WITH RETURN P/L	452,600		—

(ALL MASS DATA IN kg)

*MAINSTAGE + FLIGHT PERFORMANCE RESERVE

WBS 1.4.1.1.2 Ascent Performance Characteristics

The SPS launch vehicle ascent performance characteristics are noted in Table 1.4.1-2. A '3g' maximum acceleration thrust profile was used due to the manned capability and also to minimize the load conditions on the orbiter. The booster staging velocity of 2170 m/sec is well within the "heat sink" capability of the aluminum/titanium airframe.

WBS 1.4.1.1.3 Reentry Characteristics

The reentry characteristics for the booster and orbiter are noted in Table 1.4.1-3. The maximum deceleration for the booster is 4.27 g's and the subsonic transition altitude is 17.86 km. The orbiter reentry has been limited to a normal load factor of 1.41 g's until the subsonic transition which occurs at an altitude of 13.62 km.

WBS 1.4.1.2 Booster Stage

WBS 1.4.1.2.1 System Description

The booster stage of the 2-stage winged vehicle consists of the following subsystems.

- Structures
- Induced Environmental Protection
- Landing and Auxiliary Systems
- Ascent Propulsion
- Flyback Propulsion
- RCS Propulsion
- Prime Power
- Electrical Conversion and Distribution
- Hydraulic Conversion and Distribution
- Surface Controls
- Avionics
- Environmental Control

Each of these subsystems is discussed in the following sections including definition of the rationale for the mass and cost estimates.

WBS 1.4.1.2.1.1 Structures– The booster stage structures subsystem consists of the wing, vertical tail, and body group. The body group consists of the nose section, oxidizer (LO_2) tank, intertank, fuel (LCH_4) tank, base skirt, thrust structure, aft body flap, and fairing structures. A preliminary sizing analysis was conducted to determine the individual structural element masses exclusive of heat skin requirements. The additional materials required to satisfy heat sink requirements are incorporated into the induced environmental protection subsystem.

SPS-1951

Table 1.4.1-2 Ascent Performance Characteristics

FIRST STAGE

T/W AT IGNITION	=	1.30	
MAXIMUM DYNAMIC PRESSURE	=	35.91 kPa	(750 psf)
MAXIMUM ACCELERATION	=	3.0g	
STAGE BURN TIME	=	155.24 sec	
RELATIVE STAGING VELOCITY	=	2170 m/sec	(7,120 fps)
DYNAMIC PRESSURE AT STAGING	=	1.16 kPa	(24 psf)

SECOND STAGE

INITIAL T/W	=	0.94
MAXIMUM ACCELERATION	=	3.0 g
STAGE BURN TIME	=	350.24 sec

SPS-1954

Table 1.4.1-3 SPS Winged Vehicle Reentry Characteristics

BOOSTER

APOGEE CONDITIONS

h = 80.82 km

V_{rel} = 1955 m/sec

MAXIMUM DECELERATION CONDITION

q = 10.77 kPa

h = 32.61 km

V_{rel} = 1327 m/sec

NORMAL LOAD FACTOR = 4.27 g's

MAXIMUM DYNAMIC PRESSURE CONDITION

q = 13.29 kPa

h = 22.96 km

V_{rel} = 686 m/sec

NORMAL LOAD FACTOR = 1.49 g's

SUBSONIC TRANSITION CONDITION

h = 17.86 km

α = 15 deg

ORBITER

MAXIMUM DYNAMIC PRESSURE CONDITION

q = 13.17 kpa

h = 15.55 km

V_{rel} = 361 m/sec

NORMAL LOAD FACTOR = 1.41

SUBSONIC TRANSITION CONDITION

h = 13.62 km

α = 6.4 deg

Wing The wing box is constructed of 7075-T73 aluminum and the leading edge, trailing edge, and elevons are constructed of 6AL-4V titanium. A 4g entry condition and a 2.5g subsonic maneuver condition were considered in sizing the wing structure. A constant t/c = 10% was used. The wing mass is 129,700 kg.

Vertical Tail The vertical tail was sized for a boost max $q\beta$ condition of 177 kpa. The box structure is 7075-T73 aluminum and the remaining tail structure is 6AL-4V titanium. The mass of the vertical tail is 14,000 kg.

Nose Section The nose section consists of a fixed shell structure plus a deployable nose cap. The shell structure experiences maximum compressive loadings of 35,200 N/cm forward and 24,000 N/cm aft during the boost 3g condition. The smeared thickness of the 7075 aluminum skin-stringer panels is 0.82 cm forward and 0.68 cm aft. The smeared thickness of the 7075 aluminum nose cap is 0.38 cm. The nose section mass is 26,800 kg.

Oxidizer (LO_2) Tank—The oxidizer tank is an all welded 2219-T87 aluminum pressure vessel with integral sidewall stiffening in the cylindrical section. The smeared thickness of the sidewall panels varied from 0.79 cm forward to 0.93 cm aft. The dome membrane thickness varies between 0.28 cm and 0.40 cm for the upper dome and between 0.47 cm and 0.81 cm for the lower dome. The tank mass including slosh baffles is 36,100 kg.

Intertank The intertank is approximately 18.5 meters long and is constructed of 7075 aluminum. The intertank experiences a maximum compressive loading of 30,160 N/cm at the boost 3g onset condition. The smeared thickness of the skin-stringer panels is 0.76 cm. The mass of the intertank, which incorporates the airbreather engine support structures, is 38,000 kg.

Fuel (LCH_4) Tank The fuel tank is an all welded 2219-T87 aluminum pressure vessel with integral sidewall stiffening in the cylindrical section. The smeared thickness of the sidewall panels is 0.89 cm. The dome membrane thickness varies between 0.28 cm and 0.40 cm for the upper dome and between 0.28 and 0.46 cm for the lower dome. The tank mass including slosh baffles is 32,600 kg.

Base Skirt—The base skirt is approximately 19.7 meters long and is constructed of 7075 aluminum. The upper 14.4 meters experiences maximum compressive loadings of 40,000 N/cm forward and 44,500 N/cm aft at the boost 3g onset condition. The smeared thickness of the skin-stringer panels is 0.88 cm forward and 0.94 cm aft. The lower 5.3 meters experiences a maximum combined compressive loading of 31,100 N/cm and shear flow of 18,900 N/cm during the tanked pre-ignition condition. The smeared thickness of the skin-stringer panels is 1.50 cm in the shear-out region and 0.64 cm outside the shear-out region. The base skirt mass is 47,200 kg.

Thrust Structure--The thrust structure consists of four major beam assemblies plus interbeam stabilizing members. Sixteen thrust posts are incorporated into the beam assemblies. 7075 aluminum is used throughout. The structural elements are sized for the ignition condition using a dynamic magnification factor of 1.25. Shear flows in the individual plates vary from 15,300 N/cm to 61,300 N/cm and the web plate thicknesses vary from 0.46 cm to 1.85 cm. The average cross area of a thrust post is 186 square centimeters. The thrust structure mass is 23,900 kg.

Aft Body Flap--The constant chord body flap provides the booster stage with pitch trim control and thermally shields the main engines during entry. The flap is constructed of 6AL-4V titanium and has a mass of 2100 kg.

Fairing Structures--Fairing structures consist of the wing-to-body fairings located both forward and aft of the box carry-thru section, the tail-to-body fairing, and the engine shroud/base region fairings. The fairings are constructed of 6AL-4V titanium and have an estimated mass of 8500 kg.

WBS 1.4.1.2.1.2 Induced Environmental Protection--The induced environmental protection subsystem consists of the heat sink additions required to maintain the airframe outer skin within acceptable temperature limits, plus the base heat shield. Reusable Surface Insulation is the thermal protection system on the base heat shield. The heat sink additions weigh 38,300 kg and the base heat shield 8100 kg for a total system mass of 46,400 kg.

WBS 1.4.1.2.1.3 Landing and Auxiliary Systems--In addition to landing gear, this subsystem includes a landing drag device and auxiliary systems for upper stage separation and nose cap deployment/latching. The landing gear weight is estimated at 3.2% of design landing weight. Total subsystem mass is 34,500 kg.

WBS 1.4.1.2.1.4 Ascent Propulsion--The ascent propulsion subsystem consists of the main engines, accessories, gimbal provisions, and the fuel and oxidizer systems. Main propulsion is provided by sixteen (16) high pressure LO_2/LCH_4 gas generator cycle engines and the associated tank pressurization and propellant delivery system. The following engine characteristics were used in the analysis:

Propellant	LO_2/LCH_4
Chamber Pressure	34,500 kpa
Area Ratio	60:1
Mixture Ratio	3:1
Thrust (S.L./Vac.)	8.76×10^6N/9.68×10^6N
Specific Impulse (S.L./Vac.)	318.5 sec/352 sec

The mass of the sixteen engines and associated accessories plus gimbal provisions (for eleven engines) is 162,400 kg.

Pressurization gases are heated GO_2 for the LO_2 tank and heated GCH_4 for the LCH_4 tank. The total mass of the tank pressurization and propellant delivery systems is 42,200 kg.

WBS 1.4.1.2.1.5 Flyback Propulsion The flyback propulsion subsystem consists of the airbreathing engines, accessories, fuel system, tankage, and engine installation nacelles, ducts, and doors. Flyback thrust is provided by twelve (12) turbojet engines, each having a S.L. static thrust of 356,000 N. The flyback fuel is RP-1. The dry mass of the subsystem is 57,400 kg.

WBS 1.4.1.2.1.6 Other Subsystems The remaining subsystem masses have been estimated using historical or Shuttle predicted weights. These subsystems include RCS propulsion, prime power, electrical conversion and distribution, hydraulic conversion and distribution, aerosurface controls, avionics, and environmental control.

RCS Propulsion The reaction control system is required for stage orientation prior to entry and for control during entry. The subsystem dry mass is 5100 kg.

Prime Power Major power sources consist of batteries and airbreather engine driven generators for electrical power, and a hydrazine powered APU for hydraulic power. The subsystem mass is 4300 kg.

Electrical Conversion and Distribution The power conversion, conditioning, and cabling elements are included in this category. The subsystem mass is 4200 kg.

Hydraulic Conversion and Distribution All stage functions requiring hydraulic power are serviced by the hydraulic conversion and distribution subsystem. The hydraulic power for rocket engine thrust vector control and valve actuation is included in this category. The subsystem mass is 10,900 kg.

Surface Controls The actuation system for the aerodynamic control surfaces are included in this category. The subsystem mass is 10,300 kg.

Avionics The avionics subsystem includes elements for guidance, navigation and control, tracking, instrumentation, and data processing and software. The subsystem mass is 1500 kg.

Environmental Control The environmental control subsystem maintains a conditioned thermal environment for the avionics. The subsystem mass is 200 kg.

WBS 1.4.1.2.2 Booster Mass Characteristics

The flyback booster mass characteristics are shown in Table 1.4.1-4. The structure, induced environment protection, ascent and auxiliary propulsion, and landing subsystems account for 89% of the dry mass. The induced environment protection subsystem mass includes the additional structural thickness required for the "heat sink capability" and the base heat shield.

WBS 1.4.1.3 Orbiter Stage

WBS 1.4.1.3.1 System Description

The Orbiter of the 2-stage winged vehicle consists of the following subsystems:

- Structures
- Induced Environmental Protection
- Landing and Auxiliary Systems
- Ascent Propulsion
- OMS Propulsion
- RCS Propulsion
- Prime Power
- Electrical Conversion and Distribution
- Hydraulic Conversion and Distribution
- Surface Controls
- Avionics
- Environmental Control
- Personnel Provisions
- Personnel
- Payload Accommodations

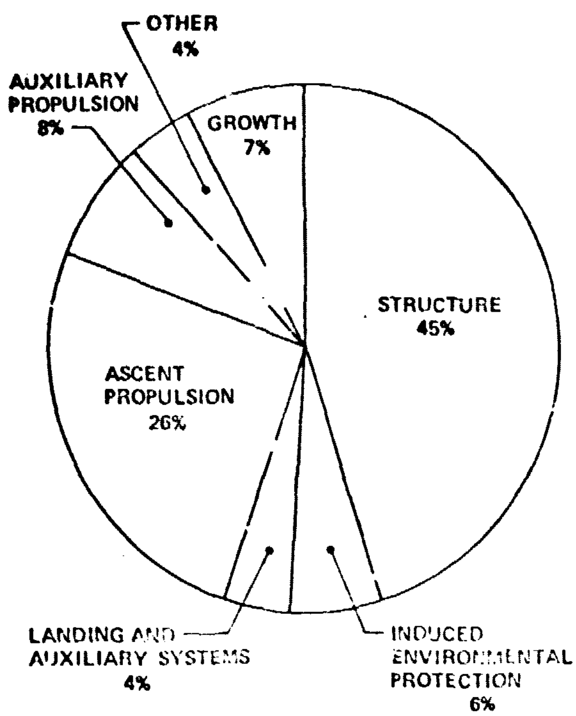
Each of these subsystems will be discussed in the following sections including definition of the rationale for the mass and cost estimates.

WBS 1.4.1.3.1.1 Structures The Orbiter structures subsystem consists of the wing, vertical tail, and body group. The body group consists of the nose section, crew module, fuel (LH_2) tank, inter-tank, P/L bay doors, oxidizer (LO_2) tank, aft skirt, thrust structure, aft body flap, and fairing structures. A preliminary sizing analysis was conducted to determine the individual structural element masses.

Wing The wing is constructed from 6Al-4V titanium. A 2.5g entry condition and a 2.5g subsonic maneuver condition were considered in sizing the wing structure. A constant t/c = 10% was used. The wing mass is 51,800 kg.

Table 1.4.1-4 Booster Mass Statement

SPS-1366



DRY MASS BREAKDOWN

	MASS (kg)
STRUCTURE	360 800
INDUCED ENVIRONMENTAL PROTECTION	46 400
LANDING AND AUXILIARY SYSTEMS	34 600
ASCENT PROPULSION	204 600
AUXILIARY PROPULSION	60 600
PRIME POWER	4 300
ELECTRICAL CONVERSION AND DISTRIBUTION	4 200
HYDRAULIC CONVERSION AND DISTRIBUTION	10 900
SURFACE CONTROLS	10 300
AVIONICS	1 500
ENVIRONMENTAL CONTROL	200
GROWTH	58 600
DRY MASS =	796 900
RESIDUALS AND RESERVES	49 800
LANDING MASS =	846 700
LOSSES DURING FLYBACK	86 200
START FLYBACK MASS =	932 900
ENTRY IN-FLIGHT LOSSES	3 700
START ENTRY MASS =	936 600
IN-FLIGHT LOSSES PRIOR TO ENTRY	27 000
STAGING MASS =	963 600
THRUST DECAY PROPELLANT	14 500
INERT MASS =	978 100

Vertical Tail–The vertical tail was sized for a boost max $q\beta$ condition of 177 kpa. It is constructed of 6AL-4V titanium. The mass of the vertical tail is 12,300 kg.

Nose Section–The nose section is constructed of 6AL-4V stiffened sandwich construction. Included in the nose section are the exterior windshields and the nose landing gear support bulkhead, wheel well and doors. The titanium sandwich is 3 cm thick and has a smeared thickness of 0.13 cm. The total mass of the nose section is 9200 kg.

Crew Module–The crew module is an all welded 2219-T87 aluminum pressure-tight vessel with integral stiffening. Included in the crew module are the interior (redundant) windshields, hatches for ingress and egress, and support provisions for other subsystem elements located within the module. The module accommodates a 4-man flight crew plus a 6-man passenger group. The crew module mass is 2800 kg.

Fuel (LH_2) Tank–The fuel tank is an all welded 6AL-4V titanium sandwich pressure vessel. The core thickness is 3 cm. The smeared thickness of the sidewall sandwich is 0.41 cm. The dome sandwich smeared thickness varies between 0.21 cm and 0.26 cm for the upper dome and between 0.22 cm and 0.28 cm for the lower dome. The tank mass is 21,200 kg.

Intertank–The intertank is constructed primarily of 6AL-4V titanium sandwich. It provides support for second stage payloads and the payload bay doors. The smeared thickness of the sidewall sandwich varies from 0.13 cm to 0.25 cm. The intertank mass is 25,900 kg.

Payload Bay Doors–The payload bay door is 24 meters long and has a surface area of 553 square meters. It consists of two panels that open at the upper centerline. Each panel consists of four equal length segments. The forward 6-meter segment incorporates deployable radiators. The door primary structure is of honeycomb and frame construction employing composite materials. The door mass is 5100 kg.

Oxidizer (LO_2) Tank–The oxidizer tank is an all welded 2219-T87 aluminum pressure vessel consisting of two elliptical domes. The dome membrane thickness varies between 0.53 cm and 0.63 cm for the upper dome and between 0.62 cm and 1.00 cm for the lower dome. The tank mass including slosh baffles is 20,300 kg.

Aft Skirt–The aft skirt is approximately 12.2 meters long and is constructed of 7075 aluminum. The skirt experiences maximum compressive loadings of 26,200 N/cm forward and 33,800 N/cm aft during the booster 3g condition. The smeared thickness of the skin-stringer panels is 0.71 cm forward and 0.81 cm aft. The aft skirt mass is 19,600 kg.

Thrust Structure The thrust structure consists of an internal cone frustum with a cruciform beam system at its lower end. Ten thrust posts are incorporated into the lower section of the cone frustiom and four thrust posts are incorporated into the cruciform beam syste. A combination 7075 aluminum/6AL-4V titanium structure is used. The structural elements are sized for the ignition condition using a dynamic magnification factor of 1.25. The average compressive loading in the upper section of the cone frustum is 12,900 N/cm and the average smeared thickness of the aluminum skin panel is 0.49 cm. The average cross section area of a titanium thrust post is 23 square centimeters. The thrust structure mass is 10,100 kg.

Aft Body Flap The constant chord body flap provides the Orbiter with pitch trim control and thermally shields the main engines during entry. The flap is an aluminum structure with honeycomb skin panels. The flap mass is 640 kg.

Fairing Structures Fairing structures consist of a forward wing-to-body fairing located in the transition region between the circular fuel tank and the "boxey" intertank, a wing-to-body fairing located under the lower half of the circular aft skirt, and a tail-to-body fairing. The fairings are aluminum structures with honeycomb skin panels. The total mass of the fairings is 3960 kg.

WBS 1.4.1.3.1.2 Induced Environmental Protection The induced environmental protection subsystem consists of (1) Reusable Surface Insulation (RSI) on the exterior surfaces of the wing, tail, and body, (2) a base heat shield incorporating RSI, (3) internal insulation for thermal control of pertinent components, and (4) purge, vent, and drain provisions. The masses of the foregoing are 44,800 kg, 1400 kg, 1100 kg, and 100 kg, respectively, yielding a total subsystem mass of 48,300 kg.

WBS 1.4.1.3.1.3 Landing and Auxiliary Systems This subsystem consists of the landing gear and payload handling manipulator arms. The landing gear weight is estimated at 3.2% of design landing weight. Total subsystem mass is 15,800 kg.

WBS 1.4.1.3.1.4 Ascent Propulsion The ascent propulsion subsystem consists of the main engines, accessories, gimbal provisions, and the fuel and oxidizer systems. Main propulsion is provided by fourteen (14) standard SSME's and the associated tank pressurization and propellant delivery systems. The following engine characteristics were used in the analysis.

Propellant	LO_2/LH_2
Chamber Pressure	20,700 kpa
Area Ratio	77.5:1
Mixture Ratio	6:1
Specific Impulse (Vac)	473 sec

The mass of the fourteen engines and associated accessories plus gimbal provisions (for ten engines) is 43,540 kg.

Pressurization gases are heated GO_2 for the LO_2 tank and heated GH_2 for the LH_2 tank. The dry mass of the tank pressurization and propellant delivery system is 17,260 kg.

WBS 1.4.1.3.1.5 OMS Propulsion - The orbital maneuver system consists of four (4) ASE engines and accessories, and associated tank pressurization and propellant delivery and storage elements. The following engine characteristics were used in the analysis:

Propellant	LO_2/LH_2
Chamber Pressure	13,800 kpa
Area Ratio	200:1/400:1
Mixture Ratio	6:1
Thrust (Vac)	89,000 N
Specific Impulse (Vac)	473 sec

The mass of the four engines and accessories is 770 kg.

Tank pressurization is provided by a high-pressure low-temperature helium gas system. The dry mass of the tank pressurization and propellant delivery and storage elements is 4830 kg.

WBS 1.4.1.3.1.6 Other Systems The remaining subsystem masses have been estimated using historical or Shuttle predicted weights. These subsystems include RCS propulsion, prime power, electrical conversion and distribution, hydraulic conversion and distribution, aerosurfaces controls, avionics, environmental control, personnel provisions, personnel, and payload accommodations.

RCS Propulsion The reaction control system provides for stage orientation on-orbit and prior to entry, and for control during entry. The subsystem dry mass is 3900 kg.

Prime Power Major power sources consist of an O_2/H_2 powered fuel cell subsystem to provide electrical power, and a hydrazine powered APU subsystem to provide hydraulic power. The dry mass of the prime power subsystem is 2500 kg.

Electrical Conversion and Distribution The power conversion, conditioning and cabling elements are included in this category. The subsystem mass is 4800 kg.

Hydraulic Conversion and Distribution All stage functions requiring hydraulic power are serviced by the hydraulic conversion and distribution subsystem. The hydraulic power for rocket engine thrust vector control and valve actuation is included in this category. The subsystem mass is 3600 kg.

Surface Controls The actuation systems for the aerodynamic control surfaces are included in this category, as are the cockpit controls. The subsystem mass is 6800 kg.

Avionics—The avionics subsystem includes elements for guidance, navigation and control, communications and tracking, displays and controls, instrumentation, and data processing and software. The subsystem mass is 2400 kg.

Environmental Control—The environmental control subsystem maintains a habitable environment for the crew and passengers, and a conditioned thermal environment for the avionics. It provides the basic life support functions for the crew and passengers, and thermal control for several subsystems. It also provides for air lock pressurization. The subsystem mass including closed loop fluids, is 2400 kg.

Personnel Provisions—The fixed life support system and personnel accommodations for the 4-man flight crew are included in this category. The subsystem mass is 500 kg.

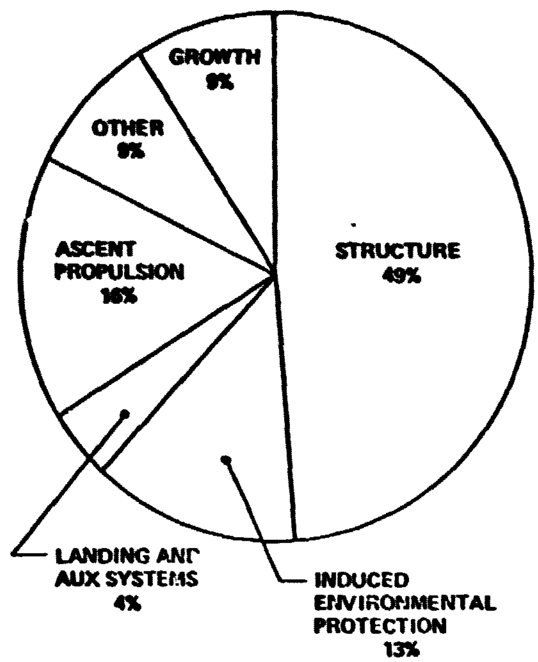
Personnel—The 4-man flight crew and their gear and accessories are included in this category. (The 6-man passenger group and their gear, accessories, and baggage are considered part of the payload.) The subsystem mass is 1200 kg.

Payload Accommodations—Removable payload support equipment is included in this category. The mass allowance is 2900 kg.

WBS 1.4.1.3.2 Orbiter Mass Characteristics

The orbiter mass characteristics are shown in Table 1.4.1-5. Structure accounts for approximately 50% of the stage dry mass. The ascent propulsion and thermal protection subsystems are an additional 29% of the dry mass. The dry mass is 86% of the inert mass with the remainder including residuals and reserves, personnel and payload accommodations, and inflight losses.

Table 1.4.1-5 Orbiter Mass Statement



DRY MASS BREAKDOWN

	MASS (kg)
STRUCTURE	182 900
INDUCED ENVIRONMENTAL PROTECTION	48 300
LANDING AND AUX SYSTEMS	15 800
ASCENT PROPULSION	60 800
AUXILIARY PROPULSION	9 500
PRIME POWER	2 500
ELECTRICAL CONVERSION AND DISTRIBUTION	4 800
HYDRAULIC CONVERSION AND DISTRIBUTION	3 600
SURFACE CONTROLS	6 800
AVIONICS	2 400
ECLSS AND PERSONNEL PROV	2 900
GROWTH	32 900
DRY MASS =	373 200
PERSONNEL AND PAYLOAD ACCOMMODATIONS	4 100
RESIDUAL AND RESERVES	14 500
LANDING MASS =	391 800
ENTRY IN-FLIGHT LOSSES	3 400
START ENTRY MASS =	395 200
IN-FLIGHT LOSSES PRIOR TO ENTRY	39 900
INERT MASS =	435 100

WBS 1.4.1.4 Launch Vehicle Costs

WBS 1.4.1.4.1 DDT&E Costs

The DDT&E cost for the flight hardware and its associated ground support equipment is shown in Figure 1.4.1-2 for both the booster and orbiter stages. The total development cost for both stages is $11.2B. Systems test, which includes all the ground and flight test hardware in addition to the test labor, accounts for in excess of 50% of the total development cost. The booster DDT&E cost includes a new rocket engine and airbreather engine development. The orbiter DDT&E reflects use of the Space Shuttle's SSME's and some of the other subsystems which were modified rather than new developments. All costs quoted are in 1977 dollars.

Since "System Test" is such a large portion of the DDT&E cost a further detail breakdown is shown in Table 1.4.1-6 for both the booster and orbiter:

The "Systems Test Labor" entry includes the labor for both ground and flight test. A five (5) flight development test program is planned for the vehicle. The labor includes all the effort to modify equipment, build test fixtures, install instrumentation and to conduct the test program. Approximately 25% of the systems test labor entry is attributable to the flight test portion and the remainder is associated with the ground test activity.

The Parametric Cost Model detailed results for both DDT&E and the TFU are tabulated in Tables 1.4.1-7 and 1.4.1-8 for both the booster and orbiter stages.

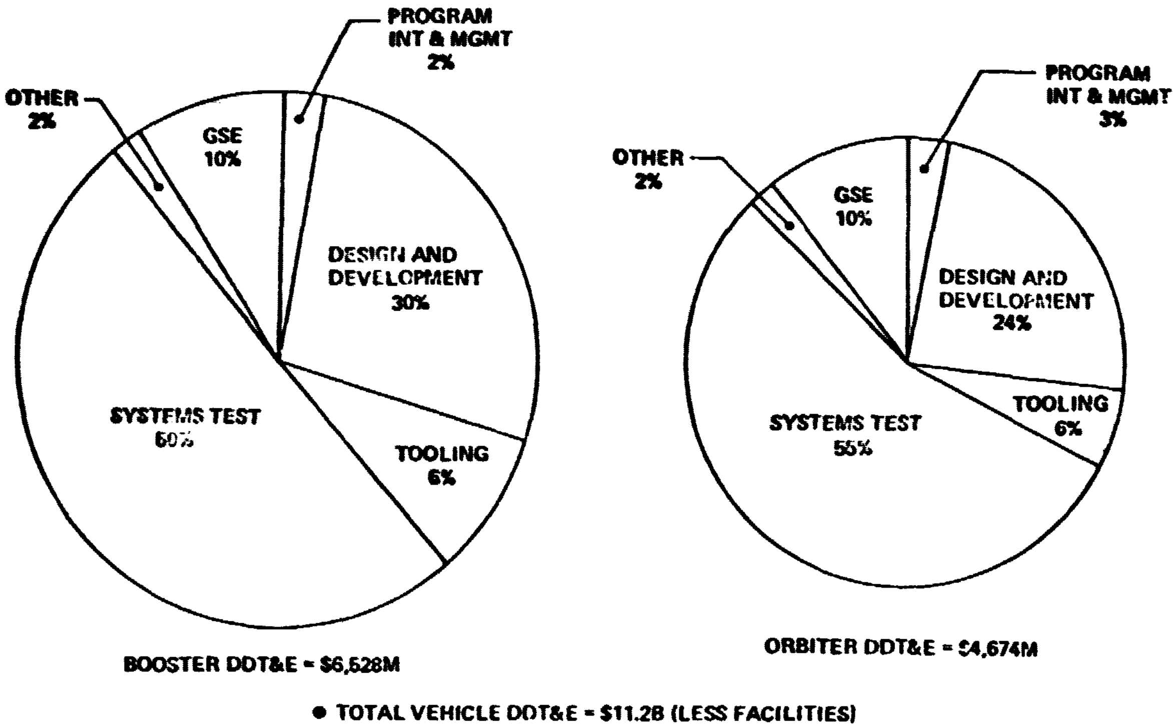


Figure 1.4.1-2 SPS Vehicle DDT&E Cost

Table 1.4.1-6 SPS Vehicle Systems Test Cost Breakdown

	BOOSTER	ORBITER
SYSTEM TEST LABOR	$767M	$626M
GROUND TEST HARDWARE	$1620M	$1236M
STRUCTURAL TEST ARTICLE	($170M)	($104M)
PROPULSION TEST ARTICLE	($725M)	($566M)
DYNAMIC TEST ARTICLE	($725M)	($566M)
FLIGHT TEST HARDWARE*	$907M	$708M
TOTAL	$3294M	$2570M

*INCLUDES REFURBISHMENT OF DYNAMIC TEST ARTICLE INTO A FLIGHT TEST UNIT.

Table 1.4.1-7 Booster DDT&E and TFU Cost Estimate

NO	NAME		SUB TO	ELEMENT	METHOD	SOUR-CES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %
1	PROGRAM COST ELEMENT		0	DDT&E	SUBS	0	0.00	0	0	0	0.0		
				OPCODE= 0									
				UNIT	SUBS	0	0.00	0				0	0
				OPCODE= 0									
2	PROG INT & MGMT		1	DDT&E	FACTOR	3	0.06	0	0	0	0.0		
				OPCODE= 2									
				UNIT	FACTOR	3	0.06	0				0	0
				OPCODE= 2									
3	SPS BOOSTER-WINGED		1	DDT&E	SUBS	0	0.00	0	0	0	0.0		
				OPCODE= 0									
				UNIT	SUBS	0	0.00	0				0	0
				OPCODE= 0									
4	FLT VEH DES & DEV		3	DDT&E	SUBS	0	0.00	0	0	0	0.0		
				OPCODE= 0									
				UNIT	SUBS	0	0.00	0				0	0
				OPCODE= 0									
5	STRUCTURE		4	DDT&E	SUBS	0	0.00	0	0	0	0.0		
				OPCODE= 0									
				UNIT	SUBS	0	0.00	0				0	0
				OPCODE= 0									
6	WING		5	DDT&E	CER	1	1.00	30	0	0	0.0		
	314600	LBS		OPCODE= 1									
				UNIT	CER	46	1.00	45				1	84
				OPCODE= 1									
7	TAIL		5	DDT&E	CER	1	1.00	30	0	0	0.0		
	33990	LBS		OPCODE= 1									
				UNIT	CER	46	1.00	45				1	84
				OPCODE= 1									
8	BODY		5	DDT&E	SUBS	0	0.00	0	0	0	0.0		
		LBS		OPCODE= 0									
				UNIT	SUBS	0	0.00	0				0	0
				OPCODE= 0									
9	NOSE		8	DDT&E	CER	1	1.00	30	0	0	0.0		
	65120	LBS		OPCODE= 1									
				UNIT	CER	46	1.00	45				1	84
				OPCODE= 1									

Table 1.4.1-7 (Continued)

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	QTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
10	CREW MODULE	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE=	8									
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE=	8									
11	FUEL TANK	8	DDT&E	CER	81	1.00	30	0	0	0.0			40,942
	78980 LBS		OPCODE=	1									
			UNIT	CER	82	1.00	45				1	84	12,170
			OPCODE=	1									
12	INTERTANK	8	DDT&E	CER	1	1.00	30	0	0	0.0			63,060
	91850 LBS		OPCODE=	1									
			UNIT	CER	46	1.00	45				1	84	20,328
			OPCODE=	1									
13	A/B FUELDTANKAGE	8	DDT&E	CER	1	1.00	30	0	0	0.0			4,593
	5060 LBS		OPCODE=	1									
			UNIT	CER	46	1.00	45				1	84	1,752
			OPCODE=	1									
14	OXIDIZER TANK	8	DDT&E	CER	81	1.00	30	0	0	0.0			[illegible]
	87450 LBS		OPCODE=	1									
			UNIT	CER	82	1.00	45				1	84	13,278
			OPCODE=	1									
15	AFT SKIRT	8	DDT&E	CER	81	1.00	30	0	0	0.0			57,314
	114510 LBS		OPCODE=	1									
			UNIT	CER	82	1.00	45				1	84	16,721
			OPCODE=	1									
16	THRUST STRUCTURE	8	DDT&E	CER	1	1.00	30	0	0	0.0			41,581
	57970 LBS		OPCODE=	1									
			UNIT	CER	46	1.00	45				1	84	13,775
			OPCODE=	1									
17	AFT BODY FLAP	8	DDT&E	CER	2	1.00	30	0	0	0.0			17,158
	4950 LBS		OPCODE=	1									
			UNIT	CER	47	1.00	45				1	84	3,967
			OPCODE=	1									
18	FAIRING STRUCTURE	8	DDT&E	CER	1	1.00	30	0	0	0.0			16,294
	20570 LBS		OPCODE=	1									
			UNIT	CER	46	1.00	45				1	84	5,736
			OPCODE=	1									

Table 1.4.1-7 (Continued)

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
19	MISC STRUCTURE	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										
20	THERMAL PROT SYS	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			14,596
			OPCODE= 0										
			UNIT	SUBS	0	0.00	0				0	0	6,263
			OPCODE= 0										
21	WING EXTERNAL TPS	20	DDT&E	CER	81	0.10	30	0	0	0.0			4,969
	76670 LBS		OPCODE= 1										
			UNIT	CER	82	0.10	45				1	84	1,656
			OPCODE= 1										
22	TAIL EXTERNAL TPS	20	DDT&E	CER	81	0.10	30	0	0	0.0			633
	7810 LBS		OPCODE= 1										
			UNIT	CER	82	0.10	45				1	84	234
			OPCODE= 1										
23	BODY EXTERNAL TPS	20	DDT&E	CER	81	0.10	30	0	0	0.0			673
	8360 LBS		OPCODE= 1										
			UNIT	CER	82	0.10	45				1	84	248
			OPCODE= 1										
24	BASE HEAT SHIELD	20	DDT&E	CER	83	2.00	30	0	0	0.0			8,319
	3110 SQF		OPCODE= 1										
			UNIT	CER	84	2.00	45				1	84	4,123
			OPCODE= 1										
25	INTERNAL TCS	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										
26	PURGE,VENT,& DRAIN	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										
27	LANDING & AUX SYS	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			193,185
			OPCODE= 0										
			UNIT	SUBS	0	0.00	0				0	0	109,855
			OPCODE= 0										

Table 1.4.1-7 (Continued)

D	NAME	SUB TO	ELEMENT	METHOD	SOUR-CES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
28	MAIN LANDING GEAR	27	DDT&E	CER	5	1.00	30	0	0	0.0			67,218
	14630 LBS			OPCODE= 1									
			UNIT	CER	50	1.00	45				4	84	21,064
				OPCODE= 1									
										AGGREGATED VALUES			[illegible]0,557
29	NOSE LANDING GEAR	27	DDT&E	CER	5	1.00	30	0	0	0.0			61,811
	13200 LBS			OPCODE= 1									
			UNIT	CER	50	1.00	45				1	84	19,352
				OPCODE= 1									
30	SEPARATION SYS	27	DDT&E	CER	5	1.00	30	0	0	0.0			25,251
	4400 LBS			OPCODE= 1									
			UNIT	CER	50	1.00	45				1	84	7,827
				OPCODE= 1									
31	DRAG DEVICE	27	DDT&E	CER	5	1.00	30	0	0	0.0			38,905
	7480 LBS			OPCODE= 1									
			UNIT	CER	50	1.00	45				1	84	12,120
				OPCODE= 1									
32	MAIN PROPULSION	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			802,504
				OPCODE= 0									
			UNIT	SUBS	0	0.00	0				0	0	199,234
				OPCODE= 0									
33	ROCKET ENGINES	32	DDT&E	CER	44	1.00	30	0	0	0.0			782,028
	2.178E6 THR			OPCODE= 1									
			UNIT	CER	80	1.00	45				16	89	12,379
				OPCODE= 1									
										AGGREGATED VALUES			149,092
34	ENGINE ACCESSORIES	32	DDT&E	CER	5	1.00	30	0	0	0.0			10,590
	1513 LBS			OPCODE= 1									
			UNIT	CER	50	1.00	45				16	89	3,248
				OPCODE= 1									
										AGGREGATED VALUES			39,121
35	PROPELLANT SYS	32	DDT&E	CER	40	1.00	30	0	0	0.0			9,885
	6394 LBS			OPCODE= 1									
			UNIT	CER	76	1.00	45				16	84	1,060
				OPCODE= 1									
										AGGREGATED VALUES			11,021
36	AUXILARY PROP	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			234,970
				OPCODE= 0									
			UNIT	SUBS	0	0.00	0				0	0	107,078
				OPCODE= 0									

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Table 1.4.1-7 (Continued)

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLFND FACTORS	SUPT FROM	OTS %	[illegible] %	MOD CMPLX	NUMBER	LRN %	COST (000)
37	RCS	36	DDT&E	CER	28	0.54	30	0	0	0.0			17,502
	3108 LBS		OPCODE=	1	40	0.46							
			UNIT	CER	73	0.54	45				4	84	5,834
			OPCODE=	1	76	0.46							
										AGGREGATED VALUES			19,543
38	FLYBACK PROPULSION	36	DDT&E	SUBS	0	0.00	0	0	0	0.0			217,467
			OPCODE=	0									
	.		UNIT	SUBS	0	0.00	0				0	0	87,534
			OPCODE=	0									
39	PRIME POWER	4	DDT&E	CER	28	0.61	30	25	75	5.0			13,741
	5170 LBS		OPCODE=	1	12	0.39							
			UNIT	CER	73	0.61	45				2	84	16,468
			OPCODE=	1	57	0.39							
										AGGREGATED VALUES			30,509
40	ELECT CONV & DIST	4	DDT&E	CER	14	0.21	30	0	0	0.0			26,011
	10230 LBS		OPCODE=	1	13	0.79							
			UNIT	CER	59	0.21	45				1	84	20,192
			OPCODE=	1	58	0.79							
41	HYD CONV & DIST	4	DDT&E	CER	5	0.75	30	10	90	5.0			48,689
	26400 LBS		OPCODE=	1	40	0.25							
			UNIT	CER	50	0.75	45				1	84	28,113
			OPCODE=	1	76	0.25							
42	SURFACE CONTROLS	4	DDT&E	CER	5	0.75	30	10	90	5.0			15,882
	6270 LBS		OPCODE=	1	40	0.25							
			UNIT	CER	50	0.75	45				4	84	8,671
			OPCODE=	1	76	0.25							
										AGGREGATED VALUES			29,046
43	AVIONICS	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			49,417
			OPCODE=	0									
			UNIT	SUBS	0	0.00	0				0	0	25,112
			OPCODE=	0									
44	G,N,& C	43	DDT&E	CER	18	1.00	30	25	75	5.0			23,640
	957 LBS		OPCODE=	1									
	.		UNIT	CER	63	1.00	45				1	84	9,457
			OPCODE=	1									
45	COMM. & TRACKING	43	DDT&E	CER	16	1.00	30	25	75	5.0			14,724
	517 LBS		OPCODE=	1									
			UNIT	CER	61	1.00	45				1	84	7,391
			OPCODE=	1									

Table 1.4.1-7 (Continued)

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
46	DISPLAYS & CONTROLS	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										
47	INSTRUMENTATION	43	DDT&E	CER	15	1.00	30	25	75	5.0			3,360
	594 LBS		OPCODE= 1										
			UNIT	CER	60	1.00	45				1	84	2,421
			OPCODE= 1										
48	DATA PROCESSING	43	DDT&E	CER	17	1.00	30	25	75	5.0			7,692
	1452 LBS		OPCODE= 1										
			UNIT	CER	62	1.00	45				1	84	5,842
			OPCODE= 1										
49	ENVIRON CONTROL	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			2,523
			OPCODE= 0										
			UNIT	SUBS	0	0.00	0				0	0	736
			OPCODE= 0										
50	CABIN & PERSONNEL	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										
51	EQUIPMENT	49	DDT&E	CER	9	1.00	30	0	0	0.0			2,523
	500 LBS		OPCODE= 1										
			UNIT	CER	54	1.00	45				1	84	736
			OPCODE= 1										
52	AIRLOCK	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										
53	PERSONNEL PROV	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			0
			OPCODE= 0										
			UNIT	SUBS	0	0.00	0				0	0	0
			OPCODE= 0										
54	LIFE SUPPORT SYS	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										

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Table 1.4.1-7 (Continued)

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
55	PERSONNEL ACCOM	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
				OPCODE= 8									
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
56	A/B ENGINES	38	DDT&E	CER	43	2.00	30	0	0	0.0			193,203
	82500 THR			OPCODE= 1									
			UNIT	CER	87	1.00	45				12	89	4,614
				OPCODE= 1									
										AGGREGATED VALUES			43,278
57	A/B ENG ACCESS	38	DDT&E	CER	5	1.00	30	0	0	0.0			6,815
	880 LBS			OPCODE= 1									
			UNIT	CER	50	1.00	45				12	89	2,078
				OPCODE= 1									
										AGGREGATED VALUES			19,492
58	NACELLES,DUCTS,ETC	38	DDT&E	CER	2	1.00	30	0	0	0.0			10,478
	2750 LBS			OPCODE= 1									
			UNIT	CER	47	1.00	45				12	84	2,328
				OPCODE= 1									
										AGGREGATED VALUES			19,213
59	FUEL SYSTEM	38	DDT&E	CER	40	1.00	30	0	0	0.0			6,969
	3300 LBS			OPCODE= 1									
			UNIT	CER	76	1.00	45				12	84	672
				OPCODE= 1									
										AGGREGATED VALUES			5,551
60	DUMMY WBS	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
				OPCODE= 8									
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
61	DUMMY WBS	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
				OPCODE= 8									
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
62	DUMMY WBS	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
				OPCODE= 8									
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
63	ASSEMBLY & CHECKOUT	3	DDT&E	N/A	0	0.00	0	0	0	0.0			0
				OPCODE= 8									
			UNIT	FACTOR	4	0.15	45				1	84	61,468
				OPCODE= 2									

Table 1.4.1-7 (Continued)

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MUD %	MOD CMPLX	NUMBER	LRN %	COST (000)
64	TOOLING	3	DDT&E	CER*	4	0.00	0	0	0	0.0			396,600
				OPCODE= 17	85	0.00							
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
65	SYSTEMS TEST	3	DDT&E	SUBS	0	0.00	0	0	0	0.0			3,293,844
				OPCODE= 0									
			UNIT	SUBS	0	0.00	0				0	0	0
				OPCODE= 0									
66	SYSTEMS TEST LABOR	65	DDT&E	CER*	4	0.00	0	0	0	0.0			766,968
				OPCODE= 12	33	0.00							
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
67	GRD TEST HDWE	65	DDT&E	SUBS	0	0.00	0	0	0	0.0			1,620,104
				OPCODE= 0									
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
68	STRUCT TEST ARTICLE	67	DDT&E	FAC UN	5	1.00	0	0	0	0.0			169,270
				OPCODE= 3									
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
69	DYN TEST ARTICLE	67	DDT&E	FAC UN	4	1.00	0	0	0	0.0			725,416
				OPCODE= 3									
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
70	PROP TEST ARTICLE	67	DDT&E	FAC UN	4	1.00	0	0	0	0.0			725,416
				OPCODE= 3	6	-1.00							
					7	-1.00							
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
71	FLT TEST HDWE	65	DDT&E	FAC UN	4	1.25	0	0	0	0.0			906,771
				OPCODE= 3									
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									
72	S E & I	3	DDT&E	CER*	4	0.00	0	0	0	0.0			75,218
				OPCODE= 12	32	0.00							
			UNIT	N/A	0	0.00	0				0	0	0
				OPCODE= 8									

Table 1.4.1-7 (Continued)

NO	NAME	SUB TO	ELEMENT METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	K %	MOD CMPLX	NUMBER	LRN %	COST (000)
73	FLT VEH D D & T	0	DDT&E FACTOR	4	1.00	0	0	0	0.0			0
			OPCODE= 2	72	1.00							
				66	1.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
74	SOFTWARE ENGR	3	DDT&E CER=	73	0.00	0	0	0	0.0			27,044
			OPCODE= 12	35	0.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
75	GSE	3	DDT&E CER=	4	0.00	0	0	0	0.0			314,693
			OPCODE= 12	38	0.00							
			UNIT CER=	4	0.00	0				0	0	153,003
			OPCODE= 17	39	0.00							
76	DDT&E GSE S/S	3	DDT&E FAC UN	75	2.00	0	0	0	0.0			306,006
			OPCODE= 3									
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									

Table 1.4.1-8 Orbiter DDT&E and TFU Cost Estimate (SPS Winged Orbiter)

NO	NAME		SUB TO	ELEMENT METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
1	PROGRAM COST ELEMENT		0	DDT&E SUBS	0	0.00	0	0	0	0.0			4,674,072
				OPCODE= 0									
				UNIT SUBS	0	0.00	0				0	0	764,473
				OPCODE= 0									
2	PROG INT & MGMT		1	DDT&E FACTOR	3	0.06	0	0	0	0.0			132,943
				OPCODE= 2									
				UNIT FACTOR	3	0.06	0				0	0	33,482
				OPCODE= 2									
3	SPS ORBITER-WINGED		1	DDT&E SUBS	0	0.00	0	0	0	0.0			4,541,132
				OPCODE= 0									
				UNIT SUBS	0	0.00	0				0	0	730,990
				OPCODE= 0									
4	FLT VEH DES & DEV		3	DDT&E SUBS	0	0.00	0	0	0	0.0			1,115,146
				OPCODE= 0									
				UNIT SUBS	0	0.00	0				0	0	566,031
				OPCODE= 0									
5	STRUCTURE		4	DDT&E SUBS	0	0.00	0	0	0	0.0			324,659
				OPCODE= 0									
				UNIT SUBS	0	0.00	0				0	0	103,645
				OPCODE= 0									
6	WING		5	DDT&E CER	1	1.00	30	0	0	0.0			83,591
	125400	LBS		OPCODE= 1									
				UNIT CER	46	1.00	45				1	84	26,450
				OPCODE= 1									
7	TAIL		5	DDT&E CER	1	1.00	30	0	0	0.0			22,862
	29920	LBS		OPCODE= 1									
				UNIT CER	46	1.00	45				1	84	7,875
				OPCODE= 1									
8	BODY		5	DDT&E SUBS	0	0.00	0	0	0	0.0			218,205
		LBS		OPCODE= 0									
				UNIT SUBS	0	0.00	0				0	0	69,319
				OPCODE= 0									
9	NOSE		8	DDT&E CER	1	1.00	30	0	0	0.0			17,471
	22220	LBS		OPCODE= 1									
				UNIT CER	46	1.00	45				1	84	6,123
				OPCODE= 1									

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Table 1.4.1-8 (Continued)

NO	NAME	SUB TO	ELEMENT METHOD	SOUR-CES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
10	CREW MODULE	8	DDT&E CER	2	1.00	30	0	0	0.0			22,150
	6710 LBS		OPCODE= 1									
			UNIT CER	47	1.00	45				1	84	5,227
			OPCODE= 1									
11	FUEL TANK	8	DDT&E CER	1	1.00	30	0	0	0.0			37,346
	51480 LBS		OPCODE= 1									
			UNIT CER	46	1.00	45				1	84	12,460
			OPCODE= 1									
12	INTERTANK	8	DDT&E CER	1	1.00	30	0	0	0.0			44,780
	62920 LBS		OPCODE= 1									
			UNIT CER	46	1.00	45				1	84	14,764
			OPCODE= 1									
13	P/L BAY DOORS	8	DDT&E CER	1	1.00	30	0	0	0.0			10,255
	12320 LBS		OPCODE= 1									
			UNIT CER	46	1.00	45				1	84	3,719
			OPCODE= 1									
14	OXIDIZER TANK	8	DDT&E CER	81	1.00	30	0	0	0.0			26,660
	49170 LBS		OPCODE= 1									
			UNIT CER	82	1.00	45				1	84	8,114
			OPCODE= 1									
15	AFT SKIRT	8	DDT&E CER	81	1.00	30	0	0	0.0			25,904
	47630 LBS		OPCODE= 1									
			UNIT CER	82	1.00	45				1	84	7,897
			OPCODE= 1									
16	THRUST STRUCTURE	8	DDT&E CER	1	1.00	30	0	0	0.0			19,027
	24420 LBS		OPCODE= 1									
			UNIT CER	46	1.00	45				1	84	6,632
			OPCODE= 1									
17	AFT BODY FLAP	8	DDT&E CER	2	1.00	30	0	0	0.0			6,444
	1540 LBS		OPCODE= 1									
			UNIT CER	47	1.00	45				1	84	1,376
			OPCODE= 1									
18	FAIRING STRUCTURE	8	DDT&E CER	1	1.00	30	0	0	0.0			8,163
	9570 LBS		OPCODE= 1									
			UNIT CER	46	1.00	45				1	84	3,003
			OPCODE= 1									

Table 1.4.1-8 (Continued)

NO	NAME	SUB TO	ELEMENT METHOD	SOUR-CES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
19	MISC STRUCTURE	0	DDT&E N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8									
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
20	THERMAL PROT SYS	4	DDT&E SUBS	0	0.00	0	0	0	0.0			164,009
			OPCODE= 0									
			UNIT SUBS	0	0.00	0				0	0	65,397
			OPCODE= 0									
21	WING EXTERNAL TPS 33462 SQF	20	DDT&E CER	83	2.00	30	0	0	0.0			58,393
			OPCODE= 1									
			UNIT CER	84	2.00	45				1	84	24,736
			OPCODE= 1									
22	TAIL EXTERNAL TPS 7282 SQF	20	DDT&E CER	83	2.00	30	0	0	0.0			16,707
			OPCODE= 1									
			UNIT CER	84	2.00	45				1	84	7,832
			OPCODE= 1									
23	BODY EXTERNAL TPS 42405 SQF	20	DDT&E CER	83	2.00	30	0	0	0.0			70,931
			OPCODE= 1									
			UNIT CER	84	2.00	45				1	84	29,573
			OPCODE= 1									
24	BASE HEAT SHIELD 1697 SQF	20	DDT&E CER	83	2.00	30	0	0	0.0			5,065
			OPCODE= 1									
			UNIT CER	84	2.00	45				1	84	2,611
			OPCODE= 1									
25	INTERNAL TCS 2860 SQF	20	DDT&E CER	8	1.00	30	0	0	0.0			7,138
			OPCODE= 1									
			UNIT CER	53	1.00	45				1	84	116
			OPCODE= 1									
26	PURGE,VENT,& DRAIN 2310 LBS	20	DDT&E CER	40	1.00	30	0	0	0.0			5,773
			OPCODE= 1									
			UNIT CER	76	1.00	45				1	84	526
			OPCODE= 1									
27	LANDING & AUX SYS	4	DDT&E SUBS	0	0.00	0	0	0	0.0			92,376
			OPCODE= 0									
			UNIT SUBS	0	0.00	0				0	0	55,977
			OPCODE= 0									

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Table 1.4.1-8 (Continued)

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
28	MAIN LANDING GEAR	27	DDT&E	CER	5	1.00	30	0	0	0.0			37.265
	7095 LBS		OPCODE= 1										
			UNIT	CER	50	1.00	45				4	84	11.603
			OPCODE= 1										
										AGGREGATED VALUES			38.868
29	NOSE LANDING GEAR	27	DDT&E	CER	5	1.00	30	0	0	0.0			35.133
	6600 LBS		OPCODE= 1										
			UNIT	CER	50	1.00	45				1	84	10.932
			OPCODE= 1										
30	SEPARATION SYS	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										
31	P/L HANDLING SYS	27	DDT&E	CER	5	1.00	30	0	0	0.0			19.977
	3300 LBS		OPCODE= 1										
			UNIT	CER	50	1.00	45				1	84	6.175
			OPCODE= 1										
32	MAIN PROPULSION	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			41.050
			OPCODE= 0										
			UNIT	SUBS	0	0.00	0				0	0	181.794
			OPCODE= 0										
33	ROCKET ENGINES	32	DDT&E	*	0	0.00	0	0	0	0.0			30.000
			OPCODE= 5										
			UNIT	*	0	0.00	0				14	89	15.060
			OPCODE= 5										
										AGGREGATED VALUES			161.514
34	ENGINE ACCESSORIES	32	DDT&E	CER	5	1.00	30	0	0	0.0			4.430
	518 LBS		OPCODE= 1										
			UNIT	CER	50	1.00	45				14	89	1.343
			OPCODE= 1										
										AGGREGATED VALUES			14.405
35	PROPELLANT SYS	32	DDT&E	CER	40	1.00	30	0	0	0.0			6.620
	2994 LBS		OPCODE= 1										
			UNIT	CER	76	1.00	45				14	84	629
			OPCODE= 1										
										AGGREGATED VALUES			5.875
36	AUXILARY PROP	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			280.354
			OPCODE= 0										
			UNIT	SUBS	0	0.00	0				0	0	23.608
			OPCODE= 0										

Table 1.4.1-8 (Continued)

O	NAME		SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
37	RCS		36	DDT&E	CER	28	0.54	30	0	0	0.0			14.245
	2365	LBS			OPCODE= 1	40	0.46							
				UNIT	CER	73	0.54	45				4	84	4.565
					OPCODE= 1	76	0.46							
											AGGREGATED VALUES			15.292
38	OMS		36	DDT&E	SUBS	0	0.00	0	0	0	0.0			266.109
					OPCODE= 0									
				UNIT	SUBS	0	0.00	0				0	0	8.316
					OPCODE= 0									
39	PRIME POWER		4	DDT&E	CER	28	0.61	30	25	75	5.0			9.229
	3080	LBS			OPCODE= 1	12	0.39							
				UNIT	CER	73	0.61	45				2	84	10.306
					OPCODE= 1	57	0.39							
											AGGREGATED VALUES			19.093
40	ELECT CONV & DIST		4	DDT&E	CER	14	0.21	30	0	0	0.0			29.077
	41660	LBS			OPCODE= 1	13	0.79							
				UNIT	CER	59	0.21	45				1	84	22.545
					OPCODE= 1	58	0.79							
41	HYD CONV & DIST		4	DDT&E	CER	5	0.75	30	10	90	5.0			20.646
	8800	LBS			OPCODE= 1	40	0.25							
				UNIT	CER	50	0.75	45				1	84	11.441
					OPCODE= 1	76	0.25							
42	SURFACE CONTROLS		4	DDT&E	CER	5	0.75	30	10	90	5.0			11.565
	4152	LBS			OPCODE= 1	40	0.25							
				UNIT	CER	50	0.75	45				4	84	6.191
					OPCODE= 1	76	0.25							
											AGGREGATED VALUES			20.738
43	AVIONICS		4	DDT&E	SUBS	0	0.00	0	0	0	0.0			100.406
					OPCODE= 0									
				UNIT	SUBS	0	0.00	0				0	0	49.716
					OPCODE= 0									
44	G.N.& C		43	DDT&E	CER	18	1.00	30	25	75	5.0			23.640
	957	LBS			OPCODE= 1									
				UNIT	CER	63	1.00	45				1	84	9.457
					OPCODE= 1									
45	COMM. & TRACKING		43	DDT&E	CER	16	1.00	30	25	75	5.0			31.625
	1397	LBS			OPCODE= 1									
				UNIT	CER	61	1.00	45				1	84	17.869
					OPCODE= 1									

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Table 1.4.1-8 (Continued)

NO	NAME	SUB TO	ELEMENT METHOD	SOUR-CES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
46	DISPLAYS & CONTROLS	43	DDT&E CER	18	1.00	30	25	75	5.0			34,087
	1540 LBS		OPCODE= 1									
			UNIT CER	63	1.00	45				1	84	14,125
			OPCODE= 1									
47	INSTRUMENTATION	43	DDT&E CER	15	1.00	30	25	75	5.0			3,360
	594 LBS		OPCODE= 1									
			UNIT CER	60	1.00	45				1	84	2,421
			OPCODE= 1									
48	DATA PROCESSING	43	DDT&E CER	17	1.00	30	25	75	5.0			7,692
	1452 LBS		OPCODE= 1									
			UNIT CER	62	1.00	45				1	84	5,842
			OPCODE= 1									
49	ENVIRON CONTROL	4	DDT&E SUBS	0	0.00	0	0	0	0.0			36,400
			OPCODE= 0									
			UNIT SUBS	0	0.00	0				0	0	10,508
			OPCODE= 0									
50	CABIN & PERSONNEL	49	DDT&E CER	9	1.00	30	0	0	0.0			17,046
	5500 LBS		OPCODE= 1									
			UNIT CER	54	1.00	45				1	84	4,851
			OPCODE= 1									
51	EQUIPMENT	49	DDT&E CER	9	1.00	30	0	0	0.0			18,125
	5940 LBS		OPCODE= 1									
			UNIT CER	54	1.00	45				1	84	5,154
			OPCODE= 1									
52	AIRLOCK	49	DDT&E CER	3	1.00	30	0	0	0.0			1,228
	110 LBS		OPCODE= 1									
			UNIT CER	48	1.00	45				1	84	502
			OPCODE= 1									
53	PERSONNEL PROV	4	DDT&E SUBS	0	0.00	0	0	0	0.0			5,370
			OPCODE= 0									
			UNIT SUBS	0	0.00	0				0	0	1,565
			OPCODE= 0									
54	LIFE SUPPORT SYS	53	DDT&E CER	9	1.00	30	0	0	0.0			3,557
	770 LBS		OPCODE= 1									
			UNIT CER	54	1.00	45				1	84	1,034
			OPCODE= 1									

Table 1.4.1-8 (Continued)

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
55	PERSONNEL ACCOM	53	DDT&E	CER	9	1.00	30	0	0	0.0			1.812
	330 LBS		OPCODE= 1										
			UNIT	CER	54	1.00	45				1	84	531
			OPCODE= 1										
56	OMS ENGINES	38	DDT&E	*	0	0.00	0	0	0	0.0			250.000
			OPCODE= 5										
			UNIT	*	0	0.00	0				4	89	1.030
			OPCODE= 5										
										AGGREGATED VALUES			3.665
57	OMS ENG ACCESS	38	DDT&E	CER	5	1.00	30	0	0	0.0			599
	44 LBS		OPCODE= 1										
			UNIT	CER	50	1.00	45				4	89	176
			OPCODE= 1										
										AGGREGATED VALUES			626
58	OMS PROP TANKS	38	DDT&E	CER	81	2.00	30	0	0	0.0			8.641
	7073 LBS		OPCODE= 1										
			UNIT	CER	82	2.00	45				1	84	2.796
			OPCODE= 1										
59	OMS PRESS TANKS	38	DDT&E	CER	81	1.00	30	0	0	0.0			2.764
	4004 LBS		OPCODE= 1										
			UNIT	CER	82	1.00	45				1	84	950
			OPCODE= 1										
60	OMS PROP SYS	38	DDT&E	CER	40	1.00	30	0	0	0.0			2.619
	517 LBS		OPCODE= 1										
			UNIT	CER	76	1.00	45				1	84	187
			OPCODE= 1										
61	OMS PRESS SYS	38	DDT&E	CER	40	1.00	30	0	0	0.0			1.484
	176 LBS		OPCODE= 1										
			UNIT	CER	76	1.00	45				1	84	89
			OPCODE= 1										
62	DUMMY WBS	0	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	N/A	0	0.00	0				0	0	0
			OPCODE= 8										
63	ASSEMBLY & CHECKOUT	3	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			OPCODE= 8										
			UNIT	FACTOR	4	0.15	45				1	84	46.224
			OPCODE= 2										

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Table 1.4.1-8 (Continued)

NO	NAME	SUB TO	ELEMENT METHOD	SOUR-CES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
64	TOOLING	3	DDT&E CER*	4	0.00	0	0	0	0.0			272,966
			OPCODE= 17	85	0.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
65	SYSTEMS TEST	3	DDT&E SUBS	0	0.00	0	0	0	0.0			2,568,760
			OPCODE= 0									
			UNIT SUBS	0	0.00	0				0	0	0
			OPCODE= 0									
66	SYSTEMS TEST LABOR	65	DDT&E CER*	4	0.00	0	0	0	0.0			625,513
			OPCODE= 12	33	0.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
67	GRD TEST HDWE	65	DDT&E SUBS	0	0.00	0	0	0	0.0			1,235,707
			OPCODE= 0									
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
68	STRUCT TEST ARTICLE	67	DDT&E FAC UN	5	1.00	0	0	0	0.0			103,645
			OPCODE= 3									
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
69	DYN TEST ARTICLE	67	DDT&E FAC UN	4	1.00	0	0	0	0.0			566,031
			OPCODE= 3									
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
70	PROP TEST ARTICLE	67	DDT&E FAC UN	4	1.00	0	0	0	0.0			566,031
			OPCODE= 3	6	-1.00							
				7	-1.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
71	FLT TEST HDWE	65	DDT&E FAC UN	4	1.25	0	0	0	0.0			707,538
			OPCODE= 3									
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
72	S E & I	3	DDT&E CER*	4	0.00	0	0	0	0.0			65,392
			OPCODE= 12	32	0.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									

Table 1.4.1-8 (Continued)

NO	NAME	SUB TO	ELEMENT METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST (000)
73	FLT VEH D D & T	0	DDT&E FACTOR	4	1.00	0	0	0	0.0			0
			OPCODE= 2	72	1.00							
				66	1.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
74	SOFTWARE ENGR	3	DDT&E CER*	73	0.00	0	0	0	0.0			23.610
			OPCODE= 12	35	0.00							
			UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									
75	GSE	3	DDT&E CER*	4	0.00	0	0	0	0.0			257.789
			OPCODE= 12	38	0.00							
			UNIT CER*	4	0.00	0				0	0	118.735
			OPCODE= 17	39	0.00							
76	DDT&E GSE S/S	3	DDT&E FAC UN	75	2.00	0	0	0	0.0			237.471
			OPCODE= 3									
	.		UNIT N/A	0	0.00	0				0	0	0
			OPCODE= 8									

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WBS 1.4.1.4.2 Production Cost

The initial unit production cost for both the SPS cargo vehicle booster and orbiter is shown in Figure 1.4.1-3. The theoretical first unit cost (TFU) for the booster of $821.4M and $638.5M for the orbiter were developed using the Boeing Parametric Cost Model (PCM). The following is a breakdown of the TFU cost by major subsystem:

Subsystem	Booster	Orbiter
Structure	21%	16%
TPS	N/A	10%
Main Propulsion	24%	28%
Landing and Aux. Sys.	13%	9%
Flyback Propulsion	11%	N/A
Other Subsystems	19%	26%

The ground support equipment TFU cost is estimated to be $162.8M and $126.0M for the booster and orbiter respectively.

