BOEING

(NASA-CR-160380) SOLAR POWER SATELLITE SYSTEM DEFINITION STUDY, VOLUME 5. PHASE 2: FINAL BRIEFING Final Report (Boeing Aerospace Co., Seattle, Wash.) 640 p HC A99/MF A01 CSCL 22B G3/15

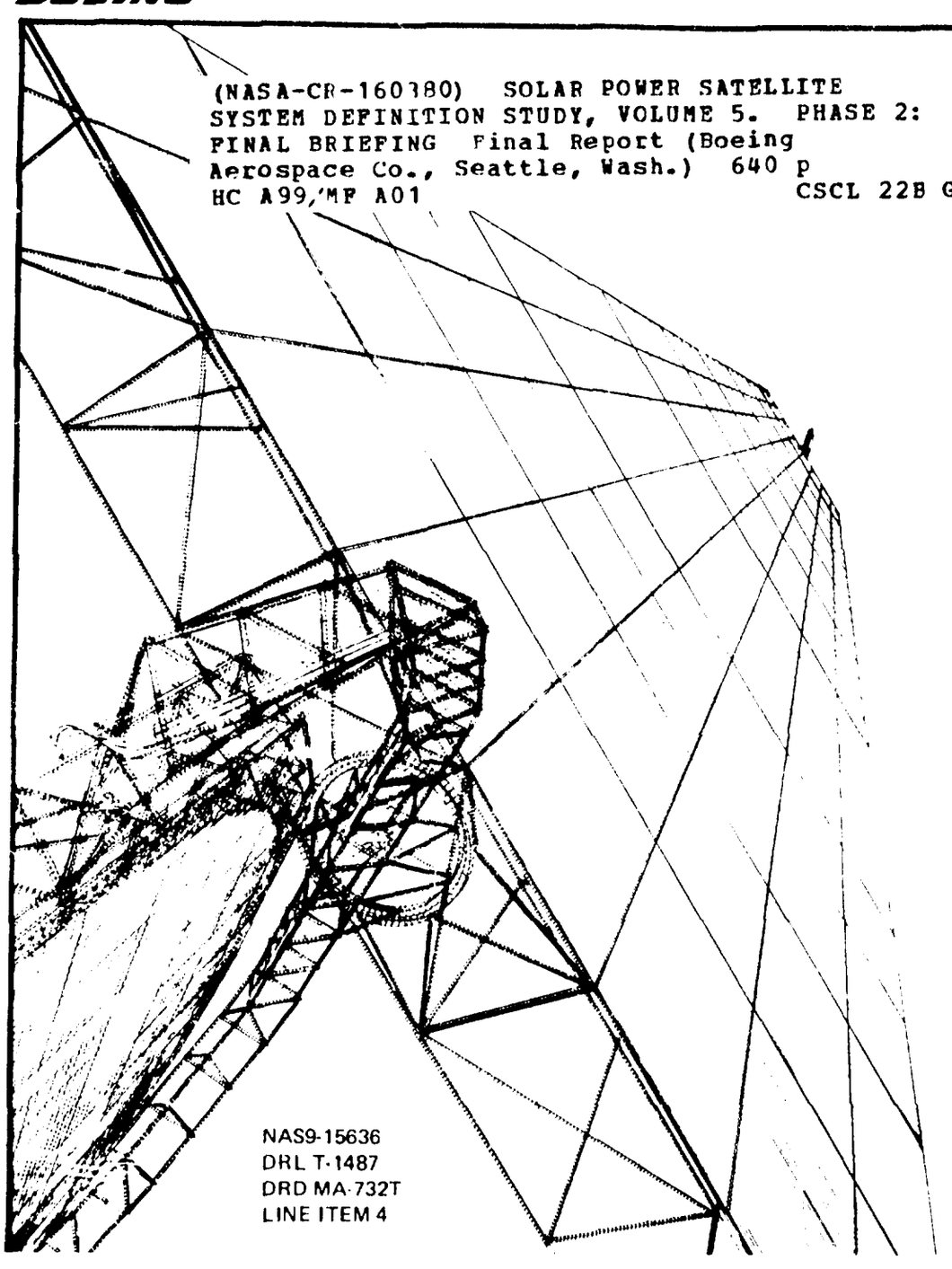
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PHASE II
VOLUME V
FINAL BRIEFING
D180-25461-5

NASA C...
160380

Solar Power Satellite System Definition Study



BOEING
GENERAL ELECTRIC
GRUMMAN
Arthur D Little Inc
TRW

NAS9-15636
DRL T-1487
DRD MA-732T
LINE ITEM 4

RECEIVED
NASA STI FACILITY
ACCESS DEPT.

Solar Power Satellite
System Definition Study

Volume V
Phase II, Final Report
FINAL BRIEFING
D180-25461-5
(Contract NAS9-15636)

November 5, 1979

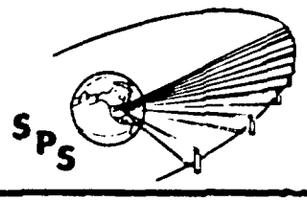
Approved by: 

G. R. Woodcock
Study Manager

Boeing Aerospace Company
Ballistic Missiles and Space Division
P.O. Box 3999
Seattle, Washington 98124

AGENDA

The SPS System Definition Study Phase II Final Briefing (Contract NAS9-15636) was presented at JSC on October 23, 1979. Also included in this briefing book are presentations by General Electric and Brown & Root, given at JSC on October 18, 1979.



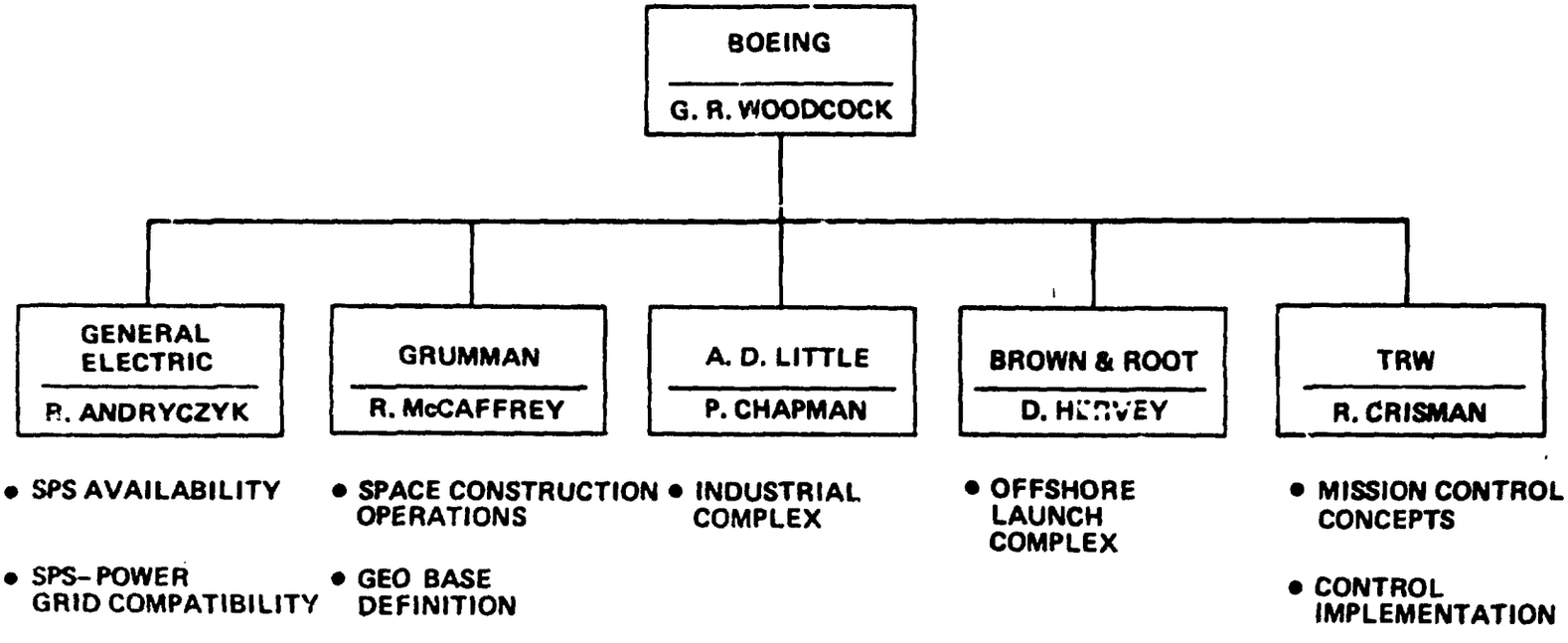
AGENDA

EXECUTIVE SUMMARY	G. Woodcock	1:15 Hr
SPS RESEARCH & DEVELOPMENT	G. Woodcock	:45 Min.
CONSTRUCTION OPS & BASE	R. McCaffrey	1:00 Hr
OPERATIONS CONTROL	R. Crisman	:30 Min.
TRANSPORTATION	E. Davis	:45 Min.
SOLID STATE SPS	E. Nalos	:40 Min.
TECHNOLOGY CONTRACT STATUS	E. Nalos	:30 Min.

STUDY CONTRACT TEAM ORGANIZATION

The Study Contract Team includes Boeing as prime contractor and Brown & Root, General Electric, Grumman, Arthur D. Little, and TRW as subcontractors. Principal task areas for the subcontractors are shown and the study team leaders for each contractor are indicated.

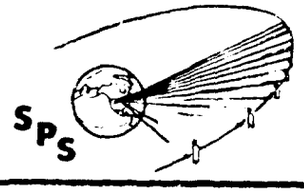
Study Contract Team Organization (Phase I Tasks Shown)



EXECUTIVE SUMMARY TOPICS

The Executive Summary covered the topics indicated. The majority of the briefing was keyed to study accomplishments and organized according to the study task work breakdown structure.

The main part of the Executive Summary was preceded by a brief summary of SPS background.



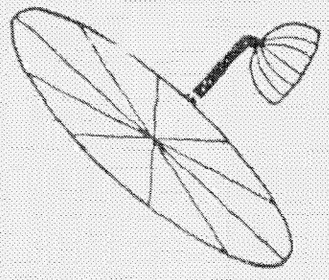
EXECUTIVE SUMMARY TOPICS

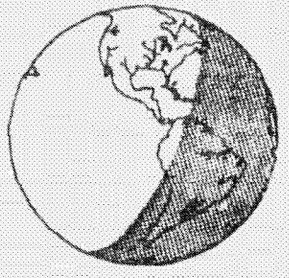
- BACKGROUND
- STUDY ACCOMPLISHMENTS
- SPS ISSUES TODAY
- RECOMMENDATIONS

EARLY SPS CONCEPTS

Illustrated here are two early SPS concepts. The first is from the original publication by Peter Glaser in 1968. The second is from the results of a pioneering study conducted by Arthur D. Little, Grumman, Raytheon, and Spectrolab Lab in 1971-1972. The latter configuration includes many features found in current configurations, including concentrating solar arrays, a microwave transmitter employing magnetron tubes, and a large space frame truss structure.

Early SPS Concepts





GLASER, 1967

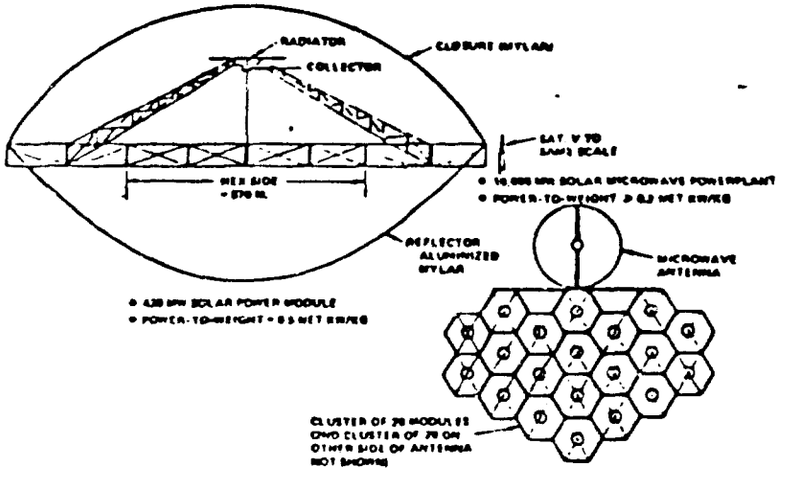
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ADL/GRUMMAN/RAYTHEON/SPECTROLAB
STUDY FOR NASA LeRC, 1972

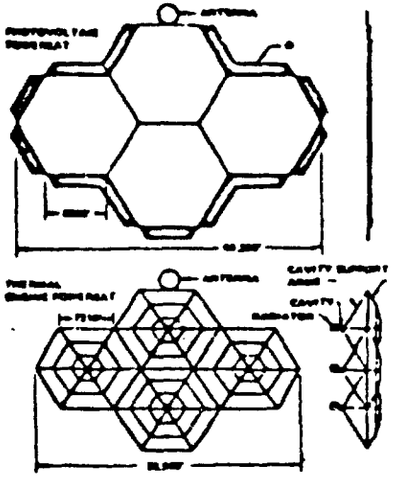
CONFIGURATION CONCEPTS CIRCA 1972-1974

Illustrated on the facing page are early configuration concepts for solar Brayton and photo-voltaic SPSs from Boeing IR&D studies. These configurations assumed that ten thousand megawatts could be transmitted from a single microwave transmitter and did not consider the effects of gravity gradients on configuration design.

Configuration Concepts Circa 1972-4



SOLAR-BRAYTON POWER SYSTEM CONCEPT



BRAYTON-PHOTOVOLTAIC COMPARISON

"THEREFORE, WHILE RECOGNIZING THAT SOLAR CELLS MAY ULTIMATELY PROVE TO BE THE BEST SOLUTION, WE EXAMINED THE ALTERNATIVE OF A SOLAR CONCENTRATOR AND HEAT ENGINE."

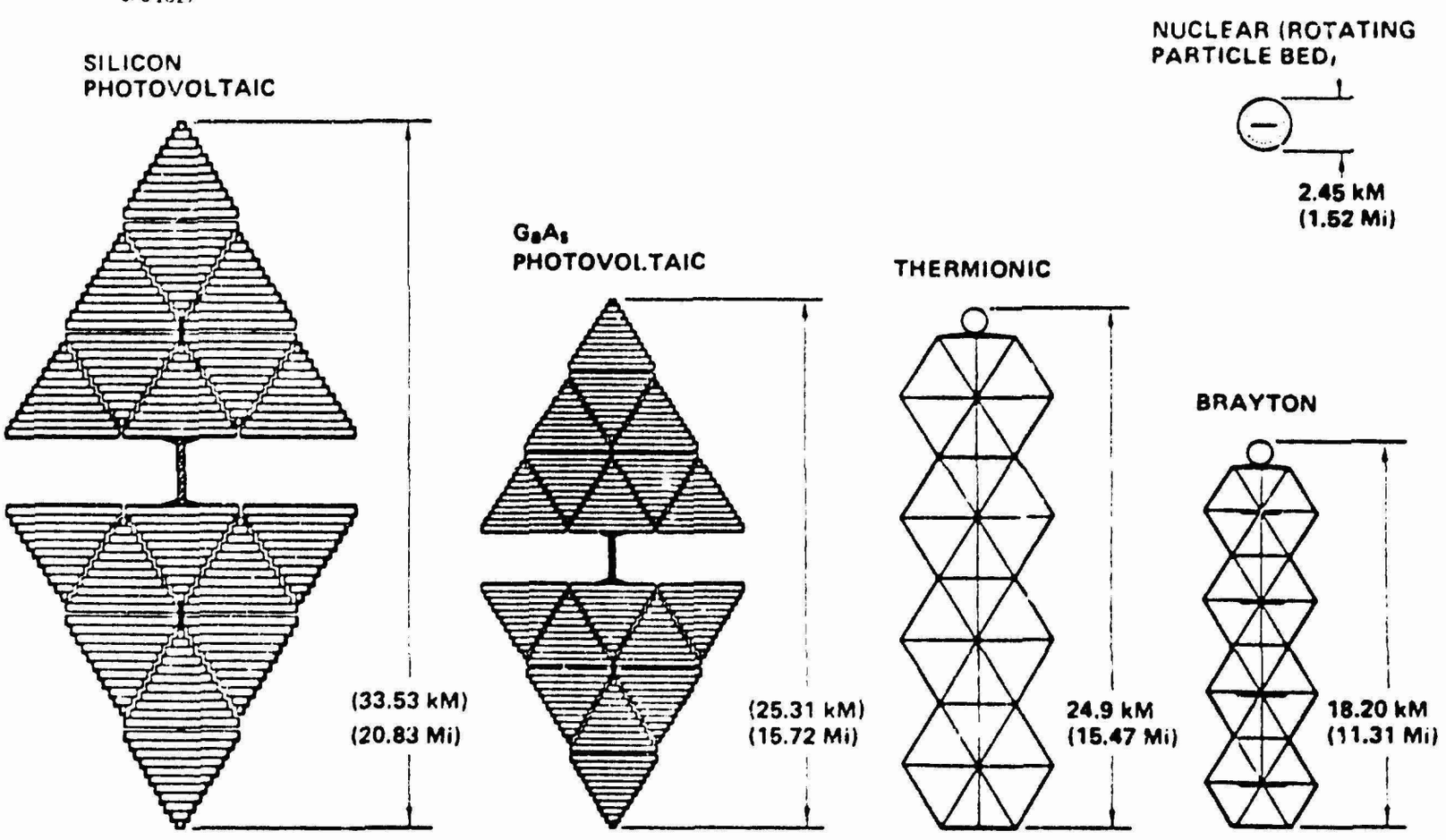
COMPARISON OF POWER SATELLITE OPTION SIZES

This illustration is representative of some of the comparative work that was conducted under a 1975 study for MSFC. As a result of these comparisons, the nuclear and thermionic options were recommended for de-emphasis. At this point, Rankine energy conversion had not been investigated.