WBS 1.4.1.4.3 Average Cost/Flight (1 Satellite/Year)

The cost/flight breakdown shown in Figure 1.4.1-4 is the average for the 400 per year launch rate and 14 years of operation. The cost/flight items follow the Shuttle User Charge Policy guidelines with the following additions.

1. Amortization of the fleet production costs
2. Inclusion of the rate tooling cost due to the hardware quantities required.

The following assumptions and criteria regarding refurbishment and replenishment spares was used to develop the average cost per flight for the vehicle:

State Element	Design Life	Refurbishment	Replenishment
Airframe	300 flights	Each 100 flight @ 30% of production cost	0.18% per flight
Rocket Engines	Indefinite	Each 50 flights @ 30% of production cost	0.50% per flight

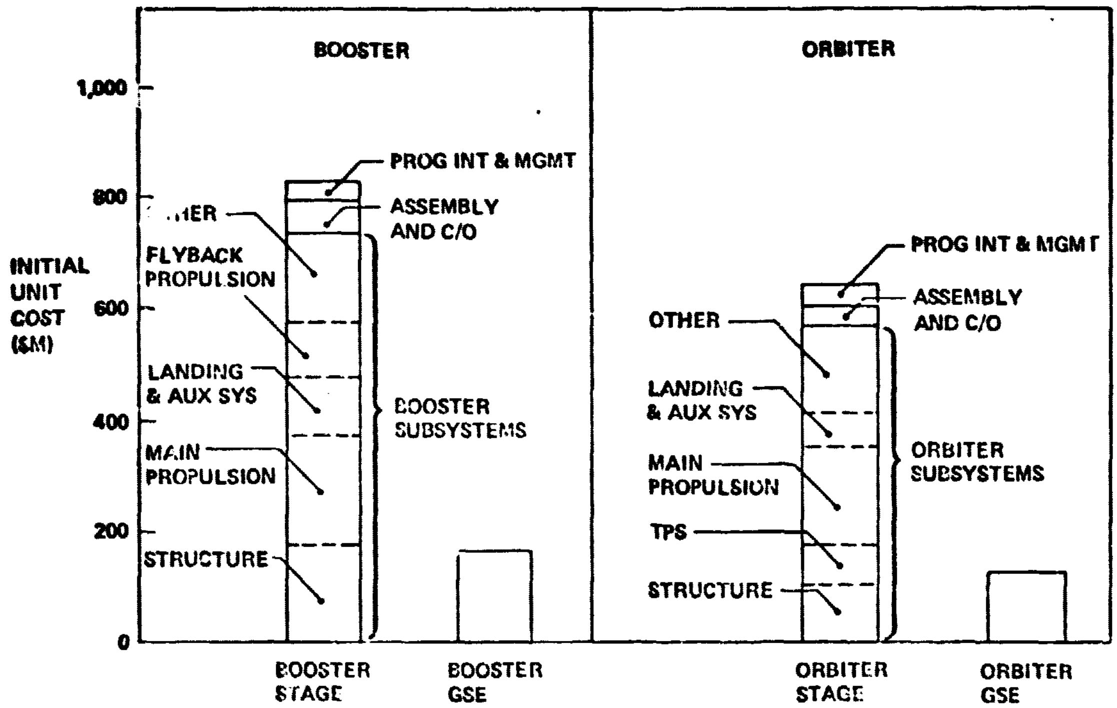
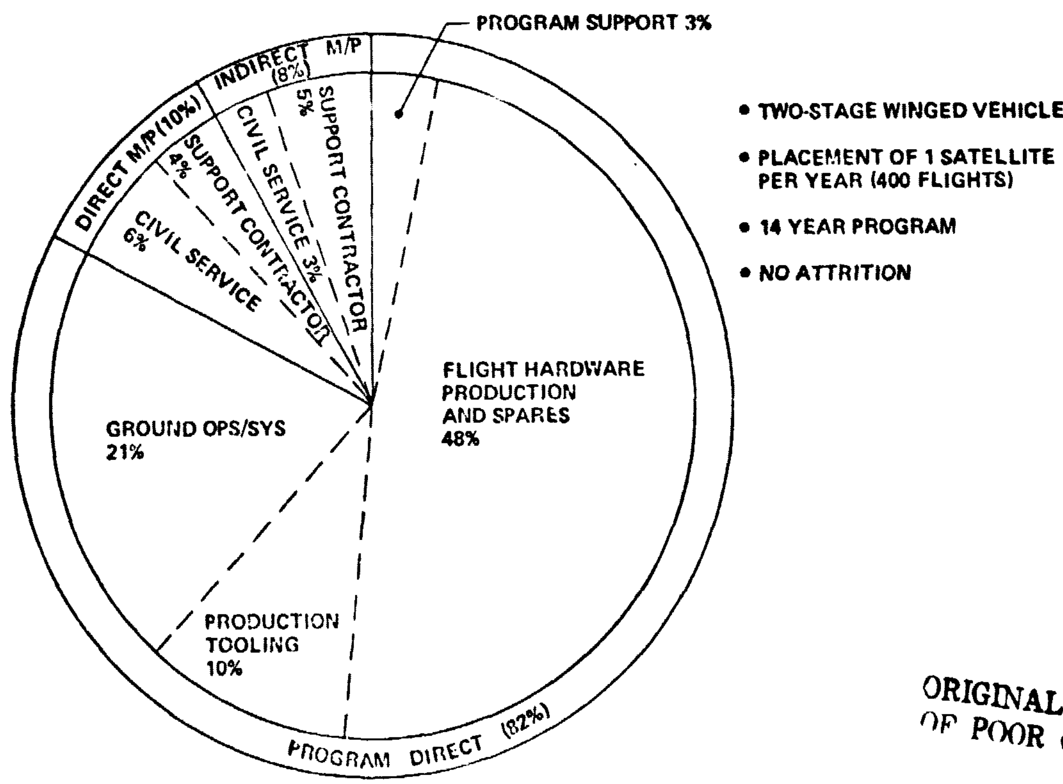


Figure 1.4.1-3 SPS Launch Vehicle Production Cost



AVERAGE COST/FLIGHT = $13.447M

Figure 1.4.1-4 SPS Launch Vehicle Average Cost/Flight (One Satellite/Year)

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The effect of design life and attrition rate variations are shown in Figure 1.4.1-5. Based on these trends the recommended goals for design life and attrition rate are 500 flights and 0.1% respectively.

Flight Hardware production and spares is the largest single item with the booster and orbiter accounting for 55% and 45%, respectively. Propellant cost amounts to 12% of the total per flight cost.

WBS 1.4.1.4.4 Effect of Launch Rate on Cost/Flight

Figure 1.4.1-6 illustrates the effect of launch rate on the average cost flight and the transport cost to low Earth orbit for the SPS cargo vehicle. The required launch rate of approximately 500 flights per satellite results in the following:

Annual Launch Rate	Cost Flight	Transport Cost	
		$ kg	($ lbm)
400 Flights	$13.447M	31.71	(14.38)
1600 Flights	$10.754M	25.36	(11.50)

A 40 launch per year rate, comparable to the planned rate for Shuttle from KSC, would result in an average cost of $23M per flight for the SPS cargo launch vehicle. Also noted on the chart, are the NASA JSC in-house cost estimates as of January 1978.

WBS 1.4.1.5 Vehicle Operations

The 2-stage winged vehicle operations plan includes prelaunch, launch, and recovery activities associated with the SPS launch vehicle. The launch site operations plan includes:

1. Both vehicles landing at the launch site
2. Stage maintenance and checkout in dedicated facilities for both the booster and orbiter
3. Mating, vehicle integration, and fueling at the launch pad

A horizontal mating operation is planned on the launcher where the two stages will be joined and then rotated to the vertical. This concept is depicted in Figure 1.4.1-7. The upper portion of the launcher erector is rotated away from the vehicle after the vehicle is in the vertical position to provide clearance for launch.

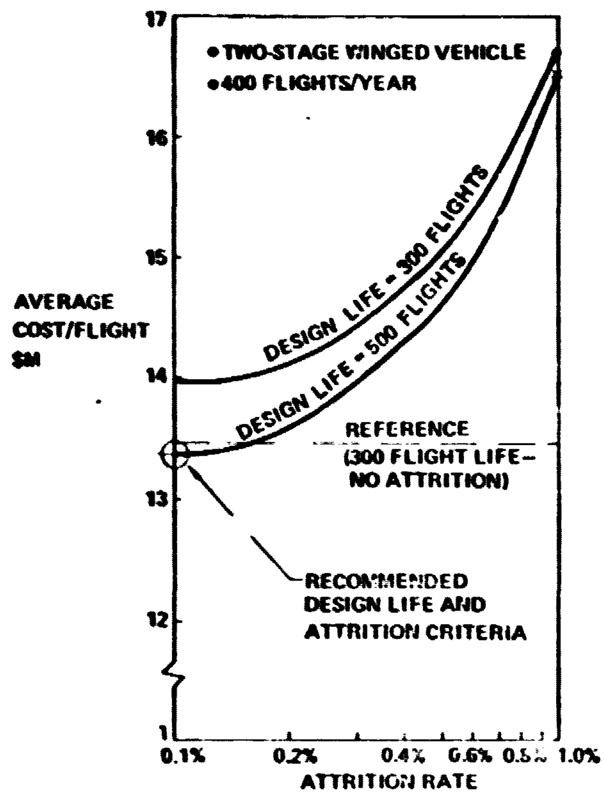

Figure 1.4.1-5 Effect of Design Life and Attrition Rate

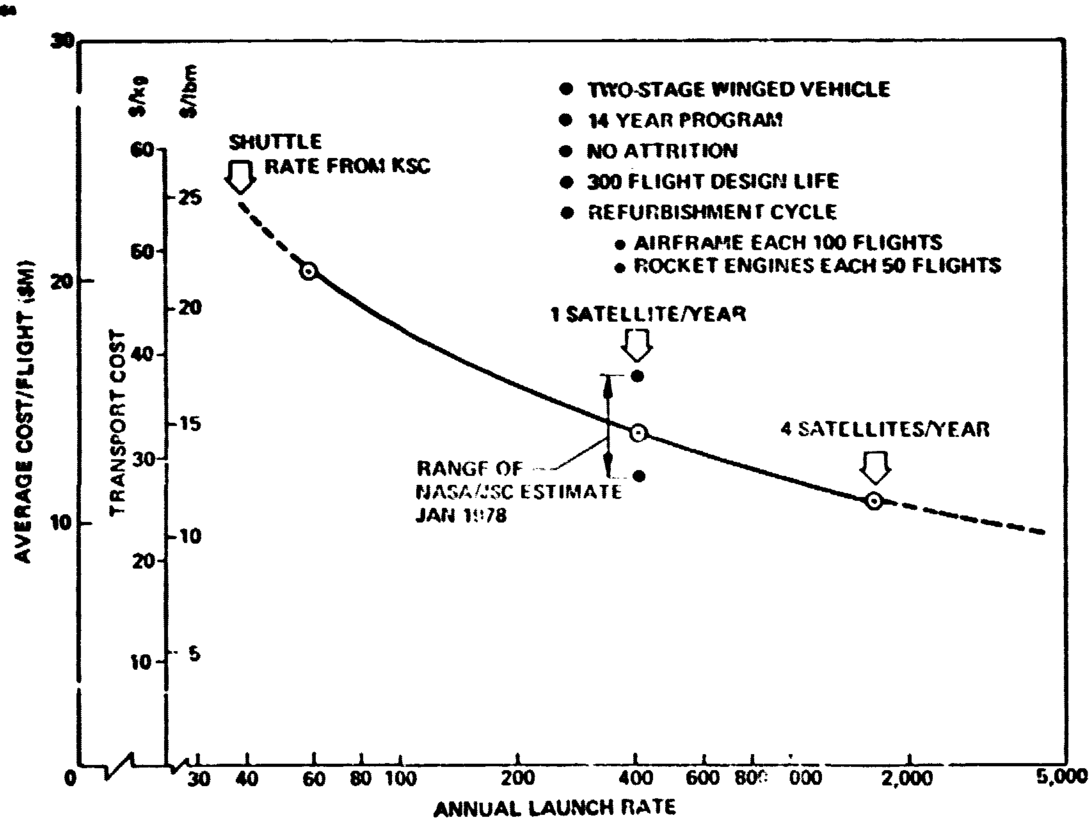

Figure 1.4.1-6 Effect of Launch Rate on Cost per Flight

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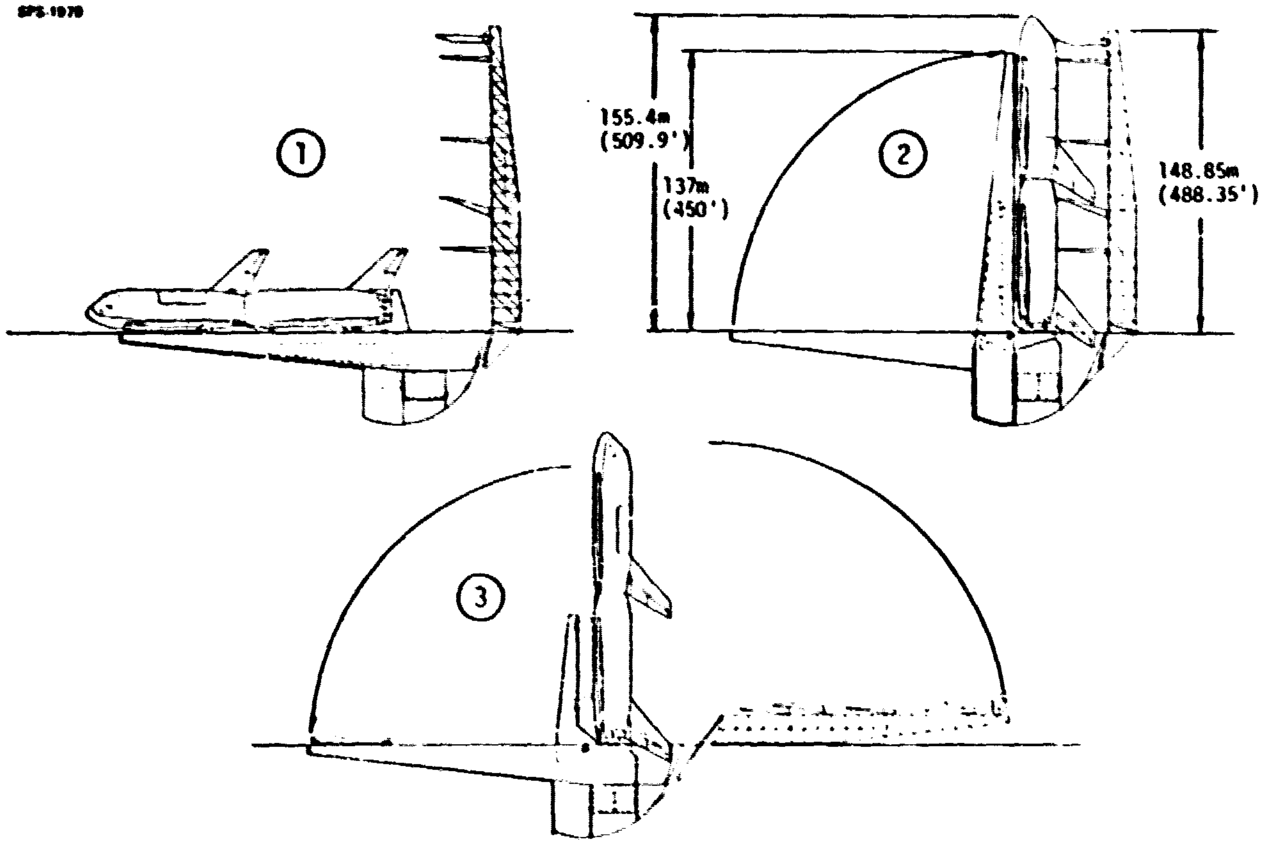


Figure 1.4.1-7 Launcher/Erector Concept

Booster Timelines

The booster timeline from launch to its move in the integration position is shown in Figure 1.4.1-8. The timelines reflect the average timelines for the operational launch vehicle system. A total of 62 hours is estimated for this portion of the turnaround with the scheduled and unscheduled maintenance activity requiring 36 hours. On-board condition monitoring equipment will enhance the operations by:

1. Providing performance monitoring of the stage subsystems.
2. Aiding in fault isolation and detection.

Rocket engine maintenance is anticipated to be the major portion of the booster operations.

Orbiter Timelines

The orbiter timeline from launch to its move to the integration position is shown on Figure 1.4.1-9. A total time of 97 hours for orbiter processing including 24 hour on-orbit stay time is estimated. The maintenance portion of the activity is estimated to require 48 hours due to the thermal protection system and the additional systems equipment required for the manned stage. A total of 12 hours has been allocated for payload installation in a parallel operation with the orbiter maintenance.

Integrated Vehicle Timelines

The vehicle integrated operations timeline is shown on Figure 1.4.1-10. These activities are at the launch site and reflect all the operations from vehicle mating through launch. This portion of the launch operations requires 34 hours for the booster and 30 hours for the orbiter. The total turnaround times for the booster and orbiter are summarized in Table 1.4.1-9. Also shown on the table for reference is the anticipated turnaround times for the 2-stage ballistic recoverable concept studied earlier. The 2-stage winged vehicle results in turnaround times which are less than those for the ballistic vehicle.

WBS 1.4.2 Personnel Carrier Vehicle

The personnel carrier vehicle provides for the transportation of the crews between earth and low earth orbit. The vehicle is a derivative of the current Space Shuttle system which incorporates a liquid propellant booster in place of the Solid Rocket Boosters (SRB's). A series-burn ascent mode was selected and as a result a reduced External Tank (ET) propellant load is required.

The personnel launch vehicle, shown in Figure 1.4.2-1 incorporates a propane fueled booster, External Tank and Space Shuttle Orbiter. Overall vehicle geometry and characteristics are shown in the figure. The overall length of 60.92 m is due to the tandem arrangement rather than the side-mounted concept in the current Shuttle system.

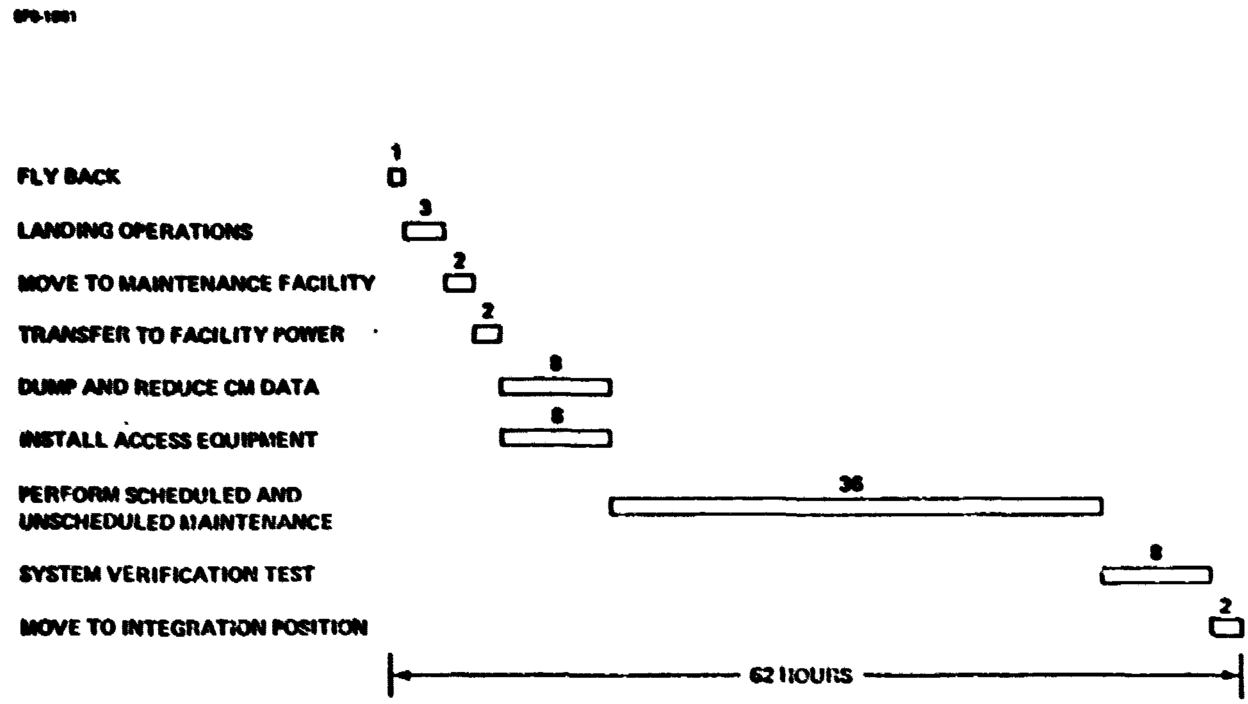


Figure 1.4.1-8 Booster Processing Timelines

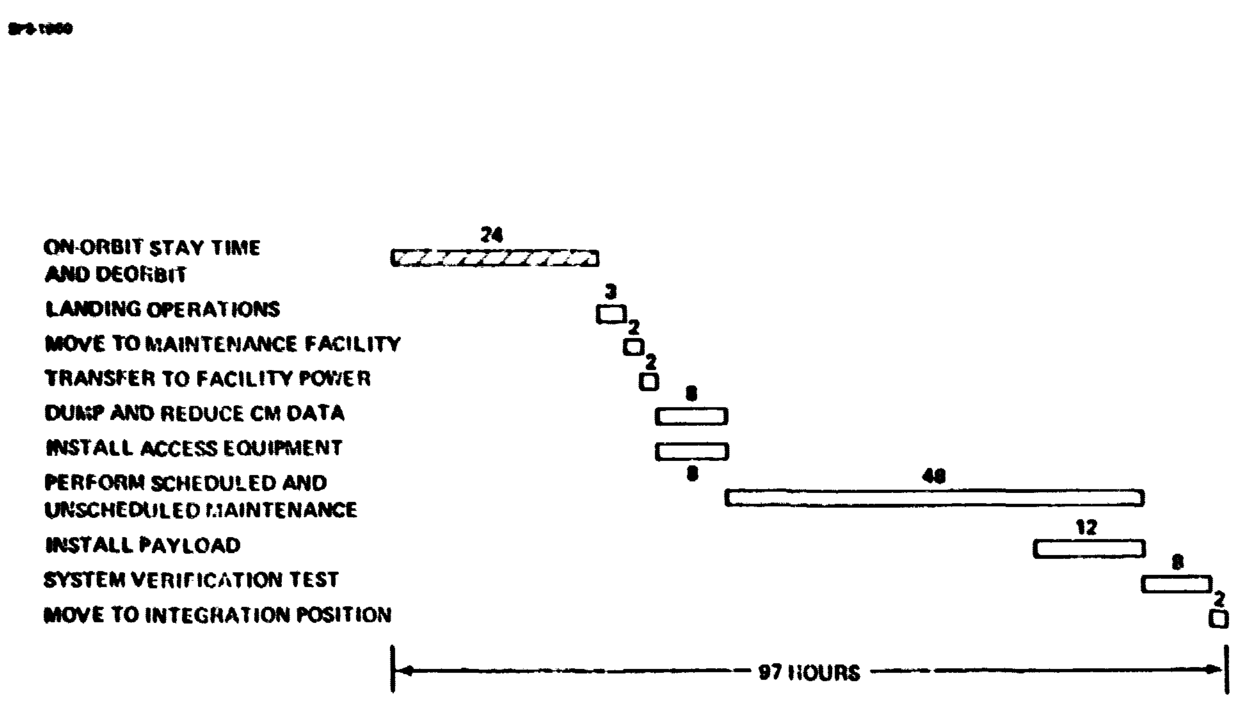


Figure 1.4.1-9 Orbiter Processing Timelines

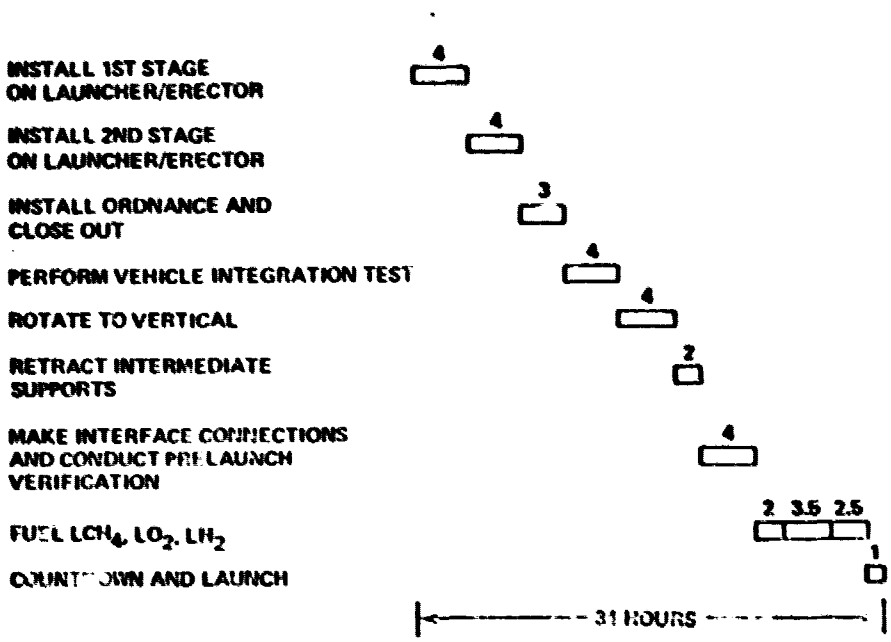
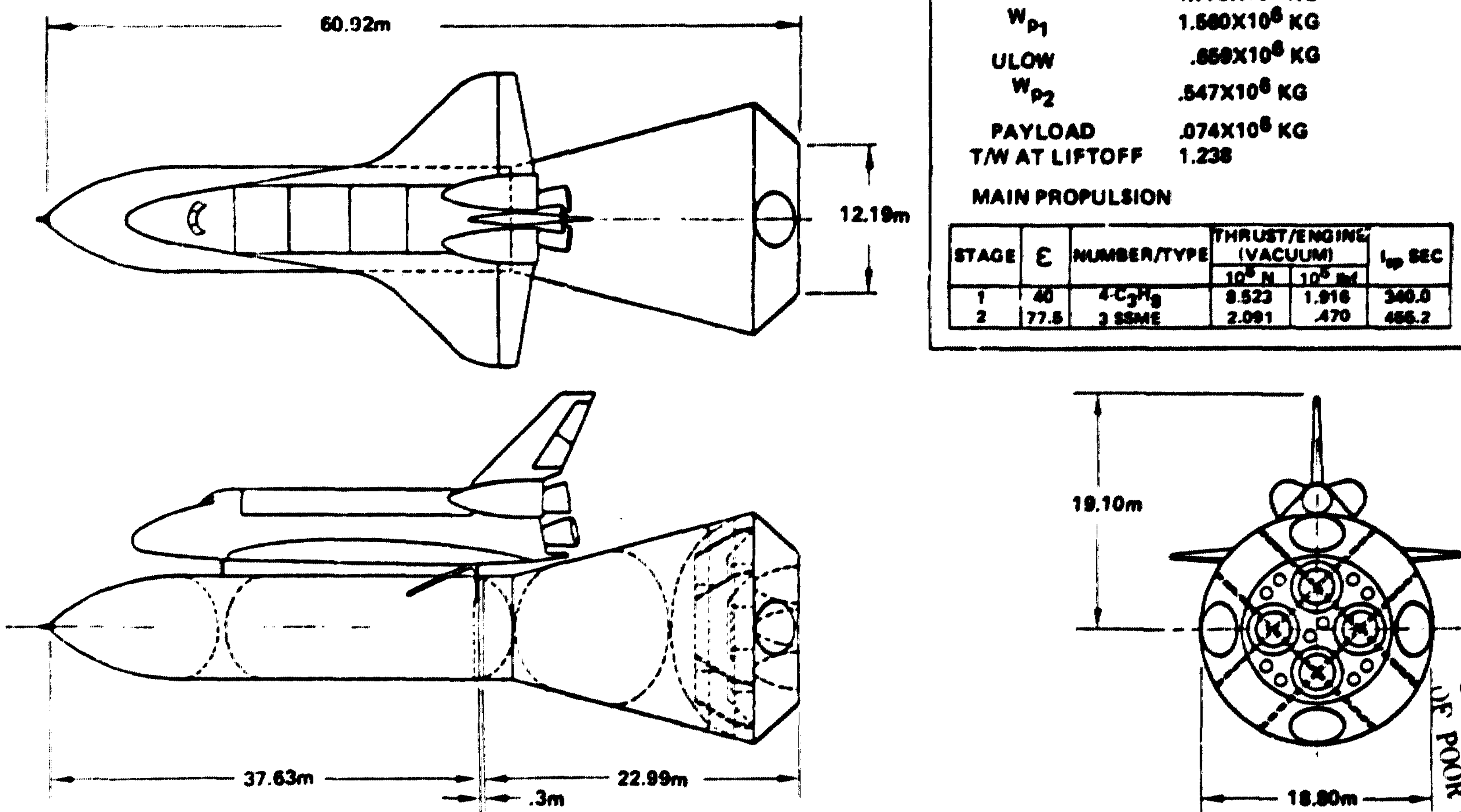


Figure 1.4.1-10 Integrated Vehicle Operations Timelines

Table 1.4.1-9 Vehicle Turnaround Analysis Summary

VEHICLE CONCEPT	STAGE OPS ONLY	INTEGRATION AND LAUNCH OPS	TOTAL TURNAROUND
WING/WING			
BOOSTER	63 HOURS	34 HOURS	97 HOURS
ORBITER	97 HOURS	30 HOURS	127 HOURS
BALLISTIC/BALLISTIC			
BOOSTER	93 HOURS	34 HOURS	127 HOURS
UPPER STAGE	102 HOURS	30 HOURS	132 HOURS



GLOW	2.512×10^6 KG
BLOW	1.779×10^6 KG
W_{P1}	1.560×10^6 KG
ULOW	$.858 \times 10^6$ KG
W_{P2}	$.547 \times 10^6$ KG
PAYLOAD	$.074 \times 10^6$ KG
T/W AT LIFTOFF	1.238

MAIN PROPULSION

STAGE	ε	NUMBER/TYPE	THRUST/ENGINE (VACUUM)		I_{sp} SEC
			10^6 N	10^6 lbf	
1	40	4-C_3H_8	8.523	1.916	340.0
2	77.5	3 SSME	2.091	.470	456.2

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Figure 1.4.2-1 Personnel Launch Vehicle

WBS 1.4.2.1 Vehicle Geometry

The overall vehicle geometry of the personnel launch vehicle is shown on Figure 1.4.2-1. All major body section locations are noted in the body station numbering system. The booster stage is 22.9 m in length with a 8.407 m diameter at the ET interface and a maximum diameter of 18.796 m. Four (4) booster engines are mounted on a 7.008 m diameter. The booster stage propellant tank volumes are 1035 m^3 for LO_2 and 593 m^3 for C_3H_8.

The ET overall length of 37.93 m reflects the shorter length as compared to the current Shuttle ET due to the reduction in propellant load from 703 075 kg to 547 038 kg.

WBS 1.4.2.2 Booster Stage

WBS 1.4.2.2.1 Booster Stage System Description

The booster stage subsystems include the ascent propulsion, structures, auxiliary propulsion system, thermal protection, prime power, power conversion and distribution, avionics and environmental control.

Ascent Propulsion The booster stage is powered by four C_3H_8/LO_2 engines which provide 8.523 X 10^6N of vacuum thrust. The following engine characteristics were used in the analysis:

Propellants	C_3H_8/LO_2
Thrust - Vacuum	8.523 X 10^6N
Chamber Pressure	20685 kpa
Mixture Ratio	2.68:1
Specific Impulse - (S.L./Vac.)	304.1/340.0 sec
Total Flow Rate/Engine	2556.5 kg/sec

The pressurization gases are heated GH_e and GO_2 for the main tanks. Individual propellant delivery lines are provided to each engine. The total mass of the ascent propulsion system is 47 138 kg.

Structure The pressurized structure (C_3H_8 and LO_2 tanks) are 2219-T87 aluminum all-welded components. The unpressurized structure is primarily 6Al-4V titanium with graphite composites incorporated on the internal structural members. The main propellant tank maximum design pressures, peak proof pressures and resultant mass are shown in Table 1.4.2-1.

The unpressurized structure was analyzed for maximum compressive load conditions and the results are shown in Table 1.4.2-2.

Table 1.4.2-1 C_3H_8 Booster Tank Sizing Results

Structural Element	Maximum Design Pressure - kpa	Maximum Proof Pressure - kpa	Typical Thickness - cm	Mass - kg
LO_2 Tank	324.5	431.6	0.27 - 0.76	10685
C_3H_8 Tank	226.9	301.3	0.45 - 1.27	28818

Table 1.4.2-2 C_3H_8 Booster Unpressurized Structure Sizing Results

Structural Element	Maximum Unit Compressive Loading	Typical Thickness - cm	Mass - kg
Forward Skirt	12630 - 15850 N/cm	0.38 - 0.48	3512
Aft Skirt	8966 - 9978 N/cm	0.27 - 0.30	7927
Base Skirt	Pressure = 77.57 kpa	0.88 - 1.00	26034
Thrust Structure	P Engine = 12.79 X 10^6N	N/A	18340

Auxiliary Propulsion The auxiliary propulsion system consists of the landing system and reaction control system. The landing system was sized to provide the terminal deceleration and 10 pressure-fed storeable propellant engines were selected. The baseline landing engine is the Aerojet Engine Model AJ10-51 which uses N_2O_4/UDMH propellants and has a thrust range of between 222400N and 667200N. The landing system dry mass is estimated to be 5192 kg. The reaction control system (RCS) provides for stage orientation prior to entry and control during the reentry. Four (4) sets of thrusters (4 thrusters/set) are installed on the vehicle. The estimated mass of the RCS system is 324 kg.

Other Subsystems The remaining subsystem masses have been estimated using historical relationships or Shuttle predicted masses. These subsystems include thermal protection, prime power, power, power conversion and distribution, avionics and environmental control.

WBS 1.4.2.2.2 Booster Mass Characteristics

The mass characteristics of the C_3H_8 booster reflect the results of a preliminary structural sizing and the incorporation of historical weight estimating relationships. A mass summary for the C_3H_8 booster is shown in Table 1.4.2-3. A 10% mass growth allowance has been included.

WBS 1.4.2.2.3 Booster Cost Estimate

The C_3H_8 booster DDT&E and 1st Unit cost estimates have been developed in a manner similar to that described in Section 1.4.1.4. The DDT&E and initial production cost for the booster are shown in Table 1.4.2-4. A DDT&E cost of $2.49B includes the basic stage design and development ($1.07B), and tooling, etc. The equivalent of 2.5 vehicles for ground test and 2 vehicles for flight test are included in the system test category.

The theoretical first unit (TFU) production cost of $221M is proportioned as follows:

Structure	24%
Ascent Propulsion	19%
Avionics	26%
GSE	10%
Program Management	8%
Other	13%

Structure, ascent propulsion and avionics account for 69% of the initial production unit cost. An estimated $100M has been included in the DDT&E cost for flight test operations.

Table 1.4.2-3 C_3H_8 Booster Mass Statement

Vehicle Element		Mass - kg
Structure		(90985)
Forward Skirt		3512
LO_2 Tank		10685
C_3H_8 Tank		28818
Thrust Structure		18340
Aft Skirt		3596
Base Skirt (Including TPS = 10410 kg)		26034
Main Propulsion		(47138)
Engines and Accessories		33669
Gimbal Control System		3148
Fuel System		4508
LO_2 System		5813
Auxiliary Propulsion		(5486)
Landing System		5162
RCS		324
Prime Power		(815)
Power Conversion and Distribution		(1733)
Avionics		(2744)
ECS		(857)
Growth (10%)		(14976)
	Dry Mass =	164734
Residuals and unusables		28460
Landing Propellant and Reserves		25515
	Inert Mass =	218709

Table 1.4.2-4 3Hg Booster DDT&E and 1st Unit Production Costs

NO	NAME	SUB TO	ELEMENT	METHOD	SOURCES	BLEND FACTORS	SUPT FROM	OTS %	MOD %	MOD CMPLX	NUMBER	LRN %	COST $000
1	TOTAL PROGRAM	0	DDT&E	SUBS	0	0.00	0	0	0	0.0			2,494,296
			UNIT	SUBS	0	0.00	0				0	0	220,955
2	PROG INTEG & MANAG	1	DDT&E	FACTOR	3	0.10	0	0	0	0.0			76,807
			UNIT	FACTOR	3	0.10	0				0	0	17,7[illegible]9
3	FLT VEH ALL STAG	1	DDT&E	SUBS	0	0.00	0	0	0	0.0			2,317,486
			UNIT	SUBS	0	0.00	0				0	0	203,175
4	FLT VEH 1ST STAGE	3	DDT&E	SUBS	0	0.00	0	0	0	0.0			2,317,486
			UNIT	SUBS	0	0.00	0				0	0	203,175
5	FLT VEH DED	4	DDT&E	SUBS	0	0.00	0	0	0	0.0			1,066,872
			UNIT	SUBS	0	0.00	0				0	0	176,227
6	STRUCTURE	5	DDT&E	SUBS	0	0.00	0	0	0	0.0			146,127
			UNIT	SUBS	0	0.00	0				0	0	52,237
7	LO2 TANK 25911 LBS	6	DDT&E	CER	62	1.00	26	0	0	0.0			14,996
			UNIT	CER	63	1.00	54				1	85	4,918
8	FUEL TANK 69886 LBS	6	DDT&E	CER	62	1.00	26	0	0	0.0			36,087
			UNIT	CER	63	1.00	54				1	85	11,459

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Table 1.4.2-4 (Continued)

9 AFT SKIRT	5720 LBS	6	DDT&E	CER	3	1.00	28	0	0	0.0			7,968
			UNIT	CER	37	1.00	54				1	85	3,030
10 THRUST STRUCTURE	44475 LBS	6	DDT&E	CER	3	1.00	28	0	0	0.0			33,502
			UNIT	CER	37	1.00	54				1	85	12,642
11 FWD SKIRT	6517 LBS	6	DDT&E	CER	3	1.00	28	0	0	0.0			7,806
			UNIT	CER	37	1.00	54				1	85	2,968
12 BASE SKIRT	63135 LBS	6	DDT&E	CER	3	1.00	28	0	0	0.0			45,764
			UNIT	CER	37	1.00	54				0	0	17,188
13 MAIN PROPULSION		5	DDT&E	SUBS	0	0.00	0	0	0	0.0			681,760
			UNIT	SUBS	0	0.00	0				0	0	42,517
14 MAIN ENGINES	1.916E6 THRUST	13	DDT&E	CER	26	1.00	28	0	0	0.0			630,153
			UNIT	CER	53	1.00	54				4	90	34,666
15 ENGINE ACCES	7635 LBS	13	DDT&E	CER	6	1.00	28	0	0	0.0			24,679
			UNIT	CER	40	1.00	54				4	90	4,472
16 PROP DELIVERY	20022 LBS	13	DDT&E	CER	4	1.00	28	0	0	0.0			18,063
			UNIT	CER	40	1.00	54				1	85	2,439

Table 1.4.2-4 (Continued)

17 PRESS SYS 5006 LBS	13	DDTEE CER	4	1.00	28	0	0	0.0			8,862
		UNIT CER	40	1.00	54				1	85	939
18 AUX PROP SYS	5	DDTEE SUBS	0	0.00	0	0	0	0.0			114,622
		UNIT SUBS	0	0.00	0				0	0	6,004
19 LANDING SYS	16	DDTEE SUBS	0	0.00	0	0	0	0.0			111,502
		UNIT SUBS	0	0.00	0				0	0	4,519
20 ENGINES 150E+03 THRUST	19	DDTEE CER	26	1.00	28	0	0	0.0			106,209
		UNIT CER	53	1.00	54				10	90	3,373
21 FUEL TANK 1113 LBS	19	DDTEE CER	62	1.00	28	0	0	0.0			1,000
		UNIT CER	63	1.00	54				1	85	333
22 LO2 TANK 2461 LBS	19	DDTEE CER	62	1.00	28	0	0	0.0			1,965
		UNIT CER	63	1.00	54				1	85	661
23 PRESSLINES 355 LBS	19	DDTEE CER	4	1.00	28	0	0	0.0			2,327
		UNIT CER	40	1.00	54				1	85	151
24 PROP RCS	16	DDTEE SUBS	0	0.00	0	0	0	0.0			3,119
		UNIT SUBS	0	0.00	0				0	0	1,485

Table 1.4.2-4 (Continued)

25	RC: ENG 29. LBS	24	DDTCE	CER	7	1.00	28	100	0	0.0			412
			UNIT	CER	39	1.00	54				1	85	1,211
26	RCS PRESLLINES 355 LBS	24	DDTCE	CER	4	1.00	28	0	0	0.0			2,327
			UNIT	CER	40	1.00	54				1	85	151
27	RCS TANKS 343 LBS	24	DDTCE	CER	62	1.00	28	0	0	0.0			379
			UNIT	CER	63	1.00	54				1	85	121
28	PRIME POWER	5	DDTCE	SUBS	0	0.00	0	0	0	0.J			18,591
			UNIT	SUBS	0	0.00	0				0	0	9,228
29	APU 1316 LBS	26	DDTCE	CER	7	1.00	28	0	0	0.0			11,298
			UNIT	CER	39	1.00	54				1	85	4,707
30	FUEL CELLS&TANKS 661 LBS	28	DDTCE	CER		1.00	28	0	0	0.0			7,293
			UNIT	CER	55	1.00	54				1	85	4,521
31	ELEC CONV/DIS	5	DDTCE	SUBS	0	0.00	0	0	0	0.0			6,594
			UNIT	SUBS	0	0.00	0				0	0	6,095
32	CONV EQU 422 LBS	31	DDTCE	CER	16	1.00	28	0	0	0.0			1,528
			UNIT	CER	49	1.00	54				1	85	1,556

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Table 1.4.2-4 (Continued)

33 CONTROLS 293 LBS	31	DDTLE	CER	18	1.00	28	0	0	0.0				1,100
		UNIT	CER	49	1.00	54					1	85	1,090
34 CABLES AND CONTROLS 1407 LBS	31	DDTLE	CER	15	1.00	28	0	0	0.0				3,965
		UNIT	CER	47	1.00	54					1	85	3,439
35 AVIONICS	5	DDTLE	SUBS	0	0.00	0	0	0	0.0				82,732
		UNIT	SUBS	0	0.00	0					0	0	56,642
36 G & N 2255 LBS	35	DDTLE	CER	17	1.00	28	0	0	0.0				70,584
		UNIT	CER	48	1.00	54					1	85	43,142
37 COMMUNICATIONS 2640 LBS	35	DDTLE	CER	18	1.00	28	0	0	0.0				7,107
		UNIT	CER	49	1.00	54					1	85	7,954
38 INSTRUMENTATION 1760 LBS	35	DDTLE	CER	18	1.00	28	0	0	0.0				5,039
		UNIT	CER	49	1.00	54					1	85	5,545
39 ECS	5	DDTLE	SUBS	0	0.00	0	0	0	0.0				7,895
		UNIT	SUBS	0	0.00	0					0	0	2,996
40 TANK PURGE 942 LBS	39	DDTLE	CER	4	1.00	28	0	0	0.0				3,796
		UNIT	CER	40	1.00	54					1	85	297

Table 1.4.1-6 (Continued)

41 COMP PARTS		39	DDTLE	CER	23	1.00	28	0	0	0.0			4,098
1137	LBS		UNIT	CER	41	1.00	54				1	85	2,699
42 HYDRAULIC SYS		5	DDTLE	CER	6	1.00	28	0	0	0.0			8,549
2090	LBS		UNIT	CER	40	1.00	54				1	85	515
43 TPS		0	DDTLE	SUBS	0	0.00	0	0	0	0.0			51
			UNIT	SUBS	0	0.00	0				0	0	8
44 TPS1		43	DDTLE	CER	3	1.00	28	0	0	0.0			6
1	LBS		UNIT	CER	37	1.00	54				1	85	1
45 TPS2		43	DDTLE	CER	3	1.00	28	0	0	0.0			6
1	LBS		UNIT	CER	37	1.00	54				1	65	1
46 TPS3		43	DDTLE	CER	3	1.00	28	0	0	0.0			6
1	LBS		UNIT	CER	37	1.00	54				1	85	1
47 TPS4		43	DDTLE	CER	3	1.00	28	0	0	0.0			6
1	LBS		UNIT	CER	37	1.00	54				1	95	1
48 TPS5		43	DDTLE	CER	3	1.00	28	0	0	0.0			6
1	LBS		UNIT	CER	37	1.00	54				1	65	1

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Table 1.4.2-4 (Continued)

49 TPS6		43	DDT&E	CER	3	1.00	28	0	0	0.0			6
1	LBS		UNIT	CER	37	1.00	54				1	85	1
50 TPS7		43	DDT&E	CER	3	1.00	28	0	0	0.0			6
1	LBS		UNIT	CER	37	1.00	54				1	85	1
51 TPS8		43	DDT&E	CER	3	1.00	28	0	0	0.0			6
1	LBS		UNIT	CER	37	1.00	54				1	85	1
52 ASSY&C/O		4	DDT&E	N/A	0	0.00	0	0	0	0.0			0
			UNIT	CER*	5 61	0.00 0.00	0				0	0	4,484
53 TOOLING		4	DDT&E	FACTOR	5	0.50	0	0	0	0.0			391,637
			UNIT	N/A	0	0.00	0				0	0	0
54 SYSTEM TEST		4	DDT&E	SUBS	0	0.00	0	0	0	0.0			861,435
			UNIT	N/A	0	0.00	0				0	0	0
55 SYS TEST LABOR		54	DDT&E	CER*	5 30	0.00 0.00	0	0	0	0.0			58,410
			UNIT	N/A	0	0.00	0				0	0	0
56 GR TEST HDWE		54	DDT&E	FAC UN	5	2.50	0	0	0	0.0			440,569
			UNIT	N/A	0	0.00	0				0	0	0

Table 1.4.2-4 (Continued)

57 FLT TEST HDWE	54	DDT&E	FAC CN	5	2.00	0	0	0	0.0			352,455
		UNIT	N/A	0	0.00	0				0	0	0
58 SE&I	4	DDT&E	CER*	5	0.00	0	0	0	0.0			29,574
				29	0.00							
		UNIT	N/A	0	0.00	0				0	0	0
59 FLT VEH UDCT	0	DDT&E	FACTOR	5	1.00	0	0	0	0.0			0
				54	1.00							
				55	1.00							
		UNIT	N/A	0	0.00	0				0	0	0
60 SOFTWARE ENGR	4	DDT&E	CER*	59	0.00	0	0	0	0.0			38,031
				33	0.00							
		UNIT	N/A	0	0.00	0				0	0	0
61 GSE	4	DDT&E	CER*	5	0.00	0	0	0	0.0			19,936
				56	0.00							
		UNIT	CER*	5	0.00	0				0	0	22,463
				57	0.00							
62 FLT TEST OPS	1	DDT&E	$	0	0.00	0	0	0	0.0			100,000
		UNIT	N/A	0	0.00	0				0	0	0
63	0	DDT&E	SUBS	0	0.00	0	0	0	0.0			0
		UNIT	SUBS	0	0.00	0				0	0	0
64	0	DDT&E	SUBS	0	0.00	0	0	0	0.0			0
		UNIT	SUBS	0	0.00	0				0	0	0

WBS 1.4.2.3 External Tank

WBS 1.4.2.3.1 System Description

The current STS External Tank (ET) was modified for the series-burn application. In addition to the propellant load reduction which results in a smaller overall ET, the boost loads are introduced into the aft portion of the LH_2 tank rather than in the intertank region. The overall changes to the ET are noted on Table 1.4.2-5 and the estimated changes in mass are shown. The mass uncertainty of the changes were accounted for as follows:

- o 5% uncertainty on deletions
- o 10% uncertainty on additions (growth)

WBS 1.4.2.3.2 ET Mass Characteristics

The mass characteristics of the ET reflect the results of incorporating the changes noted in the previous section (1.4.2.3.1). A mass summary for the External Tank is shown in Table 1.4.2-6.

WBS 1.4.2.3.3 Et Cost Estimate

The DDT&E cost estimate for the modifications to the External Tank have been estimated to be $60M. The initial ET unit cost was determined based on a review of the Shuttle User Change Policy cost estimates. The Shuttle User Change Policy identifies an ET initial unit cost of $5.496M (1975$) and subsequent units based on a 91% improvement curve. These data were escalated to 1977 dollars and the cost impacts due to the modifications assessed. The result is a theoretical first unit cost of $4.890M. A 91% improvement curve was used to determine the cost of additional units required to satisfy the program requirements.

WBS 1.4.2.4 Vehicle Performance

The personnel carrier vehicle performance was calculated based on the following ground rules:

- o Kennedy Space Center (KSC) was the launch site (latitude = 28.5°)
- o ΔV Reserves = .85% ΔV_i
- o Delivery Orbit
  - Altitude = 477 km circular
  - Inclination = 31°

Table 1.4.2-5 ET Modifications and Mass Changes

ELEMENT		MASS CHANGE
LO_2 TANK	(-1350)	
DELETE BARREL		-1069
DECREASE BAFFLES		- 113
DELETE SRB PADUPS		- 168
INTERTANK	(-2726)	
CHANGE MACHINED PANELS - SKIN STGR		-1631
SHORTEN INTERTANK BY 20"		- 159
CHANGE THRUST FRAME TO STAB. FRAME		- 356
DELETE SRB THRUST BEAM		- 625
DELETE SRB THRUST FITTINGS		- 406
MODIFY SKIN/STRINGER SECTION		+ 514
MODIFY STAB. FRAMES		- 63
LH_2 TANK	(-829)	
DELETE BARREL		-2404
DELETE FRAME XT 1377		- 221
MODIFY STRINGERS & FRAMES		+1697
DELETE SRB FITTINGS		- 100
REDUCE XT 2058 FRAME FOR SRB LOAD		- 181
ADD .81m LOWER SKIRT		+ 380
THERMAL PROTECTION	(- 952)	
LO_2 CRYO REDUCTION		- 85
ABLATION TO CRYO ONLY ON INTERTANK		- 546
LH_2 CRYO REDUCTION		- 321
PROPULSION & MECH SYSTEMS	(- 160)	
LO_2 FEEDLINE		- 131
LO_2 ANTIGEYSER LINE		12
LO_2 PRESS LINE		- 17
ELECTRICAL SYSTEM	(-88)	
SRB WIRING & SHIELDING		- 88
CHANGE UNCERTAINTY	(+ 686)	
UNCERTAINTY ON DELETIONS 5%		+ 427
GROWTH FOR ADDITIONS 10%		+ 259
TOTAL CHANGE - ET INERT WT	-5419	
UNUSABLES		
PRESSURANT, GH_2		- 107
PRESSURANT, GO_2		- 286
SUPPORTS, SRB GFE		- 231
TOTAL CHANGE ET MECO WT	-6043	
REDUCED PROPELLANT	(-160347)	
REDUCED LO_2		-137440
REDUCED LH_2		- 22907
TOTAL CHANGE ET LIFTOFF WT	-166390	

Table 1.4.2-6 External Tank Mass Statement

		KG
Structures		21,146
LO_2 Tank	4,446	
Intertank	3,276	
LH_2 Tank	13,424	
Thermal Protection		1,631
Propulsion & Mech. Sys.		1,710
Electrical Sys.		66
ORB Attachments		1,492
Change Uncertainty		686
ET Inert Mass		26,731
Unusables		1,530
ET Meco Mass		28,261

The ascent trajectory characteristics are summarized as follows:

T/W @ ignition = 1.24
Maximum Dynamic Pressure
Maximum Acceleration = 3.0 g's
Burn Time = 541.9 seconds

The personnel carrier payload performance is summarized in Table 1.4.2-7. A net payload of 73 550 kg is delivered to the 477 km orbit. The orbiter events including the suborbital jettison of the ET and the resulting vehicle mass by event are noted on Table 1.4.2-7. The Shuttle orbiter OMS system performs the majority of the orbital maneuvers.

WBS 1.4.2.5 Personnel Module

A crew carrying module for transporting personnel in the Shuttle cargo bay has been defined to establish the mass and cost of this element in the Transportation System. The module concept is shown in Figure 1.4.2-2. A crew size of 50 men per flight was baselined for purposes of this study. Four abreast seating on a single level was the selected arrangement. The lower level would be used for life support equipment and baggage.

Mass Characteristics The mass characteristics of the personnel module are noted on Table 1.4.2-8. These are preliminary estimates based on previous study results and in house IR&D activities.

Cost Estimate A preliminary cost estimate has been developed for the personnel module using the Boeing Parametric Cost Model (PCM). The DDT&E estimate of $117.5M includes a single ground test unit. The 1st unit production cost is estimated to be $24.67M. These costs were developed in the same manner as the launch vehicle costs.

WBS 1.4.2.6 Personnel Vehicle Cost per Flight

The personnel vehicle cost per flight is based on the cost per flight work breakdown structure shown in Table 1.4.2-9. The average cost flight is based on a launch rate of 256 flights per year amortized over 14 years of operation. Total program costs less the DDT&E and facilities portion are included in the average cost per flight. The equivalent hardware units to satisfy life, refurbishment and replenishment spares requirements are as follows:

BPS-681

Table 1.4-2-7 Personnel Launch Vehicle Performance Mass Statement

DRY MASS	
VEHICLE ELEMENT	10^3 KG
BOOSTER	(164.68)
STRUCTURE	80.52
THERMAL PROTECTION SYSTEM	10.41
LANDING SYSTEM & RCS	5.48
ASCENT PROPULSION	47.14
PRIME POWER	.82
POWER CONV/DIST	1.73
ECS	.86
AVIONICS	2.74
GROWTH	14.98
EXTERNAL TANK	(26.73)
ORBITER	(68.56)
DRY MASS =	(259.97)

SECOND STAGE SEQUENCE	
EVENT	MASS AFTER EVENT 10^3 KG
STAGE AT MECO	187.29
ΔV RESERVE	183.98
DROP ET	156.72
PERIGEE BURN	154.17
APOGEE CIRCULARIZATION	148.94
RCS TRIM	148.06
OMS TRIM	147.54
DEPLOY PAYLOAD (P/L = 73 550 kg)	73.99
DEORBIT ΔV	71.21

EMPTY MASS	9,958 KG
MASS OF CREW (50)	7,938 KG
TOTAL MASS	17,896 KG

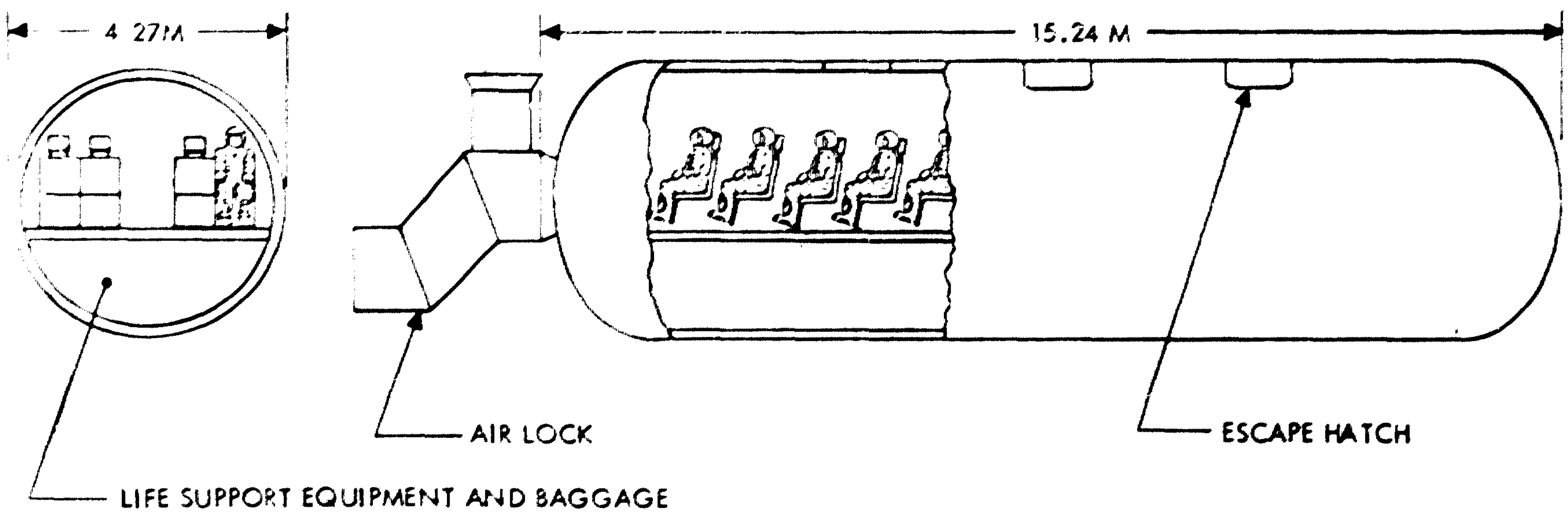


Figure 1.4.2-2 Shuttle Personnel Module

Table 1.4-2-8 Personnel Module Mass Statement

Module Element	Mass - kg
Cylinder and Bulkheads	2568
Support Structure	681
Airlock and Escape Hatches	1315
Furnishings	1134
Thermal Protection	1905
Life Support	805
Crew and Equipment	7938
Growth - 10%	1590
Total Mass	17896

Table 1.4.2-9 Personnel Carrier Average Cost/Flight (256 Flights/Year For 14 Years)

WBS ELEMENT	COST BY WBS LEVEL - $M (1977 $)			
	1	2	3	4
TOTAL PROGRAM OPERATING COST	12.619			
PROGRAM DIRECT		9.388		
PROGRAM SUPPORT			0.908	
PRODUCTION & SPARES			3.426	
ORBITER PRODUCTION				1.536
ORBITER SPARES				0.342
SSME'S				0.325
BOOSTER AIRFRAME				0.779
BOOSTER ENGINES				0.280
CREW RELATED GFE				0.165
EXPENDABLE HARDWARE - E.T.			1.858	
TOOLING			0.437	
GROUND OPS/SYS			2.759	
GROUND OPS				1.473
GSE SPARES				0.326
PROPELLANT				0.886
OTHER				0.074
DIRECT MANPOWER		1.568		
CIVIL SERVICE			0.861	
SUPPORT CONTRACTOR			0.707	
INDIRECT MANPOWER		1.663		
CIVIL SERVICE			0.755	
SUPPORT CONTRACTOR			0.908	

Hardware Element	Equivalent Units
C_3H_8 Booster Airframe	26 units
C_3H_8 Engines	175 units
Orbiters	10 units
SSME's	140 units
ET	3584 units

The average cost of the ten orbiters was established at $550M each.

The average cost per flight of $12.619M includes Program Direct (75%), Direct Manpower (12%) and Indirect Manpower (13%) categories. The Program Direct element breakdown is as follows:

Program Support	10%
Production and Spares	36%
Expendable Hardware	20%
Tooling	5%
Ground Operations Systems	29%

The Direct and Indirect Manpower costs reflect both extrapolation and modification of the Shuttle User charge data for the Personnel Vehicle Concept.

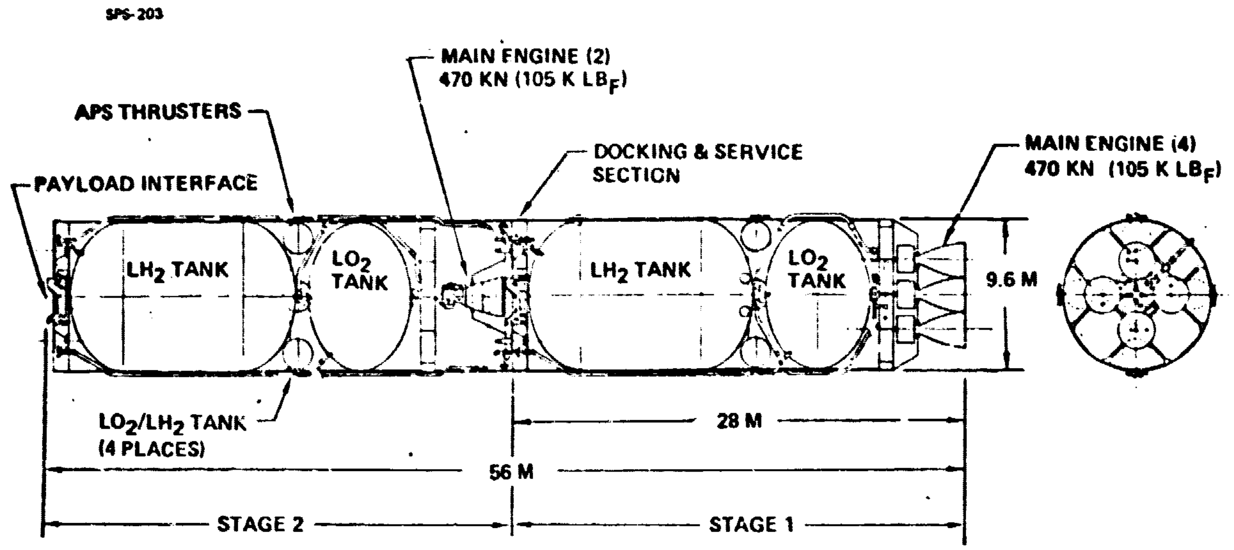
WBS 1.4.3 Chemical Orbit Transfer Vehicle

The chemical orbit transfer vehicle (OTV) is used in the satellite GEO construction concept. In this concept, satellite components are delivered to a LEO staging depot and then transferred to chemical OTV's for delivery to GEO where the construction occurs.

Various types of chemical OTV's have been investigated in the FSTS study and Part 1 of the SPS system definition study. The results of these studies have indicated a LO_2/LH_2 common stage (two stage) system to be the most desirable. This system will be summarized in the following sections and is applicable to either the photovoltaic or thermal engine satellites.

WBS 1.4.3.1 Configuration

The space-based common stage OTV is a two-stage sytem with both stages having identical propellant capacity as shown in Figure 1.4.3-1. The first stage provides approximately 2/3 of the delta V requirement for boost out of low Earth orbit at which point it is jettisioned for return to the low Earth orbit staging depot.



- PAYLOAD CAPABILITY = 400,000 KG
- OTV STARTBURN MASS = 890,000 KG
- STAGE CHARACTERISTICS (EACH
  - PROPELLANT = 415,000 KG
  - INERTS = 29,000 KG (INCLUDING NONIMPULSE PROPELLANT)
- 280 OTV FLIGHTS PER SATELLITE

Figure 1.4.3-1 Space Based Common Stage OTV GEO Construction

The second stage completes the boost from low Earth orbit as well as the remainder of the other delta V requirements to place the payload at GEO and also provides the required delta V to return the stage to the LEO staging depot. Subsystems for each stage are identical in design approach. The primary difference is the use of four engines in the first stage due to thrust-to-weight requirements. Also the second stage requires additional auxiliary propulsion due to its maneuvering requirements including docking of the payload to the construction base at GEO. The vehicle has been sized to deliver a payload of 400 000 kilograms. As a result, the stage startburn mass without payload is approximately 890 000 kilograms with the vehicle having an overall length of 56 meters.

WBS 1.4.3.2 Subsystems

Structure and Mechanisms

Main propellant containers are welded aluminum with integral stiffening as required to carry flight loads. Intertank, forward and aft skirts, and thrust structures employ graphite/epoxy composites. An Apollo Soyuz type docking system is provided at the front end of each stage for docking with payloads, refueling tankers and orbital bases. The stage-to-stage docking system provides for docking the stages together with flight loads carried through full-diameter structures. Propellant transfer connections allow either stage to be fueled independently with the stages either separated or docked together. Structure of the two stages is identical to the extent practicable.

Main Propulsion

Main engines are based on shuttle engine technology, operating with a staged-combustion cycle at 20 Mn/m^2 (3000 psia) chamber pressure, a LO_2/LH_2 mixture ratio of 5.5 to 1.0 and a retractable nozzle with extension expansion area ratio of 400 providing a specific impulse of 470 seconds. Advanced low NPSH pumps are used to minimize feed pressures. A 6 degree square gimbal pattern is employed. The engines are capable of operating in a tank-head idle (THI) mode (pumps not turning; mixed-phase propellants) for chill-down and self-ullaging at a specific impulse of 350 seconds; 60 seconds (time) in self-ullaging mode is assumed needed prior to bootstrapping to full thrust. Throttling between tank-head idle and full thrust is not required. Main propellant pressurization is derived from engine tap off after an onboard helium prepressurization.

Auxiliary Propulsion

Auxiliary propulsion is used for attitude control and low delta V maneuvers during coast periods and for terminal docking maneuvers. An independent LO_2/LH_2 system is used and provides an Isp of 375 seconds averaged over pulsing and steady state operating modes. Thrusters are mounted in quad packages analogous to the Apollo Service Module installation. Each quad has its own propellant supply to facilitate change out. Auxiliary propulsion for the two stages uses common technology but capacities and thrust levels are tailored.

Electrical Power
Primary electric power is provided by fuel cells based on shuttle technology, tailored to the OTV requirement. Reactants are stored in vacuum-jacketed pressure vessels. Product water is assumed retained onboard to minimize payload contamination potential. Ni-Cad batteries are employed for peaking and smoothing. 28 VDC power is rough-regulated and filtered with fine regulation provided by power using subsystems as needed. A potential inert mass saving (not assumed) would use low pressure reactants provided from main propellant tanks. Electric power systems for the two stages are identical except for reactant capacity and harnesses.

Avionics
Avionics functions include onboard autonomous guidance and navigation, data management, and S-band telemetry and command communications. Navigation employes Earth horizon, star and Sun sensors with an advanced high performance inertial measurement system. Cross-strapped LSI computers provide required computational capability including data management, control and configuration control. The command and telemetry system employes remote-addressable data busing and its own multiplexing. Although the avionics systems in the two stages are identical, software for each stage is tailored to the stage functions.

Thermal/Environmental Control
Main propellant tanks are insulated by aluminized mylar multilayer insulations contained within a purge bag. The insulation system is helium purged on the ground and during Earth launch. Environmental control of the avionics systems is accomplished using semi-active louvered radiators and cold plates. Active fluid loops and radiators are required for the fuel cell systems. Superalloy metal base heat shields are employed to protect the base areas from recirculating engine plume gas.

WBS 1.4.3.3 Performance

Performance characteristics associated with the common stage LO_2/LH_2 OTV are shown in Figure 1.4.3-2. Propellant requirements are shown as a function of the payload return and delivery capability. Performance ground rules used in these parametrics are as follows (values are main propellant quantities):

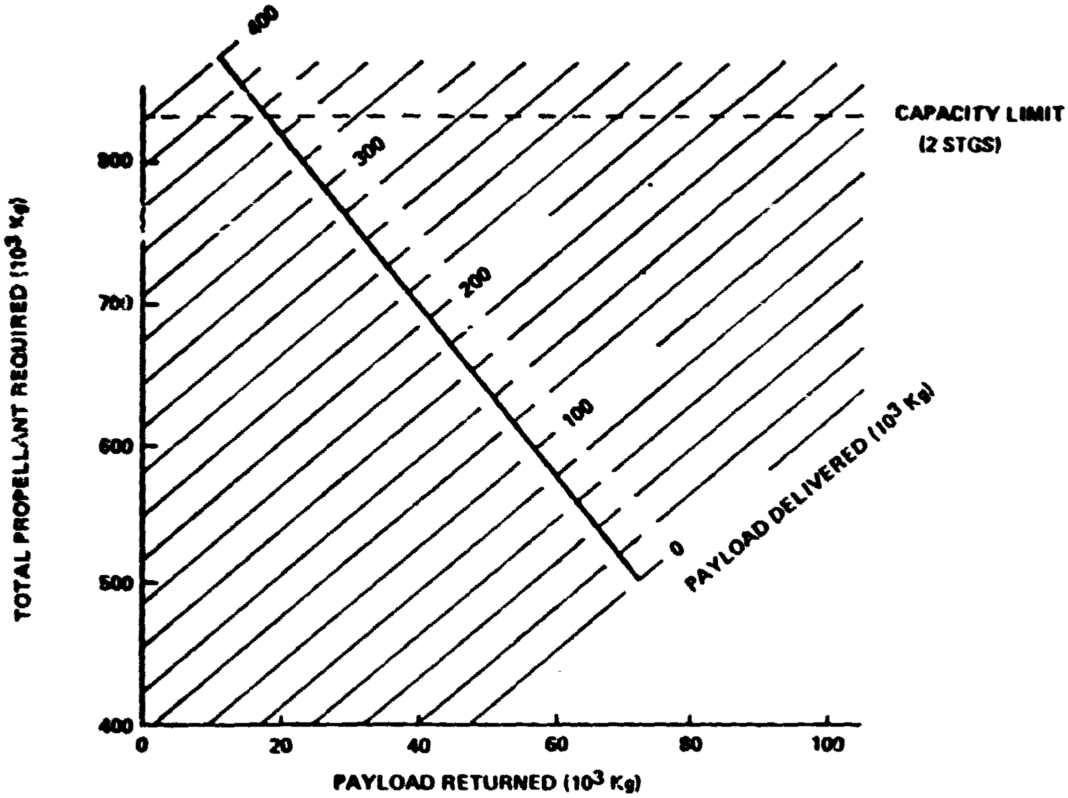


Figure 1.4.3-2 Two Stage LO_2/LH_2 OTV Performance

- o THI mode — Stg 1 100 kg per start
  - Stg 2 50 kg per start
- o Stop loss — Stg 1 20 kg
  - Stg 2 10 kg
- o Boiloff rate — 6 kg/hr each stage
- o Burnout mass scaling equations:

  Stg 1 3430 kg + 0.05567 WP_1 + 0.1725 WP_2

  Stg 2 3800 kg + 0.05317 WP_1 + 0.1725 WP_2

  Where WP_1 and WP_2 are main and auxiliary propellant capacities respectively
- o Stage λ' of 0.93
- o Staging base at 477 Km, 31 degrees

WBS 1.4.3.4 Mass

Summary level mass estimates are presented in Table 1.4.3-1 for the selected satellite OTV. A weight growth factor of 10% was used rather than 15% as in FSTS based on the judgment that the SPS LO_2/LH_2 OTV would be a second generation vehicle. Mass estimates for the systems reflect the design approach previously described.

WBS 1.4.3.5 Mission Profile and Flight Operations

Typical orbit transfer operations from LEO to GEO for the common stage OTV are illustrated in Figure 1.4.3-3. The majority of the delta V for boosting from LEO is provided by Stage 1. Stage 1 then separates and returns to the staging depot following an elliptical return phasing orbit. Stage 2 completes the boost and puts the payload into a GEO transfer and phasing orbit, as well as injecting the payload into GEO and performing the terminal rendezvous maneuver with the GEO construction base. Following removal of the payload, stage 2 uses two primary burns in returning to the LEO staging depot. A detailed mission profile indicating events, time and delta V is presented in Table 1.4.3-2.

A total mission timeline for each stage is presented in Figure 1.4.3-4. Allowing approximately eight hours for refueling and refurb results in 40 hours elapsed time before a given Stage 1 can be reused. A typical Stage 2, however, has an elapsed time of 85 hours before reuse including time for assembly between stages and between OTV and payload.

Table 1.4.3-1 Chemical OTV Mass Summary

	Stage 1 (KG)	Stage 2 (KG)
Struct and Mechanisms	13,300	14,780
Main Propulsion	7,090	4,020
Auxiliary Propulsion	820	1,120
Avionics	300	310
Electrical Power	850	820
Thermal Control	1,850	2,310
Weight Growth (10%)	2,420	2,340
Dry	26,630	25,790
Fuel Bias	640	640
Unusable LO_2/LH_2	1,810	1,810
Unusable and Reserve APS	290	660
Burnout	29,370	28,990
Main Impulse Prop	415,000	407,000
APS	2,700	6,100
Startburn	447,070	442,090

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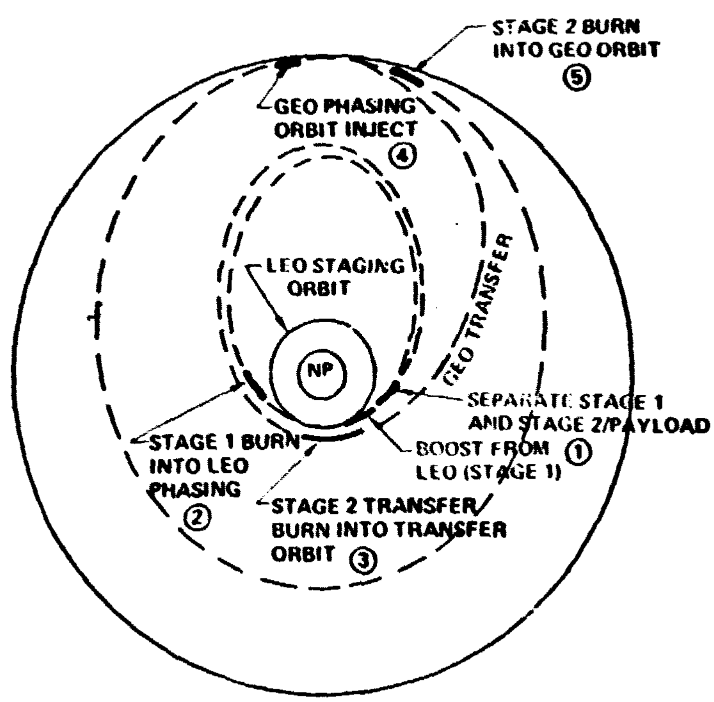

Figure 1.4.3-3 Chemical OTV Orbit Transfer Operations

Table 1.4.3-2 Mission Profile

MISSION EVENT NO. & NAME	REQUIRED TIME (HR)	DELTA V M/SEC	PROPULSION (MAIN OR AUXILIARY)	REMARK
			MISSION	
1. STANDOFF	0	3	A	PROVIDES SAFE SEPARATION DISTANCE BETWEEN FACILITY & VEHICLE
2. PHASE	12	?	A	ΔV IS ATTITUDE CONTROL
3. COAST	.5	1715	M	OTV FIRST STAGE SEPARATES AFTER THIS ΔV
4. COAST	4.2	3	A	ELLIPTIC REV
5. INJECT	.1	750	M	INCLUDES 60 M/SEC ACCUMULATED FINITE - BURN LOSS
6. COAST	5.4	3	A	TRANSFER TO GEO
7. PHASE INJ	.1	1780	M	REPRESENTATIVE FOR 15° PHASING
8. PHASE	23	3	A	
9. TPI (TERMINAL PHASE INITIATION)	.1	55	M	INCLUDES 15 M/SEC OVER IDEAL TO ALLOW FOR CORRECTIONS
10. RENDEZVOUS	2	10	A	TPI ASSUMED TO OCCUR WITHIN 50 KM OF TARGET
11. DOCK	1	10	A	
12. WAIT	8	0	-	ASSUMED DOCKED
13. STANDOFF	.1	3	A	
14. DEORBIT	.1	1820	M	
15. COAST	5.4	10	A	TRANSFER TO LEO
16. PHASE INJECT	.1	2356	M	
17. PHASE	12	3	A	ORBIT PERIGEE AT STAGING BASE ALTITUDE
18. TPI	.1	50	M	
19. RENDEZVOUS	2	20	A	
20. DOCK	1	10	A	
21. RESERVE	-	130	M	2% OF STAGE MAIN PROPULSION V BUDGET
			FIRST STAGE RECOVERY	
1. COAST	4.2	30	A	ΔV TO CORRECT DIFFERENTIAL NODAL REGRESSION BETWEEN COAST ORBIT AND STAGING BASE
2. PHASE INJECT	.1	1645	M	ELLIPTIC ORBIT - PERIGEE AT STAGING BASE ALT.
4. TPI	12	3	A	ALTITUDE CONTROL
3. PHASE	.1	50	M	
5. RENDEZVOUS	2	20	A	
6. DOCK	1	10	A	
7. RESERVE	–	85	M	2% OF STAGE MAIN PROPULSION V BUDGET

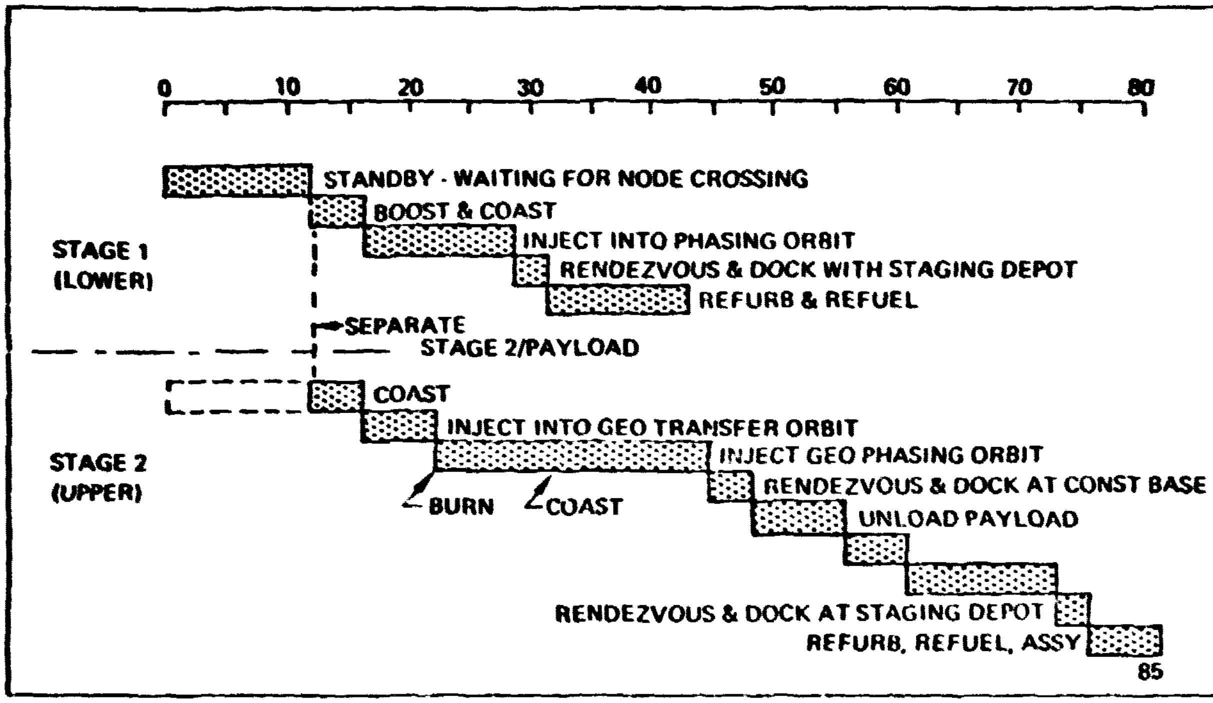

Figure 1.4.3-4 Chemical OTV Flight Operation Timeline

With the indicated turnaround times for each stage of an OTV, it is possible to establish the total stage fleet size as shown in Figure 1.4.3-5. The first two bars are associated with the first OTV flight. At the end of approximately 12 hours the second or upper stage (U1) separates from the first (lower) stage (L1). The first stage completes its operations and is available in time for the third OTV flight. The first upper stage finishes its mission and is available for another flight at the end of approximately 85 hours which allows it to be used on the flight scheduled for the fifth day. With operations conducted in this manner and the requirements for one OTV flight per day for five consecutive days per week (corresponds to launch vehicle operations) a total of two lower and four upper stages are required in the fleet in order to conduct day to day operations. Operated in this manner, as many as six independently operating stages can be in flight at one time during the construction of each satellite.

WBS 1.4.3.6 Cost

DDTE cost for the common stage LO_2/LH_2 OTV with a start burn mass of 900 000 kg is estimated at \$950 million (1977 dollars) based on cost parametrics developed in the FSTSA study. The average TFU cost for the two stages is estimated at \$82 million (1977 dollars) again using FSTSA parametrics.

Cost per flight for the LO_2/LH_2 OTV is based on the following ground rules:

- o Space Based LO_2/LH_2 Common Stage
- o Startburn Stage Mass of 445 K kg
- o Stage TFU Equal \$82M (1977 Dollars)
- o 280 OTV Flights Per Satellite
- o 4 Satellites Constructed Per Year
- o 14 Year Program Life
- o 50 Flight Design Life
- o Stage Learning Factor of 0.88
- o LO_2/LH_2 Bulk Cost of \$0.10 per kg
- o Spares Equal 50% of Operational Units

The majority of these ground rules are self-explanatory. However, several merit further explanation. The 280 flights for the orbit transfer vehicle is the number required for one satellite. A 14-year program has been assumed for the orbit transfer vehicle, since beyond that point in time it is generally assumed that a different generation of orbit transfer vehicle would be developed. A 50-flight design life has been assumed for the space based orbit transfer vehicle. This value is based on the MSFC Tug Study which assumed 50 uses for a ground based system. Assuming that the SPS OTV is a second generation vehicle, it was assumed 50 uses could be projected for a space based system.

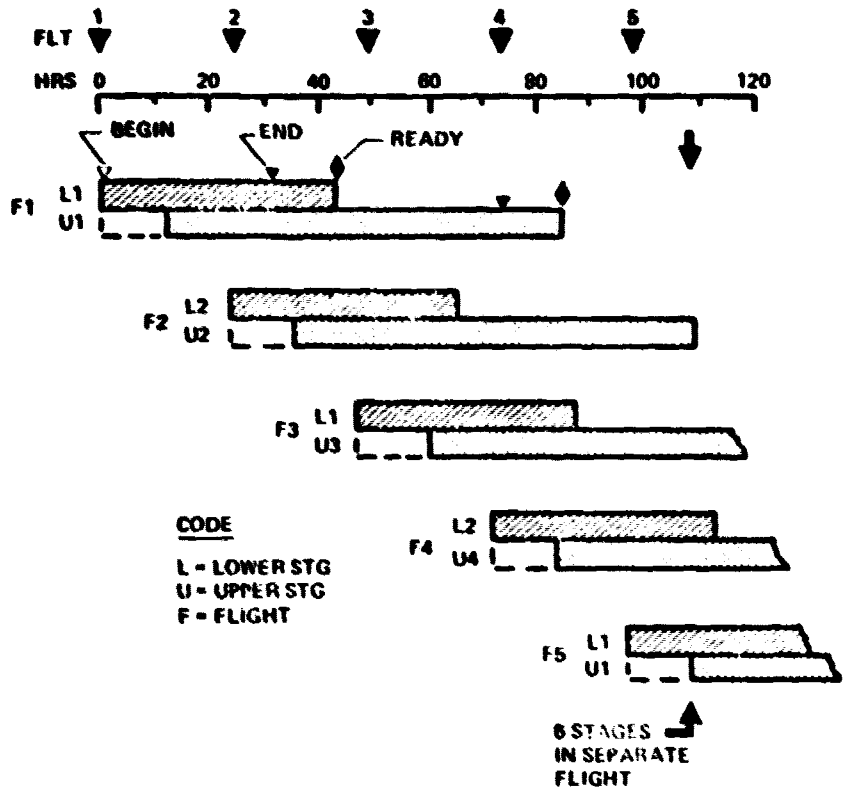

Figure 1.4.3-5 Flight Operations-Chemical Orbit Transfer

Based on the above ground rules a total of 624 stages (upper and lower) are required resulting in an average stage cost of approximately $31 million. Cost per flight for a complete two stage OTV was estimated as $2.26 million with the following breakdown.

- o Operational Units $1.24M
- o Propellant $0.40M
- o Spares $0.62M

WBS 1.4.3.7 Crew Rotation/Resupply Transportation System

The crew rotation/resupply OTV for a photovoltaic or thermal engine satellite constructed in either LEO or GEO makes use of a common stage LO_2/LH_2 OTV. The system description of this OTV is essentially the same as for the GEO construction OTV, although the size of the system does vary with its application.

The complete crew rotation/resupply transportation system required for a photovoltaic satellite is presented in Figure 1.4.3-6. In the case of LEO construction, the crew rotation resupply concept involves rotation all of the personnel (75) at the GEO base every 90 days and providing supplies for 90 days. As a result, the OTV has a startburn mass of 495 000 kg.

Should the satellite be constructed in GEO, the same OTV as used to deliver the satellite components is employed. As a result, a crew rotation resupply flight is flown once a month involving 160 personnel and supplies for 480 people and 30 days. Accordingly, the OTV has a startburn mass of 890 000 kg.

WBS 1.4.4 SPS -Installed Orbit Transfer Systems

WBS Dictionary

SPS -installed orbit transfer systems include all hardware, software, and consumables installed on SPS modules to equip them for orbit transfer from LEO to GEO. There are eight sets of this equipment in the current preferred concept as the SPS is transferred in eight modules.

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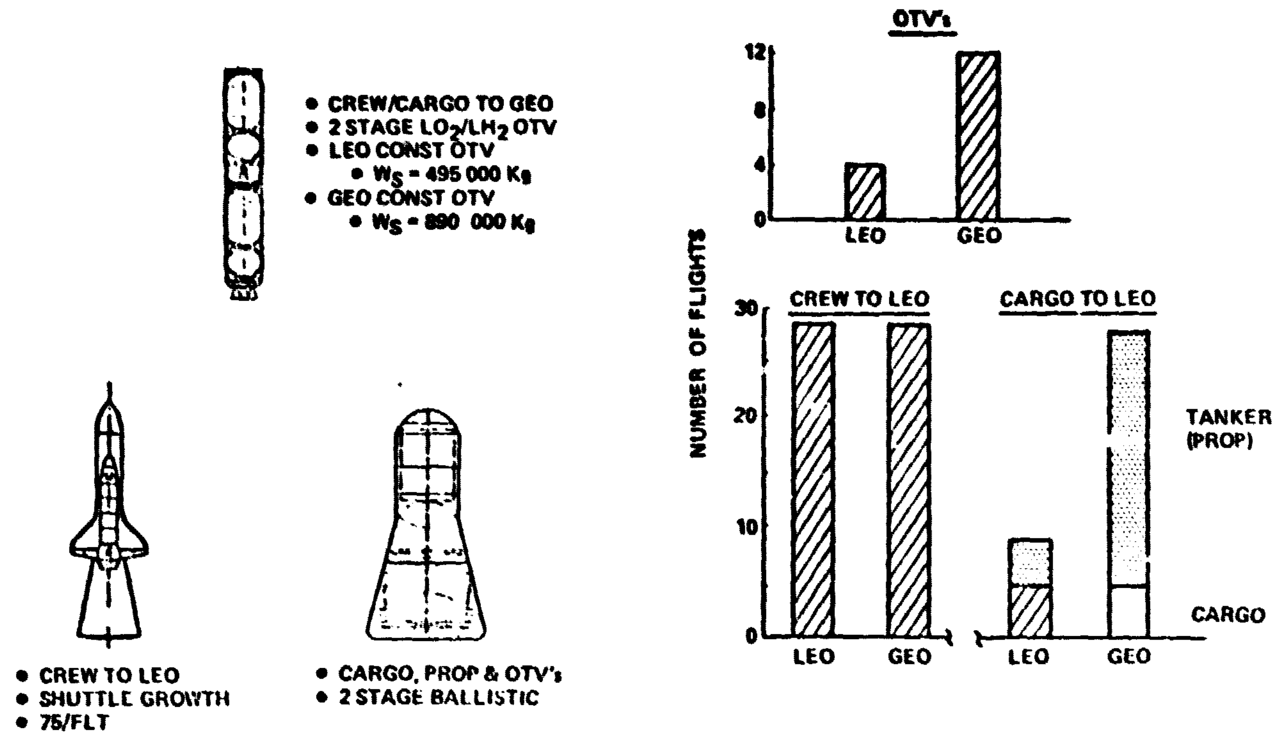


Figure 1.4.3-6 Crew Rotation/Resupply Transportation

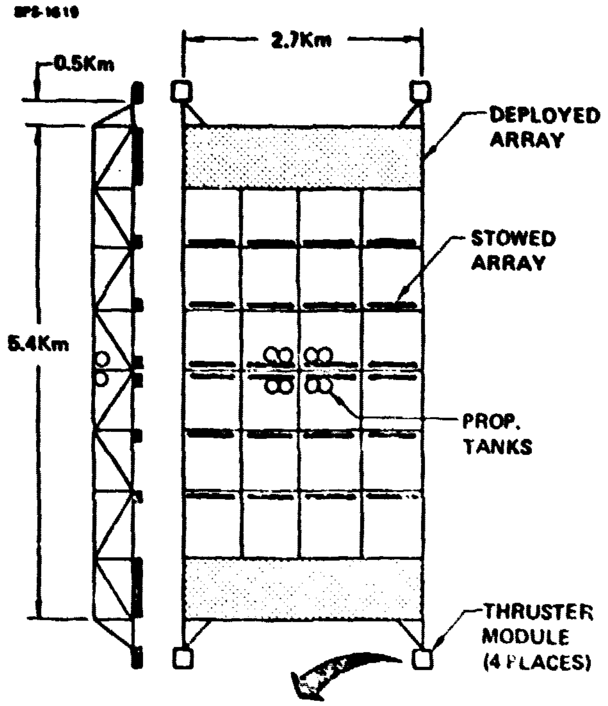
Description

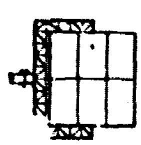
The configuration arrangement and characteristics of the system elements used in the transfer of each satellite module are shown in Figure 1.4.4-1. The general characteristics indicate a 5% oversizing of the satellite to compensate for the radiation degradation occurring during passage through the Van Allen belt and the inability to anneal out all of the damage after reaching GEO. (This ovrsizing is reflected in the satellite description). It should also be emphasized at this point, only the arrays needed to provide the required power for transfer are deployed. The remainder of arrays are stowed within radiation proof containers. Cost optimum trip times and I_{sp} values are respectively 180 days and 7,000 seconds.

Thruster modules are located at four corners of the module to provide the most effective thrust vector and satisfy control requirements. Further discussion of the thruster module is provided later in this section. A two axis gimbal system correctly positions the panel. Installation of the thruster module approximately 500 meters from the satellite in conjunction with gimbal limits prevents high velocity ions from impinging on the satellite and causing erosion. Propellant tanks for the thrusters have been located at the center of the satellite module and at the lower surface to provide a more desirable inertia characteristic (the dominating factor in the amount of gravity gradient torque). Radiators dissipate the waste heat from the power processing units.

Flight control of the module when flying a PEP attitude during transfer results in large gravity gradient torques at several positions in each revolution. Rather than provide the entire control capability with electric thrusters which are quite expensive, the electric system is sized only for the optimum transfer time with the additional required thrust provided by LO_2LH_2 thrusters. The performance penalty for this approach is actually quite small by the time 2,500 kilometer altitude is reached the gravity gradient torque is no longer a dominating force.

The mass characteristics of the electric propulsion system elements are directly proportional to the mass of the payload being transferred for the case of fixed trip time and I_{sp}. Consequently, the modules transporting the antennas require considerably more OTS hardware and propellant. The total mass of the satellite is approximately 100 million kg. An oversizing of 5 percent has been included to compensate for the inability to completely anneal out all the damage to the cells caused by radiation occurring during transfer and for the mismatch in voltage output between the damaged and undamaged cells. The structural design includes modularity and oversizing. Additonal vertical members are used around the perimeter of the satellite module, lateral beams are used at the end of the modules and the structure provides for the transfer of the 15 million kg antenna (includes growth) supported underneath the module. (It should be noted that all module structure has been sized to that dictated by the modules used to transfer the antenna.) The power distribution penalty is related to the additional length of bus caused by the oversizing of the array. The total mass penalty for a LEO constructed satellite is approximately 4.2 million kg for the selected self power transportation system. It should be noted that the array oversizing and power distribution penalty depend on the particular performance characteristics selected for the self power system.





	NO ANTENNA	WITH ANTENNA
PANEL SIZE:	24x38m	48x57m
NO. THRUSTERS:	560	1680

GENERAL CHARACTERISTICS

- 5% OVERSIZING (RADIATION)
- TRIP TIME = 180 DAYS
- ISP = 7000 SEC

MODULE CHARACTERISTICS	NO ANTENNA	WITH ANTENNA
• NO. MODULES	6	2
• MODULE MASS (10^6KG)	8.7	23.7
• POWER REQ'D (10^6Kw)	0.3	0.81
• ARRAY %	13	36
• OTS DRY (10^6KG)	1.1	2.9
• ARGON (10^6KG)	2.0	5.6
• LO_2/LH_2 (10^6KG)	1.0	2.8
• ELEC THRUST (10^3N)	4.5	12.2
• CHEM THRUST (10^3N)	12.0	5.0

Figure 1.4.4-1 Self Power Configuration Photovoltaic Satellite

Subsystem descriptions may be found in Volume 5 of the Part II final report.

Mass
Table 1.4.4-1 presents a mass summary for the orbit transfer systems.

Cost
Table 1.4.4-2 presents a cost summary for the orbit transfer system. This summary is based on the costing details presented in Volume 6 of the Part II Final Report.

WBS 1.4.5 Launch Facilities

The launch facilities and equipment requirements for the SPS cargo and personnel vehicle are identified in the following paragraphs.

2-Stage Winged Cargo Vehicle Launch Facilities
An estimate of the launch facility requirements to support the one satellite/year SPS installation rate (400 flights/year) has been developed. Three (3) launch pads are required to support the 400 flight per year launch rate. Potential locations of these launch pads at Kennedy Space Center are shown on Figure 1.4.5-1. The areas shown are north of the current Pad 39A and 39B locations. This area was proposed originally in the Saturn/Apollo program for additional launch pads.

A preliminary estimate of the launch site facility and equipment cost for the SPS launch vehicle is shown in Table 1.4.5-1. The major facility items are identified and a "ROM" cost estimate provided for each element. The cost of facilities is estimated to be $3055M and the launch site unique ground support equipment (GSE) is an additional $372M for a grand total of $3382M. The booster and orbiter processing facilities are approximately 2/3 of the total facility cost. The launch site GSE is the additional equipment required at the site and does not include stage unique GSE.

Personnel Vehicle Launch Facility
The personnel vehicle concept is a Shuttle derivative vehicle, and as a result a large portion of the Shuttle facilities/equipment can be used. The modifications/additional required are those associated with the ballistic recoverable liquid booster. Retrieval of the first stage liquid booster is accomplished by recovering the stage onboard a specialized ship for transit to port, attaching protective devices, and then towing the stage to the Vertical Assembly Building (VAB) for processing. In the first dock area of the VAB, a 200-ton stiff leg derrick will be installed to lift the stage from the water and install it on the transporter. The area selected for performing maintenance and checkout of the liquid booster stage is in a VAB high bay. Work/storage stands will be required to process the boosters and these stands will be located so that the existing 250 ton crane can be used.

Table 1.4.4-1 Orbit Transfer System Mass Summary

WBS#	ITEM & UNIT MASS	NUMBER (NO ANT)	NUMBER (W/ANT)	TOTAL (NO ANT)	TOTAL (W/ANT)	ALL-UP TOTAL
1.4.4	OTS SYSTEM	(6) MODULES	(2) MODULES	2,377,942	6,268,784 (2,844)	
1.4.4.1	THRUSTER PANEL	4	4	(1,078)		26,805 X 10^6 (12,159)
1.4.4.1.1	PANEL STRUC (1540 LB)	17	45	26,189 (11.875)	69,300 (31.43)	295,680 (134)
1.4.4.1.2	THRUSTERS (110 LB)	2,384	6,286	262,268 (119.0)	691,510 (313.7)	2,957,000 (1341)
1.4.4.1.3	PROCESSORS (18,230 LB)	34	90	620,928 (281.7)	1,637,200 (742.6)	7 X 10^6 (3175)
1.4.4.1.4	SWITCHGEAR (660 LB)	170	449	112,400 (51)	296,361 (134.4)	1,267,00[illegible] (574.8)
1.4.4.1.5	INTERRUPTER (50 LB)	2,384	6,286	119,213 (54)	314,323 (142.6)	1,34[illegible] (606.[illegible])
1.4.4.1.6	INTERRUPTER (2 LB)	2,384	6,286	4,769 (2.16)	12,573 (5.7)	53,757 (24.4)
1.4.4.1.7	CABLING (1500 LB)			25,546 (11.6)	67,355 (30.6)	287,983 (130.6)
1.4.4.1.8	INSTRUM. (200 LB)			3,406 (1.54)	8,891 (4.07)	38,398 (17.4)
1.4.4.1.9	PROP. SYS. (1500 LB)	17	45	155,146 (11.6)	673,545 (30.6)	287,983 (130.6)
1.4.4.2	THRUST FRAME (6,160 LB)*	4	4	17,485 (7.9)	46,101 (20.9)	197,109 (89.4)
1.4.4.3	GIMBAL ASSY (6,160 LB)	4	4	17,485 (7.9)	46,101 (20.9)	197,109 (89.4)
1.4.4.4	COMPUTER (100 LB)	4	4	400 (.18)	400 (.18)	3,200 (1.45)
1.4.4.5	COMMUNIC. (100 LB)	4	4	400 (.18)	400 (.18)	3,200 (1.45)

Table 1.4.4-1 Continued

1.4.4.6	STANDOFF STR (10,000 LB)	4	4	28,384 (12.87)	74,838 (33.9)	319,981 (145)
1.4.4.7	ARGON TANKS (40,000 LB)*	4	4	113,536 (51.5)	299,355 (135.8)	1,279,925 (581)
1.4.4.8	LO_2 TANKS (16,000 LB)*	4	4	45,414 (20.6)	119,741 (54.3)	511,970 (232)
1.4.4.9	LH_2 TANKS (10,000 LB)*	4	4	28,384 (12.87)	74,838 (33.9)	319,981 (145)
1.4.4.10	PROPELLANT SYS. (10,000 LB)*	4	4	28,384 (12.87)	74,838 (33.9)	319,981 (145)
1.4.4.11	CHEM. THRUSTERS	12	12	8,515 (3.86)	22,452 (10.18)	95,994 (43.5)
1.4.4.12	TCS/ RADIATOR	34	90	295,648 (134)	779 520 (353.6)	3,332,926 (1,512)
1.4.4.13	PWR DISTR (41,830)*	4	4	593,651 (269.3)	1,565,252 (710)	7,692,411 (3,036)

*VALUE IS BASED ON 4 EQUAL MODULES.

*VALUE IS BASED ON 4 EQUAL MODULES.

Table 1.4.4-2 Self-Power Orbit Transfer System Mature Industry Cost Estimate (1 SPS/YR)

ITEM & MASS (LB)	NUMBERS OF UNITS PER SPS	MATURE INDUSTRY @ 1 SPS/YR (8 OTS)	$/KG
OTS SYSTEM		1,458,160	
		69,436	
OTS		1,388,724	
THRUSTER PANEL (13,532,000)		790,432	
PANEL STRUC (1540 LB)	192	17,583	$131
THRUSTERS (110 LBS)	26,880	132,752	$ 98
PROCESSORS (18,230 LBS)	384	238,624	$ 75
SWITCHGEAR (660 LBS)	1,920	183,903	$320
INTERRUPTER (5? LBS)	26,880	79,197	$130
INTERRUPTER (2 LBS)	26,880	5,193	$212
CABLING (1500 LBS)	192	95,901	$734
INSTRUM (200 LBS)	192	26,554	1524
PROP SYS (1500 LBS)	192	?0,725	82

Table 1.4.4-2 (Continued)

ITEM & MASS (LB)	NUMBERS OF UNITS PER SPS	MATURE INDUSTRY @ 1 SPS/YR (8 OTS)	$/KG
THRUST FRAME (6160 LBS)	32	23,170	$260
GIMBAL ASSY (6160 LBS)	32	133,000	$1487
COMPUTER (100 LBS)	32	27,415	18,000
COMMUNIC (100 LBS)	32	19,240	13,000
STANDOFF STR (10,000 LBS)	32	34,907	240
ARGON TKS (40,000 LBS)	32	76,164	131
LO_2 TKS (16,000 LBS)	32	34,784	149
LH_2 TKS (10,000 LBS)	32	23,271	160
TANK INSUL	16	15,159	2
PROP SYS (10,000 LBS)	32	16,160	111
CHEM THR (1000 LBS)	96	1,435	
TCS/RAD (8630 LBS)	384	156,225	103
PWR DISTR (41,830 LBS)	160	37,362	12

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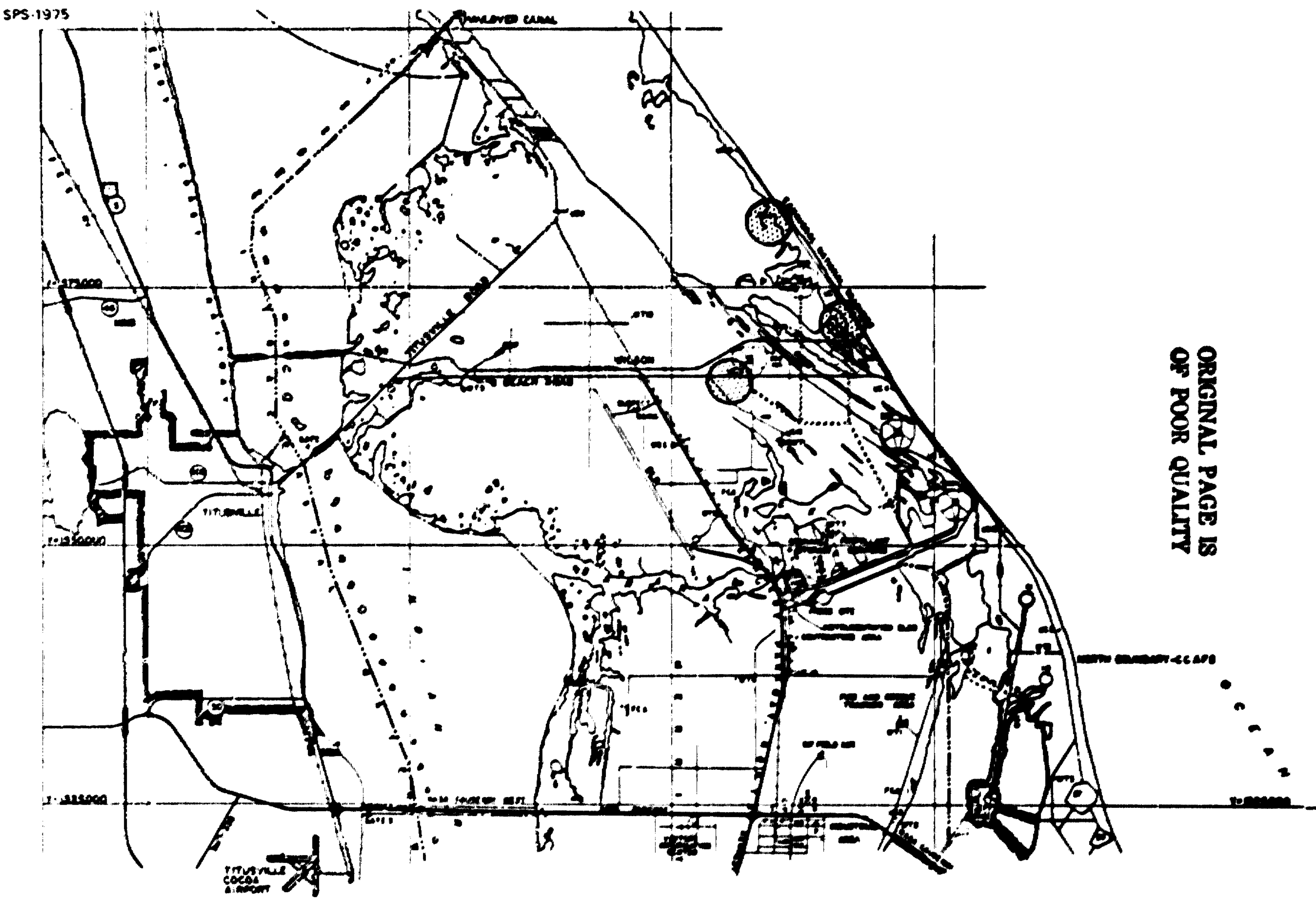

Figure 1.4.5-1 Potential Launch Pad Locations at KSC for SPS Launch Vehicle

Table 1.4.5-1 Launch Site Facility/Equipment Requirements and Cost

ITEM	QUANTITY	UNIT COST $M	TOTAL COST $M
LAUNCHER/ERECTOR	3	112	336
LAUNCH SITE INSTALLATIONS	3	65	195
LAUNCH CONTROL CENTER	1	156	159
ORBITER PROCESSING FACILITY	1	944	944
BOOSTER PROCESSING FACILITY	1	1125	1125
MAINTENANCE/ADMINISTRATION BUILDING	1	176	176
PROPELLANT STORAGE UNITS	12	9	108
RAILROADS, ROADS, PARKING LOTS, ETC.	N/A	12	12
FACILITY SUBTOTAL			3055
TEST STATIONS–COMM. & INTERFACE EQUIPMENT	192	0.25	48
LAUNCH SITE GSE	3	93	279
GSE SUBTOTAL			327
TOTAL (FACILITY & GSE) =			$3382M

The facilities and equipment required to support the personnel vehicle launch operations are identified in Table 1.4.5-2 along with the associated "ROM" cost estimate. The total cost is $97.6M for both the facilities and equipment.

WBS 1.4.6 Propellant Production and Delivery Systems

WBS Dictionary
This element includes all propellant production and delivery system elements except those elements described under WBS 1.4.5, Launch Facilities.

Description
No effort has been expended on this element under this contract.

WBS 1.4.7 Operations and Support

WBS Dictionary
This element is included in the WBS to allow for any transportation operations and support not provided under individual vehicles or under WBS 1.0.2, Space Traffic Control. This element has not been defined.

Table 1.4.5-2 Launch Facilities and Equipment For The Personnel Launch Vehicle

AREAS OR ITEMS REQUIRED	COST ESTIMATE—$M FACILITIES	EQUIPMENT
PORT FACILITIES AND EQUIPMENT	0.4	1.2
RECOVERY SHIP	30.0	–
MOBILE LAUNCHER PLATFORM	20.0	6.0
VERTICAL ASSEMBLY BLDG.	10.6	13.7
LAUNCH PAD	13.7	0.4
OTHER SUPPORT FACILITIES & EQUIPMENT	0.4	1.2
TOTALS	75.1	22.5

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APPENDIX A
SIZE SENSITIVITY ANALYSIS

A size sensitivity design model was constructed using the ISAIAH methodology. The first run of the model optimized power transmitter and rectenna sizes at the nominal power level of approximately 5,000 megawatts per link. Results are shown in Figure A1-1. The new results, although executed in somewhat more detail than earlier results, confirmed the earlier estimates that the optimum recetnna size is 3/4 of the transmitted beam diameter and that the optimum transmitter size is in the vicinity of 1.4 kilometers. However, transmitter sizes larger than on kilometer violate the peak beam intensity limit of 23 millowatts per centimeter squared. Therefore the best system uses a 1 kilometer transmitter and a rectenna diameter 3/4 of the beam diameter.

Figure A1-2 shows a joint optimization of transmitter diameter and power level holding the rectenna size constant at the optimum value. As the system power level is reduced it is possible to employ somewhat larger transmitting antennas without violating the 23 mw/cm^2 limit. Transmitter diameters larger than 1.4 kilometers do not pay off; the minimum system cost in dollars per kilowatt follows along the 23 mw/cm^2 limit to about 2500 megawatts and then follows up the 1.4 kilo meter diameter transmitter curve. Note that comparatively little cost penalty is incurred going down as low as 3000 megawatts of grid power. Below 3,000 megawatts the system cost in dollars per kilowatt begins to turn up rapidly.

The model was also used to investigate sensitivity of SPS costs to solar cell efficiency and blanket costs. Results are shown in Figure A1-3. The cost of power includes capital cost amortization with a 15% annual capital charge, and a 92% plant factor. Mass and cost values include 26% growth allowances respectively.

The size sensitivity model consisted of 37 designer selected variables and 95 computed variables. A complete design point was generated for eachsensitivity point analyzed.

Table A1-1 (72 pp. total) is a listing of design point parameters for each point investigated in the size sensitivity runs.