Comparison of Power Satellite Option Sizes

SPS 7827

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ALL ARE TO SAME SCALE, END-OF-LIFE CONFIGURATION)

SPS SYSTEM DEFINITION STUDY DESIGN EVOLUTIONS

Design evolutions of the principal types of SPS systems and space support systems are shown:

The photovoltaic SPS began with the JSC truss configuration at a geometric concentration ratio of 2. This configuration was sized for beginning-of-life output capability. The configuration was resized to allow maintenance of output capability throughout the thirty-year design life system, by periodic array addition. At the completion of part 1 of the study, a total of 10 photovoltaic options had been defined as shown. These included silicon and gallium arsenide energy conversion at concentration ratios 2 and 1 and various power maintenance methods. The lowest cost silicon system was selected for continuance into part 2. This system employed no concentration and used in situ annealing of the solar cells for power maintenance. The configuration was further defined during part 2. The system output, with the optimum rectenna size, was reduced to 9.3 GW as a result of final definitions of the efficiency chain.

The thermal engine analyses began with the 10 GW Brayton system defined under an earlier contract. Early in the subject study, an analysis of available data on plastic film reflector degradation in the space environment suggested that a 30% degradation might occur. Consequently, the concentrators were enlarged to compensate. The configuration was next divided into 16 modules with trough-shaped concentrators as shown under "constructionized Brayton." During part 1 Rankine and Thermionic systems were also evaluated. Initial evaluations indicated the Rankine system to be more massive than the Brayton system. However, a cycle temperature ratio optimization resulted in a lower overall mass. Additional design changes introduced at this point eliminated steerable facets from the concentrator by flying the system always exactly facing the sun.

Toward the end of the study, new information became available on plastic film reflectors indicating that degradation impact would not occur and the final system configuration was, therefore, resized to reflect nondegradation of the concentrator.

The principal evolution in space transportation systems was in the launch vehicle. The study began with the 230 ton payload heavy lift launch vehicle at a projected cost for transportation to orbit of $33 per kilogram. Packaging indicated that higher payload densities could make possible a reusable shroud. Staging optimization studies led to a 400 ton heavy lift launch vehicle that went through the evolution shown. Also, a two-stage winged vehicle option, based on earlier JSC studies, was added.

Studies of chemical orbiter transfer vehicles included space based and Earth launched options. The orbit transfer option taken from the Future Space Transportation System Analyses study was found to be least cost and was retained. Investigation of the means of moving the SPS hardware itself from low earth orbit to geosynchronous orbit continued to indicate a significant cost advantage to the self-power concept.

The evolution of construction concepts began with equipment concepts. The initial construction base concept was for the concentration ratio 2 satellite and included little detail other than overall size and shape. This construction base concept evolved to the illustration shown at the lower right hand corner of the chart. Most of the structure is shown blocked in with structural detail only on one small portion of the construction base. This construction base includes capabilities to construct satellite modules and transmitter antennas. Analogous construction base concepts were developed for the thermal engine system also, but are not shown on this chart.

SPS System Definition Study
Design Evolutions

BOEING

SPS-1548

	ORIENTATION	PART 1 MIDTERM	PART 1 FINAL	PART 2 MID TERM	PART 2 FINAL
PHOTOVOLTAIC SPS'S	SILICON JSC TRUSS CR 2 10 GW BOL	SILICON CR 2 10 GW EOL	10 OPTIONS SILICON CR 2 GaAs CR 1 VARIOUS POWER MAINTENANCE METHODS (NOT TO SCALE)	SILICON CR 1 10 GW EOL ANNEALABLE	SILICON CR 1 9.3 GW EOL WITH OPTIMUM RECTENNA SIZE ANNEALABLE
THERMAL ENGINE SPS'S	10 GW BRAYTON MSFC STUDY	BRAYTON WITH ENLARGED CONCENTRATORS	"CONSTRUCTIONIZED" BRAYTON	RANKINE PEP	RANKINE PEP NON-DEGRADING CONCENTRATOR (NEW PLASTIC FILM DATA)
SPACE TRANSPORTATION	230-TON HLLV HLLV STUDY $33/KG	OTV FROM FSTSA; 400-TON HLLV	400-TON HLLV'S $20/KG	SELF-POWER OTS (1/8 SPS MODULE)	
CONSTRUCTION BASES	CONSTRUCTION EQUIPMENT CONCEPTS	CR=2 CONSTRUCTION BASE	CR=1 CONSTRUCTION BASE	CR=1 CONSTRUCTION BASE WITH ANTENNA FACILITY	

HIGHLIGHTS OF SPS SYSTEM DEFINITION TO MARCH, 1978

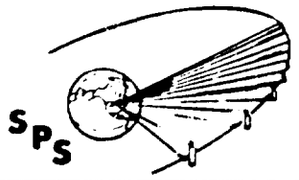
This major systems study was conducted for the Johnson Space Center under contract number NAS 915196. The study recommended silicon as the reference configuration with gallium arsenide as the alternate. Thin-film systems were also investigated but the technology base was insufficient to provide a realistic comparative assessment. A significant effort compared Rankine to Brayton cycle thermal engines. In-depth evaluation of the likely temperature limits for 30-year lifetime thermal systems drove cycle peak temperatures down to the range where potassium Rankine was a valid competitor. The construction and transportation systems aspects of the thermal engine versus photovoltaic were examined in detail with particular attention to the construction base design, its complexity, and the packaging problems attendant to thermal engine radiator systems. These analyses led to a conclusion that if projected photovoltaic costs could be achieved these systems would be roughly ten per cent less costly. Thermal engines do, however, provide a hedge against the possibility that costs will not come down as projected.

The study also developed a Klystron reference power transmitter, including detailed error analyses and efficiency chain calculations. Emphasis on the Klystron was aimed at developing efficient design detail information in order to enable evaluation relative to the amplitron or magnitron. Such a head-to-head Klystron amplitron evaluation has, however, to our knowledge, never been made.

A trade-off was made of winged versus ballistic heavy-lift launch vehicles. The cost estimates came out essentially equal. Although the winged vehicle is somewhat more expensive it can operate with smaller fleet size because turnaround time is reduced. Accordingly, the winged system was selected on the basis that it presents less developmental risks.

The performance advantages of electric propulsion for orbit-to-orbit transfer became apparent during the study. The electric propulsion system was embodied in a self power orbit transfer concept to be described later in this briefing.

This study also investigated construction operations in depth and began to look at maintenance and SPS compatibility with power grids.



Highlights of SPS System Definition to March, 1978

- **RECOMMENDED SILICON AS REFERENCE, GALLIUM ARSENIDE AS ALTERNATE**
  - SILICON LOWEST RISK, COST DIFFERENCES WITHIN UNCERTAINTY BAND
- **RECOMMENDED RANKINE OVER BRAYTON**
  - THERMAL CYCLES PRESENTED CONSTRUCTION & TRANSPORTATION PROBLEMS WHEN EXAMINED IN DETAIL
  - THERMAL CYCLES PROVIDE A HEDGE AGAINST PHOTOVOLTAICS COST PROBLEMS
- **DEVELOPED KLYSTRON REFERENCE POWER TRANSMITTER**
  - DETAILED ERROR ANALYSIS CONFIRMED POTENTIAL FOR EFFICIENT POWER TRANSFER
- **SELECTED WINGED OVER BALLISTIC HLLV**
  - ESTIMATED $33/Kg TO LEO
- **SELECTED ELECTRIC SELF-POWER ORBIT TRANSFER OVER LO_2/LH_2 OTV**
  - INDEPENDENT ELECTRIC OTV WAS NOT INVESTIGATED
- **DEVELOPED END-TO-END SPACE CONSTRUCTION APPROACH AND FACILITY CONCEPT**
  - CONSTRUCTION SIMPLICITY A FACTOR IN SELECTING CONCENTRATION RATION = 1
- **BEGAN TO ANALYZE SPS MAINTENANCE AND POWER GRID COMPATIBILITY**
  - SELECTED LEVEL-LOADED MAINTENANCE OVER CONCENTRATING ON EQUINOX PERIODS

DOE/NASA REFERENCE SYSTEM REPORT, OCTOBER 1978

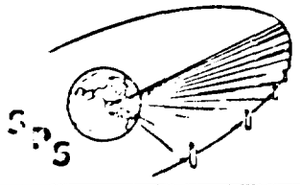
During the summer of 1978, following the study just discussed (and the study by Rockwell International for the Marshall Space Flight Center), NASA developed a reference system description published in October 1978. This system description drew data from the Boeing Study, the Rockwell Study, and NASA-Johnson and Marshall Space Center inhouse studies. Principal features of the reference system are described on the facing page. These decisions were made in parallel with the beginning of the current Boeing study for NASA Johnson Space Center. As these decisions became clear the present study adopted the ground rules wherever possible, examined alternatives in certain cases and is now in consonance with the reference system description in terms of our baseline system description.

DOE/NASA Reference System Report Oct. 1978

- DATA DRAWN FROM NASA & CONTRACTOR STUDIES
- 5,000 MEGAWATT SPS, ONE TRANSMITTER
  - SILICON AND GALLIUM ARSENIDE SOLAR CELL OPTIONS
- KLYSTRON TRANSMITTER
  - MAGNETRON & SOLID STATE RECOGNIZED AS POTENTIAL OPTIONS
- GEO CONSTRUCTION WITH INDEPENDENT ELECTRIC OTV
- TWO-STAGE VERTICAL TAKE-OFF, HORIZONTAL LANDING ROCKET HLLV

FIVE PHASES OF SPS

As a preamble to discussion of study accomplishments, it is noted that an overall SPS program approach and plan has been developed, including five phases. These program phases are occasionally referenced in the briefing material to follow.

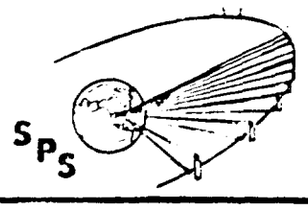


FIVE PHASES OF SPS

PHASE	OBJECTIVE
Research	o Evaluate and Select SPS Technologies o Resolve Technical, Environmental and Socio-economic Issues
Engineering Verification	o Demonstrate Conversion of SPS Technologies into Practical Engineering Hardware
Demonstration	o Demonstrate End-to-End Operational Suitability of SPS as a Baseload Electric Power Source
Investment	o Create the Industrial Base to Produce SPS Generating Capacity at 10,000 Megawatts/Yr.
Commercial Production	o Install and Maintain 300,000 Megawatts of SPS Generation Capacity over 30-Year Period.

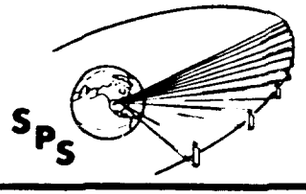
PRINCIPAL ACCOMPLISHMENTS

The following table (three pages total) summarizes the study accomplishments. These form the outline for the majority of the executive summary, in which the principal results are presented.



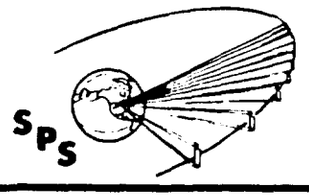
PRINCIPAL ACCOMPLISHMENTS

TASK	PHASE I	PHASE II
BASELINE CRITIQUE & UPDATE	. Developed in-depth critique of baseline . Corrected design deficiencies . Selected EOTV for orbit-to-orbit transportation	. Defined solid-state SPS option . Re-analyzed reference system with mass & cost estimate to WBS Level 5 . Updated system description
CONSTRUCTION & MAINTENANCE	. Evaluated construction options and selected end-builder (Grumman) . Developed low-cost Rectenna Construction Designs & Approach (GE)	. Defined Construction Base in more detail (Grumman) . Updated & extended maintenance analysis
INDUSTRIAL COMPLEX	. Identified Production Capacity Issues (ADL)	. Scoped Industrial Complex Needs (ADL) . Developed Industrial Complex Cost Estimates



PRINCIPAL ACCOMPLISHMENTS - Cont.

TASK	PHASE I	PHASE II
LAUNCH COMPLEX	. Evaluated Equatorial Launch	. Defined KSC Launch Site Requirements . Developed Concept for Sea-Based Launch Site (Brown & Root)
OPERATIONS	. Analyzed Depressed HLLV Trajectories	. Developed Operations Analyses for all operational elements . Developed Integrated Ops Management Approach (TRW) . Developed further depressed trajectories.
SPS/GROUND NETWORK INTEGRATION	. Updated Rectenna Description (GE) . Updated Rectenna/Network Interconnect (GE)	. Updated SPS Reliability/ Availability (GE) . Assessed SPS LOLP, Control, and Reserve Margin Suitability (GE)



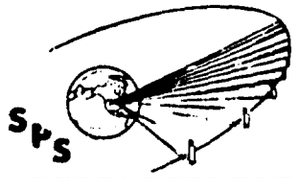
PRINCIPAL ACCOMPLISHMENTS - Cont.

TASK	PHASE I	PHASE II
TECH. ADVANCEMENT & DEVELOPMENT	. Identified Development and Demonstration Options	. Developed Detailed Ground & Flight Research Plans . Developed 4-Phase Overall Program Approach . Developed End-to-End Program Plan
COSTS & SCHEDULES	. Developed First Cut Research Schedule	. Developed Detailed Research Schedule Using Automated Network Analysis . Updated Cost Analysis & Costed to Level 5 . Developed Complete Non-Recurring Cost Estimate

CRITIQUE SUMMARY

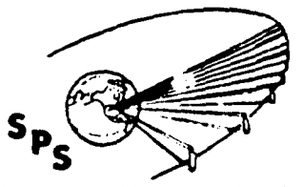
The study began with a critique of the then-current reference design. The critique was conducted by an independent panel of technical experts. Roughly 100 critique items were developed, most of an incidental nature. A number of significant items were identified and are summarized on the following two-page table.

In addition to these items, there were certain ones of an environmental nature. These were previously known and were included in the DOE environmental impact assessment activities. As they are outside the scope of the present systems definition study, they are not included here.



CRITIQUE SUMMARY

CRITIQUE ITEM	RESOLUTION
SPS Large Unit Size	Examined by GE; not a problem in SPS time frame
Space Debris from Construction Operations	Debris sources not identified; secondary or incidental sources should be worked in Engineering Verification
Long-Term Life of SPS Materials	Research Phase Emphasis
Lack of Definition of Flight Control and Computing Systems	Definition improved in present study
Plasma/High Voltage Interaction Potential	Research Phase Emphasis
Solar Array Performance, Degradation, and Annealing	Initial degradation and annealing tests confirm general approach; much emphasis required during research program.