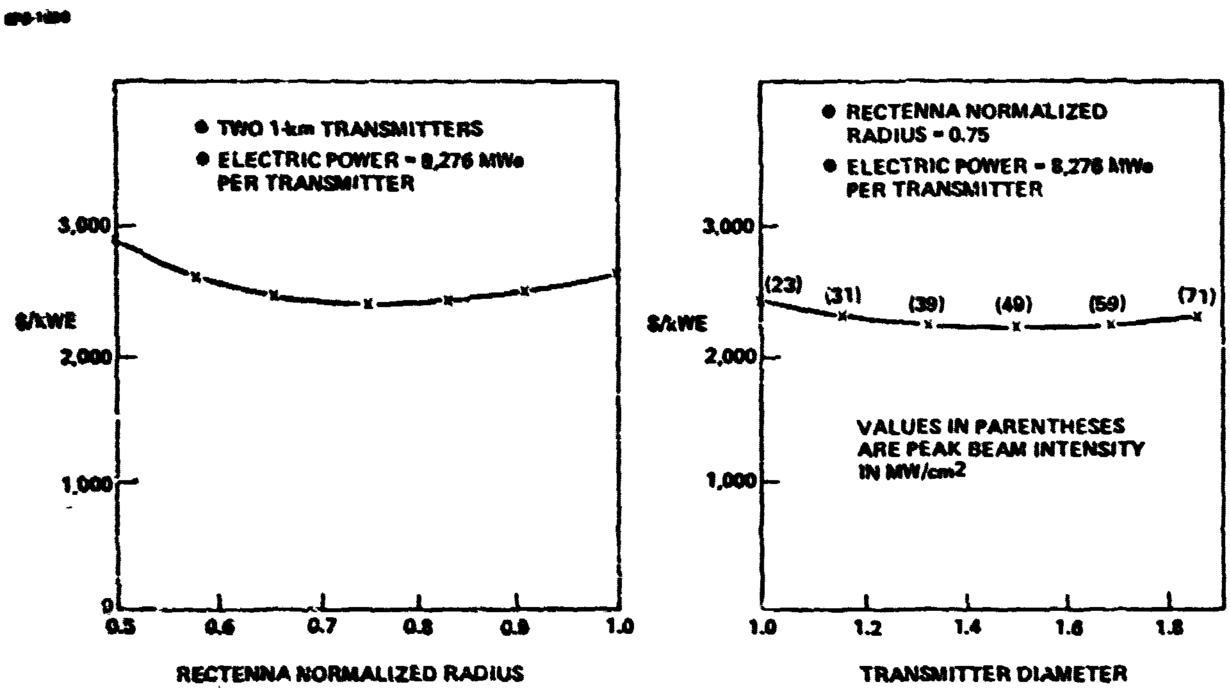

Figure A1-1 Size Sensitivity Results Power Transmission Optimization

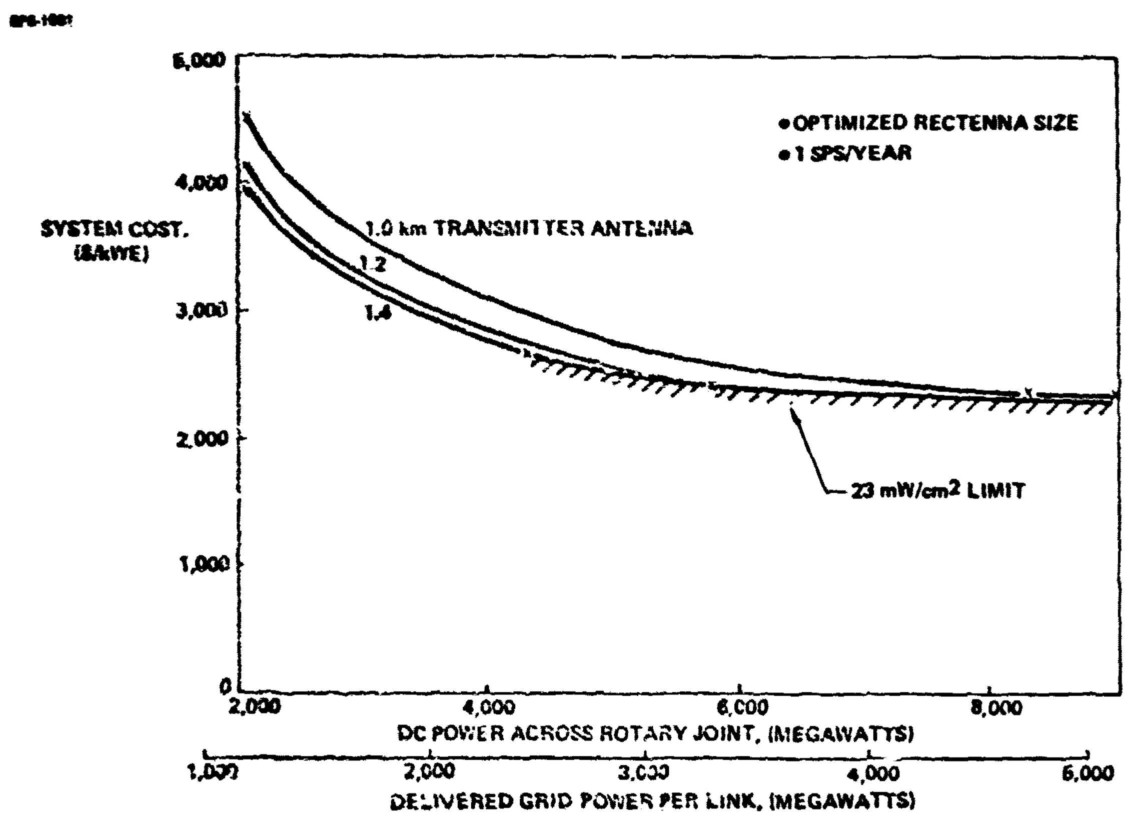

Figure A1-2 Size Sensitivity Analysis Power Level and Transmitter Diameter

SPS-1043

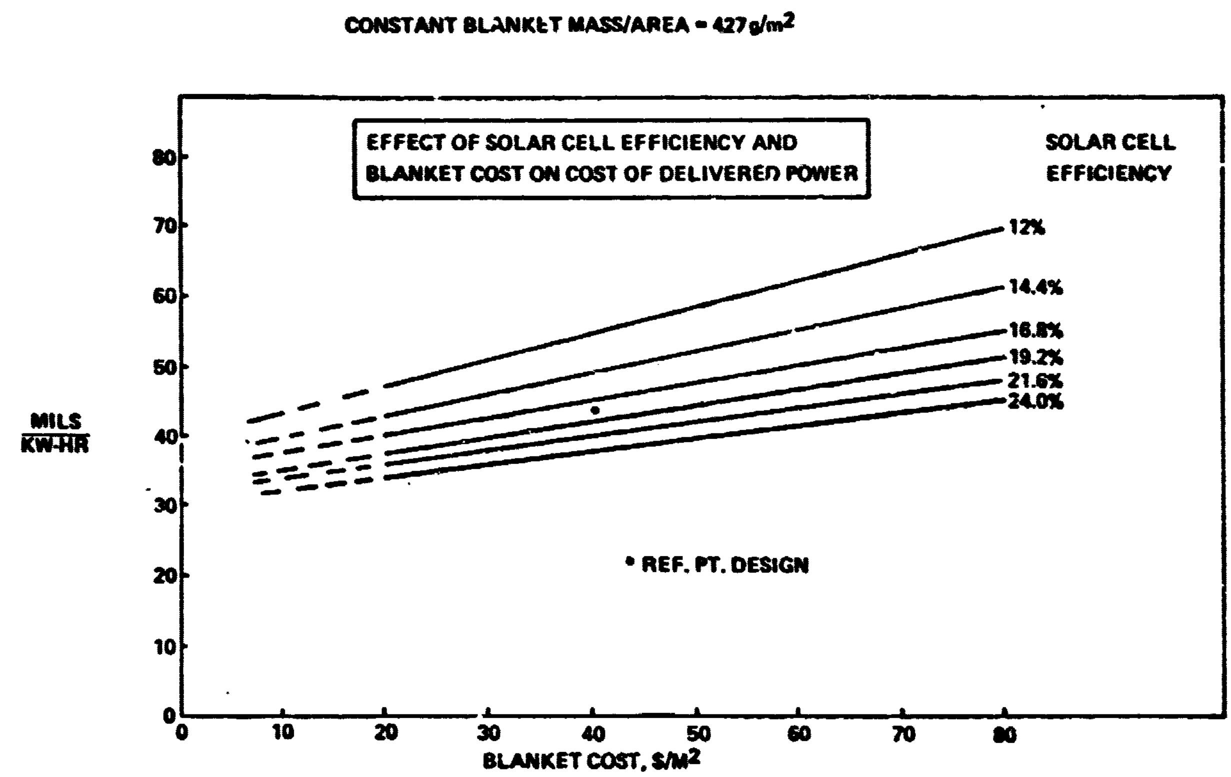

Figure A1-3 Busbar Cost of Power Relatively Insensitive to Solar Blan‹et Cost and Efficiency

Table A1-1
Rotary Joint Power = 2136 Megawatts

ANTENNA DIAMETER VALUE = 1.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.856E-01		
6	NET ENERGY CONV EFFY	=	1.260E-01		
7	AREAWISE EFFICIENCY	=	9.349E-01		
8	ANTENNA POWER DISTR EFFY	=	9.964E-01		
9	NET DC-RF EFFICIENCY	=	8.342E-01		
10	IDEAL BEAM EFFICIENCY	=	9.650E-01		
11	NET BEAM EFFICIENCY	=	8.955E-01		
12	INTERCEPT EFFICIENCY	=	9.512E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.755E-01		
14	NET RF LINK EFFY	=	8.348E-01		
15	DC-TO-DC EFFICIENCY	=	6.097E-01		
16	DC-TO-GRID EFFICIENCY	=	5.914E-01		
17	OVERALL PHYSICAL EFFY	=	7.449E-02		
18	AREA EFFECTIVE EFFY	=	6.964E-02		
19	BLANKET AREA	=	2.507E+07	M2	(6.194E+03 ACRES)
20	ANTENNA DIA	=	1.000E+00	KM	(6.214E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	1.754E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	-1.101E-01	DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25	XMTR AVG/PEAK RATIO	=	3.909E-01		
26	BEAM SPREAD FACTOR	=	1.450E+00		
27	RADIATED RF POWER	=	1.782E+03	MEGAWATT	
28	BEAM DIAMETER	=	1.318E+01	KM	(8.189E+00 MI)
29	BEAM AREA	=	1.364E+08	M2	(3.370E+04 ACRES)
30	AVERAGE BEAM POWE ENS	=	1.170E+00	MW/CM2	
31	PEAK BEAM INTENSIT	=	5.677E+00	MW/CM2	
32	POWER IN MAIN BEAM	=	1.596E+03	MEGAWATT	
33	SATELLITE LENGTH	=	7.650E+00	BAYS	
34	NUMBER OF BAYS	=	6.120E+01	BAYS	
35	XMTR PWR DISTR LOSS	=	3.644E-03		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	2.681E+01	KM2	
39	MEAN SOLAR INSOLATION	=	3.628E+01	GW	
40	SOLAR CELL OUTPUT	=	4.335E+00	GW	
41	ROTARY JOINT CURRENT "A"	=	3.377E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	1.983E+04	AMPS	
43	TOTAL PROCESSED POWER	=	6.408E+02	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	4.256E+03	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	3.618E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	5.025E+04		
47	MAX KLYSTRON PACKING DEN	=	8.719E+00	PER SUB	
48	MAX RF POWER DENSITY	=	5.804E+00	KW/M2	
49	NUMBER OF SUBARRAYS	=	7.261E+03	PER ANT	
50	RECTENNA AREA	=	7.672E+07	M2	(1.896E+04 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	1.065E+00 KW/M2			
52 DC OUTPUT POWER	=	1.302E+00 GW/LINK			
53 GRID POWER	=	2.527E+00 GW TOTAL			
54 LAND AREA PER RECT	=	1.935E+08 M2	(	4.781E+04 ACRES	)
55 "Y" MOM OF INERTIA	=	2.862E+13 KG-M2			
56 THRUST PER CORNER	=	2.181E+01 NEWTONS	(	4.903E+00 LB	)
57 NUMBER OF THRUSTERS	=	2.181E+01 PER INST			
58 CONTROL POWER	=	2.738E+01 MEGAWATT			
59 ANNUAL PROPELLANT	=	8.936E+00 TONS	(	1.970E+04 LBM	)
60 STRUCTURE MASS	=	1.408E+03 TONS	(	3.104E+06 LBM	)
61 CONTROL SYS MASS	=	4.871E+01 TONS	(	1.074E+05 LBM	)
62 SOLAR BLANKET MASS	=	1.070E+04 TONS	(	2.360E+07 LBM	)
63 POWER DISTR MASS	=	1.505E+02 TONS	(	3.318E+05 LBM	)
64 MECH & ELEC R/J MASS	=	7.567E+01 TONS	(	1.668E+05 LBM	)
65 ANT STRUC MASS	=	5.000E+02 TONS	(	1.102E+06 LBM	)
66 ANT WAVEGUIDE MASS	=	4.314E+03 TONS	(	9.511E+06 LBM	)
67 ANT KLYSTRON MASS	=	3.492E+03 TONS	(	7.699E+06 LBM	)
68 ANT CONTROL CKTS MASS	=	2.713E+02 TONS	(	5.982E+05 LBM	)
69 ANT PWR DISTR MASS	=	3.795E+02 TONS	(	8.367E+05 LBM	)
70 ANT PWR PROC&TC MASS	=	1.259E+03 TONS	(	2.776E+06 LBM	)
71 ANT MASS	=	1.022E+04 TONS	(	2.252E+07 LBM	)
72 STRUCTURE COST	=	7.039E-02 BILLION			
73 CONTROL SYS COST	=	2.192E-02 BILLION			
74 SOLAR BLANKET COST	=	8.774E-01 BILLION			
75 POWER DISTR COST	=	3.913E-03 BILLION			
76 MECH&ELEC R/J COST	=	1.589E-02 BILLION			
77 ANT STRUC COST	=	3.485E-01 BILLION			
78 ANT WAVEGUIDE COST	=	2.588E-01 BILLION			
79 ANT KLYSTRON COST	=	1.589E-01 BILLION			
80 ANT CONTROL CKTS COST	=	5.990E-02 BILLION			
81 ANT PWR DISTR COST	=	4.099E-02 BILLION			
82 ANT PWR PROC&TC COST	=	8.688E-02 BILLION			
83 ANT COST	=	9.540E-01 BILLION			
84 NO OF FREIGHT FLIGHTS	=	9.968E+01			
85 CREW SERVICE NO OF FLTS	=	5.696E+00			
86 OTS COST	=	2.674E-01 BILLION			
87 TOTAL TRANSP COST	=	2.604E+00 BILLION			
88 RECTENNA COST	=	4.451E+00 BILLION			
89 CONSTRUCTION COST	=	3.418E-01 BILLION			
90 INTEREST DURING CONSTR	=	6.876E-01 BILLION			
91 LATITUDE AREA FACTOR	=	1.419E+00			
92 TOTAL MASS	=	2.848E+04 TONS	(	6.279E+07 LBM	)
93 TOTAL COST	=	1.101E+01 BILLION			
94 COST/KWE	=	4.356E+03 $			
95 COST/KWH	=	8.097E+01 MILLS			

Table A1-1 (Continued)
Rotary Joint Power = 2136 Megawatts

ANTENNA DIAMETER VALUE = 1.200E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.856E-01		
6	NET ENERGY CONV EFFY	=	1.260E-01		
7	AREAWISE EFFICIENCY	=	9.349E-01		
8	ANTENNA POWER DISTR EFFY	=	9.962E-01		
9	NET DC-RF EFFICIENCY	=	8.340E-01		
10	IDEAL BEAM EFFICIENCY	=	9.650E-01		
11	NET BEAM EFFICIENCY	=	8.955E-01		
12	INTERCEPT EFFICIENCY	=	9.512E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.860E-01		
14	NET RF LINK EFFY	=	8.348E-01		
15	DC-TO-DC EFFICIENCY	=	6.169E-01		
16	DC-TO-GRID EFFICIENCY	=	5.984E-01		
17	OVERALL PHYSICAL EFFY	=	7.537E-02		
18	AREA EFFECTIVE EFFY	=	7.046E-02		
19	BLANKET AREA	=	2.507E+07	M2	(6.194E+03 ACRES)
20	ANTENNA DIA	=	1.200E+00	KM	(7.457E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	1.912E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	2.512E+00	DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25	XMTR AVG/PEAK RATIO	=	3.909E-01		
26	BEAM SPREAD FACTOR	=	1.450E+00		
27	RADIATED RF POWER	=	1.782E+03	MEGAWATT	
28	BEAM DIAMETER	=	1.098E+01	KM	(6.824E+00 MI)
29	BEAM AREA	=	9.472E+07	M2	(2.340E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	1.684E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	8.173E+00	MW/CM2	
32	POWER IN MAIN BEAM	=	1.595E+03	MEGAWATT	
33	SATELLITE LENGTH	=	7.650E+00	BAYS	
34	NUMBER OF BAYS	=	6.120E+01	BAYS	
35	XMTR PWR DISTR LOSS	=	3.838E-03		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	2.681E+01	KM2	
39	MEAN SOLAR INSOLATION	=	3.628E+01	GW	
40	SOLAR CELL OUTPUT	=	4.335E+00	GW	
41	ROTARY JOINT CURRENT "A"	=	3.377E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	1.983E+04	AMPS	
43	TOTAL PROCESSED POWER	=	6.408E+02	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	4.256E+03	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	3.617E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	5.024E+04		
47	MAX KLYSTRON PACKING DEN	=	6.053E+00	PER SUB	
48	MAX RF POWER DENSITY	=	4.030E+00	KW/M2	
49	NUMBER OF SUBARRAYS	=	1.046E+04	PER ANT	
50	RECTENNA AREA	=	5.328E+07	M2	(1.317E+04 ACRES)

Table A1-1 (Continued)

ORIGINAL PAGE IS
OF POOR QUALITY

51	PEAK ANT THERMAL PWR	=	7.405E-01 KW/M2			
52	DC OUTPUT POWER	=	1.318E+00 GW/LINK			
53	GRID POWER	=	2.556E+00 GW TOTAL			
54	LAND AREA PER RECT	=	1.344E+08 M2	(	3.320E+04 ACRES	)
55	"Y" MOM OF INERTIA	=	2.862E+13 KG-M2			
56	THRUST PER CORNER	=	2.151E+01 NEWTONS	(	4.903E+00 LB	)
57	NUMBER OF THRUSTERS	=	2.181E+01 PER INST			
58	CONTROL POWER	=	2.738E+01 MEGAWATT			
59	ANNUAL PROPELLANT	=	8.936E+00 TONS	(	1.970E+04 LBM	)
60	STRUCTURE MASS	=	1.408E+03 TONS	(	3.104E+06 LBM	)
61	CONTROL SYS MASS	=	4.871E+01 TONS	(	1.074E+05 LBM	)
62	SOLAR BLANKET MASS	=	1.070E+04 TONS	(	2.360E+07 LBM	)
63	POWER DISTR MASS	=	1.505E+02 TONS	(	3.318E+05 LBM	)
64	MECH & ELEC R/J MASS	=	8.907E+01 TONS	(	1.964E+05 LBM	)
65	ANT STRUC MASS	=	7.200E+02 TONS	(	1.587E+06 LBM	)
66	ANT WAVEGUIDE MASS	=	6.212E+03 TONS	(	1.370E+07 LBM	)
67	ANT KLYSTRON MASS	=	3.492E+03 TONS	(	7.698E+06 LBM	)
68	ANT CONTROL CKTS MASS	=	2.713E+02 TONS	(	5.981E+05 LBM	)
69	ANT PWR DISTR MASS	=	4.582E+02 TONS	(	1.010E+06 LBM	)
70	ANT PWR PROC&TC MASS	=	1.259E+03 TONS	(	2.776E+06 LBM	)
71	ANT MASS	=	1.241E+04 TONS	(	2.736E+07 LBM	)
72	STRUCTURE COST	=	7.039E-02 BILLION			
73	CONTROL SYS COST	=	2.192E-02 BILLION			
74	SOLAR BLANKET COST	=	8.774E-01 BILLION			
75	POWER DISTR COST	=	3.913E-03 BILLION			
76	MECH&ELEC R/J COST	=	1.870E-02 BILLION			
77	ANT STRUC COST	=	3.628E-01 BILLION			
78	ANT WAVEGUIDE COST	=	3.727E-01 BILLION			
79	ANT KLYSTRON COST	=	1.589E-01 BILLION			
80	ANT CONTROL CKTS COST	=	5.989E-02 BILLION			
81	ANT PWR DISTR COST	=	4.949E-02 BILLION			
82	ANT PWR PROC&TC COST	=	8.688E-02 BILLION			
83	ANT COST	=	1.091E+00 BILLION			
84	NO OF FREIGHT FLIGHTS	=	1.094E+02			
85	CREW SERVICE NO OF FLTS	=	6.253E+00			
86	OTS COST	=	2.936E-01 BILLION			
87	TOTAL TRANSP COST	=	2.798E+00 BILLION			
88	RECTENNA COST	=	3.160E+00 BILLION			
89	CONSTRUCTION COST	=	3.752E-01 BILLION			
90	INTEREST DURING CONSTR	=	6.309E-01 BILLION			
91	LATITUDE AREA FACTOR	=	1.419E+00			
92	TOTAL MASS	=	3.126E+04 TONS	(	6.892E+07 LBM	)
93	TOTAL COST	=	1.010E+01 BILLION			
94	COST/KWE	=	3.950E+03 $			
95	COST/KWH	=	7.342E+01 MILLS			

Table A1-1 (Continued)
Rotary Joint Power = 2136 Megawatts

ANTENNA DIAMETER VALUE = 1.400E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01			
2	NET CELL EFFICIENCY	=	1.601E-01			
3	BASIC CONVERSION EFFY	=	1.360E-01			
4	BLANKET FACTORS	=	9.399E-01			
5	BUS I-SQ-R	=	9.856E-01			
6	NET ENERGY CONV EFFY	=	1.260E-01			
7	AREAWISE EFFICIENCY	=	9.349E-01			
8	ANTENNA POWER DISTR EFFY	=	9.972E-01			
9	NET DC-RF EFFICIENCY	=	8.349E-01			
10	IDEAL BEAM EFFICIENCY	=	9.650E-01			
11	NET BEAM EFFICIENCY	=	8.955E-01			
12	INTERCEPT EFFICIENCY	=	9.512E-01			
13	RECTENNA RF-DC EFFICIENC	=	8.871E-01			
14	NET RF LINK EFFY	=	8.34[illegible]E-01			
15	DC-TO-DC EFFICIENCY	=	6.183E-01			
16	DC-TO-GRID EFFICIENCY	=	5.998E-01			
17	OVERALL PHYSICAL EFFY	=	7.554E-02			
18	AREA EFFECTIVE EFFY	=	7.062E-02			
19	BLANKET AREA	=	2.507E+07	M2	(	6.194E+03 ACRES	)
20	ANTENNA DIA	=	1.400E+00	KM	(	8.700E-01 MI	)
21	REQUIRED SIDELOBE SUPPR	=	2.047E+01	DB			
22	TAPER REQUIRED FOR SL SU	=	4.665E+00	DB			
23	TRANSMITTER POWER TAPER	=	1.[illegible]50E+01	DB			
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01				
25	XMTR AVG/PEAK RATIO	=	3.909E-01				
26	BEAM SPREAD FACTOR	=	1.450E+00				
27	RADIATED RF POWER	=	1.783E+03	MEGAWATT			
28	BEAM DIAMETER	=	9.413E+00	KM	(	5.849E+00 MI	)
29	BEAM AREA	=	6.959E+07	M2	(	1.720E+04 ACRES	)
30	AVERAGE BEAM POWER DENS	=	2.295E+00	MW/CM2			
31	PEAK BEAM INTENSITY	=	1.114E+01	MW/CM2			
32	POWER IN MAIN BEAM	=	1.597E+03	MEGAWATT			
33	SATELLITE LENGTH	=	7.650E+00	BAYS			
34	NUMBER OF BAYS	=	6.120E+01	BAYS			
35	XMTR PWR DISTR LOSS		2.761E-03				
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES	)
37	BAY SIZE	=	6.600E+02	METERS			
38	SPS AREA	=	2.681E+01	KM2			
39	MEAN SOLAR INSOLATION	=	3.628E+01	GW			
40	SOLAR CELL OUTPUT	=	4.335E+00	GW			
41	ROTARY JOINT CURRENT "A"	=	3.374E+04	AMPS			
42	ROTARY JOINT CURRENT "B"	=	1.981E+04	AMPS			
43	TOTAL PROCESSED POWER	=	6.408E+02	MEGAWATT			
44	TOTAL KLYSTRON INPUT	=	4.260E+03	MEGAWATT			
45	TOTAL KLYSTRON OUTPUT	=	3.621E+03	MEGAWATT			
46	NUMBER OF KLYSTRONS	=	5.029E+04				
47	MAX KLYSTRON PACKING DEN	=	4.452E+00	PER SUB			
48	MAX RF POWER DENSITY	=	2.964E+00	KW/M2			
49	NUMBER OF SUBARRAYS	=	1.423E+04	PER ANT			
50	RECTENNA AREA	=	3.914E+07	M2	(	9.672E+03 ACRES	)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	5.408E-01 KW/M2		
52 DC OUTPUT POWER	=	1.321E+00 GW/LINK		
53 GRID POWER	=	2.562E+00 GW TOTAL		
54 LAND AREA PER RECT	=	9.872E+07 M2	(	2.439E+04 ACRES)
55 "Y" MOM OF INERTIA	=	2.862E+13 KG-M2		
56 THRUST PER CORNER	=	2.181E+01 NEWTONS	(	4.903E+00 LB)
57 NUMBER OF THRUSTERS	=	2.181E+01 PER INST		
58 CONTROL POWER	=	2.733E+01 MEGAWATT		
59 ANNUAL PROPELLANT	=	8.936E+00 TONS	(	1.970E+04 LBM)
60 STRUCTURE MASS	=	1.408E+03 TONS	(	3.104E+06 LBM)
61 CONTROL SYS MASS	=	4.872E+01 TONS	(	1.074E+05 LBM)
62 SOLAR BLANKET MASS	=	1.070E+04 TONS	(	2.360E+07 LBM)
63 POWER DISTR MASS	=	1.504E+02 TONS	(	3.315E+05 LBM)
64 MECH & ELEC R/J MASS	=	1.025E+02 TONS	(	2.259E+05 LBM)
65 ANT STRUC MASS	=	9.800E+02 TONS	(	2.161E+06 LBM)
66 ANT WAVEGUIDE MASS	=	8.455E+03 TONS	(	1.864E+07 LBM)
67 ANT KLYSTRON MASS	=	3.495E+03 TONS	(	7.706E+06 LBM)
68 ANT CONTROL CKTS MASS	=	2.716E+02 TONS	(	5.987E+05 LBM)
69 ANT PWR DISTR MASS	=	6.180E+02 TONS	(	1.362E+06 LBM)
70 ANT PWR PROC&TC MASS	=	1.259E+03 TONS	(	2.776E+06 LBM)
71 ANT MASS	=	1.503E+04 TONS	(	3.324E+07 LBM)
72 STRUCTURE COST	=	7.039E-02 BILLION		
73 CONTROL SYS COST	=	2.192E-02 BILLION		
74 SOLAR BLANKET COST	=	8.774E-01 BILLION		
75 POWER DISTR COST	=	3.909E-03 BILLION		
76 MECH&ELEC R/J COST	=	2.152E-02 BILLION		
77 ANT STRUC COST	=	3.797E-01 BILLION		
78 ANT WAVEGUIDE COST	=	5.073E-01 BILLION		
79 ANT KLYSTRON COST	=	1.590E-01 BILLION		
80 ANT CONTROL CKTS COST	=	5.995E-02 BILLION		
81 ANT PWR DISTR COST	=	6.674E-02 BILLION		
82 ANT PWR PROC&TC COST	=	8.688E-02 BILLION		
83 ANT COST	=	1.260E+00 BILLION		
84 NO OF FREIGHT FLIGHTS	=	1.212E+02		
85 CREW SERVICE NO OF FLTS	=	6.925E+00		
86 OTS COST	=	3.253E-01 BILLION		
87 TOTAL TRANSP COST	=	3.020E+00 BILLION		
88 RECTENNA COST	=	2.581E+00 BILLION		
89 CONSTRUCTION COST	=	4.157E-01 BILLION		
90 INTEREST DURING CONSTR	=	6.143E-01 BILLION		
91 LATITUDE AREA FACTOR	=	1.419E+00		
92 TOTAL MASS	=	3.464E+04 TONS	(	7.637E+07 LBM)
93 TOTAL COST	=	9.833E+00 BILLION		
94 COST/KWE	=	3.838E+03 $		
95 COST/KWH	=	7.133E+01 MILLS		

Table A1-1 (Continued)
Rotary Joint Power = 2136 Megawatts

ANTENNA DIAMETER VALUE = 1.600E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01	
2	NET CE L EFFICIENCY	=	1.601E-01	
3	BASIC CONVERSION EFFY	=	1.360E-01	
4	BLANKET FACTORS	=	9.399E-01	
5	BUS I-SQ-R	=	9.856E-01	
6	NET ENERGY CONV EFFY	=	1.260E-01	
7	AREAWISE EFFICIENCY	=	9.349E-01	
8	ANTENNA POWER DISTR EFFY	=	9.966E-01	
9	NET DC-RF EFFICIENCY	=	8.344E-01	
10	IDEAL BEAM EFFICIENCY	=	9.650E-01	
11	NET BEAM EFFICIENCY	=	8.955E-01	
12	INTERCEPT EFFICIENCY	=	9.512E-01	
13	RECTENNA RF-DC EFFICIENC	=	8.911E-01	
14	NET RF LINK EFFY	=	8.348E-01	
15	DC-TO-DC EFFICIENCY	=	6.207E-01	
16	DC-TO-GRID EFFICIENCY	=	6.021E-01	
17	OVERALL PHYSICAL EFFY	=	7.584E-02	
18	AREA EFFECTIVE EFFY	=	7.090E-02	
19	BLANKET AREA	=	2.507E+07 M2	(6.194E+03 ACRES)
20	ANTENNA DIA	=	1.600E+00 KM	(9.942E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.162E+01 DB	
22	TAPER REQUIRED FOR SL SU	=	6.485E+00 DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01 DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01	
25	XMTR AVG/PEAK RATIO	=	3.909E-01	
26	BEAM SPREAD FACTOR	=	1.450E+00	
27	RADIATED RF POWER	=	1.732E+03 MEGAWATT	
28	BEAM DIAMETER	=	8.236E+00 KM	(5.118E+00 MI)
29	BEAM AREA	=	5.328E+07 M2	(1.317E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	2.996E+00 MW/CM2	
31	PEAK BEAM INTENSITY	=	1.444E+01 MW/CM2	
32	POWER IN MAIN BEAM	=	1.596E+03 MEGAWATT	
33	SATELLITE LENGTH	=	7.650E+00 BAYS	
34	NUMBER OF BAYS	=	6.120E+01 BAYS	
35	XMTR PWR DISTR LOSS	=	3.417E-03	
36	ADJ BAY USEFUL AREA	=	4.096E+05 M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02 METERS	
38	SPS AREA	=	2.681E+01 KM2	
39	MEAN SOLAR INSOLATION	=	3.628E+01 GW	
40	SOLAR CELL OUTPUT	=	4.335E+00 GW	
41	ROTARY JOINT CURRENT "A"	=	3.376E+04 AMPS	
42	ROTARY JOINT CURRENT "B"	=	1.983E+04 AMPS	
43	TOTAL PROCESSED POWER	=	6.408E+02 MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	4.257E+03 MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	3.619E+03 MEGAWATT	
46	NUMBER OF KLYSTRONS	=	5.026E+04	
47	MAX KLYSTRON PACKING DEN	=	3.406E+00 PER SUB	
48	MAX RF POWER DENSITY	=	2.268E+00 KW/M2	
49	NUMBER OF SUBARRAYS	=	1.859E+04 PER ANT	
50	RECTENNA AREA	=	2.997E+07 M2	(7.405E+03 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	4.156E-01 KW/M2	
52 DC OUTPUT POWER	=	1.326E+00 GW/LINK	
53 GRID POWER	=	2.572E+00 GW TCTAL	
54 LAND AREA PER RECT	=	7 558E+07 M2	(1.868E+04 ACRES)
55 "Y" MOM OF INERTIA	=	2.862E+13 KG-M2	
"6 THRUST PER CORNER	=	2.181E+01 NEWTONS	(4.903E+00 LB)
57 NUMBER OF THRUSTERS	=	2.181E+01 PER INST	
58 CONTROL POWER	=	2.738E+01 MEGAWATT	
59 ANNUAL PROPELLANT	=	8.936E+00 TONS	(1.970E+04 LBM)
60 STRUCTURE MASS	=	).408E+03 TONS	(3.104E+06 LBM)
61 CONTROL SYS MASS	=	4.871E+01 TONS	(1.074E+05 LBM)
62 SOLAR BLANKET MASS	=	1.070E+04 TONS	(2.360E+07 LBM)
63 POWER DISTR MASS	=	1.505E+02 TONS	(3.317E+05 LBM)
64 MECH & ELEC R/J MASS	=	1.159E+02 TONS	(2.554E+05 LBM)
65 ANT STRUC MASS	=	1.280E+03 TONS	(2.822E+06 LBM)
66 ANT WAVEGUIDE MASS	=	1.104E+04 TONS	(2.435E+07 LBM)
67 ANT KLYSTRON MASS	=	3.493E+03 TONS	(7.701E+06 LBM)
68 ANT CONTROL CKTS MASS	=	2.714E+02 TONS	(5.983E+55 LBM)
69 ANT PWR DISTR MASS	=	7.204E+02 TONS	(1.588E+06 LBM)
70 ANT PWR PROC&TC MASS	=	1.259E+03 TONS	(2.776E:06 LBM)
71 ANT MASS	=	1.807E+04 TONS	(3.983E+07 LBM)
72 STRUCTURE COST	=	7.039E-02 BILLION	
73 CONTROL SYS COST	=	2.192E-02 BILLION	
74 SOLAR BLANKET COST	=	8.774E-01 BILLION	
75 POWER DISTR COST	=	3.912E-03 BILLION	
76 MECH&ELEC R/J COST	=	2.433E-02 BILLION	
77 ANT STRUC COST	=	3.992E-01 BILLION	
78 ANT WAVEGUIDE COST	=	6.626E-01 BILLION	
79 ANT KLYSTRON COST	=	1.559E-01 BILLION	
80 ANT CONTROL CKTS COST	=	5.991E-02 BILLION	
81 ANT PWR DISTR COST	=	7.780E-02 BILLION	
82 ANT PWR PROC&TC COST	=	8.688E-02 BILLION	
83 ANT COST	=	1.445E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	1.345E+02	
85 CREW SERVICE NO OF FLTS	=	7.655E+00	
86 OTS COST	=	3.608E-01 BILLION	
87 TOTAL TRANSP COST	=	3.280E+00 BILLION	
88 RECTENNA COST	=	1.876E+00 BILLION	
89 CONSTRUCTION COST	=	4.611E-01 BILLION	
90 INTEREST DURING CONSTR	=	6.195E-01 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	3.842E+04 TONS	(8.471E+07 LBM)
93 TOTAL COST	=	9.916E+00 BILLION	
94 COST/KWE	=	3.855E+03 $	
95 COST/KWH	=	7.165E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 2136 Megawatts

ANTENNA DIAMETER VALUE = 1.800E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS 1-SQ-R	=	9.856E-01		
6	NET ENERGY CONV EFFY	=	1.260E-01		
7	AREAWISE EFFICIENCY	=	9.349E-01		
8	ANTENNA POWER DISTR EFFY	=	9.954E-01		
9	NLT DC-RF EFFICIENCY	=	8.334E-01		
10	IDEAL BEAM EFFICIENCY	=	9.650E-01		
11	NET BEAM EFFICIENCY	=	8.955E-01		
12	INTERCEPT EFFICIENCY	=	9.512E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.921E-01		
14	NET RF LINK EFFY	=	8.348E-01		
15	DC-TO-DC EFFICIENCY	=	6.207E-01		
16	DC-TO-GRID EFFICIENCY	=	6.021E-01		
17	OVERALL PHYSICAL EFFY	=	7.583E-02		
18	AREA EFFECTIVE EFFY	=	7.090E-02		
19	BLANKET AREA	=	2.507E+07	M2	(6.194E+03 ACRES)
20	ANTENNA DIA	=	1.800E+00	KM	(1.119E+00 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.264E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	8.170E+00	DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25	XMTR AVG/PEAK RATIO	=	3.909E-01		
26	BEAM SPREAD FACTOR	=	1.450E+00		
27	RADIATED RF POWER	=	1.780E+03	MEGAWATT	
28	BEAM DIAMETER	=	7.321E+00	KM	(4.549E+00 MI)
29	BEAM AREA	=	4.210E+07	M2	(1.040E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	3.787E-00	MW/CM2	
31	PEAK BEAM INTENSITY	=	1.837E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	1.[illegible]E+03	MEGAWATT	
33	SATELLITE LENGTH	=	7.650E+00	BAYS	
34	NUMBER OF BAYS	=	6.120E+01	BAYS	
35	XMTR PWR DISTR LOSS	=	4.612E-03		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	2.651E+01	KM2	
39	MEAN SOLAR INSOLATION	=	3.628E+01	GW	
40	SOLAR CELL OUTPUT	=	4.335E+00	GW	
41	ROTARY JOINT CURRENT "A"	=	3.350E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	1.985E+04	AMPS	
43	TOTAL PROCESSED POWER	=	6.408E+02	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	4.252E+03	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	3.614E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	5.020E+04		
47	MAX KLYSTRON PACKING DEN	=	2.688E+00	PER SUB	
48	MAX RF POWER DENSITY	=	1.[illegible]90E+00	KW M2	
49	NUMBER OF SUBARRAYS	=	2.353E+04	PER ANT	
50	RECTENNA AREA	=	2.368E+07	M2	(5.851E+03 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	3.305E-01 KW/M2	
52 DC OUTPUT POWER	=	1.326E+00 GW/LINK	
53 GRID POWER	=	2.572E+00 GW TOTAL	
54 LAND AREA PER RECT	=	5.972E+07 M2	(1.476E+04 ACRES)
55 "Y" MOM OF INERTIA	=	2.862E+13 KG-M2	
56 THRUST PER CORNER	=	2.181E+01 NEWTONS	(4.903E+00 LB)
57 NUMBER OF THRUSTERS	=	2.181E+01 PER INST	
58 CONTROL POWER	=	2.738E+01 MEGAWATT	
59 ANNUAL PROPELLANT	=	8.936E+00 TONS	(1.970E+04 LBM)
60 STRUCTURE MASS	=	1.408E+03 TONS	(3.104E+06 LBM)
61 CONTROL SYS MASS	=	4.871E+01 TONS	(1.074E+05 LBM)
62 SOLAR BLANKET MASS	=	1.070E+04 TONS	(2.360E+07 LBM)
63 POWER DISTR MASS	=	1.506E+02 TONS	(3.321E+05 LBM)
64 MECH & ELEC R/J MASS	=	1.293E+02 TONS	(2.859E+05 LBM)
65 ANT STRUC MASS	=	1.620E+03 TONS	(3.571E+06 LBM)
66 ANT WAVEGUIDE MASS	=	1.398E+04 TONS	(3.081E+07 LBM)
67 ANT KLYSTRON MASS	=	3.489E+03 TONS	(7.692E+06 LBM)
68 ANT CONTROL CKTS MASS	=	2.711E+02 TONS	(5.976E+05 LBM)
69 ANT PWR DISTR MASS	=	7.370E+02 TONS	(1.625E+06 LBM)
70 ANT PWR PROC&TC MASS	=	1.259E+03 TONS	(2.776E+06 LBM)
71 ANT MASS	=	2.135E+04 TONS	(4.708E+07 LBM)
72 STRUCTURE COST	=	7.039E-02 BILLION	
73 CONTROL SYS COST	=	2.192E-02 BILLION	
74 SOLAR BLANKET COST	=	8.774E-01 BILLION	
75 POWER DISTR COST	=	3.916E-03 BILLION	
76 MECH&ELEC R/J COST	=	2.715E-02 BILLION	
77 ANT STRUC COST	=	4.213E-0[illegible] [illegible]ION	
78 ANT WAVEGUIDE COST	=	8.386E-0[illegible] [illegible]LLION	
79 ANT KLYSTRON COST	=	1.587E-01 BILLION	
80 ANT CONTROL CKTS COST	=	5.954E-02 BILLION	
81 ANT PWR DISTR COST	=	7.959E-02 BILLION	
82 ANT PWR PROC&TC COST	=	8.688E-02 BILLION	
83 ANT COST	=	1.645E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	1.490E+02	
85 CREW SERVICE NO OF FLTS	=	8.516E+00	
86 OTS COST	=	3.998E-01 BILLION	
87 TOTAL TRANSP COST	=	3.550E+00 BILLION	
88 RECTENNA COST	=	1.529E+00 BILLION	
89 CONSTRUCTION COST	=	5.110E-01 BILLION	
90 INTEREST DURING CONSTR	=	6.382E-01 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	4.258E+04 TONS	(9.387E+07 LBM)
93 TOTAL COST	=	[illegible].022E+01 BILLION	
94 COST/KWE	=	3.972E+03 $	
95 COST/KWH	=	7.382E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 2136 Megawatts

ANTENNA DIAMETER VALUE = 2.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01			
2	NET CELL EFFICIENCY	=	1.601E-01			
3	BASIC CONVERSION EFFY	=	1.360E-01			
4	BLANKET FACTORS	=	9.399E-01			
5	BUS I-SQ-R	=	9.856E-01			
6	NET ENERGY CONV EFFY	=	1.260E-01			
7	AREAWISE EFFICIENCY	=	9.349E-01			
8	ANTENNA POWER DISTR EFFY	=	9.948E-01			
9	NET DC-RF EFFICIENCY	=	8.329E-01			
10	IDEAL BEAM EFFICIENCY	=	9.650E-01			
11	NET BEAM EFFICIENCY	=	8.955E-01			
12	INTERCEPT EFFICIENCY	=	9.512E-01			
13	RECTENNA RF-DC EFFICIENC	=	8.926E-01			
14	NET RF LINK EFFY	=	8.348E-01			
15	DC-TO-DC EFFICIENCY	=	6.207E-01			
16	DC-TO-GRID EFFICIENCY	=	6.020E-01			
17	OVERALL PHYSICAL EFFY	=	7.583E-02			
18	AREA EFFECTIVE EFFY	=	7.089E-02			
19	BLANKET AREA	=	2.507E+07	M2	(	6.194E+03 ACRES)
20	ANTENNA DIA	=	2.000E+00	KM	(	1.243E+00 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.355E+01	DB		
22	TAPER REQUIRED FOR SL SU	=	9.463E+00	DB		
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB		
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01			
25	XMTR AVG/PEAK RATIO	=	3.909E-01			
26	BEAM SPREAD FACTOR	=	1.450E+00			
27	RADIATED RF POWER	=	1.779E+03	MEGAWATT		
28	BEAM DIAMETER	=	6.559E+00	KM	(	4.094E+00 MI)
29	BEAM AREA	=	3.410E+07	M2	(	8.426E+03 ACRES)
30	AVERAGE BEAM POWER DENS	=	4.672E+00	MW/CM2		
31	PEAK BEAM INTENSITY	=	2.267E+01	MW/CM2		
32	POWER IN MAIN BEAM	=	1.593E+03	MEGAWATT		
33	SATELLITE LENGTH	=	7.650E+00	BAYS		
34	NUMBER OF BAYS	=	6.120E+01	BAYS		
35	XMTR PWR DISTR LOSS	=	5.211E-03			
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS		
38	SPS AREA	=	2.681E+01	KM2		
39	MEAN SOLAR INSOLATION	=	3.628E+01	GW		
40	SOLAR CELL OUTPUT	=	4.335E+00	GW		
41	ROTARY JOINT CURRENT "A"	=	3.38[illegible]+04	AMPS		
42	ROTARY JOINT CURRENT "B"	=	1.986E+04	AMPS		
43	TOTAL PROCESSED POWER	=	6.408E+02	MEGAWATT		
44	TOTAL KLYSTRON INPUT	=	4.250E+03	MEGAWATT		
45	TOTAL KLYSTRON OUTPUT	=	3.612E+03	MEGAWATT		
46	NUMBER OF KLYSTRONS	=	5.017E+04			
47	MAX KLYSTRON PACKING DEN	=	2.176E+00	PER SUB		
48	MAX RF POWER DENSITY	=	1.449E+00	KW/M2		
49	NUMBER OF SUBARRAYS	=	2.905E+04	PER ANT		
50	RECTENNA AREA	=	1.918E+07	M2	(	4.739E+03 ACRES)

Table A1-1 (Continued)

51	P[illegible]K [illegible]IT THERMAL PWR	=	2.686E-01	KW/M2			
52	DC OUTPUT POWER	=	1.326E+00	GW/LINK			
53	GRID POWER	=	2.572E+00	GW TOTAL			
54	LAND AREA PER RECT	=	4.837E+07	M2	(	1.195E+04 ACRES	)
55	"Y" MOM OF INERTIA	=	2.862E+13	KG-M2			
56	THRUST PER CORNER	=	2.181E+01	NEWTONS	(	4.903E+00 LB	)
57	NUMBER OF THRUSTERS	=	2.181E+01	PER INST			
58	CONTROL POWER	=	2.738E+01	MEGAWATT			
59	ANNUAL PROPELLANT	=	8.936E+00	TONS	(	1.970E+04 LBM	)
60	STRUCTURE MASS	=	1.408E+03	TONS	(	3.104E+06 LBM	)
61	CONTROL SYS MASS	=	4.871E+01	TONS	(	1.074E+05 LBM	)
62	SOLAR BLANKET MASS	=	1.070E+04	TONS	(	2.360E+07 LBM	)
63	POWER DISTR MASS	=	1.507E+02	TONS	(	3.323E+05 LBM	)
64	MECH & ELEC R/J MASS	=	1.427E+02	TONS	(	3.145E+05 LBM	)
65	ANT STRUC MASS	=	2.000E+03	TONS	(	4.409E+06 LBM	)
66	ANT WAVEGUIDE MASS	=	1.726E+04	TONS	(	3.804E+07 LBM	)
67	ANT KLYSTRON MASS	=	3.487E+03	TONS	(	7.687E+06 LBM	)
68	ANT CONTROL CKTS MASS	=	2.709E+02	TONS	(	5.973E+05 LBM	)
69	ANT PWR DISTR MASS	=	8.477E+02	TONS	(	1.869E+06 LBM	)
70	ANT PWR PROC&TC MASS	=	1.259E+03	TONS	(	2.776E+06 LBM	)
71	ANT MASS	=	2.512E+04	TONS	(	5.538E+07 LBM	)
72	STRUCTURE COST	=	7.039E-02	BILLION			
73	CONTROL SYS COST	=	2.192E-02	BILLION			
74	SOLAR BLANKET COST	=	8.774E-01	BILLION			
75	POWER DISTR COST	=	3.919E-03	BILLION			
76	MECH&ELEC R/J COST	=	2.956E-02	BILLION			
77	ANT STRUC COST	=	4.460E-01	BILLION			
78	ANT WAVEGUIDE COST	=	1.035E+00	BILLION			
79	ANT KLYSTRON COST	=	1.586E-01	BILLION			
80	ANT CONTROL CKTS COST	=	5.980E-02	BILLION			
81	ANT PWR DISTR COST	=	9.155E-02	BILLION			
82	ANT PWR PROC&TC COST	=	6.688E-02	BILLION			
83	ANT COST	=	1.878E+00	BILLION			
84	NO OF FREIGHT FLIGHTS	=	1.657E+02				
85	CREW SERVICE NO OF FLTS	=	9.469E+00				
86	OTS COST	=	4.446E-01	BILLION			
87	TOTAL TRANSP COST	=	3.853E+00	BILLION			
88	RECTENNA COST	=	1.281E+00	BILLION			
89	CONSTRUCTION COST	=	5.631E-01	BILLION			
90	INTEREST DURING CONSTR	=	6.693E-01	BILLION			
91	LATITUDE AREA FACTOR	=	1.419E+00				
92	TOTAL MASS	=	4.734E+04	TONS	(	1.044E+08 LBM	)
93	TOTAL COST	=	1.07[illegible]E+01	BILLION			
94	COST/KWE	=	4.166E+03	$			
95	COST/KWH	=	7.743E+01	MILLS			

Table A1-1 (Continued)
Rotary Joint Power = 3418 Megawatts

ANTENNA DIAMETER VALUE = 1.000E+00

SOLUTION RESULTS

1 LIGHT INPUT EFFICIENCY	=	8.579E-01		
2 NET CELL EFFICIENCY	=	1.601E-01		
3 BASIC CONVERSION EFFY	=	1.360E-01		
4 BLANKET FACTORS	=	9.399E-01		
5 BUS I-SQ-R	=	9.767E-01		
6 NET ENERGY CONV EFFY	=	1.242E-01		
7 AREAWISE EFFICIENCY	=	9.359E-01		
8 ANTENNA POWER DISTR EFFY	=	9.912E-01		
9 NET DC-RF EFFICIENCY	=	8.299E-01		
10 IDEAL BEAM EFFICIENCY	=	9.650E-01		
11 NET BEAM EFFICIENCY	=	8.955E-01		
12 INTERCEPT EFFICIENCY	=	9.512E-01		
13 RECTENNA RF-DC EFFICIENC	=	8.867E-01		
14 NET RF LINK EFFY	=	8.348E-01		
15 DC-TO-DC EFFICIENCY	=	6.143E-01		
16 DC-TO-GRID EFFICIENCY	=	5.959E-01		
17 OVERALL PHYSICAL EFFY	=	7.436E-02		
18 AREA EFFECTIVE EFFY	=	6.961E-02		
19 BLANKET AREA	=	4.047E+07 M2	(1.000E+04 ACRES)	
20 ANTENNA DIA	=	1.000E+00 KM	(6.214E-01 MI)	
21 REQUIRED SIDELOBE SUPPR	=	1.955E+01 DB		
22 TAPER REQUIRED FOR SL SU	=	3.207E+00 DB		
23 TRANSMITTER POWER TAPER	=	1.000E+01 DB		
24 RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25 XMTR AVG/PEAK RATIO	=	5.909E-01		
26 BEAM SPREAD FACTOR	=	1.450E+00		
27 RADIATED RF POWER	=	2.876E+03 MEGAWATT		
28 BEAM DIAMETER	=	1.318E+01 KM	(8.189E+00 MI)	
29 BEAM AREA	=	1.364E+08 M2	(3.370E+04 ACRES)	
30 AVERAGE BEAM POWER DENS	=	1.662E+00 MW/CM2		
31 PEAK BEAM INTENSITY	=	9.024E+00 MW/CM2		
32 POWER IN MAIN BEAM	=	2.542E+03 MEGAWATT		
33 SATELLITE LENGTH	=	1.235E+01 BAYS		
34 NUMBER OF BAYS	=	9.861E+01 BAYS		
35 XMTR PWR DISTR LOSS	=	9.821E-03		
36 ADJ BAY USEFUL AREA	=	4.096E+05 M2	(1.012E+02 ACRES)	
37 BAY SIZE	=	6.600E+02 METERS		
38 SPS AREA	=	4.324E+01 KM2		
39 MEAN SOLAR INSOLATION	=	5.851E+01 GW		
40 SOLAR CELL OUTPUT	=	6.998E+00 GW		
41 ROTARY JOINT CURRENT "A"	=	5.431E+04 AMPS		
42 ROTARY JOINT CURRENT "B"	=	3.159E+04 AMPS		
43 TOTAL PROCESSED POWER	=	1.025E+03 MEGAWATT		
44 TOTAL KLYSTRON INPUT	=	6.775E+03 MEGAWATT		
45 TOTAL KLYSTRON OUTPUT	=	5.759E+03 MEGAWATT		
46 NUMBER OF KLYSTRONS	=	7.995E+04		
47 MAX KLYSTRON PACKING DEN	=	1.369E+01 PER SUB		
48 MAX RF POWER DENSITY	=	7.238E+00 KW/M2		
49 NUMBER OF SUBARRAYS	=	7.261E+02 PER ANT		
50 RECTENNA AREA	=	7.672E+07 M2	(1.896E+04 ACRES)	

Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.753E+00 KW/M2			
52	DC OUTPUT POWER	=	2.099E+00 GW/LINK			
53	GRID POWER	=	4.073E+00 GW TOTAL			
54	LAND AREA PER RECT	=	1.935E+08 M2	(	4.781E+04 ACRES	)
55	"Y" MOM OF INERTIA	=	4.620E+13 KG-M2			
56	THRUST PER CORNER	=	3.521E+01 NEWTONS	(	7.915E+00 LB	)
57	NUMBER OF THRUSTERS	=	3.521E+01 PER INST			
58	CONTROL POWER	=	4.419E+01 MEGAWATT			
59	ANNUAL PROPELLANT	=	1.443E+01 TONS	(	3.180E+04 LBM	)
60	STRUCTURE MASS	=	2.270E+03 TONS	(	5.005E+06 LBM	)
61	CONTROL SYS MASS	=	7.863E+01 TONS	(	1.734E+05 LBM	)
62	SOLAR BLANKET MASS	=	1.728E+04 TONS	(	3.810E+07 LBM	)
63	POWER DISTR MASS	=	3.908E+02 TONS	(	8.615E+05 LBM	)
64	MECH & ELEC R/J MASS	=	8.100E+01 TONS	(	1.786E+05 LBM	)
65	ANT STRUC MASS	=	5.000E+02 TONS	(	1.102E+06 LBM	)
66	ANT WAVEGUIDE MASS	=	4.314E+03 TONS	(	9.511E+06 LBM	)
67	ANT KLYSTRON MASS	=	5.559E+03 TONS	(	1.225E+07 LBM	)
68	ANT CONTROL CKTS MASS	=	4.319E+02 TONS	(	9.522E+05 LBM	)
69	ANT PWR DISTR MASS	=	4.646E+02 TONS	(	1.024E+06 LBM	)
70	ANT PWR PROC&TC MASS	=	2.015E+03 TONS	(	4.442E+06 LBM	)
71	ANT MASS	=	1.328E+04 TONS	(	2.929E+07 LBM	)
72	STRUCTURE COST	=	1.135E-01 BILLION			
73	CONTROL SYS COST	=	3.538E-02 BILLION			
74	SOLAR BLANKET COST	=	1.417E+00 BILLION			
75	POWER DISTR COST	=	1.016E-02 BILLION			
76	MECH&ELEC R/J COST	=	1.701E-02 BILLION			
77	ANT STRUC COST	=	3.485E-01 BILLION			
78	ANT WAVEGUIDE COST	=	2.588E-01 BILLION			
79	ANT KLYSTRON COST	=	2.529E-01 BILLION			
80	ANT CONTROL CKTS COST	=	9.534E-02 BILLION			
81	ANT PWR DISTR COST	=	5.018E-02 BILLION			
82	ANT PWR PROC&TC COST	=	1.390E-01 BILLION			
83	ANT COST	=	1.145E+00 BILLION			
84	NO OF FREIGHT FLIGHTS	=	1.472E+02			
85	CREW SERVICE NO OF FLTS	=	8.413E+00			
86	OTS COST	=	3.950E-01 BILLION			
87	TOTAL TRANSP COST	=	3.517E+00 BILLION			
88	RECTENNA COST	=	4.525E+00 BILLION			
89	CONSTRUCTION COST	=	5.048E-01 BILLION			
90	INTEREST DURING CONSTR	=	8.420E-01 BILLION			
91	LATITUDE AREA FACTOR	=	1.419E+00			
92	TOTAL MASS	=	4.207E+04 TONS	(	9.274E+07 LBM	)
93	TOTAL COST	=	1.348E+01 BILLION			
94	COST/KWE	=	3.309E+03 $			
95	COST/KWH	=	6.151E+01 MILLS			

Table A1-1 (Continued)

Rotary Joint Power = 3418 Megawatts

ANTENNA DIAMETER VALUE = 1.200E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01			
2	NET CELL EFFICIENCY	=	1.601E-01			
3	BASIC CONVERSION EFFY	=	1.360E-01			
4	BLANKET FACTORS	=	9.399E-01			
5	BUS I-SQ-R	=	9.767E-01			
6	NET ENERGY CONV EFFY	=	1.248E-01			
7	AREAWISE EFFICIENCY	=	9.357E-01			
8	ANTENNA POWER DISTR EFFY	=	9.911E-01			
9	NET DC-RF EFFICIENCY	=	8.298E-01			
10	IDEAL BEAM EFFICIENCY	=	9.650E-01			
11	NET BEAM EFFICIENCY	=	8.955E-01			
12	INTERCEPT EFFICIENCY	=	9.512E-01			
13	RECTENNA RF-DC EFFICIENC	=	8.904E-01			
14	NET RF LINK EFFY	=	8.348E-01			
15	DC-TO-DC EFFICIENCY	=	6.168E-01			
16	DC-TO-GRID EFFICIENCY	=	5.983E-01			
17	OVERALL PHYSICAL EFFY	=	7.468E-02			
18	AREA EFFECTIVE EFFY	=	6.989E-02			
19	BLANKET AREA	=	4.047E+07	M2	(	1.000E+04 ACRES)
20	ANTENNA DIA	=	1.200E+00	KM	(	7.457E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.114E+01	DB		
22	TAPER REQUIRED FOR SL SU	=	5.724E+00	DB		
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB		
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01			
25	XMTR AVG/PEAK RATIO	=	3.909E-01			
26	BEAM SPREAD FACTOR	=	1.450E+00			
27	RADIATED RF POWER	=	2.836E+03	MEGAWATT		
28	BEAM DIAMETER	=	1.098E+01	KM	(	6.824E+00 MI)
29	BEAM AREA	=	9.472E+07	M2	(	2.340E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	2.681E+00	MW/CM2		
31	PEAK BEAM INTENSITY	=	1.301E+01	MW/CM2		
32	POWER IN MAIN BEAM	=	2.540E+03	MEGAWATT		
33	SATELLITE LENGTH	=	1.235E+01	BAYS		
34	NUMBER OF BAYS	=	9.881E+01	BAYS		
35	XMTR PWR DISTR LOSS	=	8.950E-03			
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS		
38	SPS AREA	=	4.324E+01	KM2		
39	MEAN SOLAR INSOLATION	=	5.851E+01	GW		
40	SOLAR CELL OUTPUT	=	6.998E+00	GW		
41	ROTARY JOINT CURRENT "A"	=	5.431E+04	AMPS		
42	ROTARY JOINT CURRENT "B"	=	3.190E+04	AMPS		
43	TOTAL PROCESSED POWER	=	1.025E+03	MEGAWATT		
44	TOTAL KLYSTRON INPUT	=	6.774E+03	MEGAWATT		
45	TOTAL KLYSTRON OUTPUT	=	5.758E+03	MEGAWATT		
46	NUMBER OF KLYSTRONS	=	7.997E+04			
47	MAX KLYSTRON PACKING DEN	=	9.636E+00	PER SUB		
48	MAX RF POWER DENSITY	=	6.414E+00	KW/M2		
49	NUMBER OF SUBARRAYS	=	1.046E+04	PER ANT		
50	RECTENNA AREA	=	5.328E+07	M2	(	1.317E+04 ACRES)