CRITIQUE SUMMARY - Cont.

CRITIQUE ITEM	RESOLUTION
Power Distribution Faults	Multiple-bus system selected to reduce fault currents
SPS EMI/RFI	. Satellites flying through beam found to be minor problem. . Selected fiber optics for on-board data and phase distribution. . Much emphasis required during research program.
Power Transmitter Structure	Design simplified
Power Processor Life	Design changed
MPTS Performance	. Continued analysis supports achievability . Much emphasis required during research program

CUMULATIVE COST COMPARISON

Cost trends with time for the three orbit transfer/construction locations options are shown here.

The three concepts compared were:

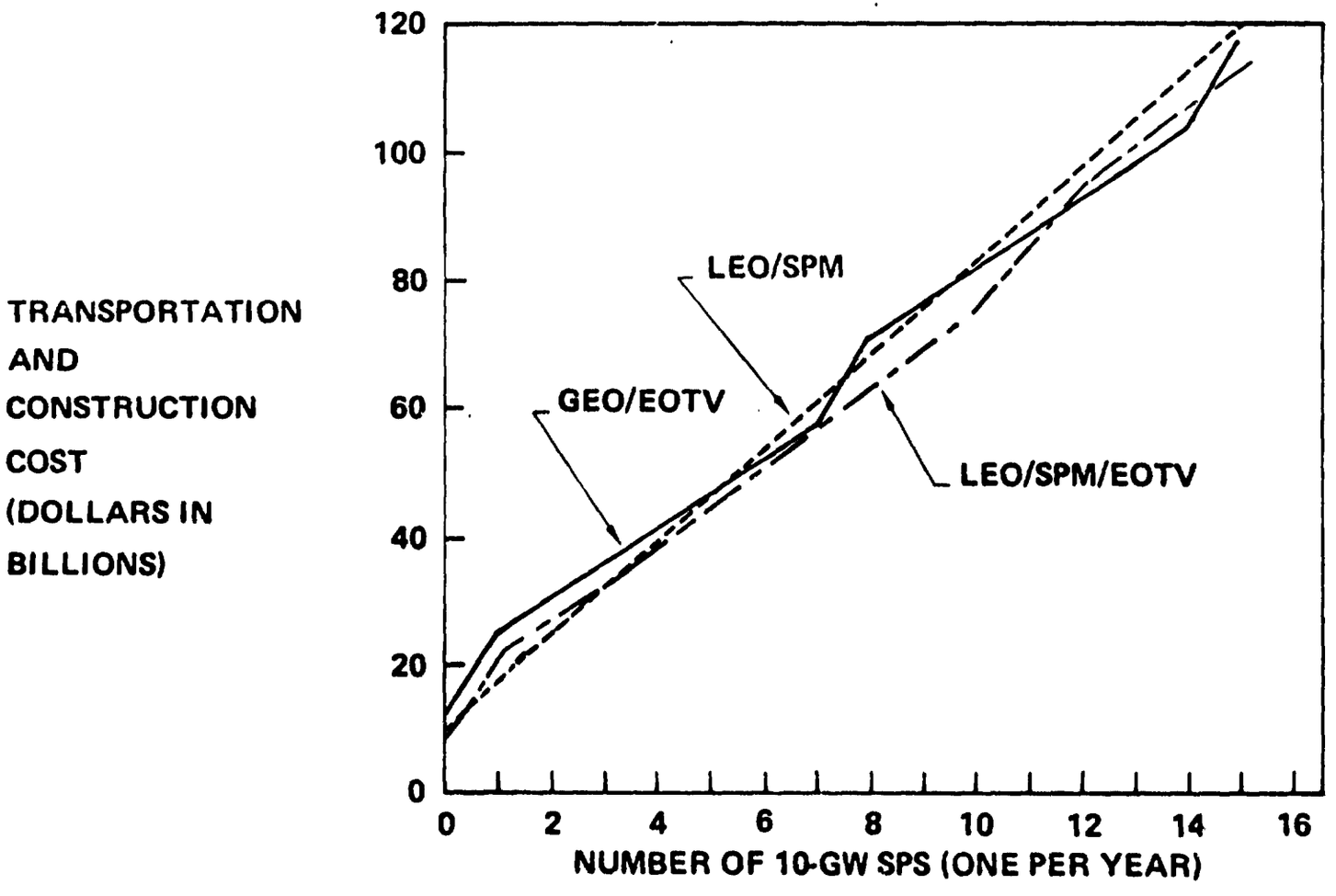
(1) LEO/SPM: Construction of the SPS in low Earth orbit and use of self-power to move SPS modules to GEO.

(2) LEO/SPM/EOTV: The same with use of EOTV's to return self-power propulsion equipment to LEO for reuse.

(3) GEO/EOTV: Construction at GEO with use of EOTV's for all cargo orbit transfer.

Although a front-end cost advantage was seen for LEO/SPM, the overall trade was too close to call; the DOE/NASA baseline (GEO/EOTV) was retained.

Cumulative Cost Comparison



2.5 GW SOLID STATE SPS CONFIGURATION

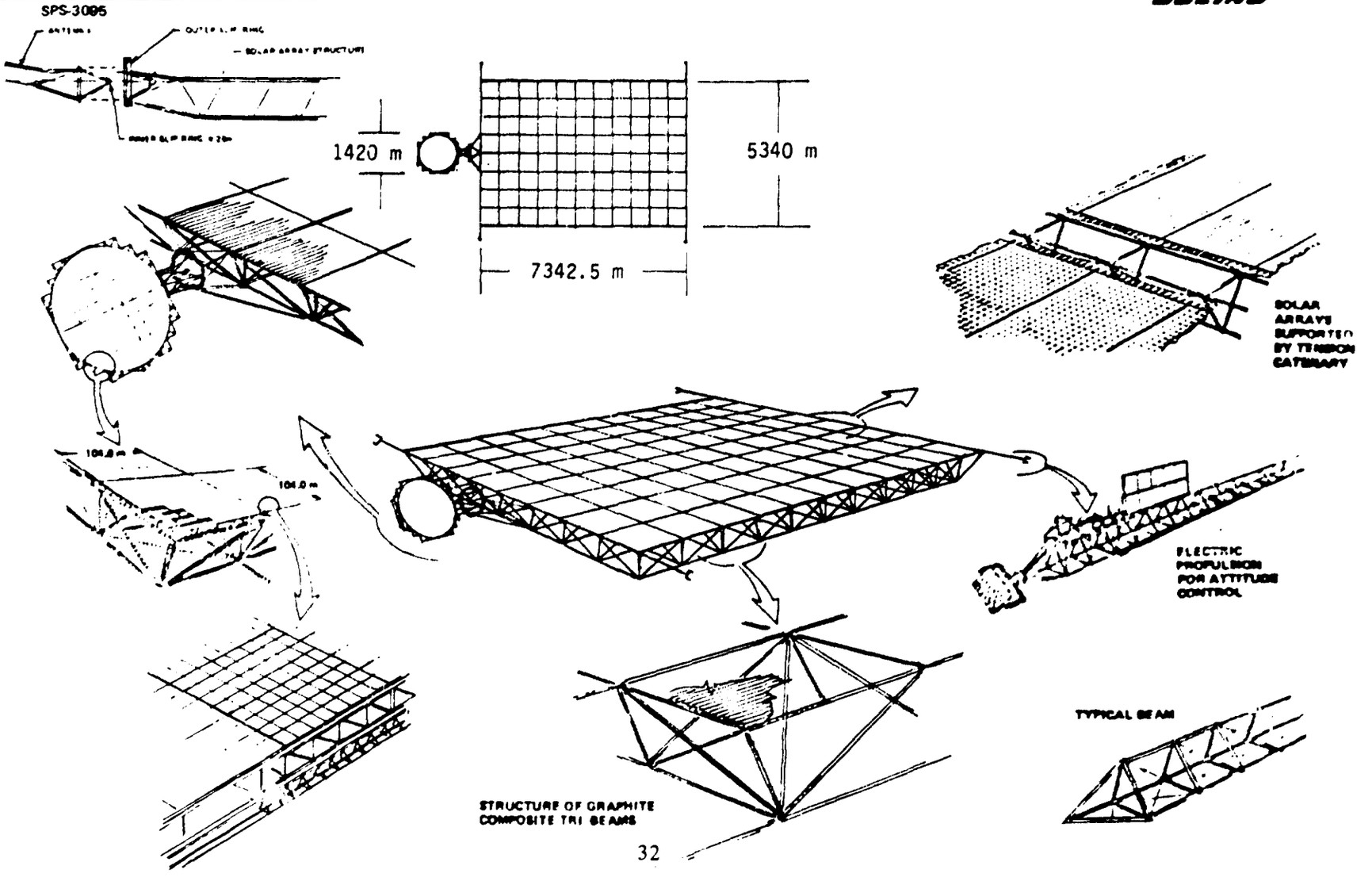
A solid-state reference configuration was created in Phase II. This configuration is similar to the reference configuration with the following major differences.

- The power delivered to the grid is 2500 megawatts rather than 5000 megawatts.
- The array size is 8 x 11 bays rather than 8 x 16 bays.
- The array voltage is 5.5 KV rather than 44 KV.
- The transmitter aperture is 1.4 km rather than 1.0 km.
- The transmitter employs gallium arsenide FET's rather than klystrons.

This system is presented in more detail under the heading "SOLID STATE SPS" later in this briefing book.

2.5 GW SOLID STATE SPS CONFIGURATION

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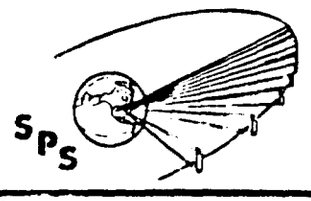


SOLID-STATE MASS SUMMARY

The solid-state mass estimate is presented here.

The mass is about 70% of the klystron reference system although the power is only 50%. This arises because of the comparatively low distribution voltage, which leads to high distribution losses (thus proportionately more solar array) and a heavy distribution conductor system.

Future work is expected to reduce this penalty.

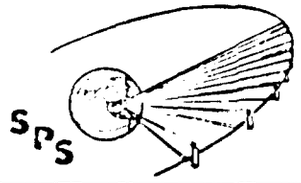


SOLID-STATE SPS MASS SUMMARY

1.1 SPS	35,204	
1.1.1 ENERGY CONVERSION	22,087	
1.1.1.1 STRUCTURE	2,851	Detailed estimate
1.1.1.2 CONCENTRATORS	(0)	Not required
1.1.1.3 SOLAR BLANKETS	14,409	Scaled from reference
1.1.1.4 POWER DISTRIBUTION	4,400	Detailed estimate
1.1.1.5 THERMAL CONTROL	(0)	Allocated to subsystems
1.1.1.6 MAINTENANCE	427	Scaled from reference
1.1.2 POWER TRANSMISSION	6,365	
1.1.2.1 STRUCTURE	460	Scaled from reference
1.1.2.2 TRANSMITTER SUBARRAYS	4,480	Detailed estimate
1.1.2.3 POWER DISTR. & COND.	1,262	Scaled from 1.1.1.4
1.1.2.4 PHASE DISTR.	25	Scaled from reference
1.1.2.5 MAINTENANCE	20	Docking ports only
1.1.2.6 ANTENNA MECH POINTING	118	Scaled by Mass x Area
1.1.3 INFO MGMT & CONTROL	145	Scaled from reference
1.1.4 ATTITUDE CONTROL & STATIONKEEPING	146	Scaled from reference
1.1.5 COMMUNICATIONS	0.2	Same as reference
1.1.6 INTERFACE	113	Est. based on simplification
1.1.7 GROWTH & CONTING. (22%)	6,348	Same % as reference

2.5 GW SOLID STATE SATELLITE SYSTEM
RECURRING COSTS

The solid-state cost estimate summary is presented here. The cost per kilowatt is about 35% greater than for the reference system. As with mass, this arises mainly because of the low distribution voltage.



2.5 GW SOLID STATE SATELLITE SYSTEM RECURRING COSTS

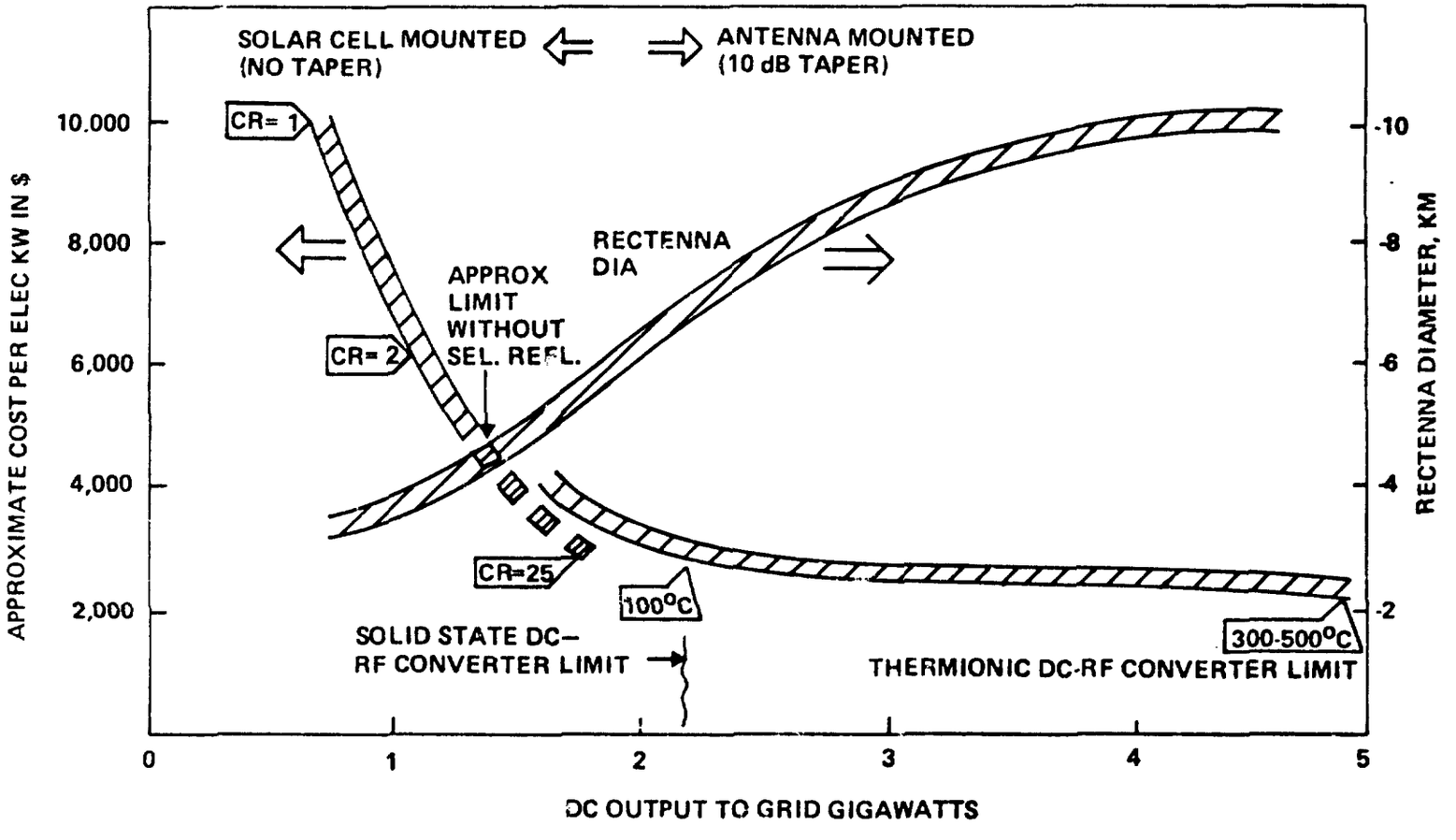
ITEM	COST ($M)
SATELLITE	3,722
LESS IMPLICIT AMORTIZATION	327
	3,395
CONSTRUCTION AND SUPPORT	664
SPACE TRANSPORTATION	2,154
GROUND TRANSPORTATION	20
RECTENNA	1,290
MISSION CONTROL	10
MGMT AND INTEGRATION	385
MASS GROWTH (17% Net Hardware)	577
TOTAL DIRECT OUTLAY	8,505

SPS COST TRENDS

This cost trend chart was developed early in Phase II to compare solid-state "sandwich" configurations to the klystron reference systems. "Sandwich" configurations employ solar cells and microwave amplifiers in a sandwich (back-to-back) configuration. Sunlight is concentrated on the array by plastic film reflectors. Sandwich configurations are thermally limited to low powers. The sandwich configuration appears to trend very similarly to the antenna baseline configurations. The sandwich appears to trend below the baseline only when advanced technologies such as very high efficiency solar cells or selective reflectors are employed. These kinds of technologies, however, would also improve the cost performance of the reference systems.

The antenna-mounted solid-state system is also spotted on the chart. It falls slightly above the trend line. Further work on the power distribution problem is expected to move it down to, or slightly below, the trend line. Note that this chart uses 1977 dollars whereas other data in this briefing are in 1979 dollars.

SPS Cost Trends



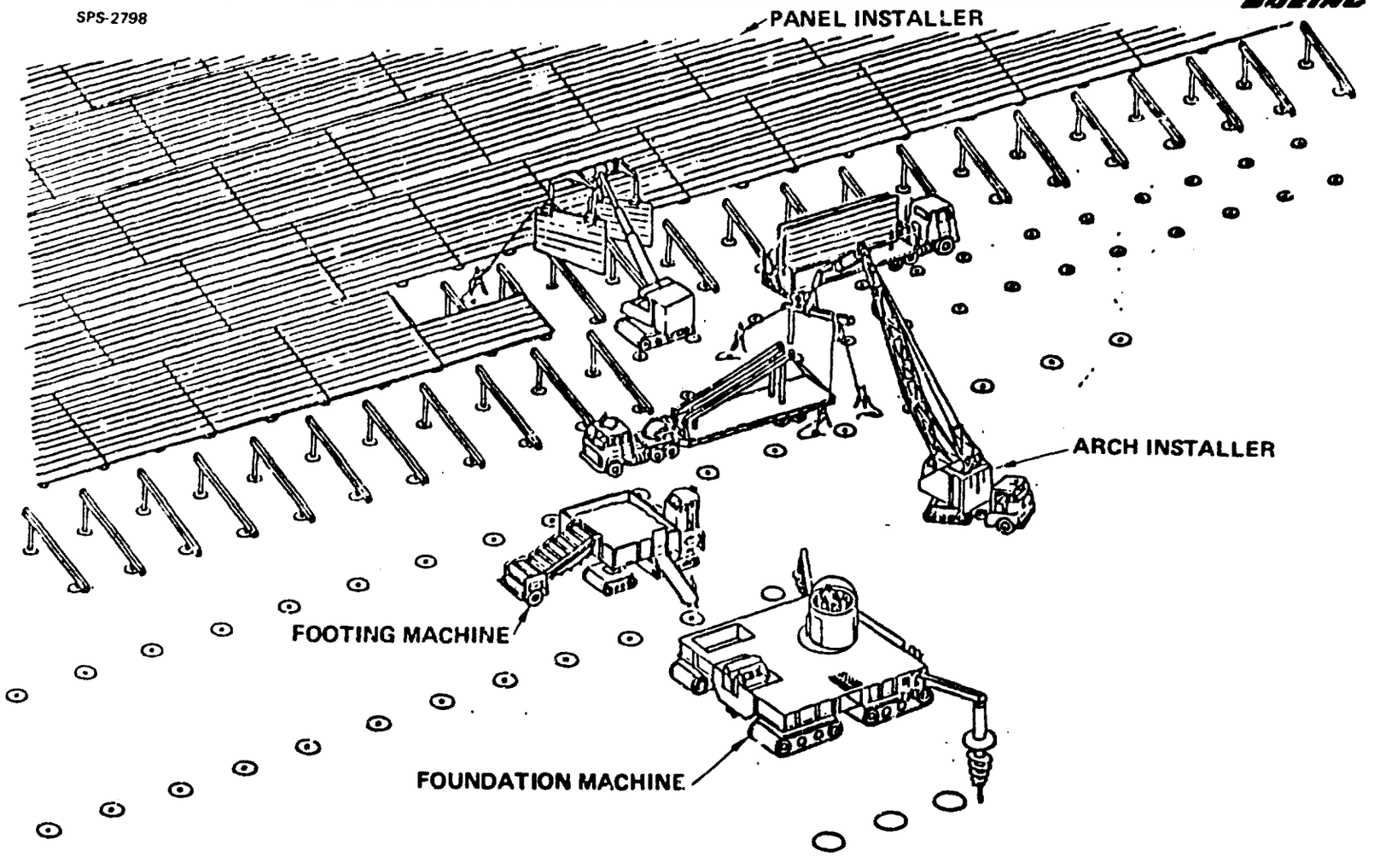
5-GIGAWATT RECTENNA CONSTRUCTION CONCEPT

As a part of the study, General Electric analyzed rectenna construction with the objective of defining a mechanization and structural concept that could reduce rectenna costs from the earlier estimates. A pictorial summary of the construction concept is illustrated here. The basic support structure is steel reinforced concrete. This support structure is emplaced by construction equipment employing advanced technology location systems to allow precise location of the footings. Support and rectenna panels are manufactured at the site in portable factory buildings and moved for installation as illustrated.

Five GW Rectenna Construction Concept

SPS-2798

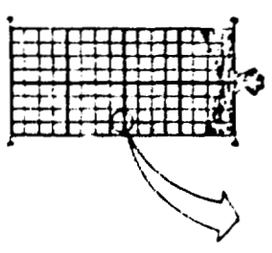
BOEING



MAIN BUS MAINTENANCE ACCESS SYSTEM

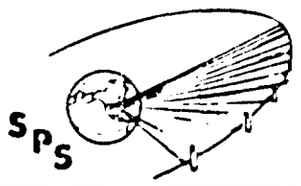
The 1977 study examined maintenance of the klystrons on the power transmitter and did some comparisons of various means of flying and operating missions. During that study it was assumed that repair of components of the geosynchronous base would require the same size crew as the remove/replace operations at the satellites. During the present study further analysis was conducted on the maintenance systems in order to establish how maintenance access for all system components could be accomplished and to estimate actual crew counts both for remove/replace operations and for equipment repair operations at the geosynchronous base. Illustrated on this figure is a representative access concept for gaining access to power buses and switch gear. Additional definition of installation specifics was required in order to accomplish the maintenance analysis. Illustrated is the multiple bus power distribution system and a flying cherrypicker which is a part of the maintenance system.

Main Bus Maintenance Access System



MAINTENANCE ANALYSIS SUMMARY

The facing page summarizes the results of the maintenance and indicates the estimated cost of maintenance to be approximately 0.3 cent per kilowatt hour. This cost is categorized in utility language as operations and maintenance cost.



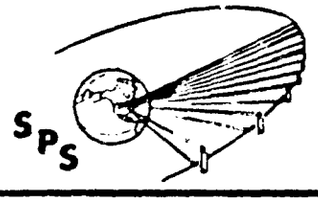
MAINTENANCE COST SUMMARY: 40 SPS

ITEM	NUMBER	COST ($M79)	REMARKS
HLLV	80 Flights	936	
PLV	38 "	460	
EOTV	5 "	226	
POTV	36 "	88	
TOTAL TRANSPORTATION OPS		1710	
MAINTENANCE CREW	650	1785	Assumes 10 support people on ground per space worker
SPARES		800	
MISSION CONTROL		20	
TOTAL ANNUAL COST		4315	23rd year of production program

$$\text{O\&M COST} = \frac{4315 \times 10^6}{5 \times 10^6 \text{ KWH} \times 8766 \text{ HR/Y} \times 0.9 \text{ Plant Factor} \times 40 \text{ SPS's}} = 0.27¢/\text{KWH}$$

INDUSTRIAL INFRASTRUCTURE SUMMARY
SPS HARDWARE PRODUCTION

The ground-based industrial infrastructure required for SPS production was scoped by Arthur D. Little. Investment cost estimates are rough order-of-magnitude. Most of these investments would be absorbed by the private sector.



INDUSTRIAL INFRASTRUCTURE SUMMARY
SPS HARDWARE PRODUCTION

ITEM	CURRENT CAPACITY	SPS CAPACITY REQUIRED	INVESTMENT COST ($M79)	REMARKS
Solar Array	≈1 MW/YR	18,000 MW/YR	5000	Photovoltaics consume only about 5% of current semiconductor silicon production
Ion Thrusters	Nil	5000 to 10000 units per year	None	Can be absorbed by existing infrastructure
Klystrons	7000/yr	200,000/YR	1500	Present magnetron production is ≈ 2 GW/YR
Rectenna	N/A	2 rectennas/yr	250	Materials consumption small compared to existing productive capacity
Graphite Fibers	150 T/Yr	≈10,000 T/YR	549	About twice projected U.S. capacity in 1993.
Other			1625	Mostly electronics
TOTAL			8924	

PROPELLANT PRODUCTION REQUIREMENTS
SPS CONSTRUCTION AT 10,000 MEGAWATTS/YR

Propellant production requirements to sustain SPS production at 10,000 megawatts per year are summarized. Plant capital cost and energy requirements were derived by a Boeing Commercial Airplane Company study of synthetic fuels for commercial aircraft.

The energy investment in propellants is small. If the electricity requirement is met by coal-fired generation, the total coal consumption approximately doubles. Stated another way, 25,000 tons/day of coal for one year can generate, if used directly, about 2,000 megawatt-years of electricity. Used to produce SPS rocket propellant, the same quantity of coal contributes the transportation energy requirement to generate 300,000 megawatt-years of electricity.

PROPELLANT PRODUCTION REQUIREMENTS
SPS CONSTRUCTION AT 10,000 MEGAWATTS/YR

	METRIC TONS/YR				TOTAL TONS/DAY [1]	PLANT CAPITAL COST $M79	
	HLLV	POTV	EOTV	PLV			
LO_2	2,671,000	3,722	1,060	57,700	9,000 [2]	650	From Coal [6] and Air
LCH_4	642,600	-0-	-0-	18,700	2,200 [3]	615	
LH_2	123,704	745	353	3,036	420 [4]	500	
ARGON	-0-	-0-	14,400	-0-	47 [5]	-0-	

[1] Capacity required at start of program; includes 20% margin

[2] 1979 U.S. capacity is about 30,000 tons/day

[3] About 0.2% of U.S. Natural Gas Consumption in 1977

[4] Today's capacity is 100 T/Day

[5] Byproduct of LO_2 Plant

[6] 12,250 T/D coal + 1000 megawatts electric power. Coal use is 0.7% of U.S.'77

LAUNCH SITE SELECTION

The launch site analysis task was motivated by the premise that selection of a low-latitude site would offer signifidant cost advantages with respect to operations from the Kennedy Space Center, where earth-to-low-orbit space transportation arrives at a 30° inclination orbit. With a 30° inclination orbit for staging or construction operations, a 30° plane change is required to reach a geosynchronous equatorial orbit. It was presumed that this plane change would incur significant performance penalties relative to a zero-degree or low-inclination low earth orbit. However, with electric propulsion this performance difference in terms of cost is minimal. Therefore, the principal motivation for leaving KSC for a remote site will stem from the eventuality of SPS operations outgrowing KSC. Our estimates to date indicate that KSC can handle approximately 10 gigawatts per year of SPS construction. It should be recognized that a significant delta V advantage of equatorial launch exists for chemical orbit transfer to GEO.

Remote site options include land-based sites such as the mouth of the Amazon in Brazil and ocean-based sites employing large flating structures such as the western Pacific low latitude sites identified by Jim Akkerman in studies at the Johnson Space Center. Large uncertainties were identified in the Part I study as to the cost of large floating structures. The two orders of magnitude range is indicated on the facing page.

Launch Site Selection

- PERFORMANCE ADVANTAGE FOR LOW LATITUDE IS SMALL (<10%) FOR ELECTRIC PROPULSION
- PRINCIPAL MOTIVATION FOR REMOTE SITE WILL OCCUR IF SPS OPERATIONS OUTGROW KSC
- KSC APPEARS SUITED FOR ABOUT 10GW/YEAR
- OCEAN SITE POTENTIALLY ATTRACTIVE DEPENDING ON COST OF LARGE FLOATING STRUCTURES
  - AIRCRAFT CARRIERS ~ $50 000/$M^2$
  - DRYDOCKS & BARGES ~ $5 000/$M^2$
  - CONCRETE FLOATS < $500/$M^2$ (HOUSEBOATS)

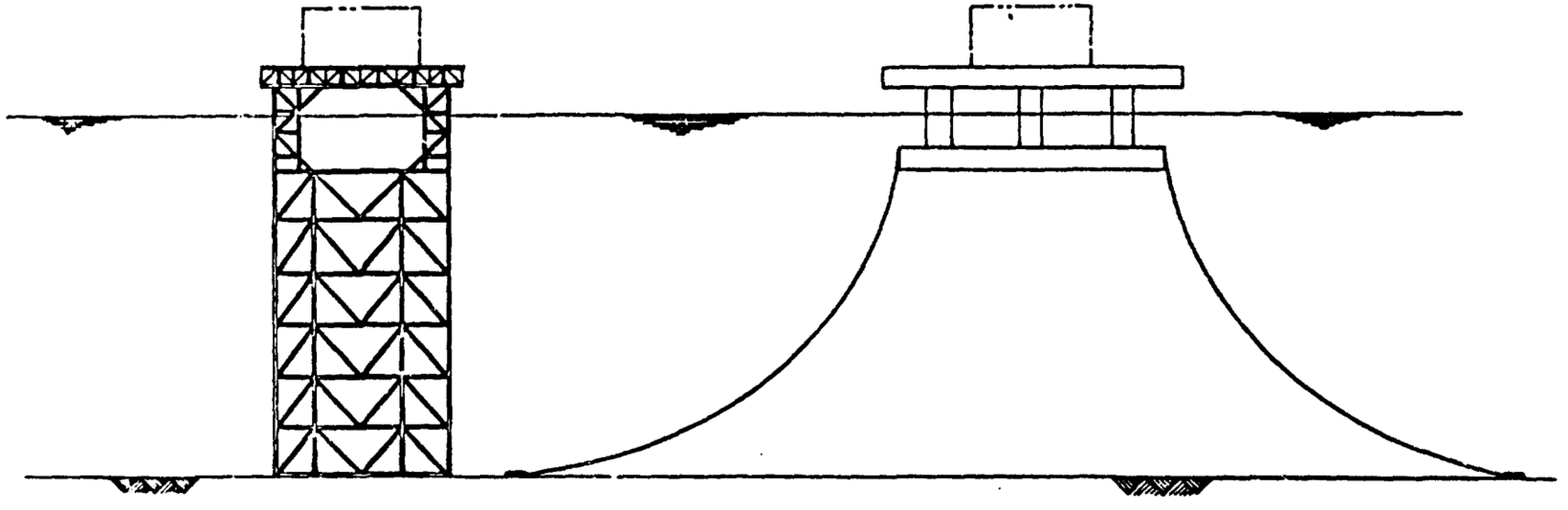
BROWN & ROOT OFFSHORE LAUNCH DESIGN CONCEPTS

In Phase II Brown & Root developed these concepts for support of an offshore launch facility. The facility would include launch and recovery facilities, the latter requiring a 91 x 4572 m (300' x 15,000') runway which dominates support structure costs. The facility would be located off the west coast of South America, roughly 325 km north of the Galapagos Islands. At that location, weather and sea states are unusually mild (the "doldrums").

BROWN & ROOT OFFSHORE LAUNCH DESIGN CONCEPTS

JACKET SUPPORTED PLATFORM

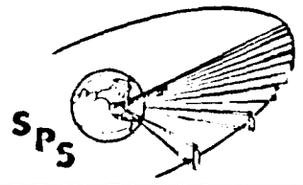
MOORED SEMISUBMERSIBLE SUPPORT MODULE



SUPPORT CONCEPTS

SIGNIFICANT RESULTS OF THE OSC STUDY

Principal conclusions of the Brown & Root study are stated. Since the offshore approach would allow most of the launch and recovery equipment to be installed on the support structure sections as they are built in a shipyard (rather than constructed at a remote site), the savings in equipment installation and checkout and site preparation could more than offset the cost of offshore structures.