ORIGINAL PAGE IS OF POOR QUALITY

Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.218E+00 KW/M2		
52	DC OUTPUT POWER	=	2.108E+00 GW/LINK		
53	GRID POWER	=	4.089E+00 GW TOTAL		
54	LAND AREA PER RECT	=	1.344E+08 M2	(	3.320E+04 ACRES)
55	"Y" MOM OF INERTIA	=	4.620E+13 KG-M2		
56	THRUST PER CORNER	=	3.521E+01 NEWTONS	(	7.915E+00 LB)
57	NUMBER OF THRUSTERS	=	3.521E+01 PER INST		
58	CONTROL POWER	=	4.419E+01 MEGAWATT		
59	ANNUAL PROPELLANT	=	1.443E+01 TONS	(	3.180E+04 LBM)
60	STRUCTURE MASS	=	2.270E+03 TONS	(	5.005E+06 LBM)
61	CONTROL SYS MASS	=	7.863E+01 TONS	(	1.734E+05 LBM)
62	SOLAR BLANKET MASS	=	1.728E+04 TONS	(	3.810E+07 LBM)
63	POWER DISTR MASS	=	3.908E+02 TONS	(	8.616E+05 LBM)
64	MECH & ELEC R/J MASS	=	9.440E+01 TONS	(	2.081E+05 LBM)
65	ANT STRUC MASS	=	7.200E+02 TONS	(	1.587E+06 LBM)
66	ANT WAVEGUIDE MASS	=	6.212E+03 TONS	(	1.370E+07 LBM)
67	ANT KLYSTRON MASS	=	5.558E+03 TONS	(	1.225E+07 LBM)
68	ANT CONTROL CKTS MASS	=	4.318E+02 TONS	(	9.520E+05 LBM)
69	ANT PWR DISTR MASS	=	5.729E+02 TONS	(	1.263E+06 LBM)
70	ANT PWR PROC&TC MASS	=	2.015E+03 TONS	(	4.442E+06 LBM)
71	ANT MASS	=	1.551E+04 TONS	(	3.419E+07 LBM)
72	STRUCTURE COST	=	1.135E-01 BILLION		
73	CONTROL SYS COST	=	3.518E-02 BILLION		
74	SOLAR BLANKET COST	=	1.417E+00 BILLION		
75	POWER DISTR COST	=	1.016E-02 BILLION		
76	MECH&ELEC R/J COST	=	1.982E-02 BILLION		
77	ANT STRUC COST	=	3.628E-01 BILLION		
78	ANT WAVEGUIDE COST	=	3.727E-01 BILLION		
79	ANT KLYSTRON COST	=	2.529E-01 BILLION		
80	ANT CONTROL CKTS COST	=	9.533E-02 BILLION		
81	ANT PWR DISTR COST	=	6.188E-02 BILLION		
82	ANT PWR PROC&TC COST	=	1.390E-01 BILLION		
83	ANT COST	=	1.285E+00 BILLION		
84	NO OF FREIGHT FLIGHTS	=	1.571E+02		
85	CREW SERVICE NO OF FLTS	=	8.978E+00		
86	OTS COST	=	4.215E-01 BILLION		
87	TOTAL TRANSP COST	=	3.698E+00 BILLION		
88	RECTENNA COST	=	3.234E+00 BILLION		
89	CONSTRUCTION COST	=	5.387E-01 BILLION		
90	INTEREST DURING CONSTR	=	7.845E-01 BILLION		
91	LATITUDE AREA FACTOR	=	1.419E+00		
92	TOTAL MASS	=	4.489E+04 TONS	(	9.896E+07 LBM)
93	TOTAL COST	=	1.256E+01 BILLION		
94	COST/KWE	=	3.071E+03 $		
95	COST/KWH	=	5.708E+01 MILLS		

Table A1-1 (Continued)
Rotary Joint Power = 3418 Megawatts

ANTENNA DIAMETER VALUE = 1.400E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01			
2	NET CELL EFFICIENCY	=	1.601E-01			
3	BASIC CONVERSION EFFY	=	1.360E-01			
4	BLANKET FACTORS	=	9.399E-01			
5	BUS I-SQ-R	=	9.767E-01			
6	NET ENERGY CONV EFFY	=	1.248E-01			
7	AREAWISE EFFICIENCY	=	9.359E-01			
8	ANTENNA POWER DISTR EFFY	=	9.929E-01			
9	NET DC-RF EFFICIENCY	=	8.313E-01			
10	IDEAL BEAM EFFICIENCY	=	9.650E-01			
11	NET BEAM EFFICIENCY	=	8.955E-01			
12	INTERCEPT EFFICIENCY	=	9.512E-01			
13	RECTENNA RF-DC EFFICIENC	=	8.920E-01			
14	NET RF LINK EFFY	=	8.348E-01			
15	DC-TO-DC EFFICIENCY	=	6.191E-01			
16	DC-TO-GRID EFFICIENCY	=	6.005E-01			
17	OVERALL PHYSICAL EFFY	=	7.496E-02			
18	AREA EFFECTIVE EFFY	=	7.015E-02			
19	BLANKET AREA	=	4.047E+07	M2	(	1.000E+04 ACRES)
20	ANTENNA DIA	=	1.400E+00	KM	(	8.700E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.249E+01	DB		
22	TAPER REQUIRED FOR SL SU	=	7.924E+00	DB		
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB		
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01			
25	XMTR AVG/PEAK RATIO	=	3.909E-01			
26	BEAM SPREAD FACTOR	=	1.450E+00			
27	RADIATED RF POWER	=	2.841E+03	MEGAWATT		
28	BEAM DIAMETER	=	9.413E+00	KM	(	5.849E+00 MI)
29	BEAM AREA	=	6.959E+07	M2	(	1.720E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	3.656E+00	MW/CM2		
31	PEAK BEAM INTENSITY	=	1.774E+01	MW/CM2		
32	POWER IN MAIN BEAM	=	2.544E+03	MEGAWATT		
33	SATELLITE LENGTH	=	1.235E+01	BAYS		
34	NUMBER OF BAYS	=	9.881E+01	BAYS		
35	XMTR PWR DISTR LOSS	=	7.086E-03			
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS		
38	SPS AREA	=	4.324E+01	KM2		
39	MEAN SOLAR INSOLATION	=	5.851E+01	GW		
40	SOLAR CELL OUTPUT	=	6.998E+00	GW		
41	ROTARY JOINT CURRENT "A"	=	5.421E+04	AMPS		
42	ROTARY JOINT CURRENT "B"	=	3.184E+04	AMPS		
43	TOTAL PROCESSED POWER	=	1.025E+03	MEGAWATT		
44	TOTAL KLYSTRON INPUT	=	6.787E+03	MEGAWATT		
45	TOTAL KLYSTRON OUTPUT	=	5.769E+03	MEGAWATT		
46	NUMBER OF KLYSTRONS	=	8.012E+04			
47	MAX KLYSTRON PACKING DEN	=	7.093E+00	PER SUB		
48	MAX RF POWER DENSITY	=	4.721E+00	KW/M2		
49	NUMBER OF SUBARRAYS	=	1.423E+04	PER ANT		
50	RECTENNA AREA	=	3.914E+07	M2	(	9.672E+03 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	8.861E-01 KW/M2	
52 DC OUTPUT POWER	=	2.116E+00 GW/LINK	
53 GRID POWER	=	4.105E+00 GW TOTAL	
54 LAND AREA PER RECT	=	9.872E+07 M2	(2.439E+04 ACRES)
55 "Y" MOM OF INERTIA	=	4.620E+13 KG-M2	
56 THRUST PER CORNER	=	3.521E+01 NEWTONS	(7.915E+00 LB)
57 NUMBER OF THRUSTERS	=	3.521E+01 PER INST	
58 CONTROL POWER	=	4.419E+01 MEGAWATT	
59 ANNUAL PROPELLANT	=	1.443E+01 TONS	(3.180E+04 LBM)
60 STRUCTURE MASS	=	2.270E+03 TONS	(5.005E+06 LBM)
61 CONTROL SYS MASS	=	7.863E+01 TONS	(1.734E+05 LBM)
62 SOLAR BLANKET MASS	=	1.728E+04 TONS	(3.810E+07 LBM)
63 POWER DISTR MASS	=	3.901E+02 TONS	(8.600E+05 LBM)
64 MECH & ELEC R/J MASS	=	1.078E+02 TONS	(2.376E+05 LBM)
65 ANT STRUC MASS	=	9.800E+02 TONS	(2.161E+06 LBM)
66 ANT WAVEGUIDE MASS	=	8.455E+03 TONS	(1.864E+07 LBM)
67 ANT KLYSTRON MASS	=	5.568E+03 TONS	(1.228E+07 LBM)
68 ANT CONTROL CKTS MASS	=	4.327E+02 TONS	(9.538E+05 LBM)
69 ANT PWR DISTR MASS	=	7.837E+02 TONS	(1.728E+06 LBM)
70 ANT PWR PROC&TC MASS	=	2.015E+03 TONS	(4.442E+06 LBM)
71 ANT MASS	=	1.823E+04 TONS	(4.020E+07 LBM)
72 STRUCTURE COST	=	1.135E-01 BILLION	
73 CONTROL SYS COST	=	3.538E-02 BILLION	
74 SOLAR BLANKET COST	=	1.417E+00 BILLION	
75 POWER DISTR COST	=	1.014E-02 BILLION	
76 MECH&ELEC R/J COST	=	2.264E-02 BILLION	
77 ANT STRUC COST	=	3.797E-01 BILLION	
78 ANT WAVEGUIDE COST	=	5.073E-01 BILLION	
79 ANT KLYSTRON COST	=	2.533E-01 BILLION	
80 ANT CONTROL CKTS COST	=	9.550E-02 BILLION	
81 ANT PWR DISTR COST	=	8.464E-02 BILLION	
82 ANT PWR PROC&TC COST	=	1.390E-01 BILLION	
83 ANT COST	=	1.460E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	1.692E+02	
85 CREW SERVICE NO OF FLTS	=	9.668E+00	
86 OTS COST	=	4.539E-01 BILLION	
87 TOTAL TRANSP COST	=	3.916E+00 BILLION	
88 RECTENNA COST	=	2.455E+00 BILLION	
89 CONSTRUCTION COST	=	5.801E-01 BILLION	
90 INTEREST DURING CONSTR	=	7.676E-01 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	4.834E+04 TONS	(1.066E+08 LBM)
93 TOTAL COST	=	1.229E+01 BILLION	
94 COST/KWE	=	2.993E+03 $	
95 COST/KWH	=	5.564E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 3418 Megawatts

ANTENNA DIAMETER VALUE = 1.600E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01	
2	NET CELL EFFICIENCY	=	1.601E-01	
3	BASIC CONVERSION EFFY	=	1.360E-01	
4	BLANKET FACTORS	=	9.399E-01	
5	BUS I-SQ-R	=	9.767E-01	
6	NET ENERGY CONV EFFY	=	1.248E-01	
7	AREAWISE EFFICIENCY	=	9.359E-01	
8	ANTENNA POWER DISTR EFFY	=	9.935E-01	
9	NET DC-RF EFFICIENCY	=	8.318E-01	
10	IDEAL BEAM EFFICIENCY	=	9.650E-01	
11	NET BEAM EFFICIENCY	=	8.955E-01	
12	INTERCEPT EFFICIENCY	=	9.512E-01	
13	RECTENNA RF-DC EFFICIENC	=	8.926E-01	
14	NET RF LINK EFFY	=	8.348E-01	
15	DC-TO-DC EFFICIENCY	=	6.199E-01	
16	DC-TO-GRID EFFICIENCY	=	6.013E-01	
17	OVERALL PHYSICAL EFFY	=	7.505E-02	
18	AREA EFFECTIVE EFFY	=	7.024E-02	
19	BLANKET AREA	=	4.047E+07 M2	(1.000E+04 ACRES)
20	ANTENNA DIA	=	1.600E+00 KM	(9.942E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.365E+01 DB	
22	TAPER REQUIRED FOR SL SU	=	9.584E+00 DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01 DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01	
25	XMTR AVG/PEAK RATIO	=	3.909E-01	
26	BEAM SPREAD FACTOR	=	1.450E+00	
27	RADIATED RF POWER	=	2.843E+03 MEGAWATT	
28	BEAM DIAMETER	=	8.236E+00 KM	(5.118E+00 MI)
29	BEAM AREA	=	5.328E+07 M2	(1.317E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	4.779E+00 MW/CM2	
31	PEAK BEAM INTENSITY	=	2.319E+01 MW/CM2	
32	POWER IN MAIN BEAM	=	2.546E+03 MEGAWATT	
33	SATELLITE LENGTH	=	1.235E+01 BAYS	
34	NUMBER OF BAYS	=	9.881E+01 BAYS	
35	XMTR PWR DISTR LOSS	=	6.464E-03	
36	ADJ BAY USEFUL AREA	=	4.096E+05 M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02 METERS	
38	SPS AREA	=	4.324E+01 KM2	
39	MEAN SOLAR INSOLATION	=	5.851E+01 GW	
40	SOLAR CELL OUTPUT	=	6.998E+00 GW	
41	ROTARY JOINT CURRENT "A"	=	5.418E+04 AMPS	
42	ROTARY JOINT CURRENT "B"	=	3.182E+04 AMPS	
43	TOTAL PROCESSED POWER	=	1.025E+03 MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	6.791E+03 MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	5.772E+03 MEGAWATT	
46	NUMBER OF KLYSTRONS	=	8.017E+04	
47	MAX KLYSTRON PACKING DEN	=	5.434E+00 PER SUB	
48	MAX RF POWER DENSITY	=	3.617E+00 KW/M2	
49	NUMBER OF SUBARRAYS	=	1.859E+04 PER ANT	
50	RECTENNA AREA	=	2.997E+07 M2	(7.405E+03 ACRES)

Table A1-1 (Continued)

ORIGINAL PAGE IS OF POOR QUALITY

51 PEAK ANT THERMAL PWR	=	6.762E-01 KW/M2			
52 DC OUTPUT POWER	=	2.110E+00 GW/LINK			
53 GRID POWER	=	4.110E+00 GW TOTAL			
54 LAND AREA PER RECT	=	7.550E+07 M2	(	1.860E+04 ACRES	)
55 "Y" MOM OF INERTIA	=	4.620E+13 KG-M2			
56 THRUST PER CORNER	=	3.521E+01 NEWTONS	(	7.915E+00 LB	)
57 NUMBER OF THRUSTERS	=	3.521E+01 PER INST			
58 CONTROL POWER	=	4.419E+01 MEGAWATT			
59 ANNUAL PROPELLANT	=	1.443E+01 TONS	(	3.180E+04 LBM	)
60 STRUCTURE MASS	=	2.270E+03 TONS	(	5.005E+06 LBM	)
61 CONTROL SYS MASS	=	7.863E+01 TONS	(	1.734E+05 LBM	)
62 SOLAR BLANKET MASS	=	1.728E+04 TONS	(	3.810E+07 LBM	)
63 POWER DISTR MASS	=	3.898E+02 TONS	(	8.594E+05 LBM	)
64 MECH & ELEC R/J MASS	=	1.212E+02 TONS	(	2.672E+05 LBM	)
65 ANT STRUC MASS	=	1.280E+03 TONS	(	2.822E+06 LBM	)
66 ANT WAVEGUIDE MASS	=	1.104E+04 TONS	(	2.435E+07 LBM	)
67 ANT KLYSTRON MASS	=	5.572E+03 TONS	(	1.228E+07 LBM	)
68 ANT CONTROL CKTS MASS	=	4.329E+02 TONS	(	9.544E+05 LBM	)
69 ANT PWR DISTR MASS	=	1.022E+03 TONS	(	2.253E+06 LBM	)
70 ANT PWR PROC&TC MASS	=	2.015E+03 TONS	(	4.442E+06 LBM	)
71 ANT MASS	=	2.137E+04 TONS	(	4.710E+07 LBM	)
72 STRUCTURE COST	=	1.135E-01 BILLION			
73 CONTROL SYS COST	=	3.538E-02 BILLION			
74 SOLAR BLANKET COST	=	1.417E+00 BILLION			
75 POWER DISTR COST	=	1.014E-02 BILLION			
76 MECH&ELEC R/J COST	=	2.545E-02 BILLION			
77 ANT STRUC COST	=	3.992E-01 BILLION			
78 ANT WAVEGUIDE COST	=	6.626E-01 BILLION			
79 ANT KLYSTRON COST	=	2.535E-01 BILLION			
80 ANT CONTROL CKTS COST	=	9.556E-02 BILLION			
81 ANT PWR DISTR COST	=	1.103E-01 BILLION			
82 ANT PWR PROC&TC COST	=	1.390E-01 BILLION			
83 ANT COST	=	1.660E+00 BILLION			
84 NO OF FREIGHT FLIGHTS	=	1.830E+02			
85 CREW SERVICE NO OF FLTS	=	1.046E+01			
86 OTS COST	=	4.911E-01 BILLION			
87 TOTAL TRANSP COST	=	4.162E+00 BILLION			
88 RECTENNA COST	=	1.950E+00 BILLION			
89 CONSTRUCTION COST	=	6.276E-01 BILLION			
90 INTEREST DURING CONSTR	=	7.736E-01 BILLION			
91 LATITUDE AREA FACTOR	=	1.419E+00			
92 TOTAL MASS	=	5.230E+04 TONS	(	1.153E+08 LBM	)
93 TOTAL COST	=	1.238E+01 BILLION			
94 COST/KWE	=	3.013E+03 $			
95 COST/KWH	=	5.601E+01 MILLS			

Table A1-1 (Continued)
Rotary Joint Power = 3418 Megawatts

ANTENNA DIAMETER VALUE = 1.800E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.767E-01		
6	NET ENERGY CONV EFFY	=	1.248E-01		
7	AREAWISE EFFICIENCY	=	9.359E-01		
8	ANTENNA POWER DISTR EFFY	=	9.929E-01		
9	NET DC-RF EFFICIENCY	=	8.313E-01		
10	IDEAL BEAM EFFICIENCY	=	9.689E-01		
11	NET BEAM EFFICIENCY	=	8.991E-01		
12	INTERCEPT EFFICIENCY	=	9.541E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.917E-01		
14	NET RF LINK EFFY	=	8.407E-01		
15	DC-TO-DC EFFICIENCY	=	6.232E-01		
16	DC-TO-GRID EFFICIENCY	=	6.045E-01		
17	OVERALL PHYSICAL EFFY	=	7.546E-02		
18	AREA EFFECTIVE EFFY	=	7.063E-02		
19	BLANKET AREA	=	4.047E+07	M2	(1.000E+04 ACRES)
20	ANTENNA DIA	=	1.800E+00	KM	(1.119E+00 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.461E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	1.068E+01	DB	
23	TRANSMITTER POWER TAPER	=	1.069E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.023E-01		
25	XMTR AVG/PEAK RATIO	=	3.703E-01		
26	BEAM SPREAD FACTOR	=	1.474E+00		
27	RADIATED RF POWER	=	2.841E+03	MEGAWATT	
28	BEAM DIAMETER	=	7.445E+00	KM	(4.626E+00 MI)
29	BEAM AREA	=	4.353E+07	M2	(1.076E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	5.858E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	2.888E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	2.555E+03	MEGAWATT	
33	SATELLITE LENGTH	=	1.235E+01	BAYS	
34	NUMBER OF BAYS	=	9.881E+01	BAYS	
35	XMTR PWR DISTR LOSS	=	7.058E-03		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	4.324E+01	KM2	
39	MEAN SOLAR INSOLATION	=	5.851E+01	GW	
40	SOLAR CELL OUTPUT	=	6.998E+00	GW	
41	ROTARY JOINT CURRENT "A"	=	5.421E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	3.184E+04	AMPS	
43	TOTAL PROCESSED POWER	=	1.025E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	6.787E+03	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	5.769E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	8.012E+04		
47	MAX KLYSTRON PACKING DEN	=	4.529E+00	PER SUB	
48	MAX RF POWER DENSITY	=	3.015E+00	KW/M2	
49	NUMBER OF SUBARRAYS	=	2.353E+04	PER ANT	
50	RECTENNA AREA	=	2.449E+07	M2	(6.050E+03 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	5.657E-01 KW/M2				
52 DC OUTPUT POWER	=	2.130E+00 GW/LINK				
53 GRID POWER	=	4.132E+00 GW TOTAL				
54 LAND AREA PER RECT	=	6.175E+07 M2	(	1.526E+04	ACRES	)
55 "Y" MOM OF INERTIA	=	4.620E+13 KG-M2				
56 THRUST PER CORNER	=	3.521E+01 NEWTONS	(	7.915E+00	LB	)
57 NUMBER OF THRUSTERS	=	3.521E+01 PER INST				
58 CONTROL POWER	=	4.419E+01 MEGAWATT				
59 ANNUAL PROPELLANT	=	1.443E+01 TONS	(	3.180E+04	LBM	)
60 STRUCTURE MASS	=	2.270E+03 TONS	(	5.005E+06	LBM	)
61 CONTROL SYS MASS	=	7.863E+01 TONS	(	1.734E+05	LBM	)
62 SOLAR BLANKET MASS	=	1.728E+04 TONS	(	3.810E+07	LBM	)
63 POWER DISTR MASS	=	3.901E+02 TONS	(	8.600E+05	LBM	)
64 MECH & ELEC R/J MASS	=	1.346E+02 TONS	(	2.967E+05	LBM	)
65 ANT STRUC MASS	=	1.620E+03 TONS	(	3.571E+06	LBM	)
66 ANT WAVEGUIDE MASS	=	1.398E+04 TONS	(	3.081E+07	LBM	)
67 ANT KLYSTRON MASS	=	5.569E+03 TONS	(	1.228E+07	LBM	
68 ANT CONTROL CKTS MASS	=	4.327E+02 TONS	(	9.539E+05	LBM	)
69 ANT PWR DISTR MASS	=	1.159E+03 TONS	(	2.555E+06	LBM	)
70 ANT PWR PROC&TC MASS	=	2.015E+03 TONS	(	4.442E+06	LBM	)
71 ANT MASS	=	2.477E+04 TONS	(	5.461E+07	LBM	)
72 STRUCTURE COST	=	1.135E-01 BILLION				
73 CONTROL SYS COST	=	3.538E-02 BILLION				
74 SOLAR BLANKET COST	=	1.417E+00 BILLION				
75 POWER DISTR COST	=	1.014E-02 BILLION				
76 MECH&ELEC R/J COST	=	2.627E-02 BILLION				
77 ANT STRUC COST	=	4.213E-01 BILLION				
78 ANT WAVEGUIDE COST	=	8.336E-01 BILLION				
79 ANT KLYSTRON COST	=	2.534E-01 BILLION				
80 ANT CONTROL CKTS COST	=	9.551E-02 BILLION				
81 ANT PWR DISTR COST	=	1.252E-01 BILLION				
82 ANT PWR PROC&TC COST	=	1.390E-01 BILLION				
83 ANT COST	=	1.873E+00 BILLION				
84 NO OF FREIGHT FLIGHTS	=	1.981E+02				
85 CREW SERVICE NO OF FLTS	=	1.132E+01				
86 OTS COST	=	5.316E-01 BILLION				
87 TOTAL TRANSP COST	=	4.425E+00 BILLION				
88 RECTENNA COST	=	1.649E+00 BILLION				
89 CONSTRUCTION COST	=	6.793E-01 BILLION				
90 INTEREST DURING CONSTR	=	7.960E-01 BILLION				
91 LATITUDE AREA FACTOR	=	1.419E+00				
92 TOTAL MASS	=	5.661E+04 TONS	(	1.248E+08	LBM	)
93 TOTAL COST	=	1.274E+01 BILLION				
94 COST/KWE	=	3.084E+03 $				
95 COST/KWH	=	5.731E+01 MILLS				

ORIGINAL PAGE IS
OF POOR QUALITY

Table A1-1 (Continued)
Rotary Joint Power = 3418 Megawatts

ANTENNA DIAMETER VALUE = 2.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01				
2	NET CELL EFFICIENCY	=	1.601E-01				
3	BASIC CONVERSION EFFY	=	1.360E-01				
4	BLANKET FACTORS	=	9.399E-01				
5	BUS 1-SQ-R	=	9.767E-01				
6	NET ENERGY CONV EFFY	=	1.248E-01				
7	AREAWISE EFFICIENCY	=	9.359E-01				
8	ANTENNA POWER DISTR EFFY	=	9.924E-01				
9	NET DC-RF EFFICIENCY	=	8.309E-01				
10	IDEAL BEAM EFFICIENCY	=	9.736E-01				
11	NET BEAM EFFICIENCY	=	9.035E-01				
12	INTERCEPT EFFICIENCY	=	9.590E-01				
13	RECTENNA RF-DC EFFICIENC	=	8.959E-01				
14	NET RF LINK EFFY	=	8.492E-01				
15	DC-TO-DC EFFICIENCY	=	6.321E-01				
16	DC-TO-GRID EFFICIENCY	=	6.132E-01				
17	OVERALL PHYSICAL EFFY	=	7.654E-02				
18	AREA EFFECTIVE EFFY	=	7.163E-02				
19	BLANKET AREA	=	4.047E+07	M2	(	1.000E+04 ACRES	)
20	ANTENNA DIA	=	2.000E+00	KM	(	1.243E+00 MI	)
21	REQUIRED SIDELOBE SUPPR	=	2.544E+01	DB			
22	TAPER REQUIRED FOR SL SU	=	1.158E+01	DB			
23	TRANSMITTER POWER TAPER	=	1.158E+01	DB			
24	RECEIVER AVG/PEAK RATIO	=	1.988E-01				
25	XMTR AVG/PEAK RATIO	=	3.469E-01				
26	BEAM SPREAD FACTOR	=	1.508E+00				
27	RADIATED RF POWER	=	2.840E+03	MEGAWATT			
28	BEAM DIAMETER	=	6.851E+00	KM	(	4.257E+00 MI	)
29	BEAM AREA	=	3.687E+07	M2	(	9.109E+03 ACRES	)
30	AVERAGE BEAM POWER DENS	=	6.955E+00	MW/CM2			
31	PEAK BEAM INTENSITY	=	3.498E+01	MW/CM2			
32	POWER IN MAIN BEAM	=	2.566E+03	MEGAWATT			
33	SATELLITE LENGTH	=	1.235E+01	BAYS			
34	NUMBER OF BAYS	=	9.881E+01	BAYS			
35	XMTR PWR DISTR LOSS	=	7.589E-03				
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES	)
37	BAY SIZE	=	6.600E+02	METERS			
38	SPS AREA	=	4.324E+01	KM2			
39	MEAN SOLAR INSOLATION	=	5.851E+01	GW			
40	SOLAR CELL OUTPUT	=	6.998E+00	GW			
41	ROTARY JOINT CURRENT "A"	=	5.424E+04	AMPS			
42	ROTARY JOINT CURRENT "B"	=	3.185E+04	AMPS			
43	TOTAL PROCESSED POWER	=	1.025E+03	MEGAWATT			
44	TOTAL KLYSTRON INPUT	=	6.783E+03	MEGAWATT			
45	TOTAL KLYSTRON OUTPUT	=	5.766E+03	MEGAWATT			
46	NUMBER OF KLYSTRONS	=	8.003E+04				
47	MAX KLYSTRON PACKING DEN	=	3.914E+00	PER SUB			
48	MAX RF POWER DENSITY	=	2.605E+00	KW/M2			
49	NUMBER OF SUBARRAYS	=	2.905E+04	PER ANT			
50	RECTENNA AREA	=	2.074E+07	M2	(	5.124E+03 ACRES	)

ORIGINAL PAGE IS
OF POOR QUALITY

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	4.905E-01 KW/M2		
52 DC OUTPUT POWER	=	2.160E+00 GW/LINK		
53 GRID POWER	=	4.191E+00 GW TOTAL		
54 LAND AREA PER RECT	=	5.230E+07 M2	(1.292E+04 ACRES	)
55 "Y" MOM OF INERTIA	=	4.620E+13 KG-M2		
56 THRUST PER CORNER	=	3.521E+01 NEWTONS	(7.915E+00 LB	)
57 NUMBER OF THRUSTERS	=	3.521E+01 PER INST		
58 CONTROL POWER	=	4.419E+01 MEGAWATT		
59 ANNUAL PROPELLANT	=	1.443E+01 TONS	(3.180E+04 LBM	)
60 STRUCTURE MASS	=	2.270E+03 TONS	(5.005E+06 LBM	)
61 CONTROL SYS MASS	=	7.863E+01 TONS	(1.734E+05 LBM	)
62 SOLAR BLANKET MASS	=	1.728E+04 TONS	(3.810E+07 LBM	)
63 POWER DISTR MASS	=	3.903E+02 TONS	(8.604E+05 LBM	)
64 MECH & ELEC R/J MASS	=	1.480E+02 TONS	(3.263E+05 LBM	)
65 ANT STRUC MASS	=	2.000E+03 TONS	(4.409E+06 LBM	)
66 ANT WAVEGUIDE MASS	=	1.726E+04 TONS	(3.804E+07 LBM	)
67 ANT KLYSTRON MASS	=	5.566E+03 TONS	(1.227E+07 LBM	)
68 ANT CONTROL CKTS MASS	=	4.324E+02 TONS	(9.533E+05 LBM	)
69 ANT PWR DISTR MASS	=	1.365E+03 TONS	(3.009E+06 LBM	)
70 ANT PWR PROC&TC MASS	=	2.015E+03 TONS	(4.442E+06 LBM	)
71 ANT MASS	=	2.863E+04 TONS	(6.313E+07 LBM	)
72 STRUCTURE COST	=	1.135E-01 BILLION		
73 CONTROL SYS COST	=	3.538E-02 BILLION		
74 SOLAR BLANKET COST	=	1.417E+00 BILLION		
75 POWER DISTR COST	=	1.015E-02 BILLION		
76 MECH&ELEC R/J COST	=	3.108E-02 BILLION		
77 ANT STRUC COST	=	4.460E-01 BILLION		
78 ANT WAVEGUIDE COST	=	1.035E+00 BILLION		
79 ANT KLYSTRON COST	=	2.532E-01 BILLION		
80 ANT CONTROL CKTS COST	=	9.546E-02 BILLION		
81 ANT PWR DISTR COST	=	1.474E-01 BILLION		
82 ANT PWR PROC&TC COST	=	1.390E-01 BILLION		
83 ANT COST	=	2.116E+00 BILLION		
84 NO OF FREIGHT FLIGHTS	=	2.152E+02		
85 CREW SERVICE NO OF FLTS	=	1.230E+01		
86 OTS COST	=	5.774E-01 BILLION		
87 TOTAL TRANSP COST	=	4.718E+00 BILLION		
88 RECTENNA COST	=	1.445E+00 BILLION		
89 CONSTRUCTION COST	=	7.37?E-01 BILLION		
90 INTEREST DURING CONSTR	=	8.302E-01 BILLION		
91 LATITUDE AREA FACTOR	=	1.419E+00		
92 TOTAL MASS	=	6.149E+04 TONS	(1.356E+08 LBM	)
93 TOTAL COST	=	1.329E+01 BILLION		
94 COST/KWE	=	3.171E+03 $		
95 COST/KWH	=	5.894E+01 MILLS		

Table A1 1 (Continued)

Rotary Joint Power = 4700 Megawatts

ANTENNA DIAMETER VALUE = 1.000E+00

SOLUTION RESULTS

1 LIGHT INPUT EFFICIENCY	=	8.579E-01		
2 NET CELL EFFICIENCY	=	1.601E-01		
3 BASIC CONVERSION EFFY	=	1.360E-01		
4 BLANKET FACTORS	=	9.399E-01		
5 BUS I-SQ-R	=	9.677E-01		
6 NET ENERGY CONV EFFY	=	1.237E-01		
7 AREAWISE EFFICIENCY	=	9.364E-01		
8 ANTENNA POWER DISTR EFFY	=	9.857E-01		
9 NET DC-RF EFFICIENCY	=	8.253E-01		
10 IDEAL BEAM EFFICIENCY	=	9.650E-01		
11 NET BEAM EFFICIENCY	=	8.955E-01		
12 INTERCEPT EFFICIENCY	=	9.512E-01		
13 RECTENNA RF-DC EFFICIENC	=	8.866E-01		
14 NET RF LINK EFFY	=	8.348E-01		
15 DC-TO-DC EFFICIENCY	=	6.108E-01		
16 DC-TO-GRID EFFICIENCY	=	5.925E-01		
17 OVERALL PHYSICAL EFFY	=	7.327E-02		
18 AREA EFFECTIVE EFFY	=	6.861E-02		
19 BLANKET AREA	=	5.617E+07 M2	(	1.388E+04 ACRES)
20 ANTENNA DIA	=	1.000E+00 KM	(	6.214E-01 MI)
21 REQUIRED SIDELOBE SUPPR	=	2.092E+01 DB		
22 TAPER REQUIRED FOR SL SU	=	5.371E+00 DB		
23 TRANSMITTER POWER TAPER	=	1.000E+01 DB		
24 RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25 XMTR AVG/PEAK RATIO	=	3.909E-01		
26 BEAM SPREAD FACTOR	=	1.450E+00		
27 RADIATED RF POWER	=	3.878E+03 MEGAWATT		
28 BEAM DIAMETER	=	1.318E+01 KM	(	8.189E+00 MI)
29 BEAM AREA	=	1.364E+08 M2	(	3.370E+04 ACRES)
30 AVERAGE BEAM POWER DENS	=	2.546E+00 MW/CM2		
31 PEAK BEAM INTENSITY	=	1.235E+01 MW/CM2		
32 POWER IN MAIN BEAM	=	3.473E+03 MEGAWATT		
33 SATELLITE LENGTH	=	1.714E+01 BAYS		
34 NUMBER OF BAYS	=	1.371E+02 BAYS		
35 XMTR PWR DISTR LOSS	=	1.426E-02		
36 ADJ BAY USEFUL AREA	=	4.096E+05 M2	(	1.012E+02 ACRES)
37 BAY SIZE	=	6.600E+02 METERS		
38 SPS AREA	=	5.998E+01 KM2		
39 MEAN SOLAR INSOLATION	=	8.116E+01 GW		
40 SOLAR CELL OUTPUT	=	9.712E+00 GW		
41 ROTARY JOINT CURRENT "A"	=	7.508E+04 AMPS		
42 ROTARY JOINT CURRENT "B"	=	4.410E+04 AMPS		
43 TOTAL PROCESSED POWER	=	1.410E+03 MEGAWATT		
44 TOTAL KLYSTRON INPUT	=	9.264E+03 MEGAWATT		
45 TOTAL KLYSTRON OUTPUT	=	7.875E+03 MEGAWATT		
46 NUMBER OF KLYSTRONS	=	1.094E+05		
47 MAX KLYSTRON PACKING DEN	=	1.898E+01 PER SUB		
48 MAX RF POWER DENSITY	=	1.263E+01 KW/M2		
49 NUMBER OF SUBARRAYS	=	7.261E+03 PER ANT		
50 RECTENNA AREA	=	7.672E+07 M2	(	1.896E+04 ACRES)

ORIGINAL PAGE IS
OF POOR QUALITY

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	2.402E+00 KW/M2	
52 DC OUTPUT POWER	=	2.870E+00 GW/LINK	
53 GRID POWER	=	5.569E+00 GW TOTAL	
54 LAND AREA PER RECT	=	1.935E+08 M2	(4.781E+04 ACRES)
55 "Y" MOM OF INERTIA	=	6.411E+13 KG-M2	
56 THRUST PER CORNER	=	4.886E+01 NEWTONS	(1.098E+01 LB)
57 NUMBER OF THRUSTERS	=	4.886E+01 PER INST	
58 CONTROL POWER	=	6.133E+01 MEGAWATT	
59 ANNUAL PROPELLANT	=	2.002E+01 TONS	(4.413E+04 LBM)
60 STRUCTURE MASS	=	3.149E+03 TONS	(6.943E+06 LBM)
61 CONTROL SYS MASS	=	1.091E+02 TONS	(2.406E+05 LBM)
62 SOLAR BLANKET MASS	=	2.398E+04 TONS	(5.288E+07 LBM)
63 POWER DISTR MASS	=	7.498E+02 TONS	(1.653E+06 LBM)
64 MECH & ELEC R/J MASS	=	8.642E+01 TONS	(1.905E+05 LBM)
65 ANT STRUC MASS	=	5.000E+02 TONS	(1.102E+06 LBM)
66 ANT WAVEGUIDE MASS	=	4.314E+03 TONS	(9.511E+06 LBM)
67 ANT KLYSTRON MASS	=	7.601E+03 TONS	(1.676E+07 LBM)
68 ANT CONTROL CKTS MASS	=	5.906E+02 TONS	(1.302E+06 LBM)
69 ANT PWR DISTR MASS	=	5.256E+02 TONS	(1.159E+06 LBM)
70 ANT PWR PROC&TC MASS	=	2.770E+03 TONS	(6.107E+06 LBM)
71 ANT MASS	=	1.630E+04 TONS	(3.594E+07 LBM)
72 STRUCTURE COST	=	1.575E-01 BILLION	
73 CONTROL SYS COST	=	4.911E-02 BILLION	
74 SOLAR BLANKET COST	=	1.966E+00 BILLION	
75 POWER DISTR COST	=	1.950E-02 BILLION	
76 MECH&ELEC R/J COST	=	1.815E-02 BILLION	
77 ANT STRUC COST	=	3.435E-01 BILLION	
78 ANT WAVEGUIDE COST	=	2.588E-01 BILLION	
79 ANT KLYSTRON COST	=	3.458E-01 BILLION	
80 ANT CONTROL CKTS COST	=	1.304E-01 BILLION	
81 ANT PWR DISTR COST	=	5.677E-02 BILLION	
82 ANT PWR PROC&TC COST	=	1.911E-01 BILLION	
83 ANT COST	=	1.331E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	1.957E+02	
85 CREW SERVICE NO OF FLTS	=	1.118E+01	
86 OTS COST	=	5.251E-01 BILLION	
87 TOTAL TRANSP COST	=	4.333E+00 BILLION	
88 RECTENNA COST	=	4.597E+00 BILLION	
89 CONSTRUCTION COST	=	6.710E-01 BILLION	
90 INTEREST DURING CONSTR	=	9.937E-01 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	5.592E+04 TONS	(1.233E+08 LBM)
93 TOTAL COST	=	1.591E+01 BILLION	
94 COST/KWE	=	2.856E+03 $	
95 COST/KWH	=	5.309E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 4700 Megawatts

ANTENNA DIAMETER VALUE = 1.200E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.677E-01		
6	NET ENERGY CONV EFFY	=	1.237E-01		
7	AREAWISE EFFICIENCY	=	9.364E-01		
8	ANTENNA POWER DISTR EFFY	=	9.858E-01		
9	NET DC-RF EFFICIENCY	=	8.254E-01		
10	IDEAL BEAM EFFICIENCY	=	9.650E-01		
11	NET BEAM EFFICIENCY	=	8.955E-01		
12	INTERCEPT EFFICIENCY	=	9.512E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.920E-01		
14	NET RF LINK EFFY	=	8.348E-01		
15	DC-TO-DC EFFICIENCY	=	6.147E-01		
16	DC-TO-GRID EFFICIENCY	=	5.962E-01		
17	OVERALL PHYSICAL EFFY	=	7.373E-02		
18	AREA EFFECTIVE EFFY	=	6.904E-02		
19	BLANKET AREA	=	5.617E+07	M2	(1.388E+04 ACRES)
20	ANTENNA DIA	=	1.200E+00	KM	(7.457E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.250E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	7.946E+00	DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25	XMTR AVG/PEAK RATIO	=	3.909E-01		
26	BEAM SPREAD FACTOR	=	1.450E+00		
27	RADIATED RF POWER	=	3.879E+03	MEGAWATT	
28	BEAM DIAMETER	=	1.098E+01	KM	(6.824E+00 MI)
29	BEAM AREA	=	9.472E+07	M2	(2.340E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	3.667E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	1.779E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	3.473E+03	MEGAWATT	
33	SATELLITE LENGTH	=	1.714E+01	BAYS	
34	NUMBER OF BAYS	=	1.371E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	1.417E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	5.998E+01	KM2	
39	MEAN SOLAR INSOLATION	=	8.116E+01	GW	
40	SOLAR CELL OUTPUT	=	9.712E+00	GW	
41	ROTARY JOINT CURRENT "A"	=	7.508E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	4.409E+04	AMPS	
43	TOTAL PROCESSED POWER	=	1.410E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	9.265E+03	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	7.875E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.094E+05		
47	MAX KLYSTRON PACKING DEN	=	1.318E+01	PER SUB	
48	MAX RF POWER DENSITY	=	8.773E+00	KW/M2	
49	NUMBER OF SUBARRAYS	=	1.046E+04	PER ANT	
50	RECTENNA AREA	=	5.328E+07	M2	(1.317E+04 ACRES)

Table A1-1 (Continued)

ORIGINAL PAGE IS OF POOR QUALITY

51	PEAK ANT THERMAL PWR	=	1.722E+00	KW/M2		
52	DC OUTPUT POWER	=	2.888E+00	GW/LINK		
53	GRID POWER	=	5.603E+00	GW TOTAL		
54	LAND AREA PER RECT	=	1.344E+08	M2	(3.320E+04	ACRES)
55	"Y" MOM OF INERTIA	=	6.411E+13	KG-M2		
56	THRUST PER CORNER	=	4.886E+01	NEWTONS	(1.098E+01	LB)
57	NUMBER OF THRUSTERS	=	4.886E+01	PER INST		
58	CONTROL POWER	=	6.133E+01	MEGAWATT		
59	ANNUAL PROPELLANT	=	2.002E+01	TONS	(4.413E+04	LBM)
60	STRUCTURE MASS	=	3.149E+03	TONS	(6.943E+06	LBM)
61	CONTROL SYS MASS	=	1.091E+02	TONS	(2.406E+05	LBM)
62	SOLAR BLANKET MASS	=	2.398E+04	TONS	(5.288E+07	LBM)
63	POWER DISTR MASS	=	7.497E+02	TONS	(1.653E+06	LBM)
64	MECH & ELEC R/J MASS	=	9.982E+01	TONS	(2.201E+05	LBM)
65	ANT STRUC MASS	=	7.200E+02	TONS	(1.587E+06	LBM)
66	ANT WAVEGUIDE MASS	=	6.212E+03	TONS	(1.370E+07	LBM)
67	ANT KLYSTRON MASS	=	7.602E+03	TONS	(1.676E+07	LBM)
68	ANT CONTROL CKTS MASS	=	5.907E+02	TONS	(1.302E+06	LBM)
69	ANT PWR DISTR MASS	=	6.395E+02	TONS	(1.410E+06	LBM)
70	ANT PWR PROC&TC MASS	=	2.770E+03	TONS	(6.107E+06	LBM)
71	ANT MASS	=	1.853E+04	TONS	(4.086E+07	LBM)
72	STRUCTURE COST	=	1.575E-01	BILLION		
73	CONTROL SYS COST	=	4.911E-02	BILLION		
74	SOLAR BLANKET COST	=	1.966E+00	BILLION		
75	POWER DISTR COST	=	1.949E-02	BILLION		
76	MECH&ELEC R/J COST	=	2.096E-02	BILLION		
77	ANT STRUC COST	=	3.628E-01	BILLION		
78	ANT WAVEGUIDE COST	=	3.727E-01	BILLION		
79	ANT KLYSTRON COST	=	3.459E-01	BILLION		
80	ANT CONTROL CKTS COST	=	1.304E-01	BILLION		
81	ANT PWR DISTR COST	=	6.906E-02	BILLION		
82	ANT PWR PROC&TC COST	=	1.911E-01	BILLION		
83	ANT COST	=	1.472E+00	BILLION		
84	NO OF FREIGHT FLIGHTS	=	2.056E+02			
85	CREW SERVICE NO OF FLTS	=	1.175E+01			
86	OTS COST	=	5.517E-01	BILLION		
87	TOTAL TRANSP COST	=	4.554E+00	BILLION		
88	RECTENNA COST	=	3.306E+00	BILLION		
89	CONSTRUCTION COST	=	7.050E-01	BILLION		
90	INTEREST DURING CONSTR	=	9.355E-01	BILLION		
91	LATITUDE AREA FACTOR	=	1.419E+00			
92	TOTAL MASS	=	5.875E+04	TONS	(1.295E+08	LBM)
93	TOTAL COST	=	1.497E+01	BILLION		
94	COST/KWE	=	2.672E+03	$		
95	COST/KWH	=	4.967E+01	MILLS		

Table A1-1 (Continued)
Rotary Joint Power = 4700 Megawatts

ANTENNA DIAMETER VALUE = 1.400E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01	
2	NET CELL EFFICIENCY	=	1.601E-01	
3	BASIC CONVERSION EFFY	=	1.360E-01	
4	BLANKET FACTORS	=	9.399E-01	
5	BUS I-SQ-R	=	9.677E-01	
6	NET ENERGY CONV EFFY	=	1.237E-01	
7	AREAWISE EFFICIENCY	=	9.364E-01	
8	ANTENNA POWER DISTR EFFY	=	9.875E-01	
9	NET DC-RF EFFICIENCY	=	8.268E-01	
10	IDEAL BEAM EFFICIENCY	=	9.650E-01	
11	NET BEAM EFFICIENCY	=	8.955E-01	
12	INTERCEPT EFFICIENCY	=	9.512E-01	
13	RECTENNA RF-DC EFFICIENC	=	8.926E-01	
14	NET RF LINK EFFY	=	8.348E-01	
15	DC-TO-DC EFFICIENCY	=	6.161E-01	
16	DC-TO-GRID EFFICIENCY	=	5.976E-01	
17	OVERALL PHYSICAL EFFY	=	7.390E-02	
18	AREA EFFECTIVE EFFY	=	6.920E-02	
19	BLANKET AREA	=	5.617E+07 M2	(1.388E+04 ACRES)
20	ANTENNA DIA	=	1.400E+00 KM	(8.700E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.385E+01 DB	
22	TAPER REQUIRED FOR SL SU	=	9.822E+00 DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01 DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01	
25	XMTR AVG/PEAK RATIO	=	3.909E-01	
26	BEAM SPREAD FACTOR	=	1.450E+00	
27	RADIATED RF POWER	=	3.885E+03 MEGAWATT	
28	BEAM DIAMETER	=	9.413E+00 KM	(5.849E+00 MI)
29	BEAM AREA	=	6.959E+07 M2	(1.720E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	5.000E+00 MW/CM2	
31	PEAK BEAM INTENSITY	=	2.426E+01 MW/CM2	
32	POWER IN MAIN BEAM	=	3.479E+03 MEGAWATT	
33	SATELLITE LENGTH	=	1.714E+01 BAYS	
34	NUMBER OF BAYS	=	1.371E+02 BAYS	
35	XMTR PWR DISTR LOSS	=	1.252E-02	
36	ADJ BAY USEFUL AREA	=	4.096E+05 M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02 METERS	
38	SPS AREA	=	5.993E+01 KM2	
39	MEAN SOLAR INSOLATION	=	8.116E+01 GW	
40	SOLAR CELL OUTPUT	=	9.712E+00 GW	
41	ROTARY JOINT CURRENT "A"	=	7.495E+04 AMPS	
42	ROTARY JOINT CURRENT "B"	=	4.402E+04 AMPS	
43	TOTAL PROCESSED POWER	=	1.410E+03 MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	9.281E+03 MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	7.889E+03 MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.096E+05	
47	MAX KLYSTRON PACKING DEN	=	9.699E+00 PER SUB	
48	MAX RF POWER DENSITY	=	6.456E+00 KW/M2	
49	NUMBER OF SUBARRAYS	=	1.423E+04 PER ANT	
50	RECTENNA AREA	=	3.914E+07 M2	(9.672E+03 ACRES)

Table A1-1 (Continued)

ORIGINAL PAGE IS OF POOR QUALITY

51 PEAK ANT THERMAL FWR	=	1.255E+00 KW/M2				
52 DC OUTPUT POWER	=	2.595E+00 GW/LINK				
53 GRID POWER	=	5.616E+00 GW TOTAL				
54 LAND AREA PER RECT	=	9.872E+07 M2	(	2.439E+04 ACRES	)
55 "Y" MOM OF INERTIA	=	6.411E+13 KG-M2			
56 THRUST PER CORNER	=	4.886E+01 NEWTONS	(	1.098E+01 LB	)
57 NUMBER OF THRUSTERS	=	4.886E+01 PER INST			
58 CONTROL POWER	=	6.133E+01 MEGAWATT			
59 ANNUAL PROPELLANT	=	2.002E+01 TONS	(	4.413E+04 LBM	)
60 STRUCTURE MASS	=	3.149E+03 TONS	(	6.943E+06 LBM	)
61 CONTROL SYS MASS	=	1.091E+02 TONS	(	2.406E+05 LBM	)
62 SOLAR BLANKET MASS	=	2.398E+04 TONS	(	5.288E+07 LBM	)
63 POWER DISTR MASS	=	7.485E+02 TONS	(	1.650E+06 LBM	)
64 MECH & ELEC R/J MASS	=	1.132E+02 TONS	(	2.496E+05 LBM	)
65 ANT STRUC MASS	=	9.800E+02 TONS	(	2.161E+06 LBM	)
66 ANT WAVEGUIDE MASS	=	8.455E+03 TONS	(	1.864E+07 LBM	)
67 ANT KLYSTRON MASS	=	7.615E+03 TONS	(	1.679E+07 LBM	)
68 ANT CONTROL CKTS MASS	=	5.916E+02 TONS	(	1.304E+06 LBM	)
69 ANT PWR DISTR MASS	=	9.185E+02 TONS	(	2.025E+06 LBM	)
70 ANT PWR PROC&TC MASS	=	2.770E+03 TONS	(	6.107E+06 LBM	)
71 ANT MASS	=	2.133E+04 TONS	(	4.703E+07 LBM	)
72 STRUCTURE COST	=	1.575E-01 BILLION			
73 CONTROL SYS COST	=	4.911E-02 BILLION			
74 SOLAR BLANKET COST	=	1.966E+00 BILLION			
75 POWER DISTR COST	=	1.946E-02 BILLION			
76 MECH&ELEC R/J COST	=	2.378E-02 BILLION			
77 ANT STRUC COST	=	3.797E-01 BILLION			
78 ANT WAVEGUIDE COST	=	5.073E-01 BILLION			
79 ANT KLYSTRON COST	=	3.464E-01 BILLION			
80 ANT CONTROL CKTS COST	=	1.306E-01 BILLION			
81 ANT PWR DISTR COST	=	9.920E-02 BILLION			
82 ANT PWR PROC&TC COST	=	1.911E-01 BILLION			
83 ANT COST	=	1.654E+00 BILLION			
84 NO OF FREIGHT FLIGHTS	=	2.180E+02			
85 CREW SERVICE NO OF FLTS	=	1.246E+01			
86 OTS COST	=	5.849E-01 BILLION			
87 TOTAL TRANSP COST	=	4.766E+00 BILLION			
88 RECTENNA COST	=	2.528E+00 BILLION			
89 CONSTRUCTION COST	=	7.475E-01 BILLION			
90 INTEREST DURING CONSTR	=	9.187E-01 BILLION			
91 LATITUDE AREA FACTOR	=	1.419E+00			
92 TOTAL MASS	=	6.229E+04 TONS	(	1.373E+08 LBM	)
93 TOTAL COST	=	1.471E+01 BILLION			
94 COST/KWE	=	2.618E+03 $			
95 COST/KWH	=	4.867E+01 MILLS			

Table A1-1 (Continued)
Rotary Joint Power = 4700 Megawatts

ANTENNA DIAMETER VALUE = 1.600E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.677E-01		
6	NET ENERGY CONV EFFY	=	1.237E-01		
7	AREAWISE EFFICIENCY	=	9.364E-01		
8	ANTENNA POWER DISTR EFFY	=	9.807E-01		
9	NET DC-RF EFFICIENCY	=	8.278E-01		
10	IDEAL BEAM EFFICIENCY	=	9.707E-01		
11	NET BEAM EFFICIENCY	=	9.008E-01		
12	INTERCEPT EFFICIENCY	=	9.557E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.954E-01		
14	NET RF LINK EFFY	=	8.438E-01		
15	DC-TO-DC EFFICIENCY	=	6.255E-01		
16	DC-TO- RID EFFICIENCY	=	6.067E-01		
17	OVERALL PHYSICAL EFFY	=	7.503E-02		
18	AREA EFFECTIVE EFFY	=	7.026E-02		
19	BLANKET AREA	=	5.617E+07	M2	(1.388E+04 ACRES)
20	ANTENNA DIA	=	1.600E+00	KM	(9.942E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.491E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	1.102E+01	DB	
23	TRANSMITTER POWER TAPER	=	1.102E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.012E-01		
25	XMTR AVG/PEAK RATIO	=	3.610E-01		
26	BEAM SPREAD FACTOR	=	1.407E+00		
27	RADIATED RF POWER	=	3.890E+03	MEGAWATT	
28	BEAM DIAMETER	=	8.445E+00	KM	(5.248E+00 MI)
29	BEAM AREA	=	5.602E+07	M2	(1.384E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	6.241E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	3.099E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	3.504E+03	MEGAWATT	
33	SATELLITE LENGTH	=	1.714E+01	BAYS	
34	NUMBER OF BAYS	=	1.371E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	1.130E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	5.998E+01	KM2	
39	MEAN SOLAR INSOLATION	=	5.116E+01	GW	
40	SOLAR CELL OUTPUT	=	9.712E+00	GW	
41	ROTARY JOINT CURRENT "A"	=	7.438E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	4.396E+04	AMPS	
43	TOTAL PROCESSED POWER	=	1.410E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	9.292E+03	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	7.893E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.097E+05		
47	MAX KLYSTRON PACKING DEN	=	8.049E+00	PER SUB	
48	MAX RF POWER DENSITY	=	5.359E+02	KW/M2	
49	NUMBER OF SUBARRAYS	=	1.859E+04	PER ANT	
50	RECTENNA AREA	=	3.151E+07	M2	(7.786E+03 ACRES)

Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.033E+00 KW/M2		
52	DC OUTPUT POWER	=	2.939E+00 GW/LINK		
53	GRID POWER	=	5.702E+00 GW TOTAL		
54	LAND AREA PER RECT	=	7.947E+07 M2	(1.964E+04 ACRES	)
55	"Y" MOM OF INER'IA	=	6.411E+13 KG-M2		
56	THRUST PER CORNER	=	4.886E+01 NEWTONS	(1.098E+01 LB	)
57	NUMBER OF THRUSTERS	=	4.886E+01 PER INST		
58	CONTROL POWER	=	6.133E+01 MEGAWATT		
59	ANNUAL PROPELLANT	=	2.002E+01 TONS	(4.413E+04 LBM	)
60	STRUCTURE MASS	=	3.149E+03 TONS	(6.943E+06 LBM	)
61	CONTROL SYS MASS	=	1.091E+02 TONS	(2.406E+05 LBM	)
62	SOLAR BLANKET MASS	=	2.398E+04 TONS	(5.288E+07 LBM	)
63	POWER DISTR MASS	=	7.476E+02 TONS	(1.648E+06 LBM	)
64	MECH & ELEC R/J MASS	=	1.266E+02 TONS	(2.792E+05 LBM	)
65	ANT STRUC MASS	=	1.280E+03 TONS	(2.822E+06 LBM	)
66	ANT WAVEGUIDE MASS	=	1.104E+04 TONS	(2.435E+07 LBM	)
67	ANT KLYSTRON MASS	=	7.624E+03 TONS	(1.681E+07 LBM	)
68	ANT CONTROL CKTS MASS	=	5.924E+02 TONS	(1.306E+06 LBM	)
69	ANT PWR DISTR MASS	=	1.210E+03 TONS	(2.668E+06 LBM	)
70	ANT PWR PROC&TC MASS	=	2.770E+03 TONS	(6.107E+06 LBM	)
71	ANT MASS	=	2.452E+04 TONS	(5.406E+07 LBM	)
72	STRUCTURE COST	=	1.575E-01 BILLION		
73	CONTROL SYS COST	=	4.911E-02 BILLION		
74	SOLAR BLANKET COST	=	1.966E+00 BILLION		
75	POWER DISTR COST	=	1.944E-02 BILLION		
76	MECH&ELEC R/J COST	=	2.659E-02 BILLION		
77	ANT STRUC COST	=	3.992E-01 BILLION		
78	ANT WAVEGUIDE COST	=	6.676E-01 BILLION		
79	ANT KLYSTRON COST	=	3.469E-01 BILLION		
80	ANT CONTROL CKTS COST	=	1.308E-01 BILLION		
81	ANT PWR DISTR COST	=	1.307E-01 BILLION		
82	ANT PWR PROC&TC COST	=	1.911E-01 BILLION		
83	ANT COST	=	1.861E+00 BILLION		
84	NO OF FREIGHT FLIGHTS	=	2.321E+02		
85	CREW SERVICE NO OF FLTS	=	1.326E+01		
86	OTS COST	=	6.228E-01 BILLION		
87	TOTAL TRANSP COST	=	5.004E+00 BILLION		
88	RECTENNA COST	=	2.111E+00 BILLION		
89	CONSTRUCTION COST	=	7.959E-01 BILLION		
90	INTEREST DURING CO'STR	=	9.307E-01 BILLION		
91	LATITUDE AREA FACTUR	=	1.419E+00		
92	TOTAL MASS	=	6.632E+04 TONS	(1.462E+08 LBM	)
93	TOTAL COST	=	1.490E+01 BILLION		
94	COST/KWE	=	2.613E+03 $		
95	COST/KWH	=	4.856E+01 MILLS		

Table A1-1 (Continued)
Rotary Joint Power = 4700 Megawatts

ANTENNA DIAMETER VALUE = 1.800E+00

SOLUTION RESULTS

1 LIGHT INPUT EFFICIENCY	=	8.579E-01			
2 NET CELL EFFICIENCY	=	1.601E-01			
3 BASIC CONVERSION EFFY	=	1.360E-01			
4 BLANKET FACTORS	=	9.395E-01			
5 BUS I-SQ-R	=	9.677E-01			
6 NET ENERGY CONV EFFY	=	1.237E-01			
7 AREAWISE EFFICIENCY	=	9.364E-01			
8 ANTENNA POWER DISTR EFFY	=	9.894E-01			
9 NET DC-RF EFFICIENCY	=	8.284E-01			
10 IDEAL BEAM EFFICIENCY	=	9.752E-01			
11 NET BEAM EFFICIENCY	=	9.050E-01			
12 INTERCEPT EFFICIENCY	=	9.613E-01			
13 RECTENNA RF-DC EFFICIENC	=	8.963E-01			
14 NET RF LINK EFFY	=	8.528E-01			
15 DC-TO-DC EFFICIENCY	=	6.332E-01			
16 DC-TO-GRID EFFICIENCY	=	6.142E-01			
17 OVERALL PHYSICAL EFFY	=	7.596E-02			
18 AREA EFFECTIVE EFFY	=	7.113E-02			
19 BLANKET AREA	=	5.617E+07 M2	(	1.388E+04 ACRES	)
20 ANTENNA DIA	=	1.800E+00 KM	(	1.119E+00 MI	)
21 REQUIRED SIDELOBE SUPPR	=	2.585E+01 DB			
22 TAPER REQUIRED FOR SL SU	=	1.190E+01 DB			
23 TRANSMITTER POWER TAPER	=	1.190E+01 DB			
24 RECEIVER AVG/PEAK RATIO	=	1.974E-01			
25 XMTR AVG/PEAK RATIO	=	3.396E-01			
26 BEAM SPREAD FACTOR	=	1.520E+00			
27 RADIATED RF POWER	=	3.893E+03 MEGAWATT			
28 BEAM DIAMETER	=	7.674E+00 KM	(	4.769E+00 MI	)
29 BEAM AREA	=	4.626E+07 M2	(	1.143E+04 ACRES	)
30 AVERAGE BEAM POWER DENS	=	7.592E+00 MW/CM2			
31 PEAK BEAM INTENSITY	=	3.844E+01 MW/CM2			
32 POWER IN MAIN BEAM	=	3.523E+03 MEGAWATT			
33 SATELLITE LENGTH	=	1.714E+01 BAYS			
34 NUMBER OF BAYS	=	1.371E+02 BAYS			
35 XMTR PWR DISTR LOSS	=	1.056E-02			
36 ADJ BAY USEFUL AREA	=	4.096E+05 M2	(	1.012E+02 ACRES	)
37 BAY SIZE	=	6.600E+02 METERS			
38 SPS AREA	=	5.998E+01 KM2			
39 MEAN SOLAR INSOLATION	=	8.116E+01 GW			
40 SOLAR CELL OUTPUT	=	9.712E+00 GW			
41 ROTARY JOINT CURRENT "A"	=	7.480E+04 AMPS			
42 ROTARY JOINT CURRENT "B"	=	4.393E+04 AMPS			
43 TOTAL PROCESSED POWER	=	1.410E+03 MEGAWATT			
44 TOTAL KLYSTRON INPUT	=	9.299E+03 MEGAWATT			
45 TOTAL KLYSTRON OUTPUT	=	7.904E+03 MEGAWATT			
46 NUMBER OF KLYSTRONS	=	1.098E+05			
47 MAX KLYSTRON PACKING DEN	=	6.763E+00 PER SUB			
48 MAX RF POWER DENSITY	=	4.502E+00 KW/M2			
49 NUMBER OF SUBARRAYS	=	2.353E+04 PER ANT			
50 RECTENNA AREA	=	2.602E+07 M2	(	6.430E+03 ACRES	)

ORIGINAL PAGE IS
OF POOR QUALITY

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	8.640E-01	KW/M2	
52 DC OUTPUT POWER	=	2.976E+00	GW/LINK	
53 GRID POWER	=	5.773E+00	GW TOTAL	
54 LAND AREA PER RECT	=	6.562E+07	M2	(1.621E+04 ACRES)
55 "Y" MOM OF INERTIA	=	6.411E+13	KG-M2	
56 THRUST PER CORNER	=	4.886E+01	NEWTONS	(1.098E+01 LB)
57 NUMBER OF THRUSTERS	=	4.886E+01	PER INST	
58 CONTROL POWER	=	6.133E+01	MEGAWATT	
59 ANNUAL PROPELLANT	=	2.002E+01	TONS	(4.413E+04 LBM)
60 STRUCTURE MASS	=	3.149E+03	TONS	(6.943E+06 LBM)
61 CONTROL SYS MASS	=	1.091E+02	TONS	(2.406E+05 LBM)
62 SOLAR BLANKET MASS	=	2.398E+04	TONS	(5.288E+07 LBM)
63 POWER DISTR MASS	=	7.470E+02	TONS	(1.647E+06 LBM)
64 MECH & ELEC R/J MASS	=	1.400E+02	TONS	(3.087E+05 LBM)
65 ANT STRUC MASS	=	1.620E+03	TONS	(3.571E+06 LBM)
66 ANT WAVEGUIDE MASS	=	1.398E+04	TONS	(3.081E+07 LBM)
67 ANT KLYSTRON MASS	=	7.630E+03	TONS	(1.682E+07 LBM)
68 ANT CONTROL CKTS MASS	=	5.928E+02	TONS	(1.307E+06 LBM)
69 ANT PWR DISTR MASS	=	1.508E+03	TONS	(3.324E+06 LBM)
70 ANT PWR PROC&TC MASS	=	2.770E+03	TONS	(6.107E+06 LBM)
71 ANT MASS	=	2.810E+04	TONS	(6.194E+07 LBM)
72 STRUCTURE COST	=	1.575E-01	BILLION	
73 CONTROL SYS COST	=	4.911E-02	BILLION	
74 SOLAR BLANKET COST	=	1.966E+00	BILLION	
75 POWER DISTR COST	=	1.942E-02	BILLION	
76 MECH&ELEC R/J COST	=	2.941E-02	BILLION	
77 ANT STRUC COST	=	4.213E-01	BILLION	
78 ANT WAVEGUIDE COST	=	8.386E-01	BILLION	
79 ANT KLYSTRON COST	=	3.471E-01	BILLION	
80 ANT CONTROL CKTS COST	=	1.309E-01	BILLION	
81 ANT PWR DISTR COST	=	1.628E-01	BILLION	
82 ANT PWR PROC&TC COST	=	1.911E-01	BILLION	
83 ANT COST	=	2.092E+00	BILLION	
84 NO OF FREIGHT FLIGHTS	=	2.490E+02		
85 CREW SERVICE NO OF FLTS	=	1.417E+01		
86 OTS COST	=	6.653E-01	BILLION	
87 TOTAL TRANSP COST	=	5.267E+00	BILLION	
88 RECTENNA COST	=	1.012E+00	BILLION	
89 CONSTRUCTION COST	=	8.502E-01	BILLION	
90 INTEREST DURING CONSTR	=	9.540E-01	BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00		
92 TOTAL MASS	=	7.085E+04	TONS	(1.562E+08 LBM)
93 TOTAL COST	=	1.528E+01	BILLION	
94 COST/KWE	=	2.647E+03	$	
95 COST/KWH	=	4.921E+01	MILLS	

Table A1-1 (Continued)

Rotary Joint Power = 4700 Megawatts

ANTENNA DIAMETER VALUE = 2.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01				
2	NET CELL EFFICIENCY	=	1.601E-01				
3	BASIC CONVERSION EFFY	=	1.360E-01				
4	BLANKET FACTORS	=	9.399E-01				
5	BUS I-SQ-R	=	9.677E-01				
6	NET ENERGY CONV EFFY	=	1.237E-01				
7	AREAWISE EFFICIENCY	=	9.364E-01				
8	ANTENNA POWER DISTR EFFY	=	9.891E-01				
9	NET DC-RF EFFICIENCY	=	8.281E-01				
10	IDEAL BEAM EFFICIENCY	=	9.785E-01				
11	NET BEAM EFFICIENCY	=	9.081E-01				
12	INTERCEPT EFFICIENCY	=	9.669E-01				
13	RECTENNA RF-DC EFFICIENC	=	8.973E-01				
14	NET RF LINK EFFY	=	8.605E-01				
15	DC-TO-DC EFFICIENCY	=	6.394E-01				
16	DC-TO-GRID EFFICIENCY	=	6.202E-01				
17	OVERALL PHYSICAL EFFY	=	7.670E-02				
18	AREA EFFECTIVE EFFY	=	7.182E-02				
19	BLANKET AREA	=	5.617E+07	M2	(	1.388E+04 ACRES	)
20	ANTENNA DIA	=	2.000E+00	KM	(	1.243E+00 MI	)
21	REQUIRED SIDELOBE SUPPR	=	2.669E+01	DB			
22	TAPER REQUIRED FOR SL SU	=	1.259E+01	DB			
23	TRANSMITTER POWER TAPER	=	1.259E+01	DB			
24	RECEIVER AVG/PEAK RATIO	=	1.946E-01				
25	XMTR AVG/PEAK RATIO	=	3.252E-01				
26	BEAM SPREAD FACTOR	=	1.547E+00				
27	RADIATED RF POWER	=	3.891E+03	MEGAWATT			
28	BEAM DIAMETER	=	7.032E+00	KM	(	4.369E+00 MI	)
29	BEAM AREA	=	3.883E+07	M2	(	9.595E+03 ACRES	)
30	AVERAGE BEAM POWER DENS	=	9.091E+00	MW/CM2			
31	PEAK BEAM INTENSITY	=	4.671E+01	MW/CM2			
32	POWER IN MAIN BEAM	=	3.534E+03	MEGAWATT			
33	SATELLITE LENGTH	=	1.714E+01	BAYS			
34	NUMBER OF BAYS	=	1.371E+02	BAYS			
35	XMTR PWR DISTR LOSS	=	1.094E-02				
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES	)
37	BAY SIZE	=	6.600E+02	METERS			
38	SPS AREA	=	5.998E+01	KM2			
39	MEAN SOLAR INSOLATION	=	8.116E+01	GW			
40	SOLAR CELL OUTPUT	=	9.712E+00	GW			
41	ROTARY JOINT CURRENT "A"	=	7.483E+04	AMPS			
42	ROTARY JOINT CURRENT "B"	=	4.395E+04	AMPS			
43	TOTAL PROCESSED POWER	=	1.410E+03	MEGAWATT			
44	TOTAL KLYSTRON INPUT	=	9.296E+03	MEGAWATT			
45	TOTAL KLYSTRON OUTPUT	=	7.901E+03	MEGAWATT			
46	NUMBER OF KLYSTRONS	=	1.097E+05				
47	MAX KLYSTRON PACKING DEN	=	5.720E+00	PER SUB			
48	MAX RF POWER DENSITY	=	3.808E+00	KW/M2			
49	NUMBER OF SUBARRAYS	=	2.905E+04	PER ANT			
50	RECTENNA AREA	=	2.184E+07	M2	(	5.397E+03 ACRES	)

Table A1-1 (Continued)

51 PFSK ANT THERMAL PWR	=	7.325E-01 KW/M2			
52 DC OUTPUT POWER	=	3.005E+00 GW/LINK			
53 GRID POWER	=	3.829E+00 GW TOTAL			
54 LAND AREA PER RECT	=	5.509E+07 M2	(	1.361E+04 ACRES	)
55 "Y" MOM OF INERTIA	=	6.411E+13 KG-M2			
56 THRUST PER CORNER	=	4.886E+01 NEWTONS	(	1.098E+01 LB	)
57 NUMBER OF THRUSTERS	=	.886E+01 PER INST			
58 CONTROL POWER	=	6.133E+01 MEGAWATT			
59 ANNUAL PROPELLANT	=	2.002E+01 TONS	(	4.413E+04 LBM	)
60 STRUCTURE MASS	=	3.149E+03 TONS	(	6.943E+06 LBM	)
61 CONTROL SYS MASS	=	1.091E+02 TONS	(	2.406E+05 LBM	)
62 SOLAR BLANKET MASS	=	2.398E+04 TONS	(	5.288E+07 LBM	)
63 POWER DISTR MASS	=	7.473E+02 TONS	(	1.647E+06 LBM	)
64 MECH & ELEC R/J MASS	=	1.534E+02 TONS	(	3.382E+05 LBM	)
65 ANT STRUC MASS	=	2.000E+03 TONS	(	4.409E+06 LBM	)
66 ANT WAVEGUIDE MASS	=	1.726E+04 TONS	(	3.806E+07 LBM	)
67 ANT KLYSTRON MASS	=	7.627E+03 TONS	(	1.681E+07 LBM	)
68 ANT CONTROL CKTS MASS	=	5.926E+02 TONS	(	1.306E+06 LBM	)
69 ANT PWR DISTR MASS	=	1.817E+03 TONS	(	4.005E+06 LBM	)
70 ANT PWR PROCSTC MASS	=	2.770E+03 TONS	(	6.107E+06 LBM	)
71 ANT MASS	=	3.206E+04 TONS	(	7.068E+07 LBM	)
72 STRUCTURE COST	=	1.575E-01 BILLION			
73 CONTROL SYS COST	=	4.911E-02 BILLION			
74 SOLAR BLANKET COST	=	1.966E+00 BILLION			
75 POWER DISTR COST	=	1.943E-02 BILLION			
76 MECH&ELEC R/J COST	=	3.222E-02 BILLION			
77 ANT STRUC COST	=	4.460E-01 BILLION			
78 ANT WAVEGUIDE COST	=	1.035E+00 BILLION			
79 ANT KLYSTRON COST	=	3.470E-01 BILLION			
80 ANT CONTROL CKTS COST	=	1.303E-01 BILLION			
81 ANT PWR DISTR COST	=	1.962E-01 BILLION			
82 ANT PWR PROCSTC COST	=	1.411E-01 BILLION			
83 ANT COST	=	2.346E+00 BILLION			
84 NO OF FREIGHT FLIGHTS	=	2.655E+02			
85 CREW SERVICE NO OF FLTS	=	1.517E+01			
86 OTS COST	=	7.123E-01 BILLION			
87 TOTAL TRANSP COST	=	5.554E+00 BILLION			
88 RECTENNA COST	=	1.584E+00 BILLION			
89 CONSTRUCTION COST	=	9.103E-01 BILLION			
90 INTEREST DURING CONSTR	=	9.880E-01 BILLION			
91 LATITUDE AREA FACTOR	=	1.419E+00			
92 TOTAL MASS	=	7.586E+04 TONS	(	1.672E+08 LBM	)
93 TOTAL COST	=	1.581E+01 BILLION			
94 COST/KWE	=	2.713E+03 $			
95 COST/KWH	=	5.043E+01 MILLS			

Table A1-1 (Continued)

Rotary Joint Power = 5980 Megawatts

ANTENNA DIAMETER VALUE = 1.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS 1-SQ-R	=	9.585E-01		
6	NET ENERGY CONV EFFY	=	1.225E-01		
7	AREAWISE EFFICIENCY	=	9.367E-01		
8	ANTENNA POWER DISTR EFFY	=	9.802E-01		
9	NET DC-RF EFFICIENCY	=	8.207E-01		
10	IDEAL BEAM EFFICIENCY	=	9.650E-01		
11	NET BEAM EFFICIENCY	=	8.955E-01		
12	INTERCEPT EFFICIENCY	=	9.512E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.915E-01		
14	NET RF LINK EFFY	=	8.348E-01		
15	DC-TO-DC EFFICIENCY	=	6.108E-01		
16	DC-TO-GRID EFFICIENCY	=	5.925E-01		
17	OVERALL PHYSICAL EFFY	=	7.257E-02		
18	AREA EFFECTIVE EFFY	=	6.793E-02		
19	BLANKET AREA	=	7.213E+07	M2	(1.783E+04 ACRES)
20	ANTENNA DIA	=	1.000E+00	KM	(6.214E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.194E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	7.024E+00	DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25	XMTR AVG/PEAK RATIO	=	3.909E-01		
26	BEAM SPREAD FACTOR	=	1.450E+00		
27	RADIATED RF POWER	=	4.908E+03	MEGAWATT	
28	BEAM DIAMETER	=	1.318E+01	KM	(8.189E+00 MI)
29	BEAM AREA	=	1.364E+08	M2	(3.370E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	3.235E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	1.564E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	4.396E+03	MEGAWATT	
33	SATELLITE LENGTH	=	2.203E+01	BAYS	
34	NUMBER OF BAYS	=	1.762E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	1.978E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	7.705E+01	KM2	
39	MEAN SOLAR INSOLATION	=	1.043E+02	GW	
40	SOLAR CELL OUTPUT	=	1.248E+01	GW	
41	ROTARY JOINT CURRENT "A"	=	9.610E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	5.644E+04	AMPS	
43	TOTAL PROCESSED POWER	=	1.794E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.172E+04	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	9.966E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.384E+05		
47	MAX KLYSTRON PACKING DEN	=	2.399E+01	PER SUB	
48	MAX RF POWER DENSITY	=	1.599E+01	KW/M2	
49	NUMBER OF SUBARRAYS	=	7.261E+03	PER ANT	
50	RECTENNA AREA	=	7.672E+07	M2	(1.896E+04 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	3.250E+00 KW/M2		
52 DC OUTPUT POWER	=	3.653E+00 GW/LINK		
53 GRID POWER	=	7.087E+00 GW TOTAL		
54 LAND AREA PER SECT	=	1.935E+08 M2	(	4.781E+04 ACRES)
55 "Y" MOM OF INERTIA	=	8.238E+13 KG-M2		
56 THRUST PER CORNER	=	6.278E+01 NEWTONS	(	1.411E+01 LB)
57 NUMBER OF THRUSTERS	=	6.278E+01 PER INST		
58 CONTROL POWER	=	7.830E+01 MEGAWATT		
59 ANNUAL PROPELLANT	=	2.572E+01 TONS	(	5.671E+04 LBM)
60 STRUCTURE MASS	=	4.045E+03 TONS	(	8.918E+06 LBM)
61 CONTROL SYS MASS	=	1.402E+02 TONS	(	3.091E+05 LBM)
62 SOLAR BLANKET MASS	=	3.082E+04 TONS	(	6.794E+07 LBM)
63 POWER DISTR MASS	=	1.233E+03 TONS	(	2.719E+06 LBM)
64 MECH & ELEC R/J MASS	=	9.196E+01 TONS	(	2.027E+05 LBM)
65 ANT STRUC MASS	=	5.000E+02 TONS	(	1.102E+06 LBM)
66 ANT WAVEGUIDE MASS	=	4.314E+03 TONS	(	9.511E+06 LBM)
67 ANT KLYSTRON MASS	=	9.620E+03 TONS	(	2.121E+07 LBM)
68 ANT CONTROL CKTS MASS	=	7.475E+02 TONS	(	1.648E+06 LBM)
69 ANT PWR DISTR MASS	=	6.099E+02 TONS	(	1.345E+06 LBM)
70 ANT PWR PROC&TC MASS	=	3.526E+03 TONS	(	7.773E+06 LBM)
71 ANT MASS	=	1.932E+04 TONS	(	4.259E+07 LBM)
72 STRUCTURE COST	=	2.023E-01 BILLION		
73 CONTROL SYS COST	=	6.310E-02 BILLION		
74 SOLAR BLANKET COST	=	2.526E+00 BILLION		
75 POWER DISTR COST	=	3.206E-02 BILLION		
76 MECH&ELEC R/J COST	=	1.931E-02 BILLION		
77 ANT STRUC COST	=	3.485E-01 BILLION		
78 ANT WAVEGUIDE COST	=	2.588E-01 BILLION		
79 ANT KLYSTRON COST	=	4.377E-01 BILLION		
80 ANT CONTROL CKTS COST	=	1.650E-01 BILLION		
81 ANT PWR DISTR COST	=	6.507E-02 BILLION		
82 ANT PWR PROC&TC COST	=	2.433E-01 BILLION		
83 ANT COST	=	1.519E+00 BILLION		
84 NO OF FREIGHT FLIGHTS	=	2.454E+02		
85 CREW SERVICE NO OF FLTS	=	1.402E+01		
86 OTS COST	=	6.584E-01 BILLION		
87 TOTAL TRANSP COST	=	5.224E+00 BILLION		
88 RECTENNA COST	=	4.668E+00 BILLION		
89 CONSTRUCTION COST	=	8.414E-01 BILLION		
90 INTEREST DURING CONSTR	=	1.145E+00 BILLION		
91 LATITUDE AREA FACTOR	=	1.419E+00		
92 TOTAL MASS	=	7.011E+04 TONS	(	1.546E+08 LBM)
93 TOTAL COST	=	1.633E+01 BILLION		
94 COST/KWE	=	2.586E+03 $		
95 COST/KWH	=	4.806E+01 MILLS		

Table A1-1 (Continued)
Rotary Joint Power = 5980 Megawatts

ANTENNA DIAMETER VALUE = 1.200E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.585E-01		
6	NET ENERGY CONV EFFY	=	1.225E-01		
7	AREAWISE EFFICIENCY	=	9.367E-01		
8	ANTENNA POWER DISTR EFFY	=	9.806E-01		
9	NET DC-RF EFFICIENCY	=	8.210E-01		
10	IDEAL BEAM EFFICIENCY	=	9.650E-01		
11	NET BEAM EFFICIENCY	=	8.955E-01		
12	INTERCEPT EFFICIENCY	=	9.512E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.926E-01		
14	NET RF LINK EFFY	=	8.348E-01		
15	DC-TO-DC EFFICIENCY	=	6.118E-01		
16	DC-TO-GRID EFFICIENCY	=	5.934E-01		
17	OVERALL PHYSICAL EFFY	=	7.269E-02		
18	AREA EFFECTIVE EFFY	=	6.809E-02		
19	BLANKET AREA	=	7.218E+07	M2	(1.783E+04 ACRES)
20	ANTENNA DIA	=	1.200E+00	KM	(7.457E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.353E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	9.429E+00	DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25	XMTR AVG/PEAK RATIO	=	3.909E-01		
26	BEAM SPREAD FACTOR	=	1.450E+00		
27	RADIATED RF POWER	=	4.910E+03	MEGAWATT	
28	BEAM DIAMETER	=	1.098E+01	KM	(6.824E+00 MI)
29	BEAM AREA	=	9.472E+07	M2	(2.340E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	4.643E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	2.253E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	4.397E+03	MEGAWATT	
33	SATELLITE LENGTH	=	2.203E+01	BAYS	
34	NUMBER OF BAYS	=	1.762E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	1.942E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	7.705E+01	KM2	
39	MEAN SOLAR INSOLATION	=	1.043E+02	GW	
40	SOLAR CELL OUTPUT	=	1.248E+01	GW	
41	ROTARY JOINT CURRENT "A"	=	9.606E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	5.642E+04	AMPS	
43	TOTAL PROCESSED POWER	=	1.794E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.173E+04	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	9.970E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.385E+05		
47	MAX KLYSTRON PACKING DEN	=	1.668E+01	PER SUB	
48	MAX RF POWER DENSITY	=	1.111E+01	KW/M2	
49	NUMBER OF SUBARRAYS	=	1.046E+04	PER ANT	
50	RECTENNA AREA	=	5.328E+07	M2	(1.317E+04 ACRES)

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Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	2.253E+00 KW/M2	
52 DC OUTPUT POWER	=	3.659E+00 GW/LINK	
53 GRID POWER	=	7.098E+00 GW TOTAL	
54 LAND AREA PER RECT	=	1.344E+08 M2	(3.320E+04 ACRES)
55 "Y" MOM OF INERTIA	=	8.238E+13 KG-M2	
56 THRUST PER CORNER	=	6.278E+01 NEWTONS	(1.411E+01 LB)
57 NUMBER OF THRUSTERS	=	6.278E+01 PER INST	
58 CONTROL POWER	=	7.850E+01 MEGAWATT	
59 ANNUAL PROPELLANT	=	2.572E+01 TONS	(5.671E+04 LBM)
60 STRUCTURE MASS	=	4.045E+03 TONS	(8.918E+06 LBM)
61 CONTROL SYS MASS	=	1.402E+02 TONS	(3.091E+05 LBM)
62 SOLAR BLANKET MASS	=	3.082E+04 TONS	(6.794E+07 LBM)
63 POWER DISTR MASS	=	1.233E+03 TONS	(2.718E+06 LBM)
64 MECH & ELEC R/J MASS	=	1.054E+02 TONS	(2.323E+05 LBM)
65 ANT STRUC MASS	=	7.200E+02 TONS	(1.587E+06 LBM)
66 ANT WAVEGUIDE MASS	=	6.212E+03 TONS	(1.370E+07 LBM)
67 ANT KLYSTRON MASS	=	9.624E+03 TONS	(2.122E+07 LBM)
68 ANT CONTROL CKTS MASS	=	7.477E+02 TONS	(1.648E+06 LBM)
69 ANT PWR DISTR MASS	=	6.952E+02 TONS	(1.533E+06 LBM)
70 ANT PWR PROC&TC MASS	=	3.526E+03 TONS	(7.773E+06 LBM)
71 ANT MASS	=	2.152E+04 TONS	(4.745E+07 LBM)
72 STRUCTURE COST	=	2.023E-01 BILLION	
73 CONTROL SYS COST	=	6.310E-02 BILLION	
74 SOLAR BLANKET COST	=	2.526E+00 BILLION	
75 POWER DISTR COST	=	3.205E-02 BILLION	
76 MECH&ELEC R/J COST	=	2.213E-02 BILLION	
77 ANT STRUC COST	=	3.628E-01 BILLION	
78 ANT WAVEGUIDE COST	=	3.727E-01 BILLION	
79 ANT KLYSTRON COST	=	4.378E-01 BILLION	
80 ANT CONTROL CKTS COST	=	1.651E-01 BILLION	
81 ANT PWR DISTR COST	=	7.508E-02 BILLION	
82 ANT PWR PROC&TC COST	=	2.433E-01 BILLION	
83 ANT COST	=	1.657E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	2.552E+02	
85 CREW SERVICE NO OF FLTS	=	1.458E+01	
86 OTS COST	=	6.846E-01 BILLION	
87 TOTAL TRANSP COST	=	5.386E+00 BILLION	
88 RECTENNA COST	=	3.378E+00 BILLION	
89 CONSTRUCTION COST	=	8.749E-01 BILLION	
90 INTEREST DURING CONSTR	=	1.086E+00 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	7.291E+04 TONS	(1.607E+08 LBM)
93 TOTAL COST	=	1.738E+01 BILLION	
94 COST/KWE	=	2.448E+03 $	
95 COST/KWH	=	4.551E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 5980 Megawatts

ANTENNA DIAMETER VALUE = 1.400E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.585E-01		
6	NET ENERGY CONV EFFY	=	1.225E-01		
7	AREAWISE EFFICIENCY	=	9.367E-01		
8	ANTENNA POWER DISTR EFFY	=	9.809E-01		
9	NET DC-RF EFFICIENCY	=	8.213E-01		
10	IDEAL BEAM EFFICIENCY	=	9.699E-01		
11	NET BEAM EFFICIENCY	=	9.001E-01		
12	INTERCEPT EFFICIENCY	=	9.550E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.953E-01		
14	NET RF LINK EFFY	=	8.424E-01		
15	DC-TO-DC EFFICIENCY	=	6.194E-01		
16	DC-TO-GRID EFFICIENCY	=	6.009E-01		
17	OVERALL PHYSICAL EFFY	=	7.360E-02		
18	AREA EFFECTIVE EFFY	=	6.894E-02		
19	BLANKET AREA	=	7.218E+07	M2	(1.783E+04 ACRES)
20	ANTENNA DIA	=	1.400E+00	KM	(8.700E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.478E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	1.088E+01	DB	
23	TRANSMITTER POWER TAPER	=	1.088E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.019E-01		
25	XMTR AVG/PEAK RATIO	=	3.649E-01		
26	BEAM SPREAD FACTOR	=	1.481E+00		
27	RADIATED RF POWER	=	4.912E+03	MEGAWATT	
28	BEAM DIAMETER	=	9.617E+00	KM	(5.976E+00 MI)
29	BEAM AREA	=	7.264E+07	M2	(1.795E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	6.073E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	3.006E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	4.421E+03	MEGAWATT	
33	SATELLITE LENGTH	=	2.203E+01	BAYS	
34	NUMBER OF BAYS	=	1.762E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	1.911E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	7.705E+01	KM2	
39	MEAN SOLAR INSOLATION	=	1.043E+02	GW	
40	SOLAR CELL OUTPUT	=	1.248E+01	GW	
41	ROTARY JOINT CURRENT "A"	=	9.603E+04	AMPS	
42	ROTARY JOINT CURRENT "B"	=	5.640E+04	AMPS	
43	TOTAL PROCESSED POWER	=	1.794E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.173E+04	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	9.973E+03	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.385E+05		
47	MAX KLYSTRON PACKING DEN	=	1.313E+01	PER SUB	
48	MAX RF POWER DENSITY	=	8.742E+00	KW/M2	
49	NUMBER OF SUBARRAYS	=	1.423E+04	PER ANT	
50	RECTENNA AREA	=	4.086E+07	M2	(1.010E+04 ACRES)

Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.770E+00 KW/M2			
52	DC OUTPUT POWER	=	3.705E+00 GW/LINK			
53	GRID POWER	=	7.187E+00 GW TOTAL			
54	LAND AREA PER RECT	=	1.030E+08 M2	(	2.546E+04 ACRES	)
55	"Y" MOM OF INERTIA	=	8.238E+13 KG-M2			
56	THRUST PER CORNER	=	6.278E+01 NEWTONS	(	1.411E+01 LB	)
57	NUMBER OF THRUSTERS	=	6.278E+01 PER INST			
58	CONTROL POWER	=	7.880E+01 MEGAWATT			
59	ANNUAL PROPELLANT	=	2.572E+01 TONS	(	5.671E+04 LBM	)
60	STRUCTURE MASS	=	4.045E+03 TONS	(	8.918E+06 LBM	)
61	CONTROL SYS MASS	=	1.402E+02 TONS	(	3.091E+05 LBM	)
62	SOLAR BLANKET MASS	=	3.082E+04 TONS	(	6.794E+07 LBM	)
63	POWER DISTR MASS	=	1.232E+03 TONS	(	2.717E+06 LBM	)
64	MECH & ELEC R/J MASS	=	1.188E+02 TONS	(	2.618E+05 LBM	)
65	ANT STRUC MASS	=	9.800E+02 TONS	(	2.161E+06 LBM	)
66	ANT WAVEGUIDE MASS	=	8.455E+03 TONS	(	1.864E+07 LBM	)
67	ANT KLYSTRON MASS	=	9.627E+03 TONS	(	2.122E+07 LBM	)
68	ANT CONTROL CKTS MASS	=	7.480E+02 TONS	(	1.649E+06 LBM	)
69	ANT PWR DISTR MASS	=	1.043E+03 TONS	(	2.300E+06 LBM	)
70	ANT PWR PROC&TC MASS	=	3.526E+03 TONS	(	7.773E+06 LBM	)
71	ANT MASS	=	2.438E+04 TONS	(	5.375E+07 LBM	)
72	STRUCTURE COST	=	2.023E-01 BILLION			
73	CONTROL SYS COST	=	6.310E-02 BILLION			
74	SOLAR BLANKET COST	=	2.526E+00 BILLION			
75	POWER DISTR COST	=	3.204E-02 BILLION			
76	MECH&ELEC R/J COST	=	2.494E-02 BILLION			
77	ANT STRUC COST	=	3.797E-01 BILLION			
78	ANT WAVEGUIDE COST	=	5.073E-01 BILLION			
79	ANT KLYSTRON COST	=	4.380E-01 BILLION			
80	ANT CONTROL CKTS COST	=	1.651E-01 BILLION			
81	ANT PWR DISTR COST	=	1.127E-01 BILLION			
82	ANT PWR PROC&TC COST	=	2.433E-01 BILLION			
83	ANT COST	=	1.846E+00 BILLION			
84	NO OF FREIGHT FLIGHTS	=	2.678E+02			
85	CREW SERVICE NO OF FLTS	=	1.531E+01			
86	OTS COST	=	7.186E-01 BILLION			
87	TOTAL TRANSP COST	=	5.592E+00 BILLION			
88	RECTENNA COST	=	2.698E+00 BILLION			
89	CONSTRUCTION COST	=	9.183E-01 BILLION			
90	INTEREST DURING CONSTR	=	1.076E+00 BILLION			
91	LATITUDE AREA FACTOR	=	1.419E+00			
92	TOTAL MASS	=	7.653E+04 TONS	(	1.687E+08 LBM	)
93	TOTAL COST	=	1.722E+01 BILLION			
94	COST/KWE	=	2.396E+03 $			
95	COST/KWH	=	4.453E+01 MILLS			

Table A1-1 (Continued)
Rotary Joint Power = 5980 Megawatts

ANTENNA DIAMETER VALUE = 1.600E+00

SOLUTION RESULTS

1 LIGHT INPUT EFFICIENCY	=	8.579E-01				
2 NET CELL EFFICIENCY	=	1.601E-01				
3 BASIC CONVERSION EFFY	=	1.360E-01				
4 BLANKET FACTORS	=	9.399E-01				
5 BUS I-SQ-R	=	9.585E-01				
6 NET ENERGY CONV EFFY	=	1.225E-01				
7 AREAWISE EFFICIENCY	=	9.367E-01				
8 ANTENNA POWER DISTR EFFY	=	9.821E-01				
9 NET DC-RF EFFICIENCY	=	8.223E-01				
10 IDEAL BEAM EFFICIENCY	=	9.751E-01				
11 NET BEAM EFFICIENCY	=	9.050E-01				
12 INTERCEPT EFFICIENCY	=	9.613E-01				
13 RECTENNA RF-DC EFFICIENC	=	8.963E-01				
14 NET RF LINK EFFY	=	8.528E-01				
15 DC-TO-DC EFFICIENCY	=	6.285E-01				
16 DC-TO-GRID EFFICIENCY	=	6.096E-01				
17 OVERALL PHYSICAL EFFY	=	7.467E-02				
18 AREA EFFECTIVE EFFY	=	6.994E-02				
19 BLANKET AREA	=	7.218E+07 M2	(	1.783E+04	ACRES	)
20 ANTENNA DIA	=	1.600E+00 KM	(	9.942E-01	MI	)
21 REQUIRED SIDELOBE SUPPR	=	2.584E+01 DB				
22 TAPER REQUIRED FOR SL SU	=	1.189E+01 DB				
23 TRANSMITTER POWER TAPER	=	1.189E+01 DB				
24 RECEIVER AVG/PEAK RATIO	=	1.9[illegible]5E-01				
25 XMTR AVG/PEAK RATIO	=	3.397E-01				
26 BEAM SPREAD FACTOR	=	1.520E+00				
27 RADIATED RF POWER	=	4.918E+03 MEGAWATT				
28 BEAM DIAMETER	=	8.632E+00 KM	(	5.364E+00	MI	)
29 BEAM AREA	=	5.852E+07 M2	(	1.446E+04	ACRES	)
30 AVERAGE BEAM POWER DENS	=	7.579E+00 MW/CM2				
31 PEAK BEAM INTENSITY	=	3.837E+01 MW/CM2				
32 POWER IN MAIN BEAM	=	4.450E+03 MEGAWATT				
33 SATELLITE LENGTH	=	2.203E+01 BAYS				
34 NUMBER OF BAYS	=	1.762E+02 BAYS				
35 XMTR PWR DISTR LOSS	=	1.791E-02				
36 ADJ BAY USEFUL AREA	=	4.096E+05 M2	(	1.012E+02	ACRES	)
37 BAY SIZE	=	6.600E+02 METERS				
38 SPS AREA	=	7.705E+01 KM2				
39 MEAN SOLAR INSOLATION	=	1.043E+02 GW				
40 SOLAR CELL OUTPUT	=	1.248E+01 GW				
41 ROTARY JOINT CURRENT "A"	=	9.591E+04 AMPS				
42 ROTARY JOINT CURRENT "B"	=	5.633E+04 AMPS				
43 TOTAL PROCESSED POWER	=	1.794E+03 MEGAWATT				
44 TOTAL KLYSTRON INPUT	=	1.175E+04 MEGAWATT				
45 TOTAL KLYSTRON OUTPUT	=	9.985E+03 MEGAWATT				
46 NUMBER OF KLYSTRONS	=	1.387E+05				
47 MAX KLYSTRON PACKING DEN	=	1.081E+01 PER SUB				
48 MAX RF POWER DENSITY	=	7.195E+00 KW/M2				
49 NUMBER OF SUBARRAYS	=	1.859E+04 PER ANT				
50 RECTENNA AREA	=	3.292E+07 M2	(	8.135E+03	ACRES	)

TableA1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.446E+00 KW/M2	
52	DC OUTPUT POWER	=	3.759E+00 GW/LINK	
53	GRID POWER	=	7.292E+00 GW TOTAL	
54	LAND AREA PER RECT	=	8.302E+07 M2	(2.051E+04 ACRES)
55	"Y" MOM OF INERTIA	=	8.238E+13 KG-M2	
56	THRUST PER CORNER	=	6.278E+01 NEWTONS	(1.411E+01 LB)
57	NUMBER OF THRUSTERS	=	6.278E+01 PER INST	
58	CONTROL POWER	=	7.880E+01 MEGAWATT	
59	ANNUAL PROPELLANT	=	2.572E+01 TONS	(5.671E+04 LBM)
60	STRUCTURE MASS	=	4.045E+03 TONS	(8.918E+06 LBM)
61	CONTROL SYS MASS	=	1.402E+02 TONS	(3.091E+05 LBM)
62	SOLAP BLANKET MASS	=	3.082E+04 TONS	(6.794E+07 LBM)
63	POWER DISTR MASS	=	1.231E+03 TONS	(2.713E+06 LBM)
64	MECH & ELEC R/J MASS	=	1.322E+02 TONS	(2.914E+05 LBM)
65	ANT STRUC MASS	=	1.280E+03 TONS	(2.822E+06 LBM)
66	ANT WAVEGUIDE MASS	=	1.104E+04 TONS	(2.435E+07 LBM)
67	ANT KLYSTRON MASS	=	9.639E+03 TONS	(2.125E+07 LBM)
68	ANT CONTROL CKTS MASS	=	7.489E+02 TONS	(1.651E+06 LBM)
69	ANT PWR DISTR MASS	=	1.286E+03 TONS	(2.836E+06 LBM)
70	ANT PWR PROC&TC MASS	=	3.526E+03 TONS	(7.773E+06 LBM)
71	ANT MASS	=	2.752E+04 TONS	(6.068E+07 LBM)
72	STRUCTURE COST	=	2.023E-01 BILLION	
73	CONTROL SYS COST	=	6.310E-02 BILLION	
74	SOLAR BLANKET COST	=	2.526E+00 BILLION	
75	POWER DISTR COST	=	3.200E-02 BILLION	
76	MECH&ELEC R/J COST	=	2.775E-02 BILLION	
77	ANT STRUC COST	=	3.992E-01 BILLION	
78	ANT WAVEGUIDE COST	=	6.626E-01 BILLION	
79	ANT KLYSTRON COST	=	4.385E-01 BILLION	
80	ANT CONTROL CKTS COST	=	1.653E-01 BILLION	
81	ANT PWR DISTR COST	=	1.389E-01 BILLION	
82	ANT PWR PROC&TC COST	=	2.433E-01 BILLION	
83	ANT COST	=	2.048E+00 BILLION	
84	NO OF FREIGHT FLIGHTS	=	2.818E+02	
85	CREW SERVICE NO OF FLTS	=	1.610E+01	
86	OTS COST	=	7.559E-01 BILLION	
87	TOTAL TRANSP COST	=	5.817E+00 BILLION	
88	RECTENNA COST	=	2.266E+00 BILLION	
89	CONSTRUCTION COST	=	9.660E-01 BILLION	
90	INTEREST DURING CONSTR	=	1.085E+00 BILLION	
91	LATITUDE AREA FACTOR	=	1.419E+00	
92	TOTAL MASS	=	8.050E+04 TONS	(1.775E+08 LBM)
93	TOTAL COST	=	1.737E+01 BILLION	
94	COST/KWE	=	2.382E+03 $	
95	COST/KWH	=	4.427E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 5980 Megawatts

ANTENNA DIAMETER VALUE = 1.800E+00

SOLUTION RESULTS

1 LIGHT INPUT EFFICIENCY	=	8.579E-01		
2 NET CELL EFFICIENCY	=	1.401E-01		
3 BAS´ CONVERSION EFFY	=	1.360E-01		
4 BL. KET FACTORS	=	9.399E-01		
5 BUS I-SQ-R	=	9.585E-01		
6 NET ENERGY CONV EFFY	=	1.225E-01		
7 AREAWISE EFFICIENCY	=	9.367E-01		
8 ANTENNA POWER DISTR EFFY	=	9.851E-01		
9 NET DC-RF EFFICIENCY	=	8.248E-01		
10 IDEAL BEAM EFFICIENCY	=	9.789E-01		
11 NET BEAM EFFICIENCY	=	9.084E-01		
12 INTERCEPT EFFICIENCY	=	9.676E-01		
13 RECTENNA RF-DC EFFICIENC	=	8.974E-01		
14 NET RF LINK EFFY	=	8.615E-01		
15 DC-TO-DC EFFICIENCY	=	6.376E-01		
16 DC-TO-GRID EFFICIENCY	=	6.185E-01		
17 OVERALL PHYSICAL EFFY	=	7.576E-02		
18 AREA EFFECTIVE EFFY	=	7.096E-02		
19 BLANKET AREA	=	7.218E+07	M2	(1.783E+04 ACRES)
20 ANTENNA DIA	=	1.800E+00	KM	(1.119E+00 MI)
21 REQUIRED SIDELOBE SUPPR	=	2.680E+01	DB	
22 TAPER REQUIRED FOR SL SU	=	1.267E+01	DB	
23 TRANSMITTER POWER TAPER	=	1.267E+01	DB	
24 RECEIVER AVG/PEAK RATIO	=	1.942E-01		
25 XMTR AVG/PEAK RATIO	=	3.236E-01		
26 BEAM SPREAD FACTOR	=	1.551E+00		
27 RADIATED RF POWER	=	4.933E+03	MEGAWATT	
28 BEAM DIAMETER	=	7.829E+00	KM	(4.865E+00 MI)
29 BEAM AREA	=	4.814E+07	M2	(1.190E+04 ACRES)
30 AVERAGE BEAM POWER DENS	=	9.298E+00	MW/CM2	
31 PEAK BEAM INTENSITY	=	4.786E+01	MW/CM2	
32 POWER IN MAIN BEAM	=	4.481E+03	MEGAWATT	
33 SATELLITE LENGTH	=	2.[illegible]03E+01	BAYS	
34 NUMBER OF BAYS	=	1.762E+02	BAYS	
35 XMTR PWR DISTR LOSS	=	1.492E-02		
36 ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37 BAY SIZE	=	6.600E+02	METERS	
38 SPS AREA	=	7.705E+01	KM2	
39 MEAN SOLAR INSOLATION	=	1.043E+02	GW	
40 SOLAR CELL OUTPUT	=	1.248E+01	GW	
41 ROTARY JOINT CURRENT "A"	=	9.562E+04	AMPS	
42 ROTARY JOINT CURRENT "B"	=	5.616E+04	AMPS	
43 TOTAL PROCESSED POWER	=	1.794E+03	MEGAWATT	
44 TOTAL KLYSTRON INPUT	=	1.178E+04	MEGAWATT	
45 TOTAL KLYSTRON OUTPUT	=	1.002E+04	MEGAWATT	
46 NUMBER OF KLYSTRONS	=	1.391E+05		
47 MAX KLYSTRON PACKING DEN	=	8.995E+00	PER SUB	
48 MAX RF POWER DENSITY	=	5.988E+00	KW/M2	
49 NUMBER OF SUBARRAYS	=	2.353E+04	PER ANT	
50 RECTENNA AREA	=	2.708E+07	M2	(6.691E+03 ACRES)

Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.181E+00 KW/M2			
52	DC OUTPUT POWER	=	3.813E+00 GW/LINK			
53	GRID POWER	=	7.395E+00 GW TOTAL			
54	LAND AREA PER RECT	=	6.825E+07 M2	(	1.688E+04 ACRES	)
55	"Y" MOM OF INERTIA	=	8.238E+13 KG-M2			
56	THRUST PER CORNER	=	6.278E+01 NEWTONS	(	1.411E+01 LB	)
57	NUMBER OF THRUSTERS	=	6.278E+01 PER INST			
58	CONTROL POWER	=	7.980E+01 MEGAWATT			
59	ANNUAL PROPELLANT	=	2.572E+01 TONS	(	5.671E+04 LBM	)
60	STRUCTURE MASS	=	4.045E+03 TONS	(	8.918E+06 LBM	)
61	CONTROL SYS MASS	=	1.402E+02 TONS	(	3.091E+05 LBM	)
62	SOLAR BLANKET MASS	=	3.082E+04 TONS	(	6.794E+07 LBM	)
63	POWER DISTR MASS	=	1.227E+03 TONS	(	2.705E+06 LBM	)
64	MECH & ELEC R/J MASS	=	1.456E+02 TONS	(	3.209E+05 LBM	)
65	ANT STRUC MASS	=	1.620E+03 TONS	(	3.571E+06 LBM	)
66	ANT WAVEGUIDE MASS	=	1.398E+04 TONS	(	3.081E+07 LBM	)
67	ANT KLYSTRON MASS	=	9.668E+03 TONS	(	2.131E+07 LBM	)
68	ANT CONTROL CKTS MASS	=	7.512E+02 TONS	(	1.656E+06 LBM	)
69	ANT PWR DISTR MASS	=	1.780E+03 TONS	(	3.924E+06 LBM	)
70	ANT PWR PROC&TC MASS	=	3.526E+03 TONS	(	7.773E+06 LBM	)
71	ANT MASS	=	3.132E+04 TONS	(	6.905E+07 LBM	)
72	STRUCTURE COST	=	2.023E-01 BILLION			
73	CONTROL SYS COST	=	6.310E-02 BILLION			
74	SOLAR BLANKET COST	=	2.526E+00 BILLION			
75	POWER DISTR COST	=	3.190E-02 BILLION			
76	MECH&ELEC R/J COST	=	3.057E-02 BILLION			
77	ANT STRUC COST	=	4.213E-01 BILLION			
78	ANT WAVEGUIDE COST	=	8.386E-01 BILLION			
79	ANT KLYSTRON COST	=	4.399E-01 BILLION			
80	ANT CONTROL CKTS COST	=	1.658E-01 BILLION			
81	ANT PWR DISTR COST	=	1.922E-01 BILLION			
82	ANT PWR PROC&TC COST	=	2.433E-01 BILLION			
83	ANT COST	=	2.301E+00 BILLION			
84	NO OF FREIGHT FLIGHTS	=	2.986E+02			
85	CREW SERVICE NO OF FLTS	=	1.706E+01			
86	OTS COST	=	8.010E-01 BILLION			
87	TOTAL TRANSP COST	=	6.086E+00 BILLION			
88	RECTENNA COST	=	1.948E+00 BILLION			
89	CONSTRUCTION COST	=	1.024E+00 BILLION			
90	INTEREST DURING CONSTR	=	1.110E+00 BILLION			
91	LATITUDE AREA FACTOR	=	1.419E+00			
92	TOTAL MASS	=	8.530E+04 TONS	(	1.881E+08 LBM	)
93	TOTAL COST	=	1.778E+01 BILLION			
94	COST/KWE	=	2.403E+03 $			
95	COST/KWH	=	4.466E+01 MILLS			

Table A1-1 (Continued)

Rotary Joint Power = 5980 Megawatts

ANTENNA DIAMETER VALUE = 2.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01	
2	NET CELL EFFICIENCY	=	1.601E-01	
3	BASIC CONVERSION EFFY	=	1.360E-01	
4	BLANKET FACTORS	=	9.399E-01	
5	BUS I-SQ-R	=	9.585E-01	
6	NET ENERGY CONV EFFY	=	1.225E-01	
7	AREAWISE EFFICIENCY	=	9.367E-01	
8	ANTENNA POWER DISTR EFFY	=	9.846E-01	
9	NET DC-RF EFFICIENCY	=	8.243E-01	
10	IDEAL BEAM EFFICIENCY	=	9.816E-01	
11	NET BEAM EFFICIENCY	=	9.110E-01	
12	INTERCEPT EFFICIENCY	=	9.726E-01	
13	RECTENNA RF-DC EFFICIENC	=	8.9[illegible]E-01	
14	NET RF LINK EFFY	=	8.6[illegible]E-01	
15	DC-TO-DC EFFICIENCY	=	6.430E-01	
16	DC-TO-GRID EFFICIENCY	=	6.237E-01	
17	OVERALL PHYSICAL EFFY	=	7.640E-02	
18	AREA EFFECTIVE EFFY	=	7.156E-02	
19	BLANKET AREA	=	7.218E+07 M2	(1.783E+04 ACRES)
20	ANTENNA DIA	=	2.000E+00 KM	(1.243E+00 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.765E+01 DB	
22	TAPER REQUIRED FOR SL SU	=	1.330E+01 DB	
23	TRANSMITTER POWER TAPER	=	1.330E+01 DB	
24	RECEIVER AVG/PEAK RATIO	=	1.915E-01	
25	XMTR AVG/PEAK RATIO	=	3.117E-01	
26	BEAM SPREAD FACTOR	=	1.576E+00	
27	RADIATED RF POWER	=	4.930E+03 MEGAWATT	
28	BEAM DIAMETER	=	7.164E+00 KM	(4.452E+00 MI)
29	BEAM AREA	=	4.031E+07 M2	(9.960E+03 ACRES)
30	AVERAGE BEAM POWER DENS	=	1.114E+01 MW/CM2	
31	PEAK BEAM INTENSITY	=	5.817E+01 MW/CM2	
32	POWER IN MAIN BEAM	=	4.491E+03 MEGAWATT	
33	SATELLITE LENGTH	=	2.203E+01 BAYS	
34	NUMBER OF BAYS	=	1.762E+02 BAYS	
35	XMTR PWR DISTR LOSS	=	1.543E-02	
36	ADJ BAY USEFUL AREA	=	4.096E+05 M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02 METERS	
38	SPS AREA	=	7.705E+01 KM2	
39	MEAN SOLAR INSOLATION	=	1.643E+02 GW	
40	SOLAR CELL OUTPUT	=	1.248E+01 GW	
41	ROTARY JOINT CURRENT "A"	=	9.567E+04 AMPS	
42	ROTARY JOINT CURRENT "B"	=	5.619E+04 AMPS	
43	TOTAL PROCESSED POWER	=	1.794E+03 MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.178E+04 MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	1.001E+04 MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.390E+05	
47	MAX KLYSTRON PACKING DEN	=	7.564E+00 PER SUB	
48	MAX RF POWER DENSITY	=	5.035E+00 KW/M2	
49	NUMBER OF SUBARRAYS	=	2.905E+04 PER ANT	
50	RECTENNA AREA	=	2.267E+07 M2	(5.602E+03 ACRES)

Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	9.963E-01 KW/M2	
52	DC OUTPUT POWER	=	3.846E+00 GW/LINK	
53	GRID POWER	=	7.460E+00 GW TOTAL	
54	LAND AREA PER RECT	=	5.718E+07 M2	(1.413E+04 ACRES)
55	"Y" MOM OF INERTIA	=	8.238E+13 KG-M2	
56	THRUST PER CORNER	=	6.278E+01 NEWTONS	(1.411E+01 LB)
57	NUMBER OF THRUSTERS	=	6.278E+01 PER INST	
58	CONTROL POWER	=	7.880E+01 MEGAWATT	
59	ANNUAL PROPELLANT	=	2.572E+01 TONS	(5.671E+04 LBM)
60	STRUCTURE MASS	=	4.045E+03 TONS	(8.918E+06 LBM)
61	CONTROL SYS MASS	=	1.402E+02 TONS	(3.091E+05 LBM)
62	SOLAR BLANKET MASS	=	3.082E+04 TONS	(6.794E+07 LBM)
63	POWER DISTR MASS	=	1.228E+03 TONS	(2.707E+06 LBM)
64	MECH & ELEC R/J MASS	=	1.590E+02 TONS	(3.504E+05 LBM)
65	ANT STRUC MASS	=	2.000E+03 TONS	(4.409E+06 LBM)
66	ANT WAVEGUIDE MASS	=	1.726E+04 TONS	(3.804E+07 LBM)
67	ANT KLYSTRON MASS	=	9.663E+03 TONS	(2.130E+07 LBM)
68	ANT CONTROL CKTS MASS	=	7.508E+02 TONS	(1.655E+06 LBM)
69	ANT PWR DISTR MASS	=	2.123E+03 TONS	(4.680E+06 LBM)
70	ANT PWR PROC&TC MASS	=	3.526E+03 TONS	(7.773E+06 LBM)
71	ANT MASS	=	3.532E+04 TONS	(7.786E+07 LBM)
72	STRUCTURE COST	=	2.023E-01 BILLION	
73	CONTROL SYS COST	=	6.310E-02 BILLION	
74	SOLAR BLANKET COST	=	2.526E+00 BILLION	
75	POWER DISTR COST	=	3.192E-02 BILLION	
76	MECH&ELEC R/J COST	=	3.338E-02 BILLION	
77	ANT STRUC COST	=	4.460E-01 BILLION	
78	ANT WAVEGUIDE COST	=	1.035E+00 BILLION	
79	ANT KLYSTRON COST	=	4.396E-01 BILLION	
80	ANT CONTROL CKTS COST	=	1.657E-01 BILLION	
81	ANT PWR DISTR COST	=	2.293E-01 BILLION	
82	ANT PWR PROC&TC COST	=	2.433E-01 BILLION	
83	ANT COST	=	2.559E+00 BILLION	
84	NO OF FREIGHT FLIGHTS	=	3.162E+02	
85	CREW SERVICE NO OF FLTS	=	1.807E+01	
86	OTS COST	=	8.484E-01 BILLION	
87	TOTAL TRANSP COST	=	6.365E+00 BILLION	
88	RECTENNA COST	=	1.708E+00 BILLION	
89	CONSTRUCTION COST	=	1.084E+00 BILLION	
90	INTEREST DURING CONSTR	=	1.143E+00 BILLION	
91	LATITUDE AREA FACTOR	=	1.419E+00	
92	TOTAL MASS	=	9.035E+04 TONS	(1.992E+08 LBM)
93	TOTAL COST	=	1.829E+01 BILLION	
94	COST/KWE	=	2.451E+03 $	
95	COST/KWH	=	4.557E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 7262 Megawatts

ANTENNA DIAMETER VALUE = 1.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.491E-01		
6	NET ENERGY CONV EFFY	=	1.213E-01		
7	AREAWISE EFFICIENCY	=	9.369E-01		
8	ANTENNA POWER DISTR EFFY	=	9.747E-01		
9	NET DC-RF EFFICIENCY	=	8.161E-01		
10	IDEAL BEAM EFFICIENCY	=	9.650E-01		
11	NET BEAM EFFICIENCY	=	8.955E-01		
12	INTERCEPT EFFICIENCY	=	9.512E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.922E-01		
14	NET RF LINK EFFY	=	8.348E-01		
15	DC-TO-DC EFFICIENCY	=	6.079E-01		
16	DC-TO-GRID EFFICIENCY	=	5.897E-01		
17	OVERALL PHYSICAL EFFY	=	7.152E-02		
18	AREA EFFECTIVE EFFY	=	6.700E-02		
19	BLANKET AREA	=	8.851E+07	M2	(2.187E+04 ACRES)
20	ANTENNA DIA	=	1.000E+00	KM	(6.214E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.276E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	8.361E+00	DB	
23	TRANSMITTER POWER TAPER	=	1.000E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25	XMTR AVG/PEAK RATIO	=	3.909E-01		
26	BEAM SPREAD FACTOR	=	1.450E+00		
27	RADIATED RF POWER	=	5.927E+03	MEGAWATT	
28	BEAM DIAMETER	=	1.318E+01	KM	(8.189E+00 MI)
29	BEAM AREA	=	1.364E+08	M2	(3.370E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	3.896E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	1.883E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	5.308E+03	MEGAWATT	
33	SATELLITE LENGTH	=	2.701E+01	BAYS	
34	NUMBER OF BAYS	=	2.161E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	2.528E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	9.447E+01	KM2	
39	MEAN SOLAR INSOLATION	=	1.278E+02	GW	
40	SOLAR CELL OUTPUT	=	1.530E+01	GW	
41	ROTARY JOINT CURRENT "A"	=	1.173E+05	AMPS	
42	ROTARY JOINT CURRENT "B"	=	6.892E+04	AMPS	
43	TOTAL PROCESSED POWER	=	2.179E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.416E+04	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	1.203E+04	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.671E+05		
47	MAX KLYSTRON PACKING DEN	=	2.900E+01	PER SUB	
48	MAX RF POWER DENSITY	=	1.930E+01	KW/M2	
49	NUMBER OF SUBARRAYS	=	7.261E+03	PER ANT	
50	RECTENNA AREA	=	7.672E+07	M2	(1.896E+04 ACRES)

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Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	4.057E+00 KW/M2				
52 DC OUTPUT POWER	=	4.415E+00 GW/LINK				
53 GRID POWER	=	8.565E+00 GW TOTAL				
54 LAND AREA PER RECT	=	1.935E+08 M2	(	4.781E+04 ACRES	)
55 "Y" MOM OF INERTIA	=	1.010E+14 KG-M2			
56 THRUST PER CORNER	=	7.699E+01 NEWTONS	(	1.731E+01 LB	)
57 NUMBER OF THRUSTERS	=	7.699E+01 PER INST			
58 CONTROL POWER	=	9.663E+01 MEGAWATT			
59 ANNUAL PROPELLANT	=	3.154E+01 TONS	(	6.954E+04 LBM	)
60 STRUCTURE MASS	=	4.960E+03 TONS	(	1.093E+07 LBM	)
61 CONTROL SYS MASS	=	1.719E+02 TONS	(	3.791E+05 LBM	)
62 SOLAR BLANKET MASS	=	3.779E+04 TONS	(	8.332E+07 LBM	)
63 POWER DISTR MASS	=	1.847E+03 TONS	(	4.071E+06 LBM	)
64 MECH & ELEC R/J MASS	=	9.761E+01 TONS	(	2.152E+05 LBM	)
65 ANT STRUC MASS	=	5.000E+02 TONS	(	1.102E+06 LBM	)
66 ANT WAVEGUIDE MASS	=	4.314E+03 TONS	(	9.511E+06 LBM	)
67 ANT KLYSTRON MASS	=	1.162E+04 TONS	(	2.561E+07 LBM	)
68 ANT CONTROL CKTS MASS	=	9.025E+02 TONS	(	1.990E+06 LBM	)
69 ANT PWR DISTR MASS	=	7.686E+02 TONS	(	1.695E+06 LBM	)
70 ANT PWR PROC&TC MASS	=	4.281E+03 TONS	(	9.438E+06 LBM	)
71 ANT MASS	=	2.238E+04 TONS	(	4.934E+07 LBM	)
72 STRUCTURE COST	=	2.430E-01 BILLION			
73 CONTROL SYS COST	=	7.737E-02 BILLION			
74 SOLAR BLANKET COST	=	3.098E+00 BILLION			
75 POWER DISTR COST	=	4.801E-02 BILLION			
76 MECH&ELEC R/J COST	=	2.050E-02 BILLION			
77 ANT STRUC COST	=	3.485E-01 BILLION			
78 ANT WAVEGUIDE COST	=	2.588E-01 BILLION			
79 ANT KLYSTRON COST	=	5.285E-01 BILLION			
80 ANT CONTROL CKTS COST	=	1.992E-01 BILLION			
81 ANT PWR DISTR COST	=	8.301E-02 BILLION			
82 ANT PWR PROC&TC COST	=	2.954E-01 BILLION			
83 ANT COST	=	1.713E+00 BILLION			
84 NO OF FREIGHT FLIGHTS	=	2.966E+02			
85 CREW SERVICE NO OF FLTS	=	1.695E+01			
86 OTS COST	=	7.957E-01 BILLION			
87 TOTAL TRANSP COST	=	6.054E+00 BILLION			
88 RECTENNA COST	=	4.740E+00 BILLION			
89 CONSTRUCTION COST	=	1.017E+00 BILLION			
90 INTEREST DURING CONSTR	=	1.298E+00 BILLION			
91 LATITUDE AREA FACTOR	=	1.419E+00			
92 TOTAL MASS	=	8.474E+04 TONS	(	1.868E+08 LBM	)
93 TOTAL COST	=	2.077E+01 BILLION			
94 COST/KWE	=	2.425E+03 $			
95 COST/KWH	=	4.507E+01 MILLS			