SIGNIFICANT RESULTS OF THE OSC STUDY

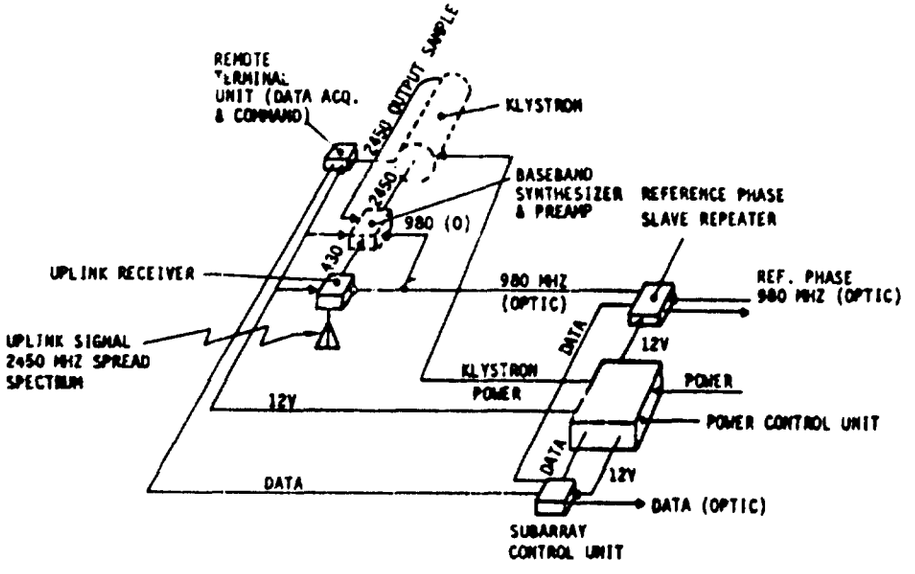
- TECHNICALLY FEASIBLE
- SIX YEARS FROM CONCEPTUAL DESIGN TO COMPLETION
- TOTAL INSTALLED COST ESTIMATES
  1. MOORED, SEMI-SUBMERSIBLE -$3,005,000,000
  2. STATIONARY, PILE-SUPPORTED -$3,917,000,000
- RUNWAY IS SIGNIFICANT COST DRIVER
- CONCEPT HAS REAL BENEFITS
- PROBABLY LEAST COST WAY TO PROVIDE A LARGE EQUATORIAL LAUNCH COMPLEX

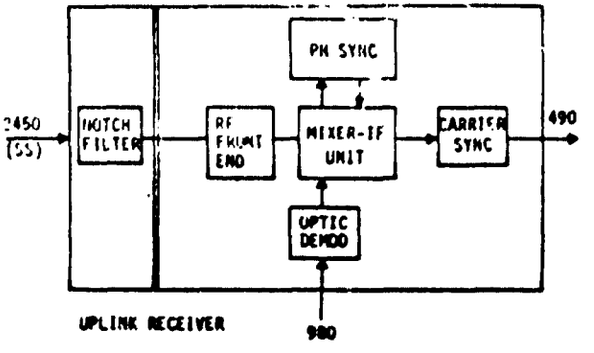
TYPICAL SYSTEM DEFINITION AT LEVEL 5
(WBS 1.1.2.2.5, SUBARRAY CONTROL CIRCUITS)

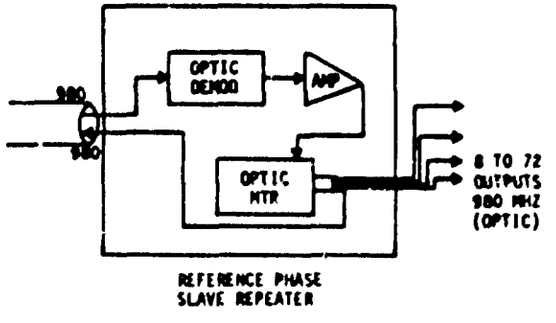
As a part of the system definition update, the level of definition was carried to WBS Level 5 on the satellite ,with details at Level 6 in most areas. The facing page illustrates a typical definition item. The mass of each box and cable was estimated and the mass of this element on each satellite was estimated by multiplying by the number of each item per satellite.

TYPICAL SYSTEM DEFINITION AT LEVEL 5

(WBS 1.1.2.2.5, SUBARRAY CONTROL CIRCUITS)







LARGE PHASED ARRAY SIMULATION OF GRATING LOBES:
EFFECT OF SUBARRAY SIZE

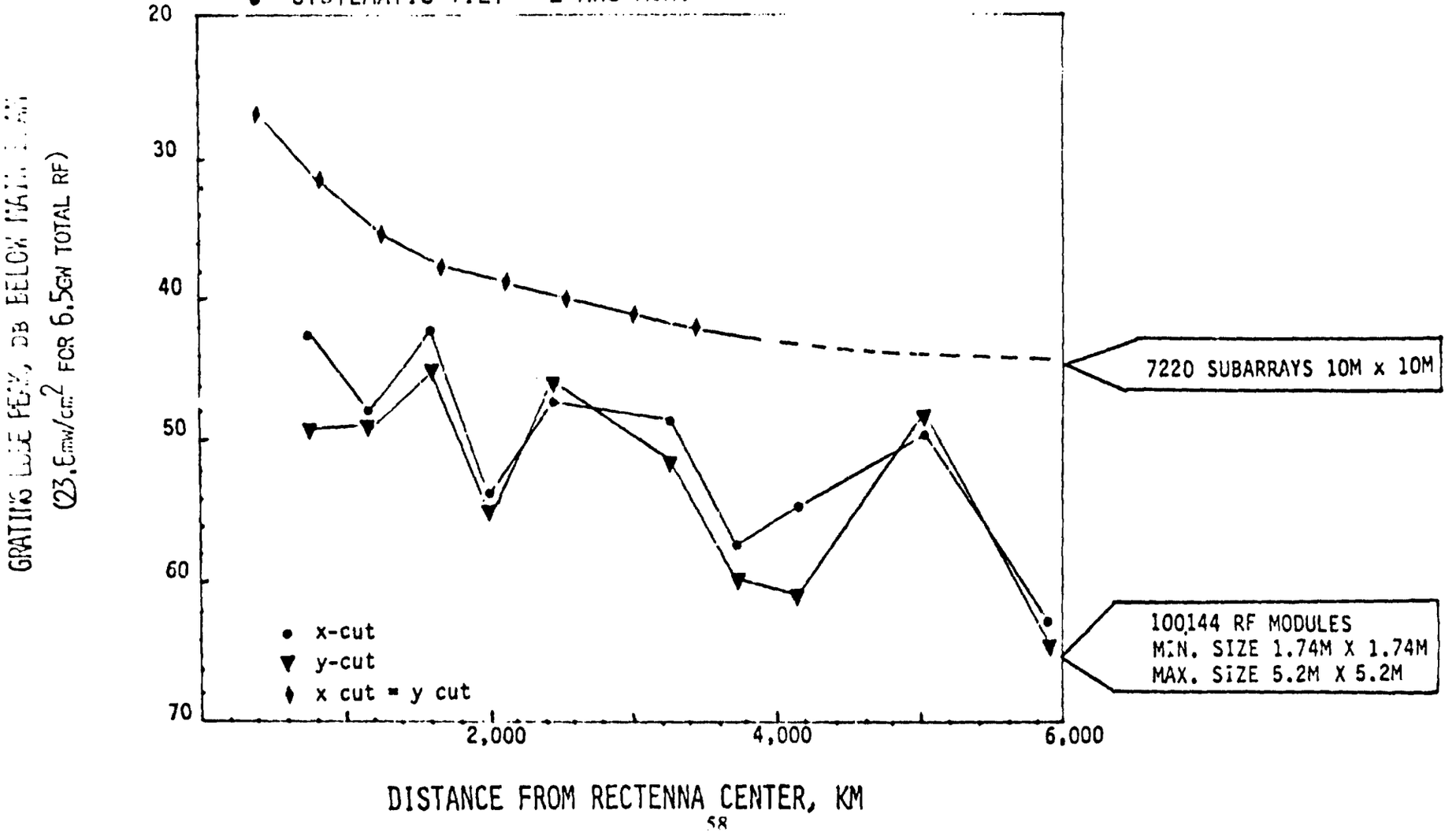
The phase control system was modified from the earlier definition by providing an uplink receiver and phase conjugator for each klystron rather than for each subarray. Two benefits result:

- The beam efficiency is improved by about 1%, with attendant value of the order of $100 million, exceeding the cost of the order of $50 million.

- The grating lobes are reduced in number and intensity. The strongest grating lobes are reduced from roughly 40 microwatts/cm^2 to less than 2 microwatts/cm^2.

LARGE PHASED ARRAY SIMULATION OF GRATING LOBES: EFFECT OF SUBARRAY SIZE

- GAUSSIAN ILLUMINATION FUNCTION 9.54DB TAPER
- ARRAY DIA. = 1 KM @ SYNCHRONOUS ORBIT, F = 2.45 GHz
- GRATING LOBE 3DB BEAMWIDTH = 5.5 KM (θ = .0086°)
- SYSTEMATIC TILT = 2 ARC MIN.



ALTERNATIVE CONSTRUCTION CONCEPTS

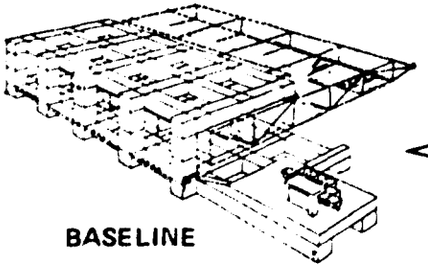
During Phase I, Grumman and Boeing jointly traded off a number of construction approaches, the most important of which are illustrated here. The four-bay end-builder was selected as a result of this tradeoff.

Alternative Construction Concepts

SPS-2268

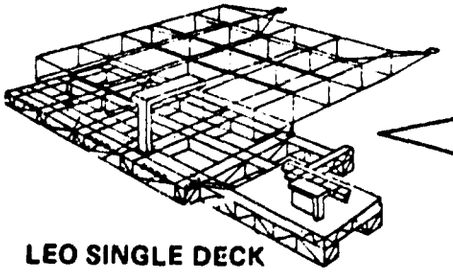
BASELINE AND DERIVATIVES

6 OPTIONS



BASELINE

- 2 DECKS
- LEO
- 10 GW SPS



LEO SINGLE DECK

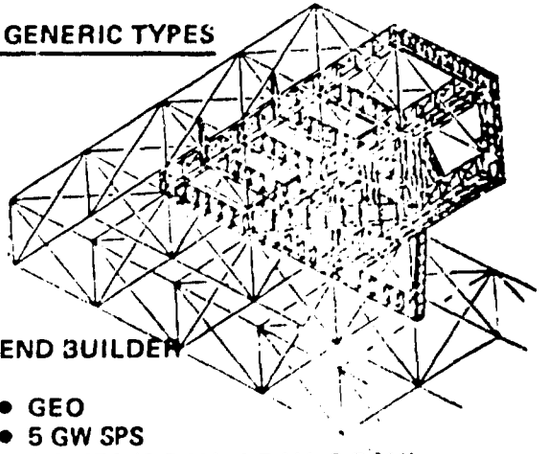
- 10 GW SPS



GEO SINGLE DECK

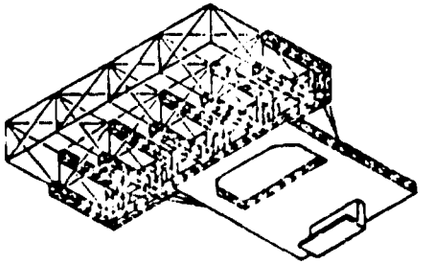
- 5 GW SPS

NEW GENERIC TYPES



END BUILDER

- GEO
- 5 GW SPS
- 3 SIZES (2-BAY, 4-BAY, 8-BAY)



INTERNAL BASE

- GEO
- 5 GW SPS

BOOTSTRAP

- GEO
- 5 GW SPS

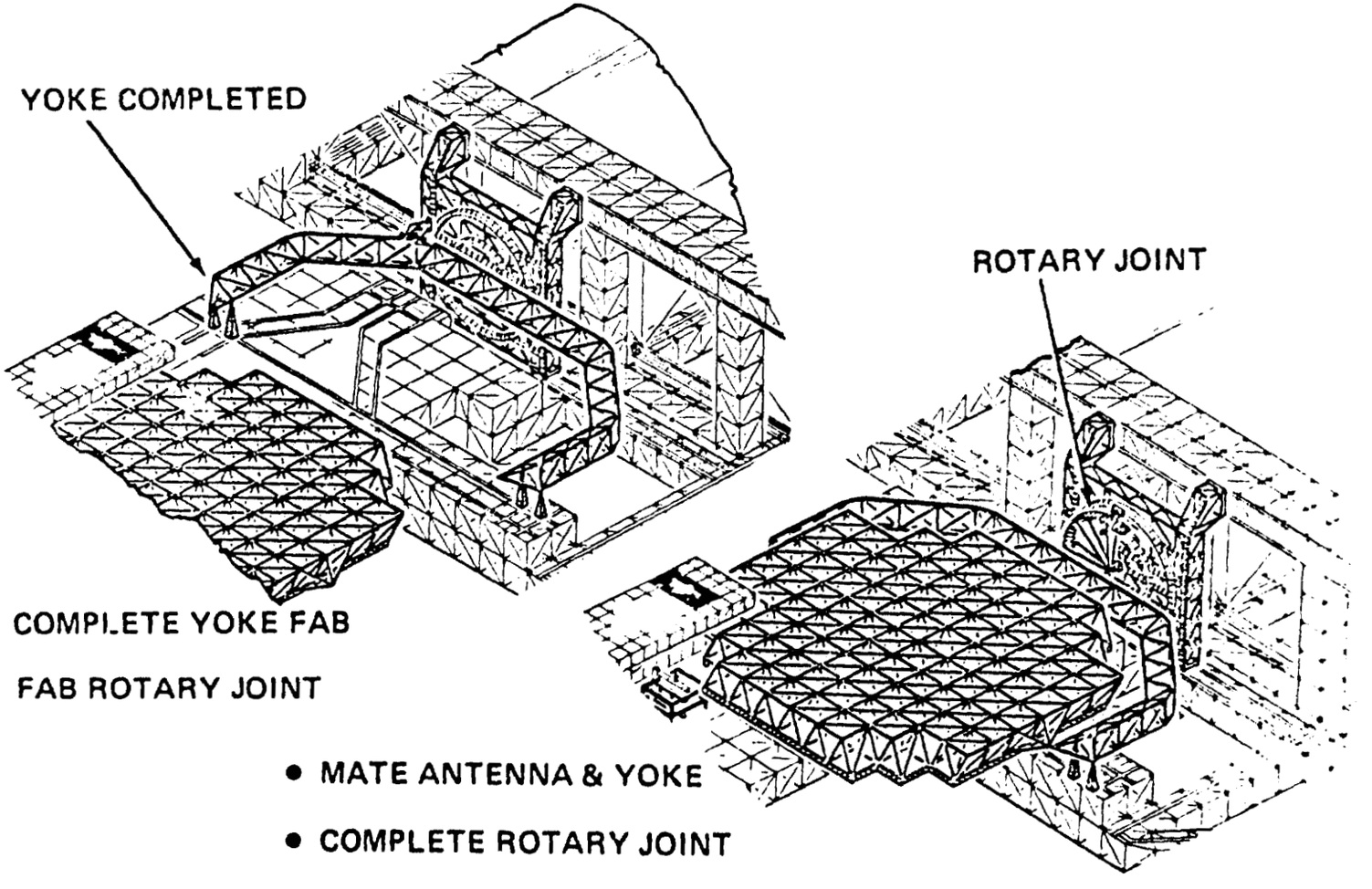
YOKE/ROTARY JOINT ASSEMBLY

During Phase II, Grumman conduct a definition effort on the geosynchronous orbit (main) construction base. Additional definition of the LEO (staging and electric orbit transfer vehicle construction) base was provided by Boeing. An example of GEO base definition is shown in this illustration of the final stages of yoke/rotary joint construction.

In the first view opposite, the yoke is shown completed and positioned ready to receive the antenna. The construction facility was positioned to the left to complete fabrication of the remaining yoke sections.

In the second view, the antenna and yoke have been mated and the yoke, supported entirely by the indexer supports has been separated from the construction facility. The facility is now free to begin fabrication of the rotary joint.

YOKE/ROTARY JOINT ASSEMBLY



- COMPLETE YOKE FAB
- FAB ROTARY JOINT
- MATE ANTENNA & YOKE
- COMPLETE ROTARY JOINT
- FAB & INSTALL YOKE/ROT. JOINT STRUTS
- INSTALL BUS

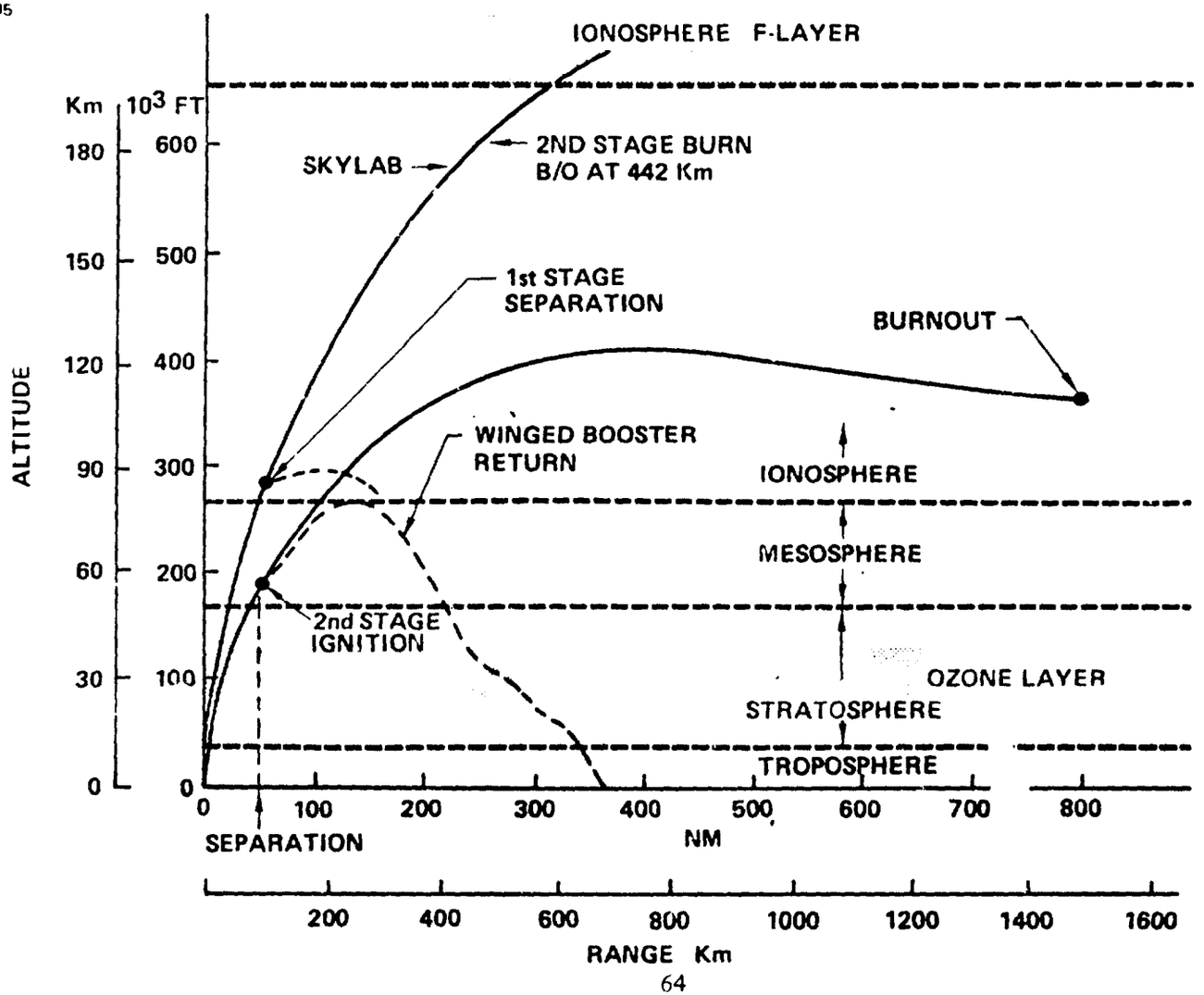
REFERENCE HLLV LAUNCH TRAJECTORY

One of the environmental issues raised with respect to SPS operations is the possibility of influences on the upper atmosphere from launch operations. This figure shows the relationship of the current baseline trajectory to the key regions of the upper atmosphere.

Some forecasts of ionosphere depletion due to SPS launches assumed the HLLV trajectory would be like the Skylab trajectory shown, which thrusted directly into the inosphere F-layer. The reference HLLV trajectory does not enter the F-layer under mainstage thrust; only the circularization and de-orbit burns occur at that altitude.

Reference HLLV Launch Trajectory and Skylab Launch

SPS-2195

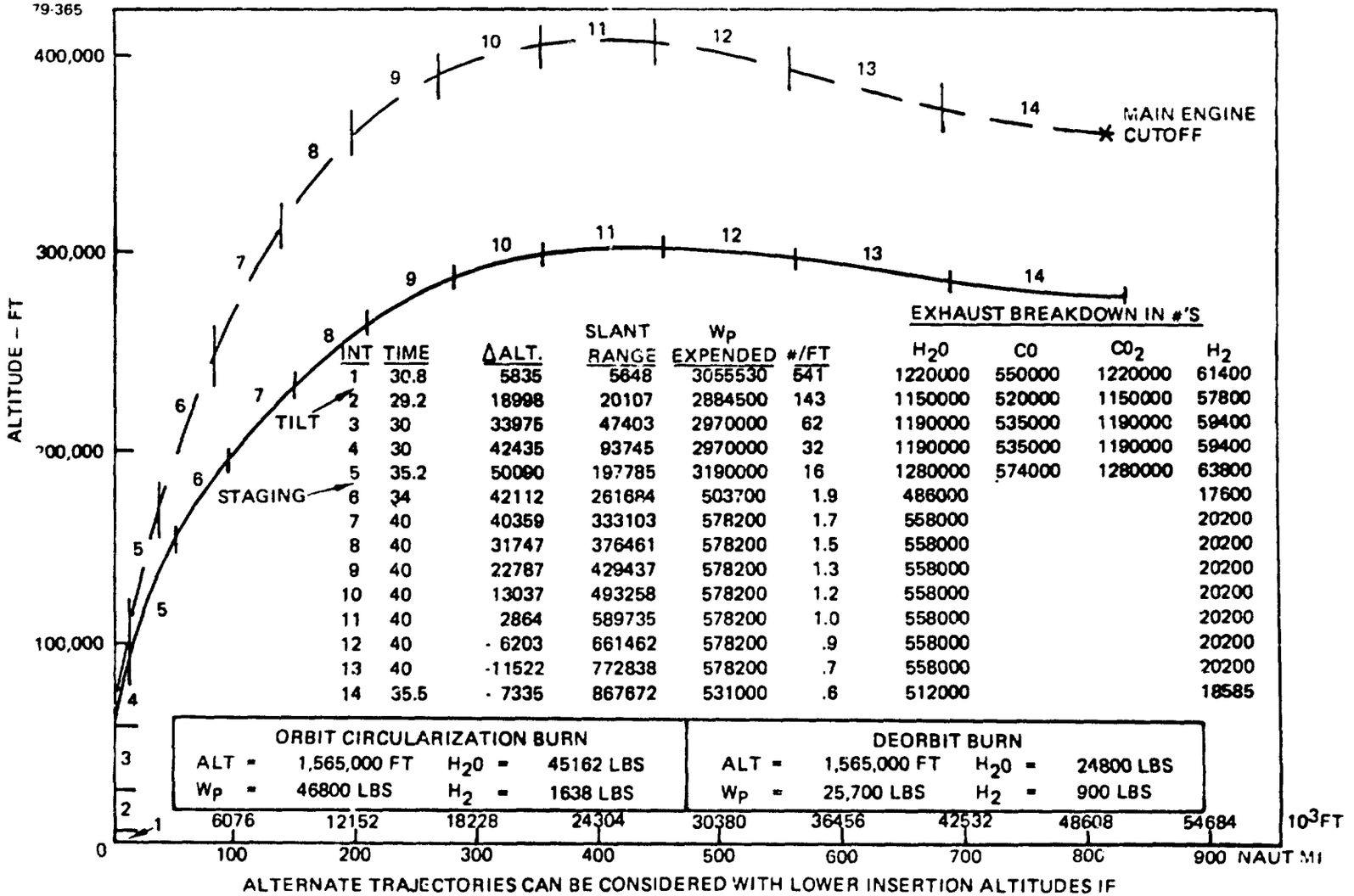


SPS HEAVY LIFT LAUNCH VEHICLE TRAJECTORY AND EXHAUST PRODUCTS DATA

This depressed trajectory was developed during Phase I.

BOEING SPS

SPS Heavy Lift Launch Vehicle Trajectory and Exhaust Products Data



INT	TIME	ΔALT.	SLANT RANGE	W_P EXPENDED	#/FT	EXHAUST BREAKDOWN IN #'S H_2O	CO	CO_2	H_2
1	30.8	5835	5648	3055530	541	1220000	550000	1220000	61400
2	29.2	18998	20107	2884500	143	1150000	520000	1150000	57800
3	30	33975	47403	2970000	62	1190000	535000	1190000	59400
4	30	42435	93745	2970000	32	1190000	535000	1190000	59400
5	35.2	50090	197785	3190000	16	1280000	574000	1280000	63800
6	34	42112	261684	503700	1.9	486000			17600
7	40	40359	333103	578200	1.7	558000			20200
8	40	31747	376461	578200	1.5	558000			20200
9	40	22787	429437	578200	1.3	558000			20200
10	40	13037	493258	578200	1.2	558000			20200
11	40	2864	589735	578200	1.0	558000			20200
12	40	- 6203	661462	578200	.9	558000			20200
13	40	-11522	772838	578200	.7	558000			20200
14	35.5	- 7335	867672	531000	.6	512000			18585

ORBIT CIRCULARIZATION BURN				DEORBIT BURN			
ALT =	1,565,000 FT	H_2O =	45162 LBS	ALT =	1,565,000 FT	H_2O =	24800 LBS
W_P =	46800 LBS	H_2 =	1638 LBS	W_P =	25,700 LBS	H_2 =	900 LBS

ALTERNATE TRAJECTORIES CAN BE CONSIDERED WITH LOWER INSERTION ALTITUDES IF ENVIRONMENTAL CONSIDERATIONS DEEM NECESSARY

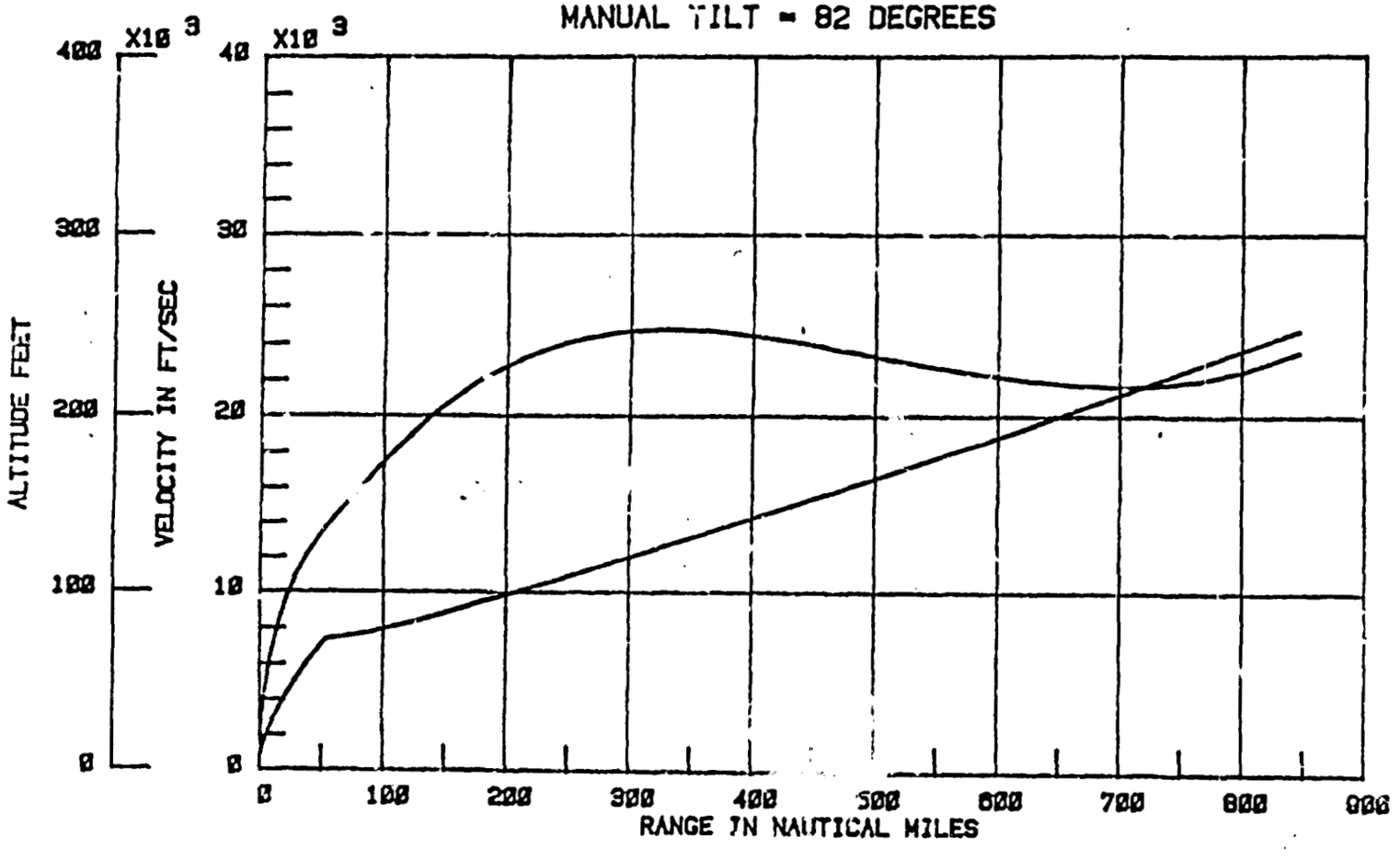
HLLV SUPPRESSED #6

During Phase II, concern was expressed that the depressed trajectory developed during Phase I may not be depressed enough. It was desired to determine if a trajectory could be found that would stay below 75 km.

We found that injecting the orbiter at a slight positive (e.g., 2°) path angle has a significant beneficial effect on a highly depressed trajectory: (1) it minimizes post-injection drag losses; (2) it suppresses the pre-injection optimal path; (3) it forces an angle of attack on the orbiter similar to that for entry so that special thermal protection should not be required.

The selected 75-km-or-less trajectory is shown.