Table A1-1 (Continued)
Rotary Joint Power = 7262 Megawatts

ANTENNA DIAMETER VALUE = 1.200E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.491E-01		
6	NET ENERGY CONV EFFY	=	1.213E-01		
7	AREAWISE EFFICIENCY	=	9.369E-02		
8	ANTENNA POWER DISTR EFFY	=	9.749E-01		
9	NET DC-RF EFFICIENCY	=	8.162E-01		
10	IDEAL BEAM EFFICIENCY	=	9.670E-01		
11	NET BEAM EFFICIENCY	=	8.974E-01		
12	INTERCEPT EFFICIENCY	=	9.526E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.923E-01		
14	NET RF LINK EFFY	=	8.378E-01		
15	DC-TO-DC EFFICIENCY	=	6.102E-01		
16	DC-TO-GRID EFFICIENCY	=	5.919E-01		
17	OVERALL PHYSICAL EFFY	=	7.179E-02		
18	AREA EFFECTIVE EFFY	=	6.726E-02		
19	BLANKET AREA	=	8.851E+07	M2	(2.187E+04 ACRES)
20	ANTENNA DIA	=	1.200E+00	KM	(7.457E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.431E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	1.036E+01	DB	
23	TRANSMITTER POWER TAPER	=	1.036E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	2.044E-01		
25	XMTR AVG/PEAK RATIO	=	3.800E-01		
26	BEAM SPREAD FACTOR	=	1.463E+00		
27	RADIATED RF POWER	=	5.928E+03	MEGAWATT	
28	BEAM DIAMETER	=	1.108E+01	KM	(6.883E+00 MI)
29	BEAM AREA	=	9.637E+07	M2	(2.381E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	5.514E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	2.698E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	5.320E+03	MEGAWATT	
33	SATELLITE LENGTH	=	2.701E+01	BAYS	
34	NUMBER OF BAYS	=	2.161E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	2.[illegible]03E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	9.447E+01	KM2	
39	MEAN SOLAR INSOLATION	=	1.273E+02	GW	
40	SOLAR CELL OUTPUT	=	1.530E+01	GW	
41	ROTARY JOINT CURRENT "A"	=	1.173E+05	AMPS	
42	ROTARY JOINT CURRENT "B"	=	6.891E+04	AMPS	
43	TOTAL PROCESSED POWER	=	2.179E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.416E+04	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	1.204E+04	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.672E+05		
47	MAX KLYSTRON PACKING DEN	=	2.072E+01	PER SUB	
48	MAX RF POWER DENSITY	=	1.379E+01	KW/M2	
49	NUMBER OF SUBARRAYS	=	1.046E+04	PER ANT	
50	RECTENNA AREA	=	5.421E+07	M2	(1.339E+04 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	2.895E+00	KW/M2	
52 DC OUTPUT POWER	=	4.431E+00	GW/LINK	
53 GRID POWER	=	8.597E+00	GW TOTAL	
54 LAND AREA PER RECT	=	1.367E+08	M2	(3.378E+04 ACRES)
55 "Y" MOM OF INERTIA	=	1.010E+14	KG-M2	
56 THRUST PER CORNER	=	7.699E+01	NEWTONS	(1.731E+01 LB)
57 NUMBER OF THRUSTERS	=	7.699E+01	PER INST	
58 CONTROL POWER	=	9.663E+01	MEGAWATT	
59 ANNUAL PROPELLANT	=	3.154E+01	TONS	(6.954E+04 LBM)
60 STRUCTURE MASS	=	4.960E+03	TONS	(1.093E+07 LBM)
61 CONTROL SYS MASS	=	1.719E+02	TONS	(3.791E+05 LBM)
62 SOLAR BLANKET MASS	=	3.779E+04	TONS	(8.332E+07 LBM)
63 POWER DISTR MASS	=	1.846E+03	TONS	(4.070E+06 LBM)
64 MECH & ELEC R/J MASS	=	1.110E+02	TONS	(2.447E+05 LBM)
65 ANT STRUC MASS	=	7.200E+02	TONS	(1.587E+06 LBM)
66 ANT WAVEGUIDE MASS	=	6.212E+03	TONS	(1.370E+07 LBM)
67 ANT KLYSTRON MASS	=	1.162E+04	TONS	(2.561E+07 LBM)
68 ANT CONTROL CKTS MASS	=	9.027E+02	TONS	(1.990E+06 LBM)
69 ANT PWR DISTR MASS	=	8.430E+02	TONS	(1.859E+06 LBM)
70 ANT PWR PROC&TC MASS	=	4.281E+03	TONS	(9.438E+06 LBM)
71 ANT MASS	=	2.458E+04	TONS	(5.418E+07 LBM)
72 STRUCTURE COST	=	2.480E-01	BILLION	
73 CONTROL SYS COST	=	7.737E-02	BILLION	
74 SOLAR BLANKET COST	=	3.098E+00	BILLION	
75 POWER DISTR COST	=	4.800E-02	BILLION	
76 MECH&ELEC R/J COST	=	2.331E-02	BILLION	
77 ANT STRUC COST	=	3.628E-01	BILLION	
78 ANT WAVEGUIDE COST	=	3.727E-01	BILLION	
79 ANT KLYSTRON COST	=	5.286E-01	BILLION	
80 ANT CONTROL CKTS COST	=	1.993E-01	BILLION	
81 ANT PWR DISTR COST	=	9.105E-02	BILLION	
82 ANT PWR PROC&TC COST	=	2.954E-01	BILLION	
83 ANT COST	=	1.850E+00	BILLION	
84 NO OF FREIGHT FLIGHTS	=	3.063E+02		
85 CREW SERVICE NO OF FLTS	=	1.750E+01		
86 OTS COST	=	8.218E-01	BILLION	
87 TOTAL TRANSP COST	=	6.209E+00	BILLION	
88 RECTENNA COST	=	3.502E+00	BILLION	
89 CONSTRUCTION COST	=	1.050E+00	BILLION	
90 INTEREST DURING CONSTR	=	1.241E+00	BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00		
92 TOTAL MASS	=	8.752E+04	TONS	(1.929E+08 LBM)
93 TOTAL COST	=	1.987E+01	BILLION	
94 COST/KWE	=	2.311E+03	$	
95 COST/KWH	=	4.295E+01	MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 7262 Megawatts

ANTENNA DIAMETER VALUE = 1.400E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01			
2	NET CELL EFFICIENCY	=	1.601E-01			
3	BASIC CONVERSION EFFY	=	1.360E-01			
4	BLANKET FACTORS	=	9.399E-01			
5	BUS I-SQ-R	=	9.491E-01			
6	NET ENERGY CONV EFFY	=	1.213E-01			
7	AREAWISE EFFICIENCY	=	9.369E-01			
8	ANTENNA POWER DISTR EFFY	=	9.748E-01			
9	NET DC-RF EFFICIENCY	=	8.161E-01			
10	IDEAL BEAM EFFICIENCY	=	9.737E-01			
11	NET BEAM EFFICIENCY	=	9.036E-01			
12	INTERCEPT EFFICIENCY	=	9.592E-01			
13	RECTENNA RF-DC EFFICIENC	=	8.960E-01			
14	NET RF LINK EFFY	=	8.496E-01			
15	DC-TO-DC EFFICIENCY	=	6.213E-01			
16	DC-TO-GRID EFFICIENCY	=	6.026E-01			
17	OVERALL PHYSICAL EFFY	=	7.309E-02			
18	AREA EFFECTIVE EFFY	=	6.848E-02			
19	BLANKET AREA	=	8.851E+07	M2	(	2.187E+04 ACRES)
20	ANTENNA DIA	=	1.400E+00	KM	(	8.700E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.552E+01	DB		
22	TAPER REQUIRED FOR SL SU	=	1.160E+01	DB		
23	TRANSMITTER POWER TAPER	=	1.161E+01	DB		
24	RECEIVER AVG/PEAK RATIO	=	1.987E-01			
25	XMTR AVG/PEAK RATIO	=	3.463E-01			
26	BEAM SPREAD FACTOR	=	1.509E+00			
27	RADIATED RF POWER	=	5.927E+03	MEGAWATT		
28	BEAM DIAMETER	=	9.794E+00	KM	(	6.086E+00 MI)
29	BEAM AREA	=	7.534E+07	M2	(	1.862E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	7.090E+00	MW/CM2		
31	PEAK BEAM INTENSITY	=	3.568E+01	MW/CM2		
32	POWER IN MAIN BEAM	=	5.356E+03	MEGAWATT		
33	SATELLITE LENGTH	=	2.701E+01	BAYS		
34	NUMBER OF BAYS	=	2.161E+02	BAYS		
35	XMTR PWR DISTR LOSS	=	2.522E-02			
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS		
38	SPS AREA	=	9.447E+01	KM2		
39	MEAN SOLAR INSOLATION	=	1.278E+02	GW		
40	SOLAR CELL OUTPUT	=	1.530E+01	GW		
41	ROTARY JOINT CURRENT "A"	=	1.173E+05	AMPS		
42	ROTARY JOINT CURRENT "B"	=	6.892E+04	AMPS		
43	TOTAL PROCESSED POWER	=	2.179E+03	MEGAWATT		
44	TOTAL KLYSTRON INPUT	=	1.416E+04	MEGAWATT		
45	TOTAL KLYSTRON OUTPUT	=	1.203E+04	MEGAWATT		
46	NUMBER OF KLYSTRONS	=	1.671E+05			
47	MAX KLYSTRON PACKING DEN	=	1.670E+01	PER SUB		
48	MAX RF POWER DENSITY	=	1.111E+01	KW/M2		
49	NUMBER OF SUBARRAYS	=	1.423E+04	PER ANT		
50	RECTENNA AREA	=	4.238E+07	M2	(	1.047E+04 ACRES)

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Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	2.335E+00 KW/M2			
52	DC OUTPUT POWER	=	4.512E+00 GW/LINK			
53	GRID POWER	=	8.753E+00 GW TOTAL			
54	LAND AREA PER RECT	=	1.069E+08 M2	(	2.641E+04 ACRES	)
55	"Y" MOM OF INERTIA	=	1.010E+14 KG-M2			
56	THRUST PER CORNER	=	7.699E+01 NEWTONS	(	1.731E+01 LB	)
57	NUMBER OF THRUSTERS	=	7.699E+01 PER INST			
58	CONTROL POWER	=	9.663E+01 MEGAWATT			
59	ANNUAL PROPELLANT	=	3.154E+01 TONS	(	6.954E+04 LBM	)
60	STRUCTURE MASS	=	4.960E+03 TONS	(	1.093E+07 LBM	)
61	CONTROL SYS MASS	=	1.719E+02 TONS	(	3.791E+05 LBM	)
62	SOLAR BLANKET MASS	=	3.779E+04 TONS	(	8.332E+07 LBM	)
63	POWER DISTR MASS	=	1.847E+03 TONS	(	4.071E+06 LBM	)
64	MECH & ELEC R/J MASS	=	1.244E+02 TONS	(	2.743E+05 LBM	)
65	ANT STRUC MASS	=	9.800E+02 TONS	(	2.161E+06 LBM	)
66	ANT WAVEGUIDE MASS	=	8.455E+03 TONS	(	1.864E+07 LBM	)
67	ANT KLYSTRON MASS	=	1.162E+04 TONS	(	2.561E+07 LBM	)
68	ANT CONTROL CKTS MASS	=	9.026E+02 TONS	(	1.990E+06 LBM	)
69	ANT PWR DISTR MASS	=	1.169E+03 TONS	(	2.577E+06 LBM	)
70	ANT PWR PROC&TC MASS	=	4.281E+03 TONS	(	9.438E+06 LBM	)
71	ANT MASS	=	2.740E+04 TONS	(	6.042E+07 LBM	)
72	STRUCTURE COST	=	2.480E-01 BILLION			
73	CONTROL SYS COST	=	7.737E-02 BILLION			
74	SOLAR BLANKET COST	=	3.098E+00 BILLION			
75	POWER DISTR COST	=	4.801E-02 BILLION			
76	MECH&ELEC R/J COST	=	2.613E-02 BILLION			
77	ANT STRUC COST	=	3.797E-01 BILLION			
78	ANT WAVEGUIDE COST	=	5.073E-01 BILLION			
79	ANT KLYSTRON COST	=	5.285E-01 BILLION			
80	ANT CONTROL CKTS COST	=	1.992E-01 BILLION			
81	ANT PWR DISTR COST	=	1.262E-01 BILLION			
82	ANT PWR PROC&TC COST	=	2.954E-01 BILLION			
83	ANT COST	=	2.036E+00 BILLION			
84	NO OF FREIGHT FLIGHTS	=	3.188E+02			
85	CREW SERVICE NO OF FLTS	=	1.822E+01			
86	OTS COST	=	8.554E-01 BILLION			
87	TOTAL TRANSP COST	=	6.406E+00 BILLION			
88	RECTENNA COST	=	2.857E+00 BILLION			
89	CONSTRUCTION COST	=	1.093E+00 BILLION			
90	INTEREST DURING CONSTR	=	1.233E+00 BILLION			
91	LATITUDE AREA FACTOR	=	1.419E+00			
92	TOTAL MASS	=	9.110E+04 TONS	(	2.008E+08 LBM	)
93	TOTAL COST	=	1.973E+01 BILLION			
94	COST/KWE	=	2.254E+03 $			
95	COST/KWH	=	4.189E+01 MILLS			

Table A1-1 (Continued)

Rotary Joint Power = 7262 Megawatts

ANTENNA DIAMETER VALUE = 1.600E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.491E-01		
6	NET ENERGY CONV EFFY	=	1.213E-01		
7	AREAWISE EFFICIENCY	=	9.369E-01		
8	ANTENNA POWER DISTR EFFY	=	9.758E-01		
9	NET DC-RF EFFICIENCY	=	8.170E-01		
10	IDEAL BEAM EFFICIENCY	=	9.781E-01		
11	NET BEAM EFFICIENCY	=	9.077E-01		
12	INTERCEPT EFFICIENCY	=	9.662E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.972E-01		
14	NET RF LINK EFFY	=	8.597E-01		
15	DC-TO-DC EFFICIENCY	=	6.301E-01		
16	DC-TO-GRID EFFICIENCY	=	6.112E-01		
17	OVERALL PHYSICAL EFFY	=	7.413E-02		
18	AREA EFFECTIVE EFFY	=	6.945E-02		
19	BLANKET AREA	=	8.851E+07	M2	(2.187E+04 ACRES)
20	ANTENNA DIA	=	1.600E+00	KM	(9.942E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.659E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	1.251E+01	DB	
23	TRANSMITTER POWER TAPER	=	1.251E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	1.949E-01		
25	XMTR AVG/PEAK RATIO	=	3.267E-01		
26	BEAM SPREAD FACTOR	=	1.544E+00		
27	RADIATED RF POWER	=	5.933E+03	MEGAWATT	
28	BEAM DIAMETER	=	8.772E+00	KM	(5.451E+00 MI)
29	BEAM AREA	=	6.043E+07	M2	(1.493E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	8.901E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	4.566E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	5.386E+03	MEGAWATT	
33	SATELLITE LENGTH	=	2.701E+01	BAYS	
34	NUMBER OF BAYS	=	2.161E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	2.421E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	9.447E+01	KM2	
39	MEAN SOLAR INSOLATION	=	1.278E+02	GW	
40	SOLAR CELL OUTPUT	=	1.530E+01	GW	
41	ROTARY JOINT CURRENT "A"	=	1.172E+05	AMPS	
42	ROTARY JOINT CURRENT "B"	=	6.884E+04	AMPS	
43	TOTAL PROCESSED POWER	=	2.179E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.417E+04	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	1.205E+04	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.673E+05		
47	MAX KLYSTRON PACKING DEN	=	1.356E+01	PER SUB	
48	MAX RF POWER DENSITY	=	9.029E+00	KW/M2	
49	NUMBER OF SUBARRAYS	=	1.859E+04	PER ANT	
50	RECTENNA AREA	=	3.399E+07	M2	(8.400E+03 ACRES)

Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.885E+00	KW/M2	
52	DC OUTPUT POWER	=	4.576E+00	GW/LINK	
53	GRID POWER	=	8.877E+00	GW TOTAL	
54	LAND AREA PER RECT	=	8.573E+07	M2	(2.118E+04 ACRES)
55	"Y" MOM OF INERTIA	=	1.010E+14	KG-M2	
56	THRUST PER CORNER	=	7.699E+01	NEWTONS	(1.731E+01 LB)
57	NUMBER OF THRUSTERS	=	7.699E+01	PER INST	
58	CONTROL POWER	=	9.663E+01	MEGAWATT	
59	ANNUAL PROPELLANT	=	3.154E+01	TONS	(6.954E+04 LBM)
60	STRUCTURE MASS	=	4.960E+03	TONS	(1.093E+07 LBM)
61	CONTROL SYS MASS	=	1.719E+02	TONS	(3.791E+05 LBM)
62	SOLAR BLANKET MASS	=	3.779E+04	TONS	(8.332E+07 LBM)
63	POWER DISTR MASS	=	1.845E+03	TONS	(4.067E+06 LBM)
64	MECH & ELEC R/J MASS	=	1.378E+02	TONS	(3.038E+05 LBM)
65	ANT STRUC MASS	=	1.280E+03	TONS	(2.822E+06 LBM)
66	ANT WAVEGUIDE MASS	=	1.104E+04	TONS	(2.435E+07 LBM)
67	ANT KLYSTRON MASS	=	1.163E+04	TONS	(2.564E+07 LBM)
68	ANT CONTROL CKTS MASS	=	9.035E+02	TONS	(1.992E+06 LBM)
69	ANT PWR DISTR MASS	=	1.396E+03	TONS	(3.079E+06 LBM)
70	ANT PWR PROC&ATC MASS	=	4.281E+03	TONS	(9.438E+06 LBM)
71	ANT MASS	=	3.053E+04	TONS	(6.731E+07 LBM)
72	STRUCTURE COST	=	2.450E-01	BILLION	
73	CONTROL SYS COST	=	7.737E-02	BILLION	
74	SOLAR BLANKET COST	=	3.098E+00	BILLION	
75	POWER DISTR COST	=	4.796E-02	BILLION	
76	MECH&ELEC R/J COST	=	2.894E-02	BILLION	
77	ANT STRUC COST	=	3.992E-01	BILLION	
78	ANT WAVEGUIDE COST	=	6.626E-01	BILLION	
79	ANT KLYSTRON COST	=	5.291E-01	BILLION	
80	ANT CONTROL CKTS COST	=	1.994E-01	BILLION	
81	ANT PWR DISTR COST	=	1.508E-01	BILLION	
82	ANT PWR PROC&TC COST	=	2.954E-01	BILLION	
83	ANT COST	=	2.237E+00	BILLION	
84	NO OF FREIGHT FLIGHTS	=	3.327E+02		
85	CREW SERVICE NO OF FLTS	=	1.901E+01		
86	OTS COST	=	8.926E-01	BILLION	
87	TOTAL TRANSP COST	=	6.622E+00	BILLION	
88	RECTENNA COST	=	2.400E+00	BILLION	
89	CONSTRUCTION COST	=	1.141E+00	BILLION	
90	INTEREST DURING CONSTR	=	1.239E+00	BILLION	
91	LATITUDE AREA FACTOR	=	1.419E+00		
92	TOTAL MASS	=	9.506E+04	TONS	(2.096E+08 LBM)
93	TOTAL COST	=	1.984E+01	BILLION	
94	COST/KWE	=	2.235E+03	$	
95	COST/KWH	=	4.154E+01	MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 7262 Megawatts

ANTENNA DIAMETER VALUE = 1.800E+00

SOLUTION RESULTS

1 LIGHT INPUT EFFICIENCY	=	8.579E-01	
2 NET CELL EFFICIENCY	=	1.601E-01	
3 BASIC CONVERSION EFFY	=	1.360E-01	
4 BLANKET FACTORS	=	9.399E-01	
5 BUS I-SQ-R	=	9.491E-01	
6 NET ENERGY CONV EFFY	=	1.213E-01	
7 AREAWISE EFFICIENCY	=	9.369E-01	
8 ANTENNA POWER DISTR EFFY	=	9.792E-01	
9 NET DC-RF EFFICIENCY	=	8.198E-01	
10 IDEAL BEAM EFFICIENCY	=	9.813E-01	
11 NET BEAM EFFICIENCY	=	9.107E-01	
12 INTERCEPT EFFICIENCY	=	9.721E-01	
13 RECTENNA RF-DC EFFICIENC	=	8.982E-01	
14 NET RF LINK EFFY	=	8.677E-01	
15 DC-TO-DC EFFICIENCY	=	6.389E-01	
16 DC-TO-GRID EFFICIENCY	=	6.193E-01	
17 OVERALL PHYSICAL EFFY	=	7.517E-02	
18 AREA EFFECTIVE EFFY	=	7.042E-02	
19 BLANKET AREA	=	8.851E+07 M2	(2.187E+04 ACRES)
20 ANTENNA DIA	=	1.800E+00 KM	(1.119E+00 MI)
21 REQUIRED SIDELOBE SUPPR	=	2.756E+01 DB	
22 TAPER REQUIRED FOR SL SU	=	1.324E+01 DB	
23 TRANSMITTER POWER TAPER	=	1.324E+01 DB	
24 RECEIVER AVG/PEAK RATIO	=	1.918E-01	
25 XMTR AVG/PEAK RATIO	=	3.129E-01	
26 BEAM SPREAD FACTOR	=	1.574E+00	
27 RADIATED RF POWER	=	5.954E+03 MEGAWATT	
28 BEAM DIAMETER	=	7.946E+00 KM	(4.938E+00 MI)
29 BEAM AREA	=	4.959E+07 M2	(1.225E+04 ACRES)
30 AVERAGE BEAM POWER DENS	=	1.093E+01 MW/CM2	
31 PEAK BEAM INTENSITY	=	5.698E+01 MW/CM2	
32 POWER IN MAIN BEAM	=	5.422E+03 MEGAWATT	
33 SATELLITE LENGTH	=	2.701E+01 BAYS	
34 NUMBER OF BAYS	=	2.161E+02 BAYS	
35 XMTR PWR DISTR LOSS	=	2.081E-02	
36 ADJ BAY USEFUL AREA	=	4.096E+05 M2	(1.012E+02 ACRES)
37 BAY SIZE	=	6.600E+02 METERS	
38 SPS AREA	=	9.447E+01 KM2	
39 MEAN SOLAR INSOLATION	=	1.278E+02 GW	
40 SOLAR CELL OUTPUT	=	1.530E+01 GW	
41 ROTARY JOINT CURRENT "A"	=	1.168E+05 AMPS	
42 ROTARY JOINT CURRENT "B"	=	6.860E+04 AMPS	
43 TOTAL PROCESSED POWER	=	2.179E+03 MEGAWATT	
44 TOTAL KLYSTRON INPUT	=	1.422E+04 MEGAWATT	
45 TOTAL KLYSTRON OUTPUT	=	1.209E+04 MEGAWATT	
46 NUMBER OF KLYSTRONS	=	1.679E+05	
47 MAX KLYSTRON PACKING DEN	=	1.123E+01 PER SUB	
48 MAX RF POWER DENSITY	=	7.477E+00 KW/M2	
49 NUMBER OF SUBARRAYS	=	2.353E+04 PER ANT	
50 RECTENNA AREA	=	2.789E+07 M2	(6.893E+03 ACRES)

Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.529E+00 KW/M2	
52	DC OUTPUT POWER	=	4.640E+00 GW/LINK	
53	GRID POWER	=	9.002E+00 GW TOTAL	
54	LAND AREA PER RECT	=	7.034E+07 M2	(1.738E+04 ACRES)
55	"V" MOM OF INERTIA	=	1.010E+14 KG-M2	
56	THRUST PER CORNER	=	7.699E+01 NEWTONS	(1.731E+01 LB)
57	NUMBER OF THRUSTERS	=	7.699E+01 PER INST	
58	CONTROL POWER	=	9.663E+01 MEGAWATT	
59	ANNUAL PROPELLANT	=	3.154E+01 TONS	(6.954E+04 LBM)
60	STRUCTURE MASS	=	4.960E+03 TONS	(1.093E+07 LBM)
61	CONTROL SYS MASS	=	1.719E+02 TONS	(3.791E+05 LBM)
62	SOLAR BLANKET MASS	=	3.779E+04 TONS	(8.332E+07 LBM)
63	POWER DISTR MASS	=	1.838E+03 TONS	(4.052E+06 LBM)
64	MECH & ELEC R/J MASS	=	1.512E+02 TONS	(3.334E+05 LBM)
65	ANT STRUC MASS	=	1.620E+03 TONS	(3.571E+06 LBM)
66	ANT WAVEGUIDE MASS	=	1.398E+04 TONS	(3.081E+07 LBM)
67	ANT KLYSTRON MASS	=	1.167E+04 TONS	(2.573E+07 LBM)
68	ANT CONTROL CKTS MASS	=	9.067E+02 TONS	(1.999E+06 LBM)
69	ANT PWR DISTR MASS	=	1.917E+03 TONS	(4.226E+06 LBM)
70	ANT PWR PROC&TC MASS	=	4.281E+03 TONS	(9.438E+06 LBM)
71	ANT MASS	=	3.437E+04 TONS	(7.578E+07 LBM)
72	STRUCTURE COST	=	2.480E-01 BILLION	
73	CONTROL SYS COST	=	7.737E-02 BILLION	
74	SOLAR BLANKET COST	=	3.098E+00 BILLION	
75	POWER DISTR COST	=	4.779E-02 BILLION	
76	MECH&ELEC R/J COST	=	3.175E-02 BILLION	
77	ANT STRUC COST	=	4.213E-01 BILLION	
78	ANT WAVEGUIDE COST	=	8.386E-01 BILLION	
79	ANT KLYSTRON COST	=	5.309E-01 BILLION	
80	ANT CONTROL CKTS COST	=	2.001E-01 BILLION	
81	ANT PWR DISTR COST	=	2.070E-01 BILLION	
82	ANT PWR PROC&TC COST	=	2.954E-01 BILLION	
83	ANT COST	=	2.493E+00 BILLION	
84	NO OF FREIGHT FLIGHTS	=	3.497E+02	
85	CREW SERVICE NO OF FLTS	=	1.998E+01	
86	OTS COST	=	9.381E-01 BILLION	
87	TOTAL TRANSP COST	=	6.884E+00 BILLION	
88	RECTENNA COST	=	2.070E+00 BILLION	
89	CONSTRUCTION COST	=	1.199E+00 BILLION	
90	INTEREST DURING CONSTR	=	1.264E+00 BILLION	
91	LATITUDE AREA FACTOR	=	1.419E+00	
92	TOTAL MASS	=	9.990E+04 TONS	(2.202E+08 LBM)
93	TOTAL COST	=	2.023E+01 BILLION	
94	COST/KWE	=	2.247E+03 $	
95	COST/KWH	=	4.177E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 7262 Megawatts

ANTENNA DIAMETER VALUE = 2.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01				
2	NET CELL EFFICIENCY	=	1.601E-01				
3	BASIC CONVERSION EFFY	=	1.360E-01				
4	BLANKET FACTORS	=	9.399E-01				
5	BUS I-SQ-R	=	9.491E-01				
6	NET ENERGY CONV EFFY	=	1.213E-01				
7	AREAWISE EFFICIENCY	=	9.359E-01				
8	ANTENNA POWER DISTR EFFY	=	9.790E-01				
9	NET DC-RF EFFICIENCY	=	8.197E-01				
10	IDEAL BEAM EFFICIENCY	=	9.839E-01				
11	NET BEAM EFFICIENCY	=	9.131E-01				
12	INTERCEPT EFFICIENCY	=	9.765E-01				
13	RECTENNA RF-DC EFFICIENC	=	8.984E-01				
14	NET RF LINK EFFY	=	8.738E-01				
15	DC-TO-DC EFFICIENCY	=	6.435E-01				
16	DC-TO-GRID EFFICIENCY	=	6.242E-01				
17	OVERALL PHYSICAL EFFY	=	7.571E-02				
18	AREA EFFECTIVE EFFY	=	7.093E-02				
19	BLANKET AREA	=	8.851E+07	M2	(	2.187E+04 ACRES	)
20	ANTENNA DIA	=	2.000E+00	KM	(	1.243E+00 MI	)
21	REQUIRED SIDELOBE SUPPR	=	2.841E+01	DB			
22	TAPER REQUIRED FOR SL SU	=	1.387E+01	DB			
23	TRANSMITTER POWER TAPER	=	1.387E+01	DB			
24	RECEIVER AVG/PEAK RATIO	=	1.886E-01				
25	XMTR AVG/PEAK RATIO	=	3.010E-01				
26	BEAM SPREAD FACTOR	=	1.600E+00				
27	RADIATED RF POWER	=	5.953E+03	MEGAWATT			
28	BEAM DIAMETER	=	7.272E+00	KM	(	4.519E+00 MI	)
29	BEAM AREA	=	4.154E+07	M2	(	1.026E+04 ACRES	)
30	AVERAGE BEAM POWER DENS	=	1.309E+01	MW/CM2			
31	PEAK BEAM INTENSITY	=	6.938E+01	MW/CM2			
32	POWER IN MAIN BEAM	=	5.436E+03	MEGAWATT			
33	SATELLITE LENGTH	=	2.701E+01	BAYS			
34	NUMBER OF BAYS	=	2.161E+02	BAYS			
35	XMTR PWR DISTR LOSS	=	2.095E-02				
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES	)
37	BAY SIZE	=	6.600E+02	METERS			
38	SPS AREA	=	9.447E+01	KM2			
39	MEAN SOLAR INSOLATION	=	1.278E+02	GW			
40	SOLAR CELL OUTPUT	=	1.530E+01	GW			
41	ROTARY JOINT CURRENT "A"	=	1.168E+05	AMPS			
42	ROTARY JOINT CURRENT "B"	=	6.861E+04	AMPS			
43	TOTAL PROCESSED POWER	=	2.179E+03	MEGAWATT			
44	TOTAL KLYSTRON INPUT	=	1.422E+04	MEGAWATT			
45	TOTAL KLYSTRON OUTPUT	=	1.209E+04	MEGAWATT			
46	NUMBER OF KLYSTRONS	=	1.679E+05				
47	MAX KLYSTRON PACKING DEN	=	9.456E+00	PER SUB			
48	MAX RF POWER DENSITY	=	6.295E+00	KW/M2			
49	NUMBER OF SUBARRAYS	=	2.905E+04	PER ANT			
50	RECTENNA AREA	=	2.336E+07	M2	(	5.773E+03 ACRES	)

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Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	1.289E+00 KW/M2	
52	DC OUTPUT POWER	=	4.673E+00 GW/LINK	
53	GRID POWER	=	9.066E+00 GW TOTAL	
54	LAND AREA PER RECT	=	5.892E+07 M2	(1.456E+04 ACRES)
55	"Y" MOM OF INERTIA	=	1.010E+14 KG-M2	
56	THRUST PER CORNER	=	7.699E+01 NEWTONS	(1.731E+01 LB)
57	NUMBER OF THRUSTERS	=	7.699E+01 PER INST	
58	CONTROL POWER	=	9.663E+01 MEGAWATT	
59	ANNUAL PROPELLANT	=	3.154E+01 TONS	(6.954E+04 LBM)
60	STRUCTURE MASS	=	4.960E+03 TONS	(1.093E+07 LBM)
61	CONTROL SYS MASS	=	1.719E+02 TONS	(3.791E+05 LBM)
62	SOLAR BLANKET MASS	=	3.779E+04 TONS	(8.332E+07 LBM)
63	POWER DISTR MASS	=	1.838E+03 TONS	(4.05[illegible]E+06 LBM)
64	MECH & ELEC R/J MASS	=	1.646E+02 TONS	(3.629E+05 LBM)
65	ANT STRUC MASS	=	2.000E+03 TONS	(4.409E+06 LBM)
66	ANT WAVEGUIDE MASS	=	1.726E+04 TONS	(3.804E+07 LBM)
67	ANT KLYSTRON MASS	=	1.167E+04 TONS	(2.572E+07 LBM)
68	ANT CONTROL CKTS MASS	=	9.066E+02 TONS	(1.999E+06 LBM)
69	ANT PWR DISTR MASS	=	2.276E+03 TONS	(5.017E+06 LBM)
70	ANT PWR PROC&TC MASS	=	4.281E+03 TONS	(9.438E+06 LBM)
71	ANT MASS	=	3.839E+04 TONS	(8.463E+07 LBM)
72	STRUCTURE COST	=	2.480E-01 BILLION	
73	CONTROL SYS COST	=	7.737E-02 BILLION	
74	SOLAR BLANKET COST	=	3.098E+00 BILLION	
75	POWER DISTR COST	=	4.780E-02 BILLION	
76	MECH&ELEC R/J COST	=	3.457E-02 BILLION	
77	ANT STRUC COST	=	4.460E-01 BILLION	
78	ANT WAVEGUIDE COST	=	1.035E+00 BILLION	
79	ANT KLYSTRON COST	=	5.308E-01 BILLION	
80	ANT CONTROL CKTS COST	=	2.001E-01 BILLION	
81	ANT PWR DISTR COST	=	2.458E-01 BILLION	
82	ANT PWR PROC&TC COST	=	2.954E-01 BILLION	
83	ANT COST	=	2.753E+00 BILLION	
84	NO OF FREIGHT FLIGHTS	=	3.674E+02	
85	CREW SERVICE NO OF FLTS	=	2.100E+01	
86	OTS COST	=	9.857E-01 BILLION	
87	TOTAL TRANSP COST	=	7.156E+00 BILLION	
88	RECTENNA COST	=	1.323E+00 BILLION	
89	CONSTRUCTION COST	=	1.260E+00 BILLION	
90	INTEREST DURING CONSTR	=	1.295E+00 BILLION	
91	LATITUDE AREA FACTOR	=	1.419E+00	
92	TOTAL MASS	=	1.050E+05 TONS	(2.314E+08 LBM)
93	TOTAL COST	=	2.073E+01 BILLION	
94	COST/KWE	=	2.286E+03 $	
95	COST/KWH	=	4.250E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 8544 Megawatts

ANTENNA DIAMETER VALUE = 1.000E+00

SOLUTION RESULTS

1 LIGHT INPUT EFFICIENCY	=	8.579E-01		
2 NET CELL EFFICIENCY	=	1.601E-01		
3 BASIC CONVERSION EFFY	=	1.360E-01		
4 BLANKET FACTORS	=	9.399E-01		
5 BUS I-SQ-R	=	9.395E-01		
6 NET ENERGY CONV EFFY	=	1.201E-01		
7 AREAWISE EFFICIENCY	=	9.370E-01		
8 ANTENNA POWER DISTR EFFY	=	9.689E-01		
9 NET DC-RF EFFICIENCY	=	8.112E-01		
10 IDEAL BEAM EFFICIENCY	=	9.650E-01		
11 NET BEAM EFFICIENCY	=	8.955E-01		
12 INTERCEPT EFFICIENCY	=	9.512E-01		
13 RECTENNA RF-DC EFFICIENC	=	8.926E-01		
14 NET RF LINK EFFY	=	6.348E-01		
15 DC-TO-DC EFFICIENCY	=	6.045E-01		
16 DC-TO-GRID EFFICIENCY	=	5.864E-01		
17 OVERALL PHYSICAL EFFY	=	7.040E-02		
18 AREA EFFECTIVE EFFY	=	6.597E-02		
19 BLANKET AREA	=	1.052E+08 M2	(	2.599E+04 ACRES)
20 ANTENNA DIA	=	1.000E+00 KM	(	6.214E-01 MI)
21 REQUIRED SIDELOBE SUPPR	=	2.344E+01 DB		
22 TAPER REQUIRED FOR SL SU	=	9.318E+00 DB		
23 TRANSMITTER POWER TAPER	=	1.000E+01 DB		
24 RECEIVER AVG/PEAK RATIO	=	2.061E-01		
25 XMTR AVG/PEAK RATIO	=	3.909E-01		
26 BEAM SPREAD FACTOR	=	1.450E+00		
27 RADIATED RF POWER	=	6.931E+03 MEGAWATT		
28 BEAM DIAMETER	=	1.318E+01 KM	(	8.189E+00 MI)
29 BEAM AREA	=	1.364E+08 M2	(	3.370E+04 ACRES)
30 AVERAGE BEAM POWER DENS	=	4.552E+00 MW/CM2		
31 PEAK BEAM INTENSITY	=	2.208E+01 MW/CM2		
32 POWER IN MAIN BEAM	=	6.207E+03 MEGAWATT		
33 SATELLITE LENGTH	=	3.210E+01 BAYS		
34 NUMBER OF BAYS	=	2.568E+02 BAYS		
35 XMTR PWR DISTR LOSS	=	3.107E-02		
36 ADJ BAY USEFUL AREA	=	4.096E+05 M2	(	1.012E+02 ACRES)
37 BAY SIZE	=	6.400E+02 METERS		
38 SPS AREA	=	1.123E+02 KM2		
39 MEAN SOLAR INSOLATION	=	1.519E+02 GW		
40 SOLAR CELL OUTPUT	=	1.819E+01 GW		
41 ROTARY JOINT CURRENT "A"	=	1.389E+05 AMPS		
42 ROTARY JOINT CURRENT "B"	=	8.157E+04 AMPS		
43 TOTAL PROCESSED POWER	=	2.563E+03 MEGAWATT		
44 TOTAL KLYSTRON INPUT	=	1.656E+04 MEGAWATT		
45 TOTAL KLYSTRON OUTPUT	=	1.407E+04 MEGAWATT		
46 NUMBER OF KLYSTRONS	=	1.955E+05		
47 MAX KLYSTRON PACKING DEN	=	3.391E+01 PER SUB		
48 MAX RF POWER DENSITY	=	2.258E+01 KW/M2		
49 NUMBER OF SUBARRAYS	=	7.261E+03 PER ANT		
50 RECTENNA AREA	=	7.672E+07 M2	(	1.896E+04 ACRES)

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Table A1-1 (Continued)

51	PEAK ANT THERMAL PWR	=	4.909E+00	KW/M2			
52	DC OUTPUT POWER	=	5.165E+00	GW/LINK			
53	GRID POWER	=	1.002E+01	GW TOTAL			
54	LAND AREA PER RECT	=	1.935E+08	M2	(	4.781E+04 ACRES	)
55	"V" MOM OF INERTIA	=	1.201E+14	KG-M2			
56	THRUST PER CORNER	=	9.150E+01	NEWTONS	(	2.057E+01 LB	)
57	NUMBER OF THRUSTERS	=	9.150E+01	PER INST			
58	CONTROL POWER	=	1.148E+02	MEGAWATT			
59	ANNUAL PROPELLANT	=	3.749E+01	TONS	(	8.265E+04 LBM	)
60	STRUCTURE MASS	=	5.894E+03	TONS	(	1.299E+07 LBM	)
61	CONTROL SYS MASS	=	2.043E+02	TONS	(	4.505E+05 LBM	)
62	SOLAR BLANKET MASS	=	4.492E+04	TONS	(	9.903E+07 LBM	)
63	POWER DISTR MASS	=	2.597E+03	TONS	(	5.726E+06 LBM	)
64	MECH & ELEC R/J MASS	=	1.034E+02	TONS	(	2.279E+05 LBM	)
65	ANT STRUC MASS	=	5.000E+02	TONS	(	1.102E+06 LBM	)
66	ANT WAVEGUIDE MASS	=	4.314E+03	TONS	(	9.511E+06 LBM	)
67	ANT KLYSTRON MASS	=	1.358E+04	TONS	(	2.995E+07 LBM	)
68	ANT CONTROL CKTS MASS	=	1.056E+03	TONS	(	2.327E+06 LBM	)
69	ANT PWR DISTR MASS	=	1.002E+03	TONS	(	2.209E+06 LBM	)
70	ANT PWR PROC&TC MASS	=	5.037E+03	TONS	(	1.110E+07 LBM	)
71	ANT MASS	=	2.549E+04	TONS	(	5.620E+07 LBM	)
72	STRUCTURE COST	=	2.947E-01	BILLION			
73	CONTROL SYS COST	=	9.196E-02	BILLION			
74	SOLAR BLANKET COST	=	3.682E+00	BILLION			
75	POWER DISTR COST	=	6.753E-02	BILLION			
76	MECH&ELEC R/J COST	=	2.171E-02	BILLION			
77	ANT STRUC COST	=	3.485E-01	BILLION			
78	ANT WAVEGUIDE COST	=	2.588E-01	BILLION			
79	ANT KLYSTRON COST	=	6.181E-01	BILLION			
80	ANT CONTROL CKTS COST	=	2.330E-01	BILLION			
81	ANT PWR DISTR COST	=	1.082E-01	BILLION			
82	ANT PWR PROC&TC COST	=	3.475E-01	BILLION			
83	ANT COST	=	1.914E+00	BILLION			
84	NO OF FREIGHT FLIGHTS	=	3.493E+02				
85	CREW SERVICE NO OF FLTS	=	1.996E+01				
86	OTS COST	=	9.372E-01	BILLION			
87	TOTAL TRANSP COST	=	6.879E+00	BILLION			
88	RECTENNA COST	=	4.811E+00	BILLION			
89	CONSTRUCTION COST	=	1.198E+00	BILLION			
90	INTEREST DURING CONSTR	=	1.452E+00	BILLION			
91	LATITUDE AREA FACTOR	=	1.419E+00				
92	TOTAL MASS	=	9.980E+04	TONS	(	2.200E+08 LBM	)
93	TOTAL COST	=	2.324E+01	BILLION			
94	COST/KWE	=	2.319E+03	$			
95	COST/KWH	=	4.311E+01	MILLS			

Table A1-1 (Continued)
Rotary Joint Power = 8544 Megawatts

ANTENNA DIAMETER VALUE = 1.200E+00

SOLUTION RESULTS

1 LIGHT INPUT EFFICIENCY	=	8.579E-01		
2 NET CELL EFFICIENCY	=	1.601E-01		
3 BASIC CONVERSION EFFY	=	1.360E-01		
4 BLANKET FACTORS	=	9.399E-01		
5 BUS I-SQ-R	=	9.395E-01		
6 NET ENERGY CONV EFFY	=	1.201E-01		
7 AREAWISE EFFICIENCY	=	9.370E-01		
8 ANTENNA POWER DISTR EFFY	=	9.692E-01		
9 NET DC-RF EFFICIENCY	=	8.115E-0.		
10 IDEAL BEAM EFFICIENCY	=	9.707E-01		
11 NET BEAM EFFICIENCY	=	9.009E-01		
12 INTERCEPT EFFICIENCY	=	9.558E-01		
13 RECTENNA RF-DC EFFICIENC	=	8.955E-01		
14 NET RF LINK EFFY	=	8.439E-01		
15 DC-TO-DC EFFICIENCY	=	6.132E-01		
16 DC-TO-GRID EFFICIENCY	=	5.948E-01		
17 OVERALL PHYSICAL EFFY	=	7.142E-02		
18 AREA EFFECTIVE EFFY	=	6.692E-02		
19 BLANKET AREA	=	1.052E+08	M2	(2.599E+04 ACRES)
20 ANTENNA DIA	=	1.200E+00	KM	(7.457E-01 MI)
21 REQUIRED SIDELOBE SUPPR	=	2.492E+01	DB	
22 TAPER REQUIRED FOR SL SU	=	1.103E+01	DB	
23 TRANSMITTER POWER TAPER	=	1.103E+01	DB	
24 RECEIVER AVG/PEAK RATIO	=	2.012E-01		
25 XMTR AVG/PEAK RATIO	=	3.608E-01		
26 BEAM SPREAD FACTOR	=	1.487E+00		
27 RADIATED RF POWER	=	6.933E+03	MEGAWATT	
28 BEAM DIAMETER	=	1.126E+01	KM	(6.999E+00 MI)
29 BEAM AREA	=	9.963E+07	M2	(2.462E+04 ACRES)
30 AVERAGE BEAM POWER DENS	=	6.253E+00	MW/CM2	
31 PEAK BEAM INTENSITY	=	3.105E+01	MW/CM2	
32 POWER IN MAIN BEAM	=	6.246E+03	MEGAWATT	
33 SATELLITE LENGTH	=	3.210E+01	BAYS	
34 NUMBER OF BAYS	=	2.568E+02	BAYS	
35 XMTR PWR DISTR LOSS	=	3.076E-02		
36 ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37 BAY SIZE	=	6.600E+02	METERS	
38 SPS AREA	=	1.123E+02	KM2	
39 MEAN SOLAR INSOLATION	=	1.519E+02	GW	
40 SOLAR CELL OUTPUT	=	1.819E+01	GW	
41 ROTARY JOINT CURRENT "A"	=	1.388E+05	AMPS	
42 ROTARY JOINT CURRENT "B"	=	8.154E+04	AMPS	
43 TOTAL PROCESSED POWER	=	2.563E+03	MEGAWATT	
44 TOTAL KLYSTRON INPUT	=	1.656E+04	MEGAWATT	
45 TOTAL KLYSTRON OUTPUT	=	1.408E+04	MEGAWATT	
46 NUMBER OF KLYSTRONS	=	1.955E+05		
47 MAX KLYSTRON PACKING DEN	=	2.552E+01	PER SUB	
48 MAX RF POWER DENSITY	=	1.699E+01	KW/M2	
49 NUMBER OF SUBARRAYS	=	1.046E+04	PER ANT	
50 RECTENNA AREA	=	5.604E+07	M2	(1.385E+04 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	3.688E+00 KW/M2			
52 DC OUTPUT POWER	=	5.239E+00 GW/LINK			
53 GRID POWER	=	1.016E+01 GW TOTAL			
54 LAND AREA PER RECT	=	1.413E+08 M2	(	3.492E+04 ACRES	)
55 "Y" MOM OF INERTIA	=	1.201E+14 KG-M2			
56 THRUST PER CORNER	=	9.150E+01 NEWTONS	(	2.057E+01 LB	)
57 NUMBER OF THRUSTERS	=	9.150E+01 PER INST			
58 CONTROL POWER	=	1.148E+02 MEGAWATT			
59 ANNUAL PROPELLANT	=	3.749E+01 TONS	(	8.265E+04 LBM	)
60 STRUCTURE MASS	=	5.894E+03 TONS	(	1.299E+07 LBM	)
61 CONTROL SYS MASS	=	2.043E+02 TONS	(	4.505E+05 LBM	)
62 SOLAR BLANKET MASS	=	4.492E+04 TONS	(	9.903E+07 LBM	)
63 POWER DISTR MASS	=	2.597E+03 TONS	(	5.724E+06 LBM	)
64 MECH & ELEC R/J MASS	=	1.168E+02 TONS	(	2.574E+05 LBM	)
65 ANT STRUC MASS	=	7.200E+02 TONS	(	1.587E+06 LBM	)
66 ANT WAVEGUIDE MASS	=	6.212E+03 TONS	(	1.370E+07 LBM	)
67 ANT KLYSTRON MASS	=	1.359E+04 TONS	(	2.996E+07 LBM	)
68 ANT CONTROL CKTS MASS	=	1.056E+03 TONS	(	2.328E+06 LBM	)
69 ANT PWR DISTR MASS	=	1.033E+03 TONS	(	2.277E+06 LBM	)
70 ANT PWR PROC&TC MASS	=	5.037E+03 TONS	(	1.110E+07 LBM	)
71 ANT MASS	=	2.765E+04 TONS	(	6.095E+07 LBM	)
72 STRUCTURE COST	=	2.947E-01 BILLION			
73 CONTROL SYS COST	=	9.196E-02 BILLION			
74 SOLAR BLANKET COST	=	3.682E+00 BILLION			
75 POWER DISTR COST	=	6.751E-02 BILLION			
76 MECH&ELEC R/J COST	=	2.452E-02 BILLION			
77 ANT STRUC COST	=	3.628E-01 BILLION			
78 ANT WAVEGUIDE COST	=	3.727E-01 BILLION			
79 ANT KLYSTRON COST	=	6.183E-01 BILLION			
80 ANT CONTROL CKTS COST	=	2.331E-01 BILLION			
81 ANT PWR DISTR COST	=	1.115E-01 BILLION			
82 ANT PWR PROC&TC COST	=	3.475E-01 BILLION			
83 ANT COST	=	2.046E+00 BILLION			
84 NO OF FREIGHT FLIGHTS	=	3.589E+02			
85 CREW SERVICE NO OF FLTS	=	2.051E+01			
86 OTS COST	=	9.620E-01 BILLION			
87 TOTAL TRANSP COST	=	7.026E+00 BILLION			
88 RECTENNA COST	=	3.670E+00 BILLION			
89 CONSTRUCTION COST	=	1.230E+00 BILLION			
90 INTEREST DURING CONSTR	=	1.402E+00 BILLION			
91 LATITUDE AREA FACTOR	=	1.419E+00			
92 TOTAL MASS	=	1.025E+05 TONS	(	2.260E+08 LBM	)
93 TOTAL COST	=	2.243E+01 BILLION			
94 COST/KWE	=	2.207E+03 $			
95 COST/KWH	=	4.102E+01 MILLS			

Table A1-1 (Continued)

Rotary Joint Power = 8544 Megawatts

ANTENNA DIAMETER VALUE = 1.400E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.395E-01		
6	NET ENERGY CONV EFFY	=	1.201E-01		
7	AREAWISE EFFICIENCY	=	9.370E-01		
8	ANTENNA POWER DISTR EFFY	=	9.688E-01		
9	NET DC-RF EFFICIENCY	=	8.111E-01		
10	IDEAL BEAM EFFICIENCY	=	9.764E-01		
11	NET BEAM EFFICIENCY	=	9.062E-01		
12	INTERCEPT EFFICIENCY	=	9.633E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.966E-01		
14	NET RF LINK EFFY	=	8.556E-01		
15	DC-TO-DC EFFICIENCY	=	6.222E-01		
16	DC-TO-GRID EFFICIENCY	=	6.036E-01		
17	OVERALL PHYSICAL EFFY	=	7.247E-02		
18	AREA EFFECTIVE EFFY	=	6.790E-02		
19	BLANKET AREA	=	1.052E+08	M2	(2.599E+04 ACRES)
20	ANTENNA DIA	=	1.400E+00	KM	(8.700E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.615E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	1.215E+01	DB	
23	TRANSMITTER POWER TAPER	=	1.215E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	1.964E-01		
25	XMTR AVG/PEAK RATIO	=	3.340E-01		
26	BEAM SPREAD FACTOR	=	1.530E+00		
27	RADIATED RF POWER	=	6.930E+03	MEGAWATT	
28	BEAM DIAMETER	=	9.932E+00	KM	(6.172E+00 MI)
29	BEAM AREA	=	7.748E+07	M2	(1.915E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	8.092E+00	MW/CM2	
31	PEAK BEAM INTENSITY	=	4.120E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	6.280E+03	MEGAWATT	
33	SATELLITE LENGTH	=	3.213E+01	BAYS	
34	NUMBER OF BAYS	=	2.568E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	3.118E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	1.123E+02	KM2	
39	MEAN SOLAR INSOLATION	=	1.519E+02	GW	
40	SOLAR CELL OUTPUT	=	1.819E+01	GW	
41	ROTARY JOINT CURRENT "A"	=	1.389E+05	AMPS	
42	ROTARY JOINT CURRENT "B"	=	8.158E+04	AMPS	
43	TOTAL PROCESSED POWER	=	2.563E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.656E+04	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	1.407E+04	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.954E+05		
47	MAX KLYSTRON PACKING DEN	=	2.024E+01	PER SUB	
48	MAX RF POWER DENSITY	=	1.347E+01	KW/M2	
49	NUMBER OF SUBARRAYS	=	1.423E+04	PER ANT	
50	RECTENNA AREA	=	4.358E+07	M2	(1.077E+04 ACRES)

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	2.932E+00 KW/M2	
52 DC OUTPUT POWER	=	5.316E+00 GW/LINK	
53 GRID POWER	=	1.631E+01 GW TOTAL	
54 LAND AREA PER RECT	=	1.099E+08 M2	(2.716E+04 ACRES)
55 "Y" MOM OF INERTIA	=	1.201E+14 KG-M2	
56 THRUST PER CORNER	=	9.150E+01 NEWTONS	(2.057E+01 LB)
57 NUMBER OF THRUSTERS	=	9.150E+01 PER INST	
58 CONTROL POWER	=	1.148E+02 MEGAWATT	
59 ANNUAL PROPELLANT	=	3.749E+01 TONS	(8.265E+04 LBM)
60 STRUCTURE MASS	=	5.894E+03 TONS	(1.299E+07 LBM)
61 CONTROL SYS MASS	=	2.043E+02 TONS	(4.505E+05 LBM)
62 SOLAR BLANKET MASS	=	4.492E+04 TONS	(9.903E+07 LBM)
63 POWER DISTR MASS	=	2.598E+03 TONS	(5.727E+06 LBM)
64 MECH & ELEC R/J MASS	=	1.302E+02 TONS	(2.870E+05 LBM)
65 ANT STRUC MASS	=	9.800E+02 TONS	(2.16.E+06 LBM)
66 ANT WAVEGUIDE MASS	=	8.455E+03 TONS	(1.864E+07 LBM)
67 ANT KLYSTRON MASS	=	1.358E+04 TONS	(2.995E+07 LBM)
68 ANT CONTROL CKTS MASS	=	1.055E+03 TONS	(2.327E+06 LBM)
69 ANT PWR DISTR MASS	=	1.310E+03 TONS	(2.889E+06 LBM)
70 ANT PWR PROC&TC MASS	=	5.037E+03 TONS	(1.110E+07 LBM)
71 ANT MASS	=	3.042E+04 TONS	(6.707E+07 LBM)
72 STRUCTURE COST	=	2.947E-01 BILLION	
73 CONTROL SYS COST	=	9.196E-02 BILLION	
74 SOLAR BLANKET COST	=	3.682E+00 BILLION	
75 POWER DISTR COST	=	6.754E-02 BILLION	
76 MECH&ELEC R/J COST	=	2.734E-02 BILLION	
77 ANT STRUC COST	=	3.797E-01 BILLION	
78 ANT WAVEGUIDE COST	=	5.073E-01 BILLION	
79 ANT KLYSTRON COST	=	6.180E-01 BILLION	
80 ANT CONTROL CKTS COST	=	2.330E-01 BILLION	
81 ANT PWR DISTR COST	=	1.415E-01 BILLION	
82 ANT PWR PROC&TC COST	=	3.475E-01 BILLION	
83 ANT COST	=	2.227E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	3.712E+02	
85 CREW SERVICE NO OF FLTS	=	2.121E+01	
86 OTS COST	=	9.958E-01 BILLION	
87 TOTAL TRANSP COST	=	7.213E+00 BILLION	
88 RECTENNA COST	=	2.998E+00 BILLION	
89 CONSTRUCTION COST	=	1.273E+00 BILLION	
90 INTEREST DURING CONSTR	=	1.389E+00 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	1.060E+05 TONS	(2.338E+08 LBM)
93 TOTAL COST	=	2.224E+01 BILLION	
94 COST/KWE	=	2.156E+03 $	
95 COST/KWH	=	4.008E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 8544 Megawatts

ANTENNA DIAMETER VALUE = 1.600E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01			
2	NET CELL EFFICIENCY	=	1.601E-01			
3	BASIC CONVERSION EFFY	=	1.360E-01			
4	BLANKET FACTORS	=	9.399E-01			
5	BUS I-SQ-R	=	9.395E-01			
6	NET ENERGY CONV EFFY	=	1.201E-01			
7	AREAWISE EFFICIENCY	=	9.370E-01			
8	ANTENNA POWER DISTR EFFY	=	9.688E-01			
9	NET DC-RF EFFICIENCY	=	8.111E-01			
10	IDEAL BEAM EFFICIENCY	=	9.803E-01			
11	NET BEAM EFFICIENCY	=	9.097E-01			
12	INTERCEPT EFFICIENCY	=	9.702E-01			
13	RECTENNA RF-DC EFFICIENC	=	8.979E-01			
14	NET RF LINK EFFY	=	8.650E-01			
15	DC-TO-DC EFFICIENCY	=	6.300E-01			
16	DC-TO-GRID EFFICIENCY	=	6.111E-01			
17	OVERALL PHYSICAL EFFY	=	7.337E-02			
18	AREA EFFECTIVE EFFY	=	6.875E-02			
19	BLANKET AREA	=	1.052E+08	M2	(	2.599E+04 ACRES)
20	ANTENNA DIA	=	1.600E+00	KM	(	9.942E-01 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.722E+01	DB		
22	TAPER REQUIRED FOR SL SU	=	1.299E+01	DB		
23	TRANSMITTER POWER TAPER	=	1.299E+01	DB		
24	RECEIVER AVE/PEAK RATIO	=	1.929E-01			
25	XMTR AVG/PEAK RATIO	=	3.176E-01			
26	BEAM SPREAD FACTOR	=	1.563E+00			
27	RADIATED RF POWER	=	6.930E+03	MEGAWATT		
28	BEAM DIAMETER	=	8.880E+00	KM	(	5.518E+00 MI)
29	BEAM AREA	=	6.194E+07	M2	(	1.531E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	1.017E+01	MW/CM2		
31	PEAK BEAM INTENSITY	=	5.271E+01	MW/CM2		
32	POWER IN MAIN BEAM	=	6.304E+03	MEGAWATT		
33	SATELLITE LENGTH	=	3.210E+01	BAYS		
34	NUMBER OF BAYS	=	2.568E+02	BAYS		
35	XMTR PWR DISTR LOSS	=	3.123E-02			
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(	1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS		
38	SPS AREA	=	1.123E+02	KM2		
39	MEAN SOLAR INSOLATION	=	1.519E+02	GW		
40	SOLAR CELL OUTPUT	=	1.619E+01	GW		
41	ROTARY JOINT CURRENT "A"	=	1.389E+05	AMPS		
42	ROTARY JOINT CURRENT "B"	=	8.158E+04	AMPS		
43	TOTAL PROCESSED POWER	=	2.563E+03	MEGAWATT		
44	TOTAL KLYSTRON INPUT	=	1.655E+04	MEGAWATT		
45	TOTAL KLYSTRON OUTPUT	=	1.407E+04	MEGAWATT		
46	NUMBER OF KLYSTRONS	=	1.954E+05			
47	MAX KLYSTRON PACKING DEN	=	1.630E+01	PER SUB		
48	MAX RF POWER DENSITY	=	1.085E+01	KW/M2		
49	NUMBER OF SUBARRAYS	=	1.859E+04	PER ANT		
50	RECTENNA AREA	=	3.484E+07	M2	(	8.609E+03 ACRES)