HLLV SUPPRESSED #6

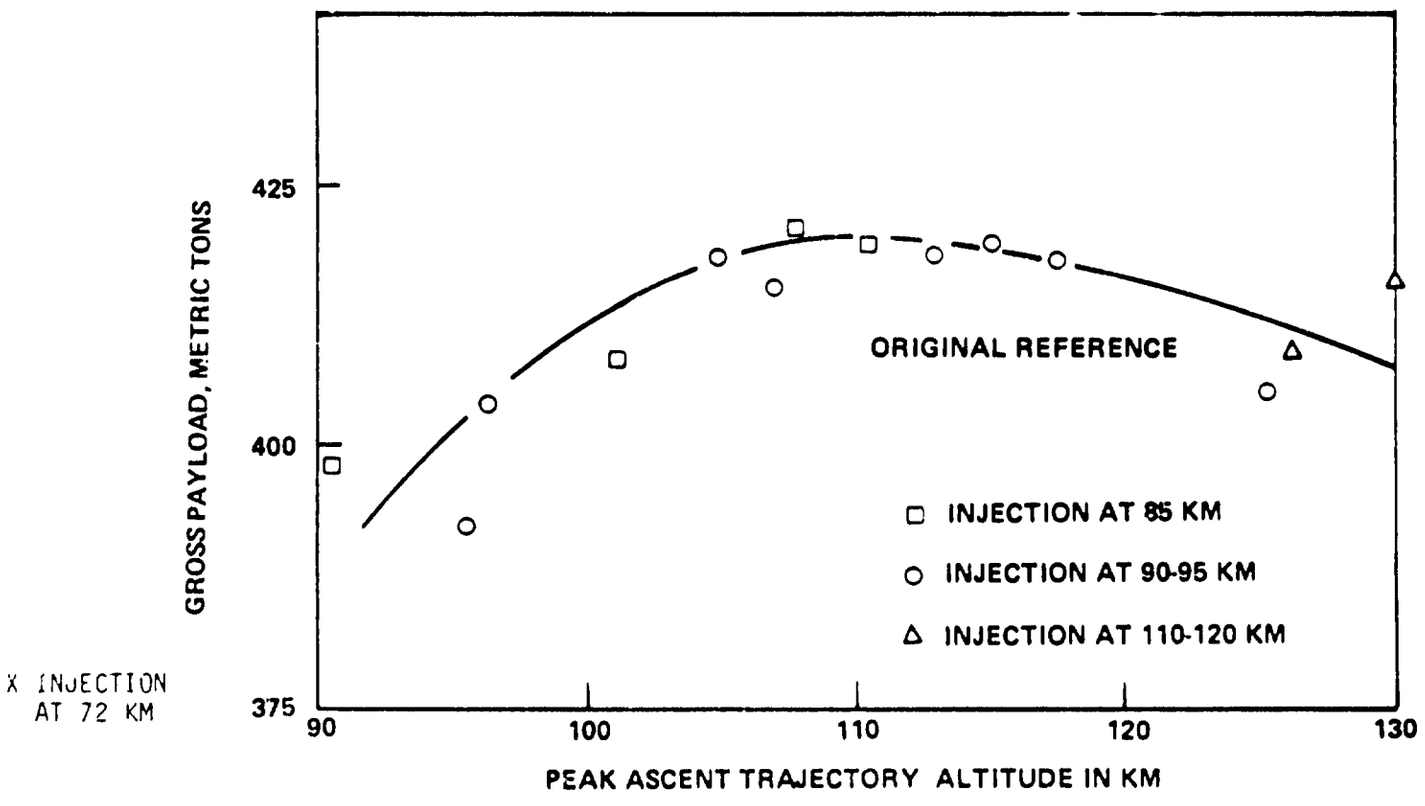


LAUNCH TRAJECTORY SUPPRESSION RESULTS

A number of ascent trajectories were simulated using various strategies to minimize trajectory altitude. Results are summarized on the facing page. It was found that the best trajectories had a peak ascent altitude of about 110 kilometers. Trajectories could be suppressed to keep the path below 100 kilometers with a slight performance penalty. Suppression to 75 km incurs about a 10% penalty.

The suppressed trajectories were not fully optimized and no credit was taken for the reduced flyback range. Ultimate penalties will be slightly less than indicated here.

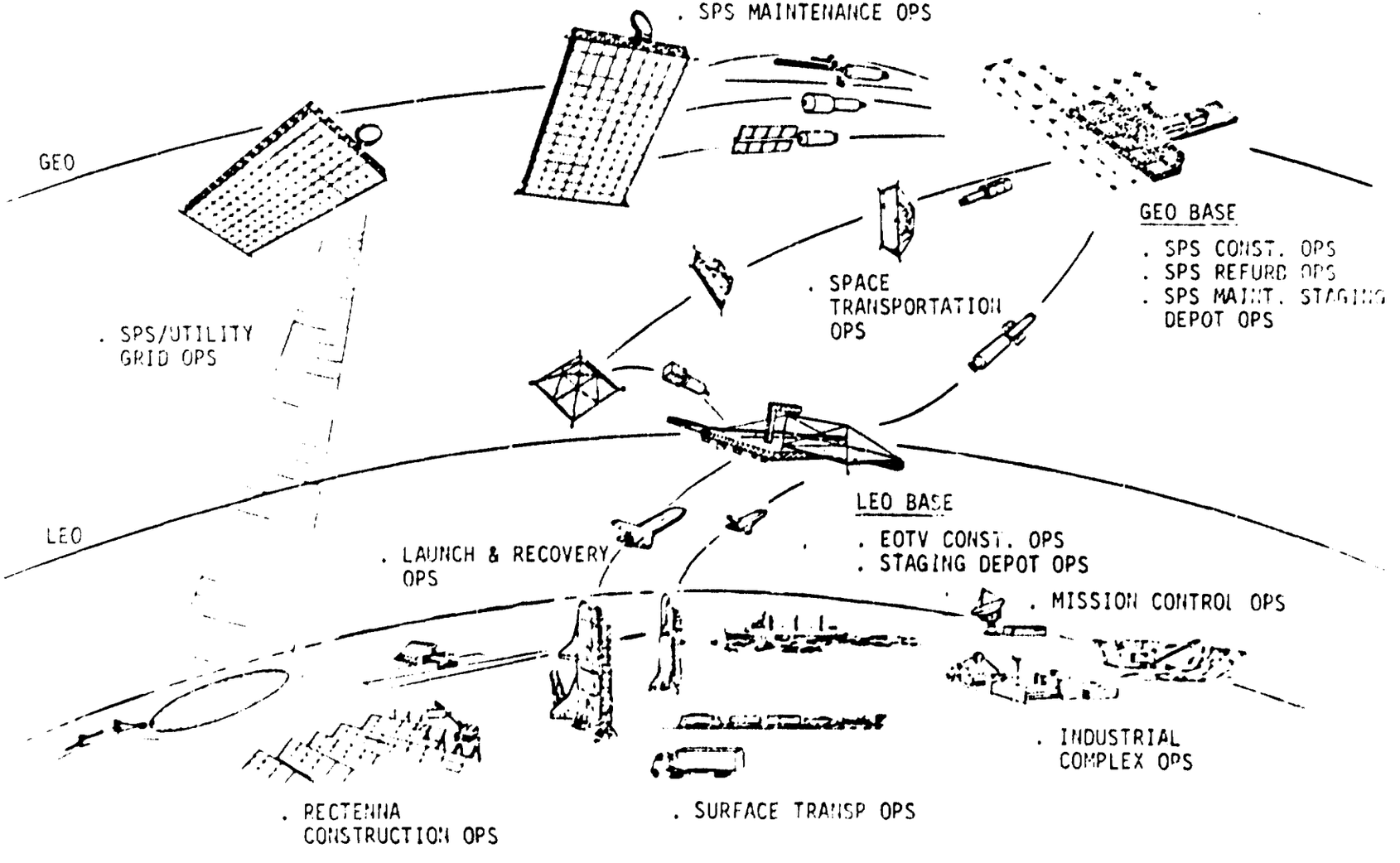
Launch Trajectory Suppression Results



INTEGRATED SPS PROGRAM OPERATIONS

An integrated operations description was developed, including all operations required to effect SPS construction, operation, and maintenance.

INTEGRATED SPS PROGRAM OPERATIONS



SPS PROGRAM OPERATIONS RELATIVE DEPTH OF ANALYSIS

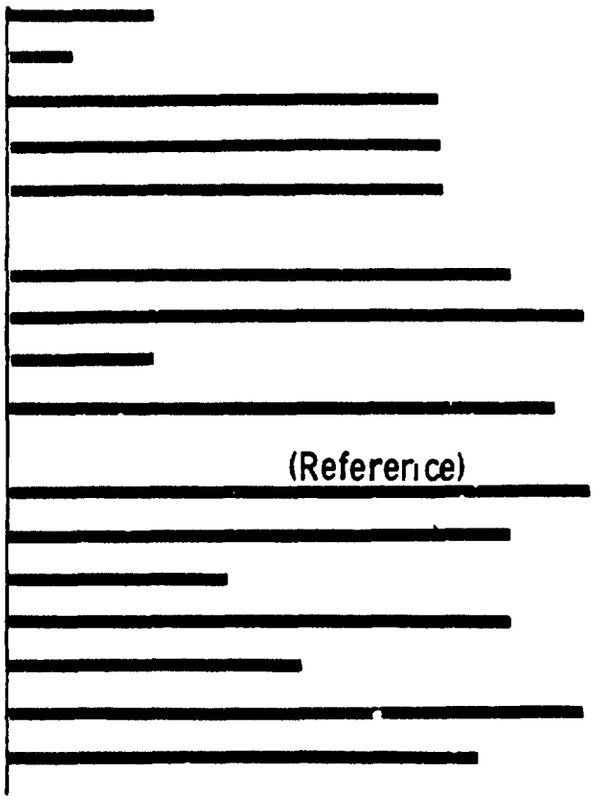
Illustrated here is a judgemental comparison of relative depth of analysis achieved on the operational elements.

SPS PROGRAM OPERATIONS RELATIVE DEPTH OF ANALYSIS

OPERATIONS

- Industrial Complex Ops
- Surface Transp Ops
- Rectenna Const. Ops
- Rectenna/Utility Grid Ops
- Launch Site Ops
- LEO Base Ops
  - . EOTV Const
  - . Logistics
  - . Base Ops
- LEO-to-GEO Cargo Transp Ops
- GEO Base Ops
  - . SPS Const
  - . Logistics
  - . Base Ops
  - . SPS Refurb Ops
- Space Vehicle Maint Ops
- SPS Maint Ops
- Personnel Transp Ops

RELATIVE DEPTH OF ANALYSIS



AVAILABLE SPS POWER TO UTILITY GRID

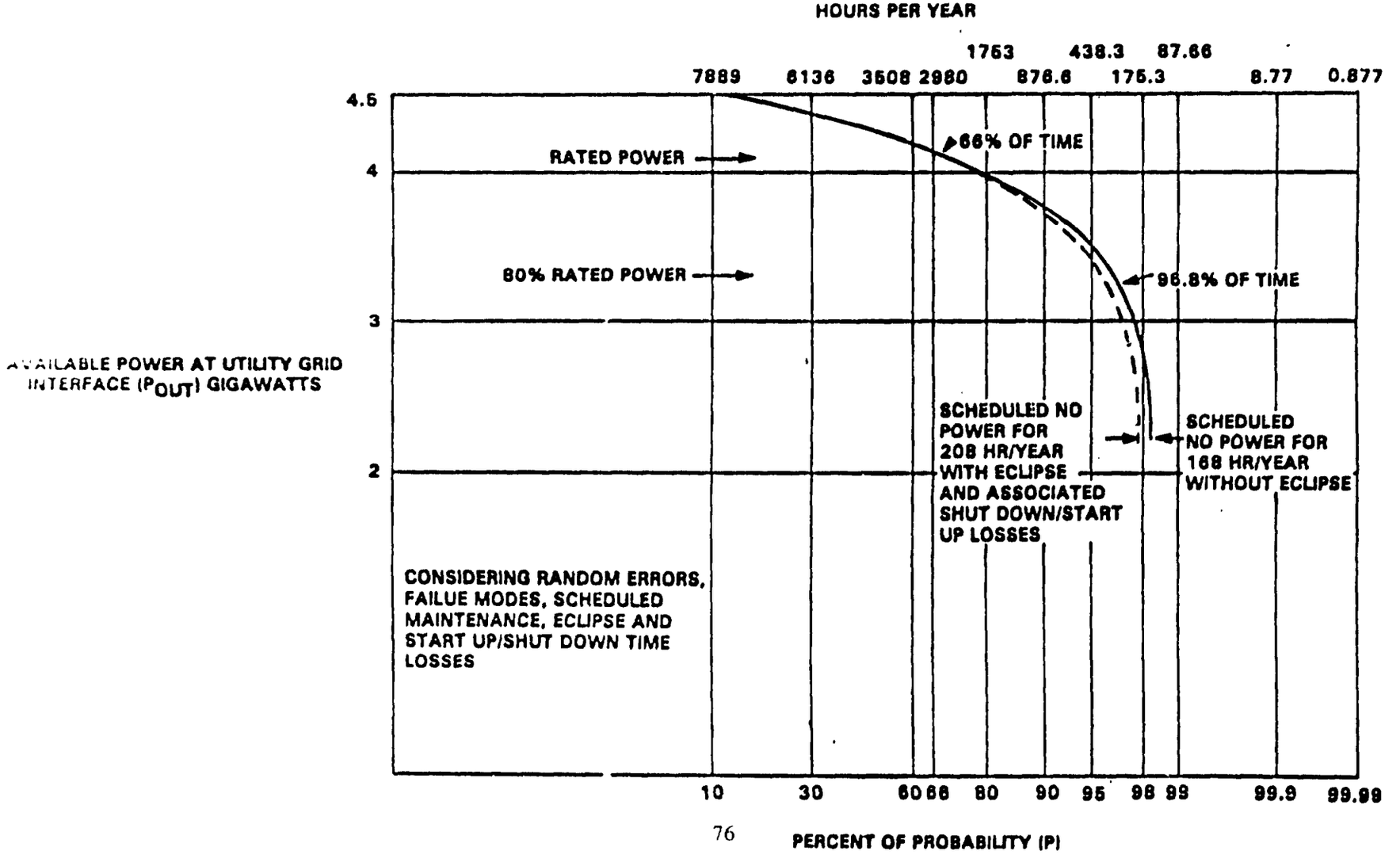
CHART SHOWS AVAILABLE SPS POWER TO UTILITY GRID CONSIDERING RANDOM ERRORS, FAILURE MODES, SCHEDULED MAINTENANCE AND ECLIPSE, INCLUDING SHUT DOWN AND START UP TIMES. TOTAL SYSTEM DOWN TIME IS 207.8 HOUR PER YEAR (2.37%).