ORIGINAL PAGE IS OF POOR QUALITY

Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	2.361E+00 KW/M2	
52 DC OUTPUT POWER	=	5.383E+00 GW/LINK	
53 GRID POWER	=	1.044E+01 GW TOTAL	
54 LAND AREA PER RECT	=	8.786E+07 M2	(2.171E+04 ACRES)
55 "V" MOM OF INERTIA	=	1.201E+14 KG-M2	
56 THRUST PER CORNER	=	9.150E+01 NEWTONS	(2.057E+01 LB)
57 NUMBER OF THRUSTERS	=	9.150E+01 PER INST	
58 CONTROL POWER	=	1.148E+02 MEGAWATT	
59 ANNUAL PROPELLANT	=	3.749E+01 TONS	(8.265E+04 LBM)
60 STRUCTURE MASS	=	5.894E+03 TONS	(1.299E+07 LBM)
61 CONTROL SYS MASS	=	2.043E+02 TONS	(4.505E+05 LBM)
62 SOLAR BLANKET MASS	=	4.492E+04 TONS	(9.903E+07 LBM)
63 POWER DISTR MASS	=	2.598E+03 TONS	(5.727E+06 LBM)
64 MECH & ELEC R/J MASS	=	1.436E+02 TONS	(3.165E+05 LBM)
65 ANT STRUC MASS	=	1.280E+03 TONS	(2.822E+06 LBM)
66 ANT WAVEGUIDE MASS	=	1.104E+04 TONS	(2.435E+07 LBM)
67 ANT KLYSTRON MASS	=	1.358E+04 TONS	(2.994E+07 LBM)
68 ANT CONTROL CKTS MASS	=	1.055E+03 TONS	(2.327E+06 LBM)
69 ANT PWR DISTR MASS	=	1.450E+03 TONS	(3.197E+06 LBM)
70 ANT PWR PROC&TC MASS	=	5.037E+03 TONS	(1.110E+07 LBM)
71 ANT MASS	=	3.345E+04 TONS	(7.374E+07 LBM)
72 STRUCTURE COST	=	2.947E-01 BILLION	
73 CONTROL SYS COST	=	9.196E-02 BILLION	
74 SOLAR BLANKET COST	=	3.682E+00 BILLION	
75 POWER DISTR COST	=	6.754E-02 BILLION	
76 MECH&ELEC R/J COST	=	3.015E-02 BILLION	
77 ANT STRUC COST	=	3.992E-01 BILLION	
78 ANT WAVEGUIDE COST	=	6.626E-01 BILLION	
79 ANT KLYSTRON COST	=	6.180E-01 BILLION	
80 ANT CONTROL CKTS COST	=	2.330E-01 BILLION	
81 ANT PWR DISTR COST	=	1.566E-01 BILLION	
82 ANT PWR PROC&TC COST	=	3.475E-01 BILLION	
83 ANT COST	=	2.417E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	3.846E+02	
85 CREW SERVICE NO OF FLTS	=	2.198E+01	
86 OTS COST	=	1.032E+00 BILLION	
87 TOTAL TRANSP COST	=	7.416E+00 BILLION	
88 RECTENNA COST	=	2.522E+00 BILLION	
89 CONSTRUCTION COST	=	1.319E+00 BILLION	
90 INTEREST DURING CONSTR	=	1.393E+00 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	1.099E+05 TONS	(2.422E+08 LBM)
93 TOTAL COST	=	2.230E+01 BILLION	
94 COST/KWE	=	2.135E+03 $	
95 COST/KWH	=	3.969E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 8544 Megawatts

ANTENNA DIAMETER VALUE = 1.800E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01	
2	NET CELL EFFICIENCY	=	1.601E-01	
3	BASIC CONVERSION EFFY	=	1.360E-01	
4	BLANKET FACTORS	=	9.399E-01	
5	BUS I-SQ-R	=	9.395E-01	
6	NET ENERGY CONV EFFY	=	1.201E-01	
7	AREAWISE EFFICIENCY	=	9.370E-01	
8	ANTENNA POWER DISTR EFFY	=	9.726E-01	
9	NET DC-RF EFFICIENCY	=	8.143E-01	
10	IDEAL BEAM EFFICIENCY	=	9.833E-01	
11	NET BEAM EFFICIENCY	=	9.125E-01	
12	INTERCEPT EFFICIENCY	=	9.755E-01	
13	RECTENNA RF-DC EFFICIENC	=	8.984E-01	
14	NET RF LINK EFFY	=	8.723E-01	
15	DC-TO-DC EFFICIENCY	=	6.381E-01	
16	DC-TO-GRID EFFICIENCY	=	6.190E-01	
17	OVERALL PHYSICAL EFFY	=	7.432E-02	
18	AREA EFFECTIVE EFFY	=	6.964E-02	
19	BLANKET AREA	=	1.052E+05 M2	(2.599E+04 ACRES)
20	ANTENNA DIA	=	1.800E+00 KM	(1.119E+00 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.819E+01 DB	
22	TAPER REQUIRED FOR SL SU	=	1.370E+01 DB	
23	TRANSMITTER POWER TAPER	=	1.370E+01 DB	
24	RECEIVER AVG/PEAK RATIO	=	1.895E-01	
25	XMTR AVG/PEAK RATIO	=	3.041E-01	
26	BEAM SPREAD FACTOR	=	1.593E+00	
27	RADIATED RF POWER	=	6.958E+03 MEGAWATT	
28	BEAM DIAMETER	=	8.045E+00 KM	(4.999E+00 MI)
29	BEAM AREA	=	5.083E+07 M2	(1.256E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	1.249E+01 MW/CM2	
31	PEAK BEAM INTENSITY	=	6.591E+01 MW/CM2	
32	POWER IN MAIN BEAM	=	6.349E+03 MEGAWATT	
33	SATELLITE LENGTH	=	3.210E+01 BAYS	
34	NUMBER OF BAYS	=	2.568E+02 BAYS	
35	XMTR PWR DISTR LOSS	=	2.739E-02	
36	ADJ BAY USEFUL AREA	=	4.096E+05 M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02 METERS	
38	SPS AREA	=	1.123E+02 KM2	
39	MEAN SOLAR INSOLATION	=	1.519E+02 GW	
40	SOLAR CELL OUTPUT	=	1.819E+01 GW	
41	ROTARY JOINT CURRENT "A"	=	1.384E+05 AMPS	
42	ROTARY JOINT CURRENT "B"	=	8.126E+04 AMPS	
43	TOTAL PROCESSED POWER	=	2.563E+03 MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.662E+04 MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	1.413E+04 MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.962E+05	
47	MAX KLYSTRON PACKING DEN	=	1.350E+01 PER SUB	
48	MAX RF POWER DENSITY	=	8.990E+00 KW/M2	
49	NUMBER OF SUBARRAYS	=	2.353E+04 PER ANT	
50	RECTENNA AREA	=	2.859E+07 M2	(7.065E+03 ACRES)

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Table A1-1 (Continued)

51 PEAK ANT THERMAL PWR	=	1.913E+00 KW/M2	
52 DC OUTPUT POWER	=	5.452E+00 GW/LINK	
53 GRID POWER	=	1.058E+01 GW TOTAL	
54 LAND AREA PER RECT	=	7.211E+07 M2	(1.782E+04 ACRES)
55 "V" MOM OF INERTIA	=	1.201E+14 KG-M2	
56 THRUST PER CORNER	=	9.150E+01 NEWTONS	(2.057E+01 LB)
57 NUMBER OF THRUSTERS	=	9.150E+01 PER INST	
58 CONTROL POWER	=	1.148E+02 MEGAWATT	
59 ANNUAL PROPELLANT	=	3.749E+01 TONS	(8.265E+04 LBM)
60 STRUCTURE MASS	=	5.894E+03 TONS	(1.299E+07 LBM)
61 CONTROL SYS MASS	=	2.043E+02 TONS	(4.505E+05 LBM)
62 SOLAR BLANKET MASS	=	4.492E+04 TONS	(9.903E+07 LBM)
63 POWER DISTR MASS	=	2.588E+03 TONS	(5.705E+06 LBM)
64 MECH & ELEC R/J MASS	=	1.570E+02 TONS	(3.461E+05 LBM)
65 ANT STRUC MASS	=	1.620E+03 TONS	(3.571E+06 LBM)
66 ANT WAVEGUIDE MASS	=	1.398E+04 TONS	(3.081E+07 LBM)
67 ANT KLYSTRON MASS	=	1.364E+04 TONS	(3.006E+07 LBM)
68 ANT CONTROL CKTS MASS	=	1.060E+03 TONS	(2.336E+06 LBM)
69 ANT PWR DISTR MASS	=	2.003E+03 TONS	(4.416E+06 LBM)
70 ANT PWR PROC&TC MASS	=	5.037E+03 TONS	(1.110E+07 LBM)
71 ANT MASS	=	3.733E+04 TONS	(8.230E+07 LBM)
72 STRUCTURE COST	=	2.947E-01 BILLION	
73 CONTROL SYS COST	=	9.196E-02 BILLION	
74 SOLAR BLANKET COST	=	3.682E+00 BILLION	
75 POWER DISTR COST	=	6.728E-02 BILLION	
76 MECH&ELEC R/J COST	=	3.297E-02 BILLION	
77 ANT STRUC COST	=	4.213E-01 BILLION	
78 ANT WAVEGUIDE COST	=	8.386E-01 BILLION	
79 ANT KLYSTRON COST	=	6.204E-01 BILLION	
80 ANT CONTROL CKTS COST	=	2.339E-01 BILLION	
81 ANT PWR DISTR COST	=	2.163E-01 BILLION	
82 ANT PWR PROC&TC COST	=	3.475E-01 BILLION	
83 ANT COST	=	2.678E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	4.017E+02	
85 CREW SERVICE NO OF FLTS	=	2.296E+01	
86 OTS COST	=	1.078E+00 BILLION	
87 TOTAL TRANSP COST	=	7.674E+00 BILLION	
88 RECTENNA COST	=	2.184E+00 BILLION	
89 CONSTRUCTION COST	=	1.377E+00 BILLION	
90 INTEREST DURING CONSTR	=	1.417E+00 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	1.148E+05 TONS	(2.530E+08 LBM)
93 TOTAL COST	=	2.268E+01 BILLION	
94 COST/KWE	=	2.144E+03 $	
95 COST/KWH	=	3.985E+01 MILLS	

Table A1-1 (Continued)
Rotary Joint Power = 8544 Megawatts

ANTENNA DIAMETER VALUE = 2.000E+00

SOLUTION RESULTS

1	LIGHT INPUT EFFICIENCY	=	8.579E-01		
2	NET CELL EFFICIENCY	=	1.601E-01		
3	BASIC CONVERSION EFFY	=	1.360E-01		
4	BLANKET FACTORS	=	9.399E-01		
5	BUS I-SQ-R	=	9.395E-01		
6	NET ENERGY CONV EFFY	=	1.201E-01		
7	AREAWISE EFFICIENCY	=	9.370E-01		
8	ANTENNA POWER DISTR EFFY	=	9.722E-01		
9	NET DC-RF EFFICIENCY	=	8.139E-01		
10	IDEAL BEAM EFFICIENCY	=	9.857E-01		
11	NET BEAM EFFICIENCY	=	9.147E-01		
12	INTERCEPT EFFICIENCY	=	9.791E-01		
13	RECTENNA RF-DC EFFICIENC	=	8.986E-01		
14	NET RF LINK EFFY	=	8.777E-01		
15	DC-TO-DC EFFICIENCY	=	6.420E-01		
16	DC-TO-GRID EFFICIENCY	=	6.227E-01		
17	OVERALL PHYSICAL EFFY	=	7.476E-02		
18	AREA EFFECTIVE EFFY	=	7.005E-02		
19	BLANKET AREA	=	1.052E+08	M2	(2.599E+04 ACRES)
20	ANTENNA DIA	=	2.000E+00	KM	(1.243E+00 MI)
21	REQUIRED SIDELOBE SUPPR	=	2.905E+01	DB	
22	TAPER REQUIRED FOR SL SU	=	1.433E+01	DB	
23	TRANSMITTER POWER TAPER	=	1.434E+01	DB	
24	RECEIVER AVG/PEAK RATIO	=	1.860E-01		
25	XMTR AVG/PEAK RATIO	=	2.923E-01		
26	BEAM SPREAD FACTOR	=	1.621E+00		
27	RADIATED RF POWER	=	6.954E+03	MEGAWATT	
28	BEAM DIAMETER	=	7.364E+00	KM	(4.576E+00 MI)
29	BEAM AREA	=	4.259E+07	M2	(1.052E+04 ACRES)
30	AVERAGE BEAM POWER DENS	=	1.494E+01	MW/CM2	
31	PEAK BEAM INTENSITY	=	8.031E+01	MW/CM2	
32	POWER IN MAIN BEAM	=	6.361E+03	MEGAWATT	
33	SATELLITE LENGTH	=	3.210E+01	BAYS	
34	NUMBER OF BAYS	=	2.568E+02	BAYS	
35	XMTR PWR DISTR LOSS	=	2.783E-02		
36	ADJ BAY USEFUL AREA	=	4.096E+05	M2	(1.012E+02 ACRES)
37	BAY SIZE	=	6.600E+02	METERS	
38	SPS AREA	=	1.123E+02	KM2	
39	MEAN SOLAR INSOLATION	=	1.519E+02	GW	
40	SOLAR CELL OUTPUT	=	1.819E+01	GW	
41	ROTARY JOINT CURRENT "A"	=	1.384E+05	AMPS	
42	ROTARY JOINT CURRENT "B"	=	8.129E+04	AMPS	
43	TOTAL PROCESSED POWER	=	2.563E+03	MEGAWATT	
44	TOTAL KLYSTRON INPUT	=	1.661E+04	MEGAWATT	
45	TOTAL KLYSTRON OUTPUT	=	1.412E+04	MEGAWATT	
46	NUMBER OF KLYSTRONS	=	1.961E+05		
47	MAX KLYSTRON PACKING DEN	=	1.138E+01	PER SUB	
48	MAX RF POWER DENSITY	=	7.572E+00	KW/M2	
49	NUMBER OF SUBARRAYS	=	2.905E+04	PER ANT	
50	RECTENNA AREA	=	2.396E+07	M2	(5.920E+03 ACRES)

Table A1-1 (Continued)

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51 PEAK ANT THERMAL PWR	=	1.616E+00 KW/M2	
52 DC OUTPUT POWER	=	5.485E+00 GW/LINK	
53 GRID POWER	=	1.064E+01 GW TOTAL	
54 LAND AREA PER RECT	=	6.042E+07 M2	(1.493E+04 ACRES)
55 "Y" MOM OF INERTIA	=	1.201E+14 KG-M2	
56 THRUST PER CORNER	=	9.150E+01 NEWTONS	(2.057E+01 LB)
57 NUMBER OF THRUSTERS	=	9.150E+01 PER INST	
58 CONTROL POWER	=	1.148E+02 MEGAWATT	
59 ANNUAL PROPELLANT	=	3.749E+01 TONS	(8.265E+04 LBM)
60 STRUCTURE MASS	=	5.894E+03 TONS	(1.299E+07 LBM)
61 CONTROL SYS MASS	=	2.043E+02 TONS	(4.505E+05 LBM)
62 SOLAR BLANKET MASS	=	4.492E+04 TONS	(9.903E+07 LBM)
63 POWER DISTR MASS	=	2.589E+03 TONS	(5.707E+06 LBM)
64 MECH & ELEC R/J MASS	=	1.704E+02 TONS	(3.756E+05 LBM)
65 ANT STRUC MASS	=	2.000E+03 TONS	(4.409E+06 LBM)
66 ANT WAVEGUIDE MASS	=	1.726E+04 TONS	(3.804E+07 LBM)
67 ANT KLYSTRON MASS	=	1.363E+04 TONS	(3.005E+07 LBM)
68 ANT CONTROL CKTS MASS	=	1.059E+03 TONS	(2.335E+06 LBM)
69 ANT PWR DISTR MASS	=	2.299E+03 TONS	(5.069E+06 LBM)
70 ANT PWR PROC&TC MASS	=	5.037E+03 TONS	(1.110E+07 LBM)
71 ANT MASS	=	4.128E+04 TONS	(9.101E+07 LBM)
72 STRUCTURE COST	=	2.947E-01 BILLION	
73 CONTROL SYS COST	=	9.196E-02 BILLION	
74 SOLAR BLANKET COST	=	3.682E+00 BILLION	
75 POWER DISTR COST	=	6.731E-02 BILLION	
76 MECH&ELEC R/J COST	=	3.578E-02 BILLION	
77 ANT STRUC COST	=	4.460E-01 BILLION	
78 ANT WAVEGUIDE COST	=	1.035E+00 BILLION	
79 ANT KLYSTRON COST	=	6.201E-01 BILLION	
80 ANT CONTROL CKTS COST	=	2.338E-01 BILLION	
81 ANT PWR DISTR COST	=	2.483E-01 BILLION	
82 ANT PWR PROC&TC COST	=	3.475E-01 BILLION	
83 ANT COST	=	2.931E+00 BILLION	
84 NO OF FREIGHT FLIGHTS	=	4.192E+02	
85 CREW SERVICE NO OF FLTS	=	2.395E+01	
86 OTS COST	=	1.125E+00 BILLION	
87 TOTAL TRANSP COST	=	7.934E+00 BILLION	
88 RECTENNA COST	=	1.932E+00 BILLION	
89 CONSTRUCTION COST	=	1.437E+00 BILLION	
90 INTEREST DURING CONSTR	=	1.446E+00 BILLION	
91 LATITUDE AREA FACTOR	=	1.419E+00	
92 TOTAL MASS	=	1.198E+05 TONS	(2.640E+08 LBM)
93 TOTAL COST	=	2.315E+01 BILLION	
94 COST/KWE	=	2.175E+03 $	
95 COST/KWH	=	4.043E+01 MILLS	

APPENDIX B
STAGING COST OPTIMIZATION

1.0 INTRODUCTION

An optimization of the average operating cost as a function of staging velocity was performed as required by Task IV of the Part III work statement. The aim of this optimization was to utilize the mass, performance and cost data of previous launch vehicle point designs to develop parametric trends. These trends were used to determine the staging velocities that would result in minimum costs per flight for both winged and ballistic two-stage vehicles. In addition, a launch vehicle with a winged upper stage and ballistic booster was evaluated using the parametric trends.

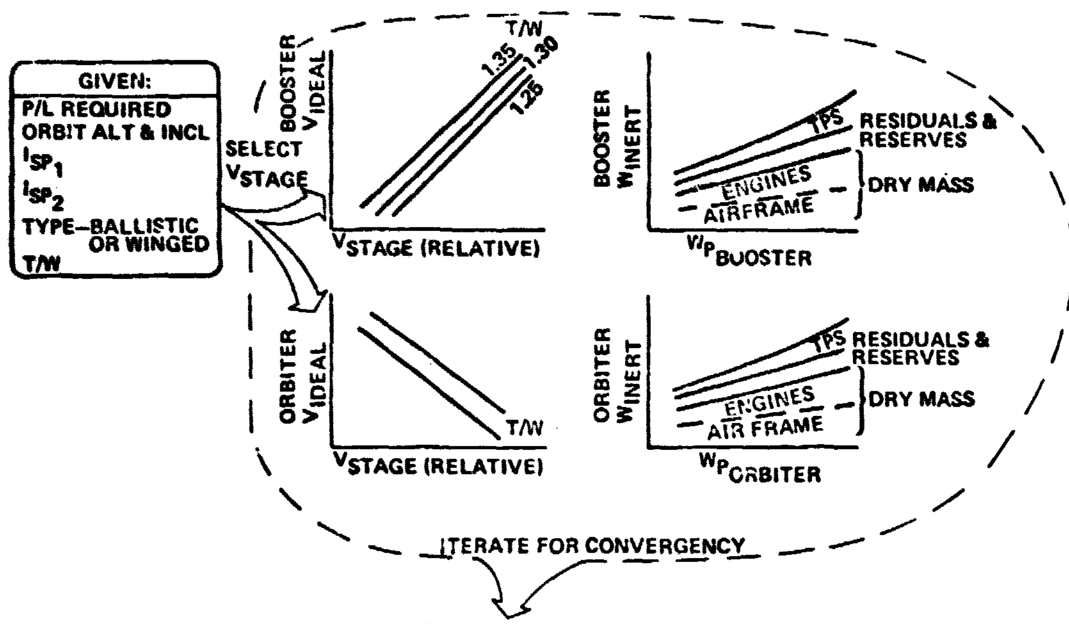
2.0 METHOD OF ANALYSIS

In order to simplify the analysis and reduce the number of independent variables certain performance characteristics were fixed. Initial thrust to weight ratios for the first and second stages were set at 1:30 and .95 respectively. High chamber pressure LCH_4/LO_2 engines in the 8.9 x 10^6 newton (2x10^6 lbf) thrust class were used for the booster and standard SSME's were used for the orbiter.

The vehicles were sized to deliver a payload of 400 metric tons to a 477 km altitude low earth orbit (LEO) inclined at 31°. All cost calculations were based on a 14 year operational program with a 400 flight per year launch rate.

The method used to determine the vehicle sizing and cost per flight for a particular staging velocity is illustrated in Figures 1 and 2. Stage ideal velocity requirements for the given staging velocity are determined from parametric equations. These equations were derived from the loss data of previous vehicle point designs.

The ideal velocity requirements are used in conjunction with the groundrule engine Isp's and initial assumed mass fractions to calculate the propellant masses for each stage. Mass fractions are then developed from parametric equations using the staging velocity and calculated propellant masses. The new mass fractions are used to re-calculate the propellant masses. The sequence is iterated until the solution converges. The parametric equations for mass fractions were developed from the ballistic and winged launch vehicle point design mass estimates.



VEHICLE CHARACTERISTICS

	BOOSTER	ORBITER
W_P	X	X
A/F MASS	X	X
ENGINES MASS	X	X
TPS MASS	X	X

Figure 1 Sizing Methodology

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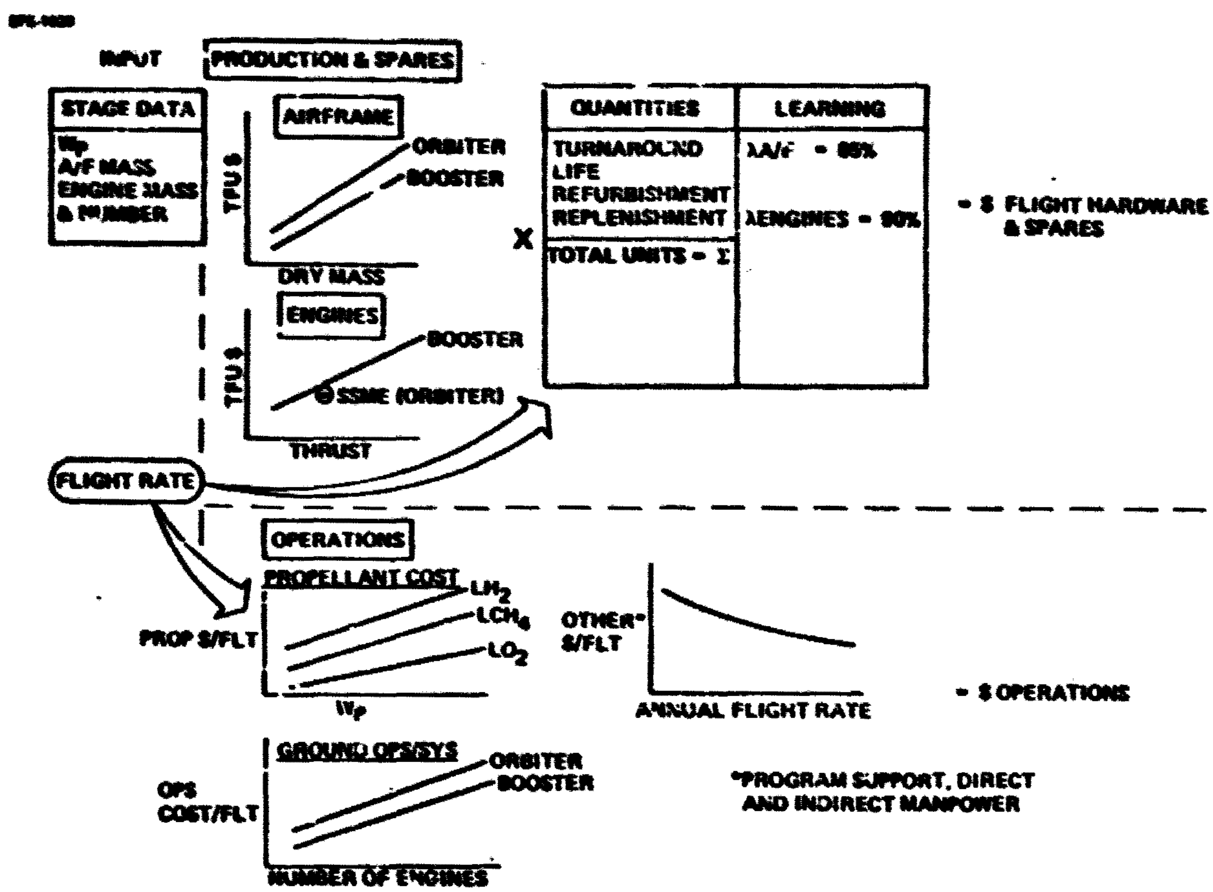

Figure 2 Costing Methodology

Once the propellant quantities and mass fractions are determined the cost/flight can be developed. The quantity of engines and airframes come from life and refurbishment criteria listed in Table 1. The theoretical first unit costs are generated from the parametric relationships based on Boeing Parametric Cost Model results for the previous point design launch vehicles. When the appropriate learning curves are applied to the TFU costs and the flight requirements, the production and spares costs are produced for the various hardware elements. The propellant costs are calculated using the burden factors and unit costs as shown in Table 2.

Ground operations and systems cost trends were developed as a function of the number of engines from the previous SPS ballistic and winged vehicles cost per flight data. These costs are combined with the hardware and propellant costs and added to those overhead costs which are essentially flight rate dependent, to give the total average cost per flight.

3.0 OPTIMIZATION RESULTS

The staging velocity optimization runs were performed for the following 2-stage vehicle options:

Option #1) Ballistic recoverable booster and orbiter with a LCH_4/LO_2 booster and SSME powered orbiter

Option #2) Same as #1 except winged recoverable booster and orbiter

Option #3) Same as #1 except ballistic recoverable booster and winged orbiter.

The results of the staging velocity optimization for a 400 flight/year 14 year program are shown in Figure 3. The options with ballistic recoverable boosters tend to optimize in the 10,000 to 11,000 fps staging velocity (relative velocity) range. The winged vehicle optimum staging velocity appears to be in the 6000 to 7000 fps staging velocity range. The sensitivities to propellant cost variations were evaluated for a +25% and +50% change in the liquid methane and liquid hydrogen costs as stated in Table 2. The impact of LH_2 cost variations on the Option #1 and #2 concepts are shown on Figure 4. The locus of the optimum staging velocities shows a slight increase in the optimum velocity as LH_2 costs increase. The impact of LCH_4 cost variations, shown in Figure 5, has a slight reverse effect as compared to increased LH_2 costs. The locus of the optimum staging velocities for increased methane cost shows a slight decrease in the optimum velocity.

Table 1. Life and Refurbishment Criteria

AIRFRAME

DESIGN LIFE	=	300 FLIGHTS
REFURBISHMENT	=	30% OF UNIT COST EACH 100 FLIGHTS
REPLENISHMENT SPARES	=	0.18% OF UNIT COST/FLIGHT

ROCKET ENGINES

DESIGN LIFE	=	INDEFINITE
REFURBISHMENT	=	30% OF UNIT COST EACH 50 FLIGHTS
REPLENISHMENT SPARES	=	0.50% OF UNIT COST/FLIGHT

AIRBREATHER ENGINES

DESIGN LIFE	=	INDEFINITE
REFURBISHMENT	=	15% OF UNIT COST EACH 500 FLIGHTS
REPLENISHMENT SPARES	=	0.10% OF UNIT COST/FLIGHT

Table 2. Unit Propellant Costs

PROPELLANT	BURDEN FACTOR	UNIT PROPELLANT COST $/kg
LCH_4	1.05	$0.395
LO_2	1.05	$0.037
LH_2	1.05	$1.534

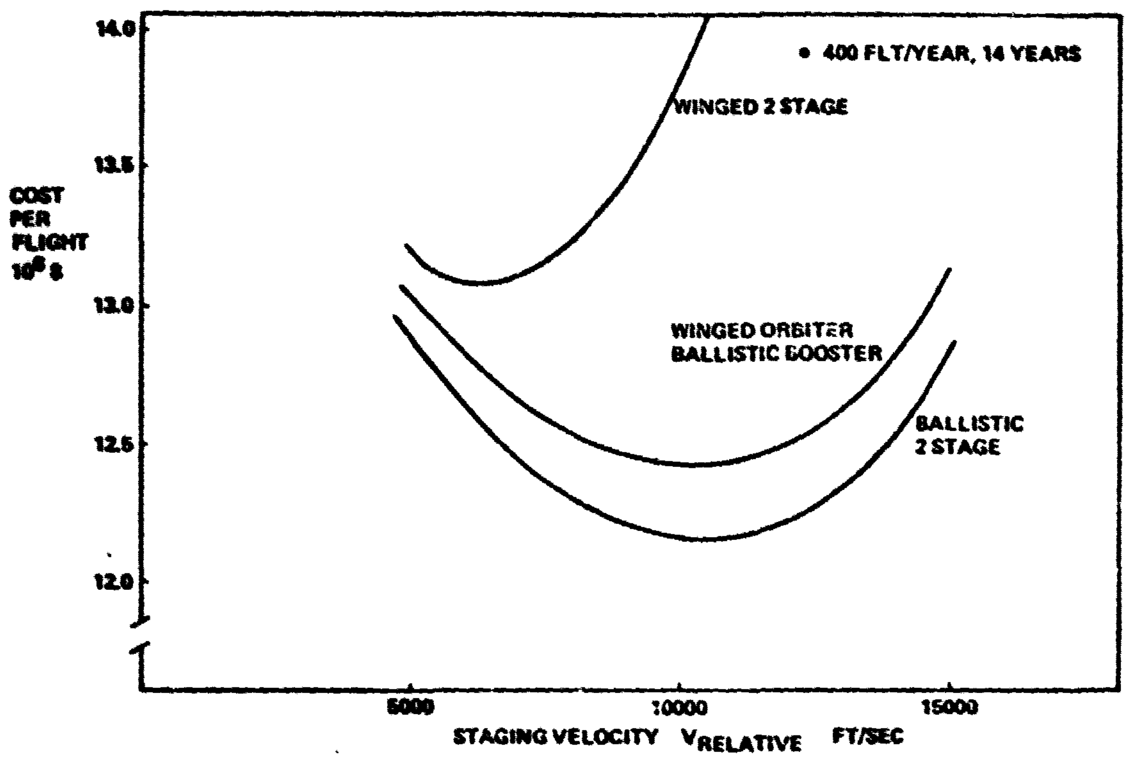

Figure 3 Average Cost/Flight as a Function of Staging Velocity

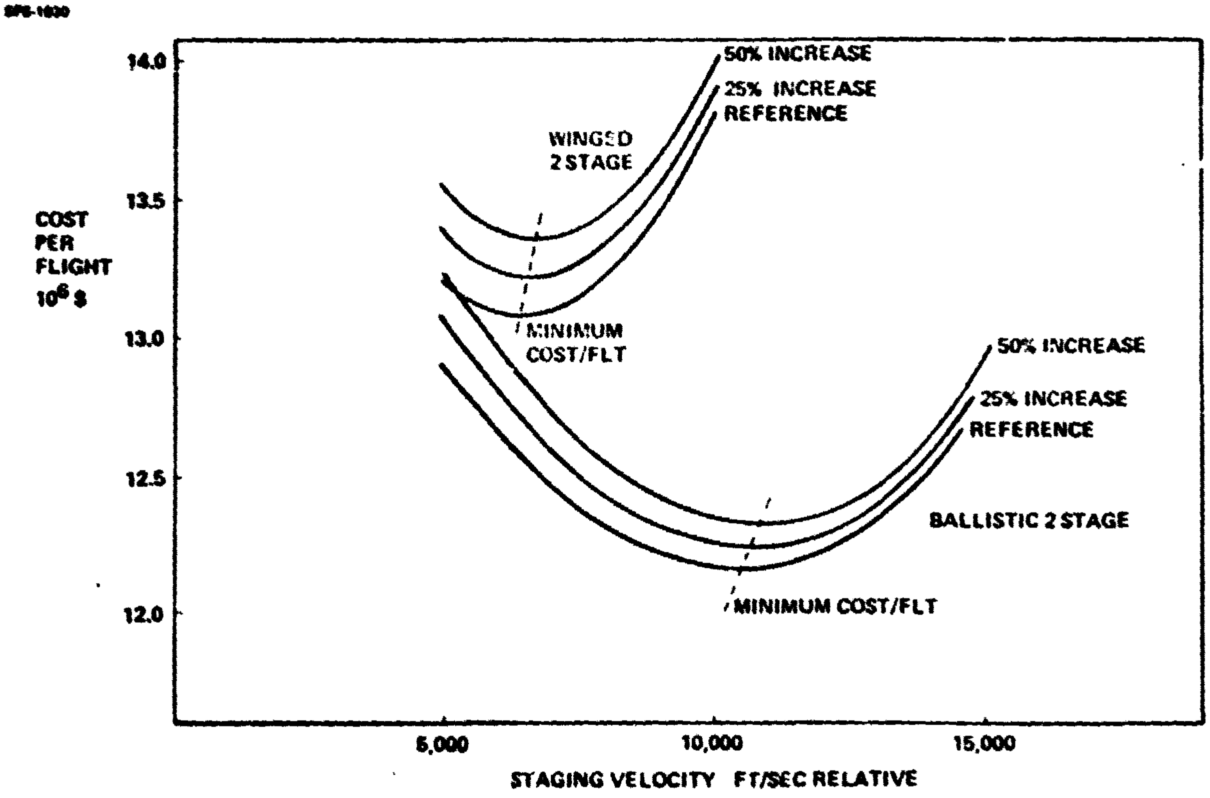

Figure 4 Impact of LH_2 Cost on Cost/Flight

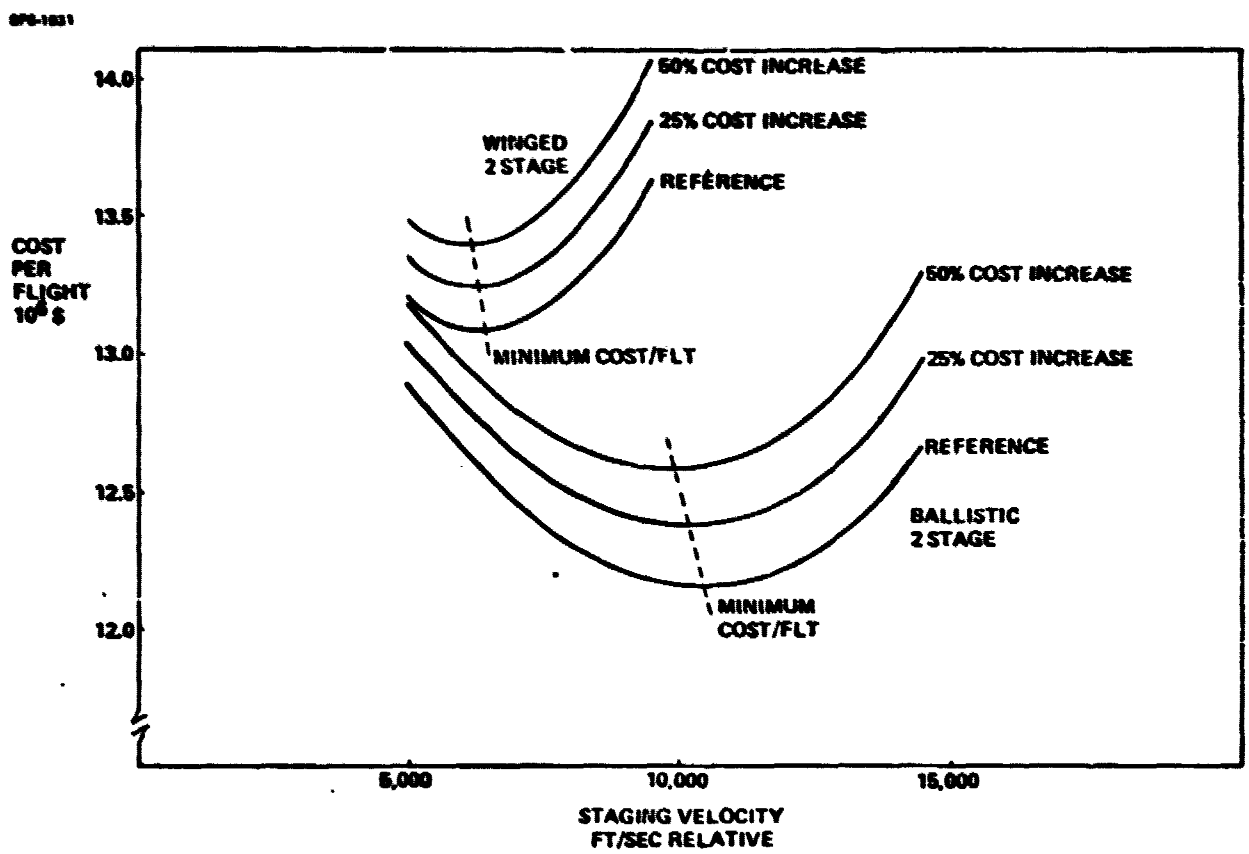

Figure 5 Impact on LCH_4 Cost on Cost/Flight

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APPENDIX C
LOW THRUST ORBIT TRANSFER SIMULATION

A six-degree-of-freedom orbit transfer simulation computer code was used to simulate the self-powered orbit transfer of SPS modules from low Earth orbit to geosynchronous orbit. The important features of this simulation include full three axis calculation of gravity gradients, determination of occultation when the vehicle passes through the Earth's shadow, an optimal plane change/altitude change thrusting law and incorporation of a joint chemical/electric thrusting orbit transfer performance. A summary block diagram of the integrating algorithm is shown in Figure C-1.

Earlier studies employing simpler orbit transfer simulation codes had indicated that the optimal trip time for the self-powered orbit transfer is about 180 days. The electric thrust required to accomplish a transfer in this length of time is, in the case investigated, not sufficient to control the vehicle attitude when the orbit altitude is less than about 2500 kilometers. Accordingly, it was necessary to supplement electric thrust with additional chemical thrust during the early phase of the transfer.

Preliminary analyses were conducted using the orbit transfer code before the thrusting algorithm was incorporated. These showed that the amount of total thrust required to control gravity gradient was sensitive to various parameters including the (1) seasonal sun–Earth geometry, (2) the relative orbit position compared to the sun position, and (3) the spacecraft clock angle with respect to the orbit geometry. (The clock angle is an angle of roll around the sunward looking line.) These earlier results were reported in the Part II final report volume 5.

The results discussed here considered a combination of sun geometry and orbit geometry that is nearly a worst case for gravity gradient problems.

The selected calendar date was January 1, 1990, when the sun has just passed solstice. The orbit inclination was 30° with the orbit line of nodes oriented such that the angle between the orbit plane and the Earth-sun vector was nearly maximized. This causes the vehicle to fly tilted with respect to the orbit radius vector such that the gravity gradient is at its maximum value, as illustrated in Figure C-2. The moments of inertia of the spacecraft are such that the gravity gradient torques about the x and z axes are large. The gravity gradient torques about the three axes are plotted for the first rev of the transfer in Figure C-3. Note that the x and z peaks are separated in time such that the gravity gradient torque is high during most of the orbit.

SPS-1751

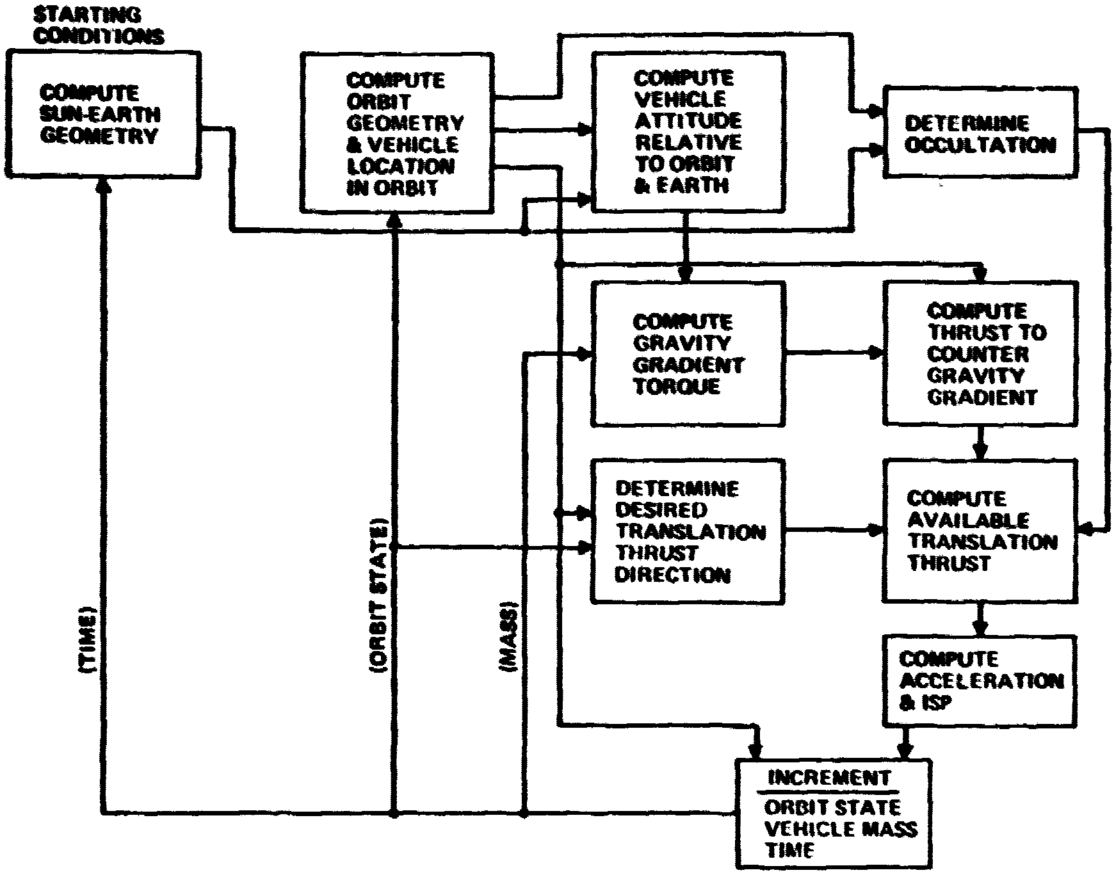

Figure C-1 Integration Step Flow

SPS-1754

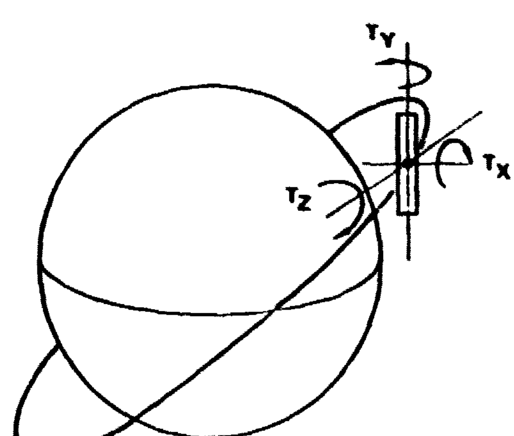

Figure C-2 Representative Satellite/Orbit Geometry

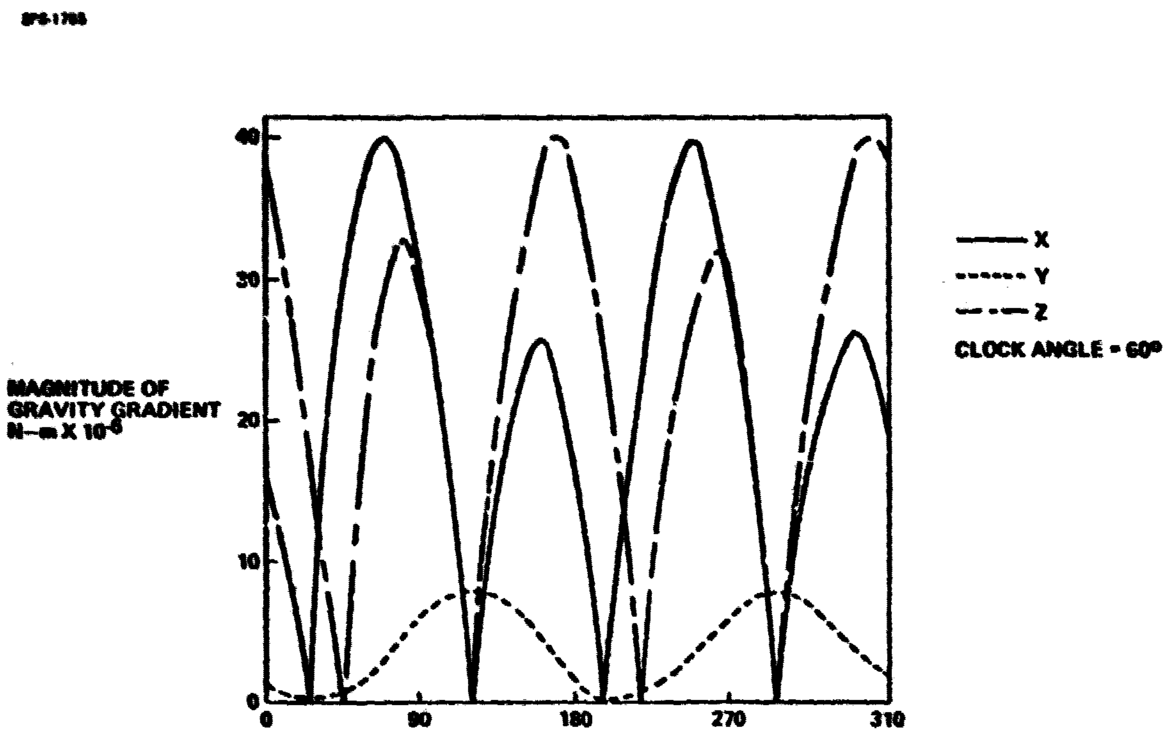

Figure C-3 Gravity Gradient Torques

The thrust and performance law used established a ceiling value on total thrust. Electric thrust is always operated at the maximum available value (for this analysis 2000 neutons per corner), except during shadow periods when no electric thrust is available. Chemical thrust is used to augment the total thrust up to the ceiling value. During shadow periods chemical thrust is used as required to maintain vehicle attitude, but no translational impulse is applied. The addition of chemical thrust at a lower specific impulse (400 seconds) rapidly dilutes the net average total specific impulse as illustrated in Figure C-4. The transfer simulation code computes a net integrated average effective specific impulse. This includes the chemical and electric mixing effects and the losses of effective thrust because of gravity gradients and sun occultations. This cumulative average ISP is a sensitive indicator of the effective performance achieved by the system under these transfer conditions. Gravity gradient torque can be altered by changing the spacecraft clock angle. There are probably variable-clock-angle optimal strategies, but these were not investigated. Simulations were run for approximately 16 revs, to investigate the effects of spacecraft clock angle and the value of thrust ceiling. These results are shown in Figure C-5. For the particular sun and orbit geometry considered, the best clock angle was 60°. Using this clock angle the thrust ceiling was varied to determine the optimal value of the thrust ceiling. This was found to be 6000 newtons per corner, (2000 newtons electric thrust and 4000 newtons chemical thrust).

The specific impulse history for the first rev is illustrated in Figure C-6. This history shows the effective specific impulse (the instantaneous value of translation thrust divided by total propellant flow.) It also shows the cumulative average specific impulse. Note that the effective specific impulse goes to zero when all thrust is required for gravity gradient control or during occultation periods. The thrust ceiling law is used to set maximum thrust unless more thrust than that is required to control gravity gradient. In those cases, the thrust ceiling is violated and total thrust is made equal to the amount required to control attitude. Also, if the thrust ceiling is less than the available electric thrust then the available electric thrust is used.

Using the optimum clock angle and thrust ceiling, a simulation was run from LEO to GEO. The results of this simulation are shown in Figure C-7. The overall mass ratio was 1.31 corresponding to the cumulative average Isp of 2000 sec. Although the propellant requirements are somewhat greater than earlier estimates, this is cost-compensated by the reduced trip time (116 days vs. 180 days).

This result does not represent an optimum transfer. True optimization of this system is an enormously complex problem, involving at least the following parameters:

SPS-1766

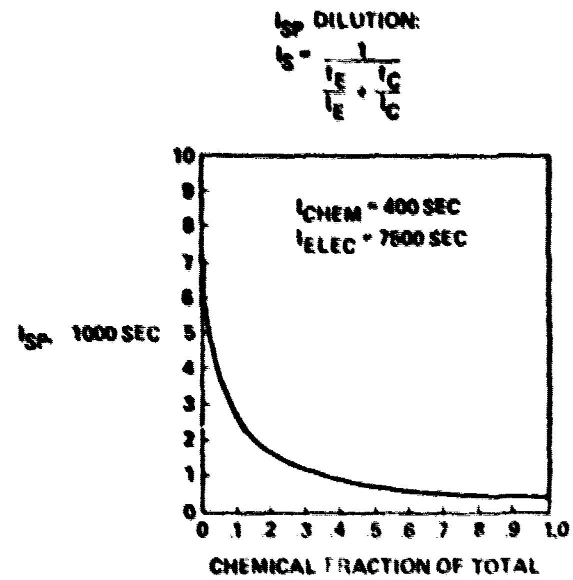

Figure C-4 I_{sp} Dilution By Chem Thrust

SPS-1757

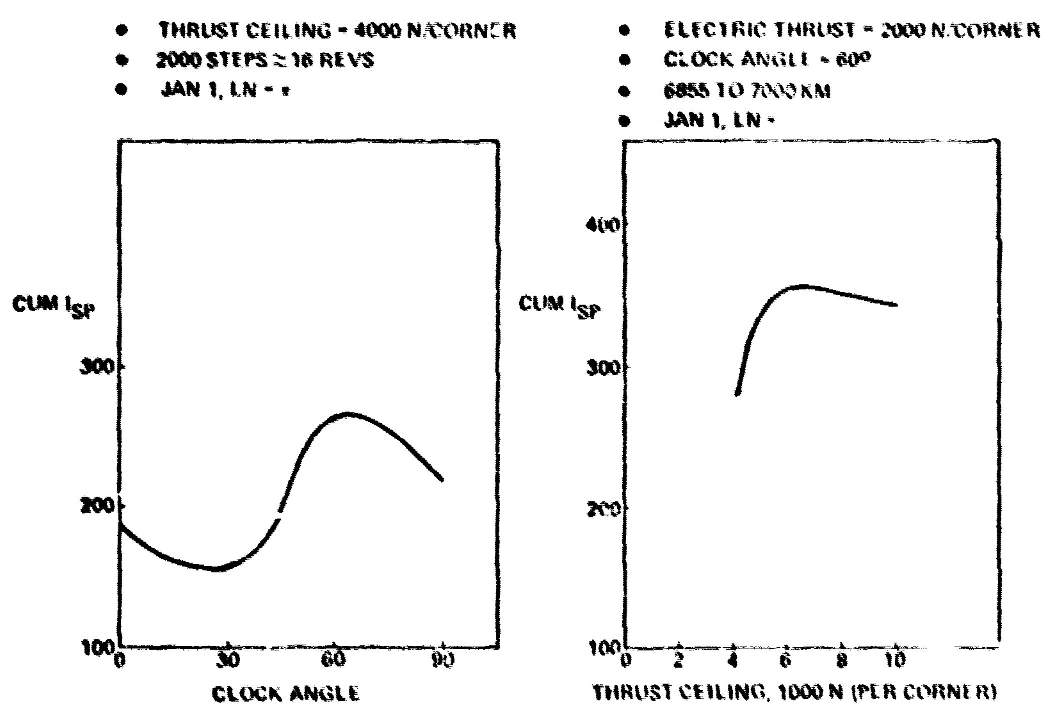

Figure C-5 Clock Angle and Thrust Optimization

SPS-1758

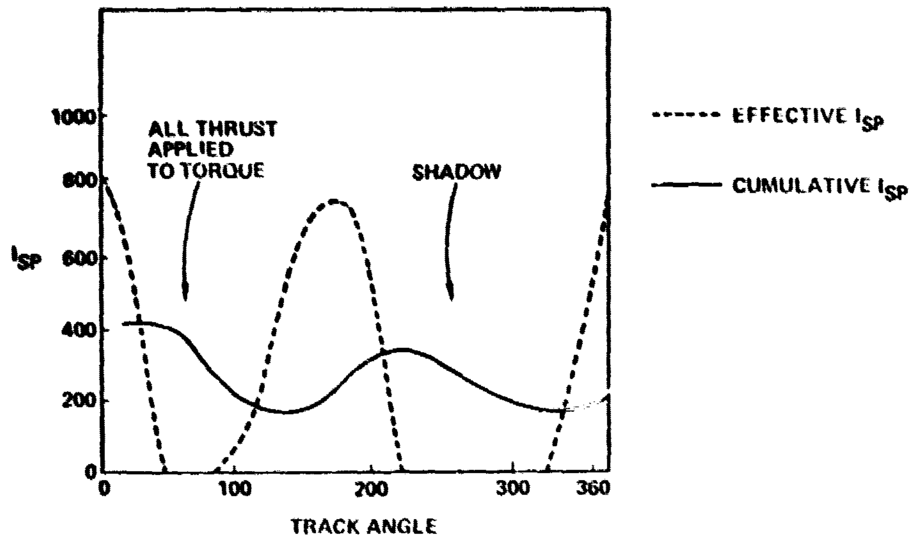

Figure C-6 I_{sp} History, First Rev.

SPS-1759

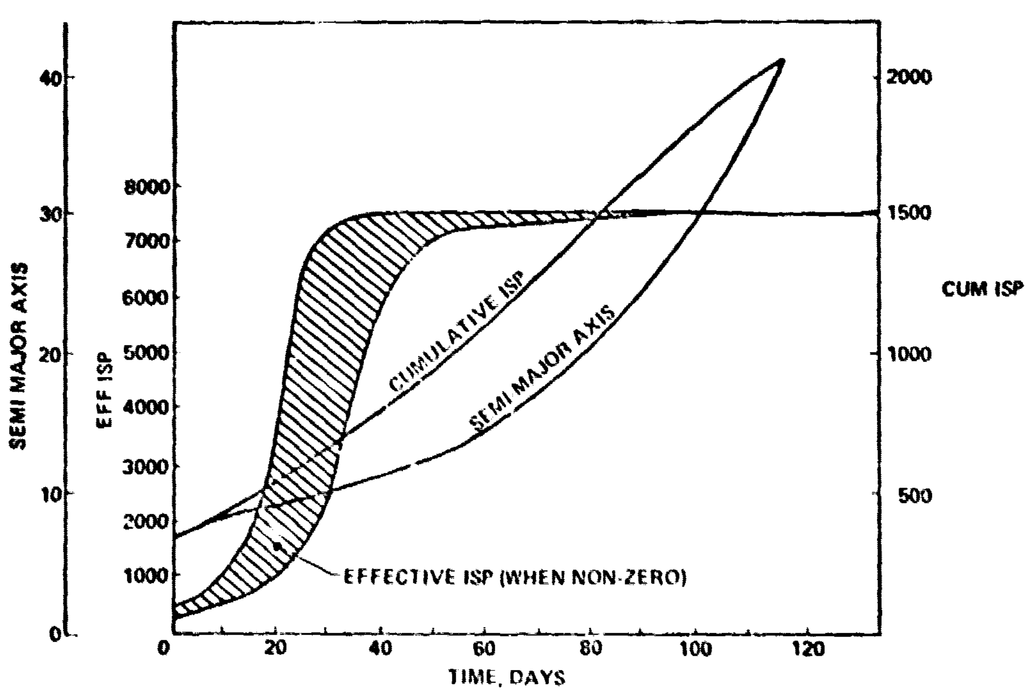

Figure C-7 Simulation Results for LEO-GEO Transfer

1. Orbit transfer guidance laws
2. Attitude strategies
3. Attitude control laws
4. Thrusting algorithms
5. Trip time and Isp
6. Chemical/electric blending vs. time
7. Configuration arrangement optimization
8. The range of departure geometries, considering season and orbit orientation.