GENERAL ELECTRIC

AVAILABLE SPS POWER TO UTILITY GRID

CONSIDERING RANDOM ERRORS AND FAILURE MODES, SCHEDULED MAINTENANCE, ECLIPSE AND START UP/SHUT DOWN TIME LOSSES

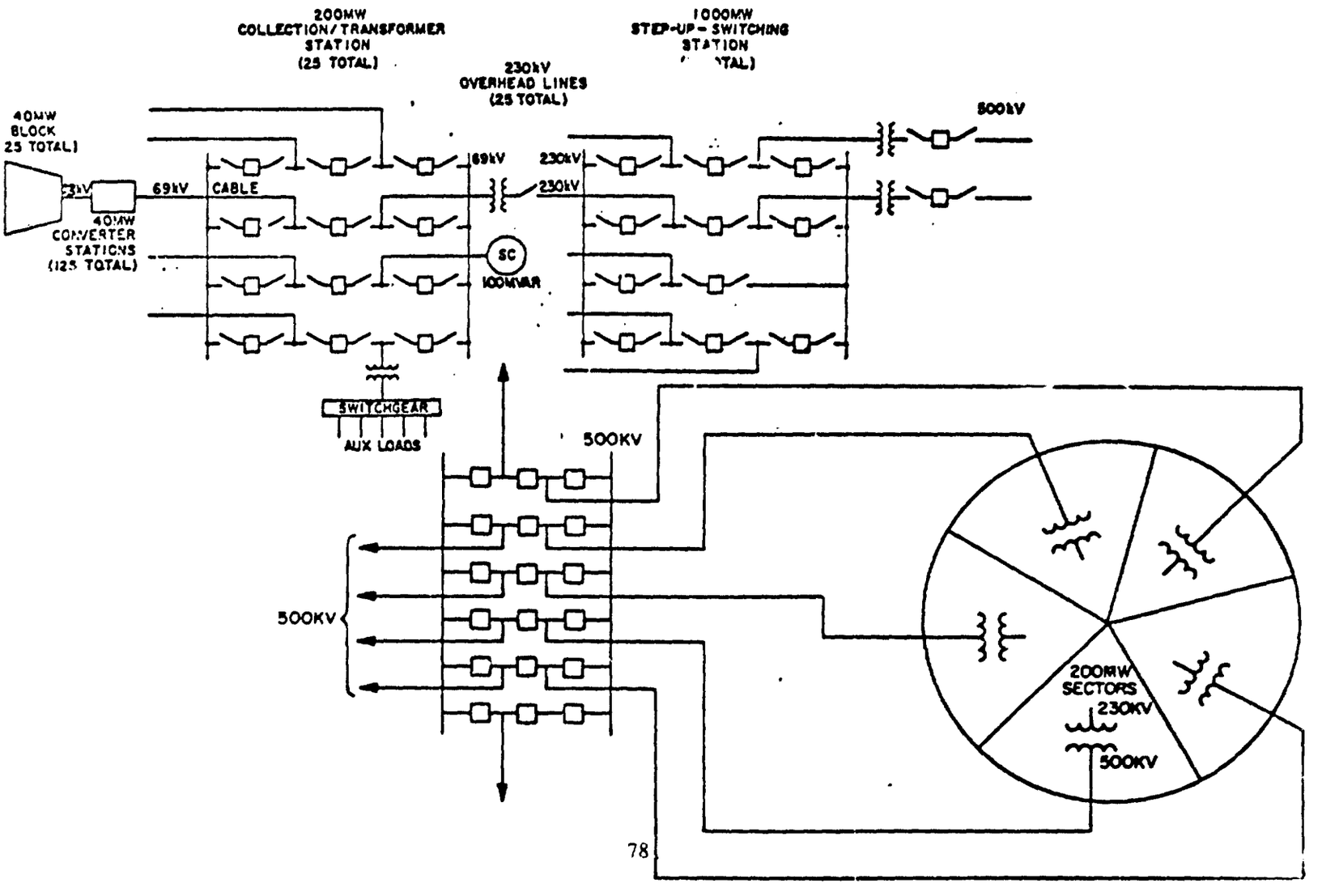
space division



GRID CONNECTION APPROACH

This description of the rectenna-to-power grid connection approach was developed by General Electric's Electric Utility Systems Engineering Division. The equipment needed to interface an SPS to a utility grid is all standard utility engineering state-of-the-art.

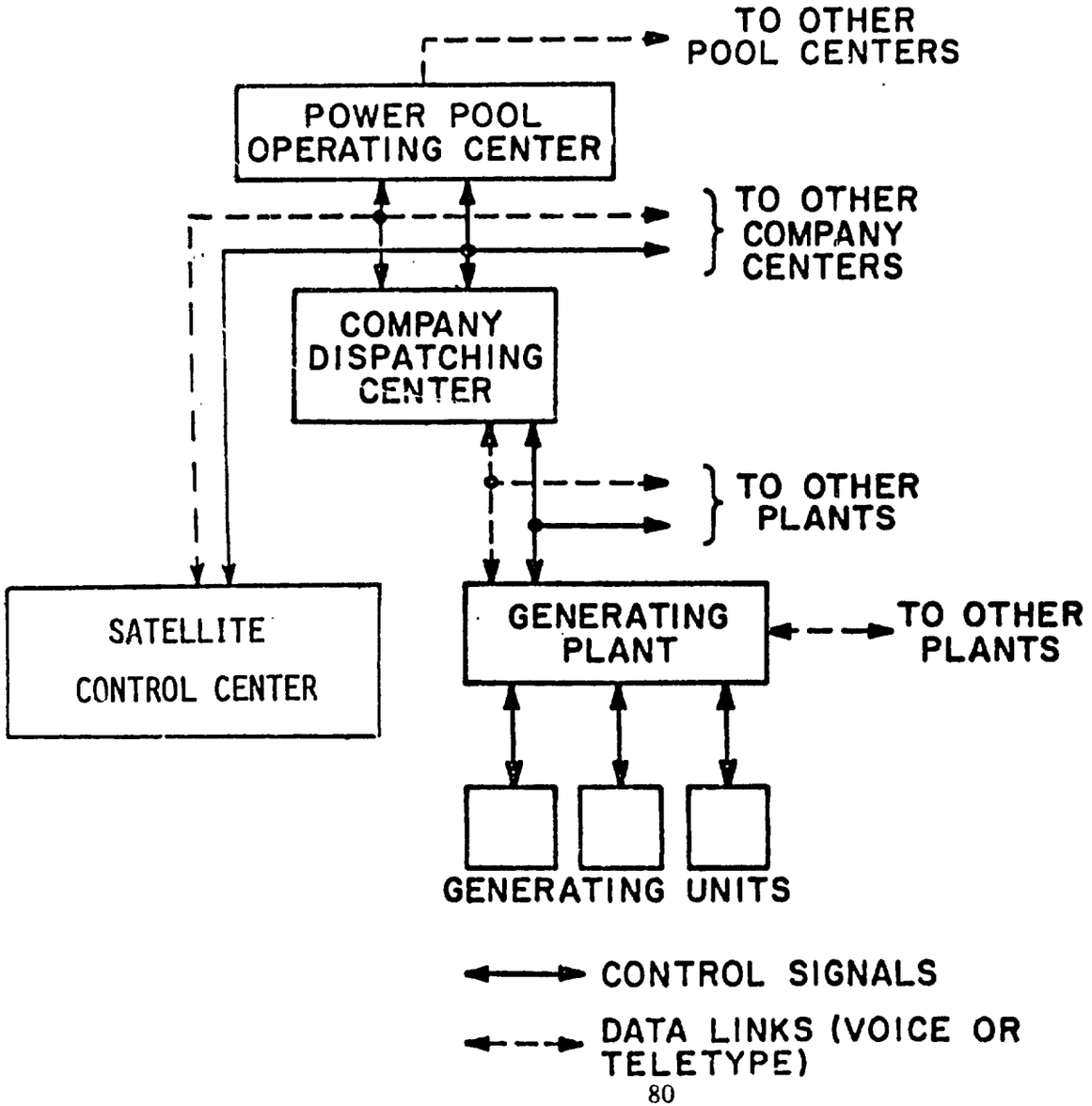
GRID CONNECTION APPROACH



UTILITY SYSTEM CONTROL STRUCTURE

General Electric's EUSED Division also examined the operational suitability of SPS for base-load operations and how SPS would be controlled. They found that: 1) The large unit size (2500 to 5000 megawatts) is not a problem for the expected level of utility interconnection and power pool size in the year 2000 and beyond. 2) SPS can load-follow if necessary. A number of ways of varying SPS output were found. 3) Since SPS's do not have rotating inertia, they cannot contribute to frequency control in the same way that rotating generators do. This does not appear to be a problem unless SPS's are more than about 20% of a power pool's capacity. In such a situation it would be necessary to develop a technique for synthesizing frequency control capability.

UTILITY SYSTEM CONTROL STRUCTURE



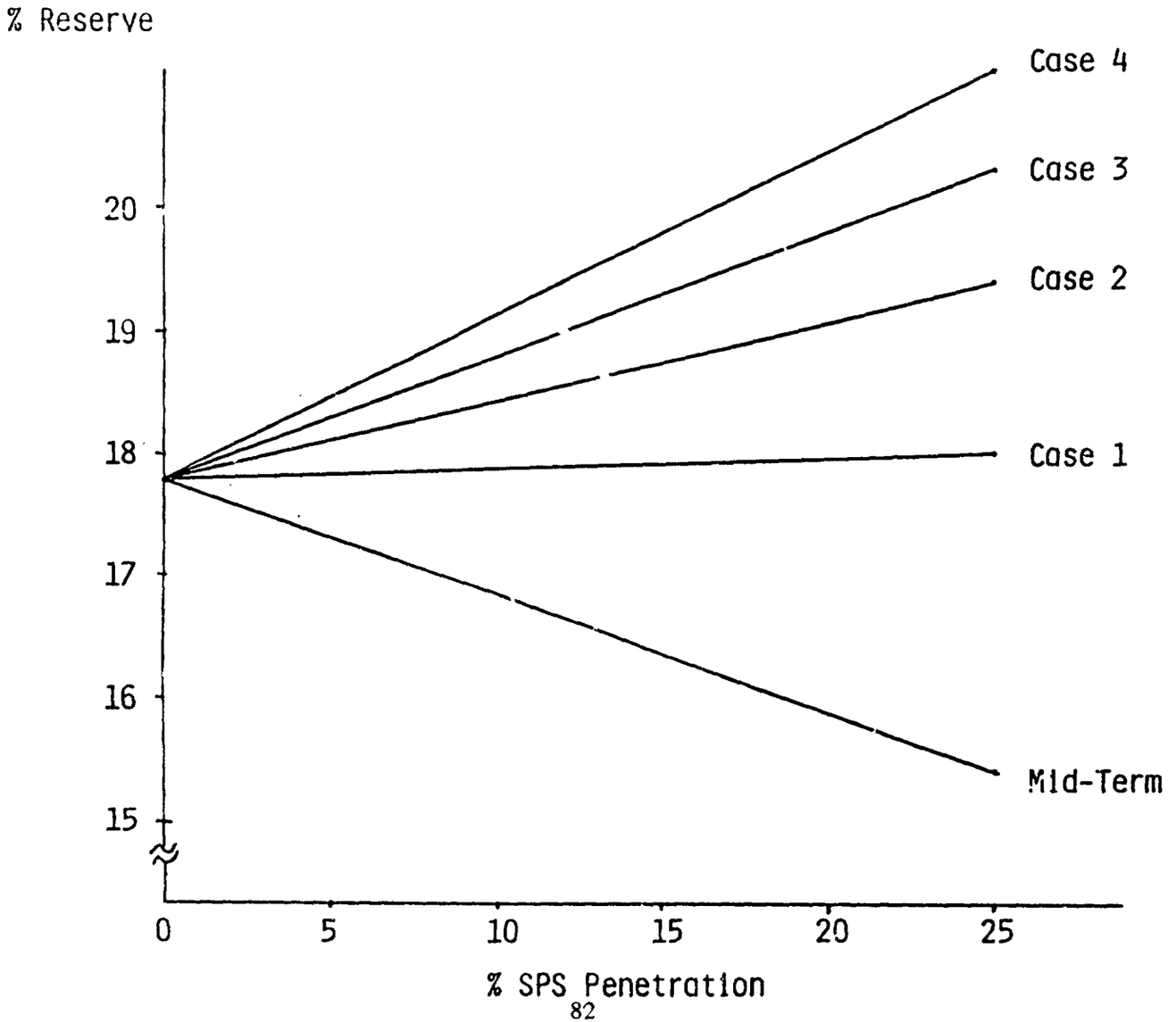
UTILITY SYSTEM RESERVE LEVELS VS. SPS PENETRATION

A sensitivity study was conducted on the effect of SPS's on utility reserve margin requirements. The "mid-term" curve assumes reliability of the SPS as estimated in the maintenance task. The other curves represent progressively worse reliability. Case 4 includes 30% probability of unplanned outage of 1500 megawatts and 3% probability of unplanned complete outage.

Planned outages such as eclipse period do not affect reserve margin requirements.

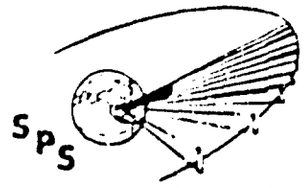
It was concluded that SPS is not likely to have a major effect on reserve margin requirements.

UTILITY SYSTEM RESERVE LEVELS VS. SPS PENETRATION



FIVE PHASES OF SPS

The five phases are repeated here as a reminder.



FIVE PHASES OF SPS

BOEING

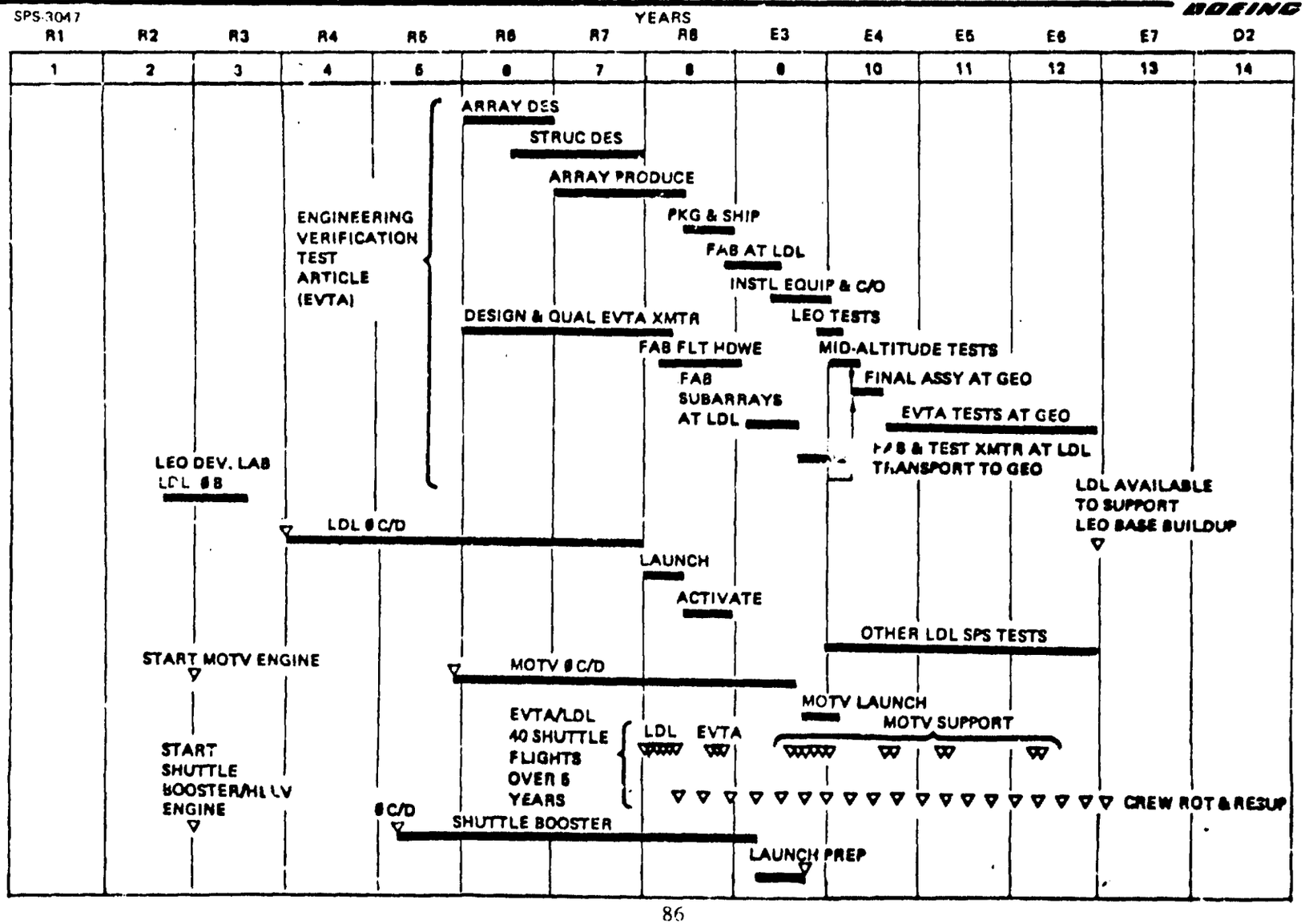
PHASE	OBJECTIVE
Research	o Evaluate and Select SPS Technologies o Resolve Technical, Environmental and Socio-economic Issues
Engineering Verification	o Demonstrate Conversion of SPS Technologies into Practical Engineering Hardware
Demonstration	o Demonstrate End-to-End Operational Suitability of SPS as a Baseload Electric Power Source
Investment	o Create the Industrial Base to Produce SPS Generating Capacity at 10,000 Megawatts/Yr.
Commercial Production	o Install and Maintain 300,000 Megawatts of SPS Generation Capacity over 30-Year Period.

ENGINEERING VERIFICATION PROGRAM SCHEDULE

Development, test, and operations plans and requirements were prepared for each phase, including test hardware, experiment programs, and support systems. Major flight projects were identified.

Illustrated here is the schedule for the Engineering Verification Phase.

ENGINEERING VERIFICATION PROGRAM SCHEDULE



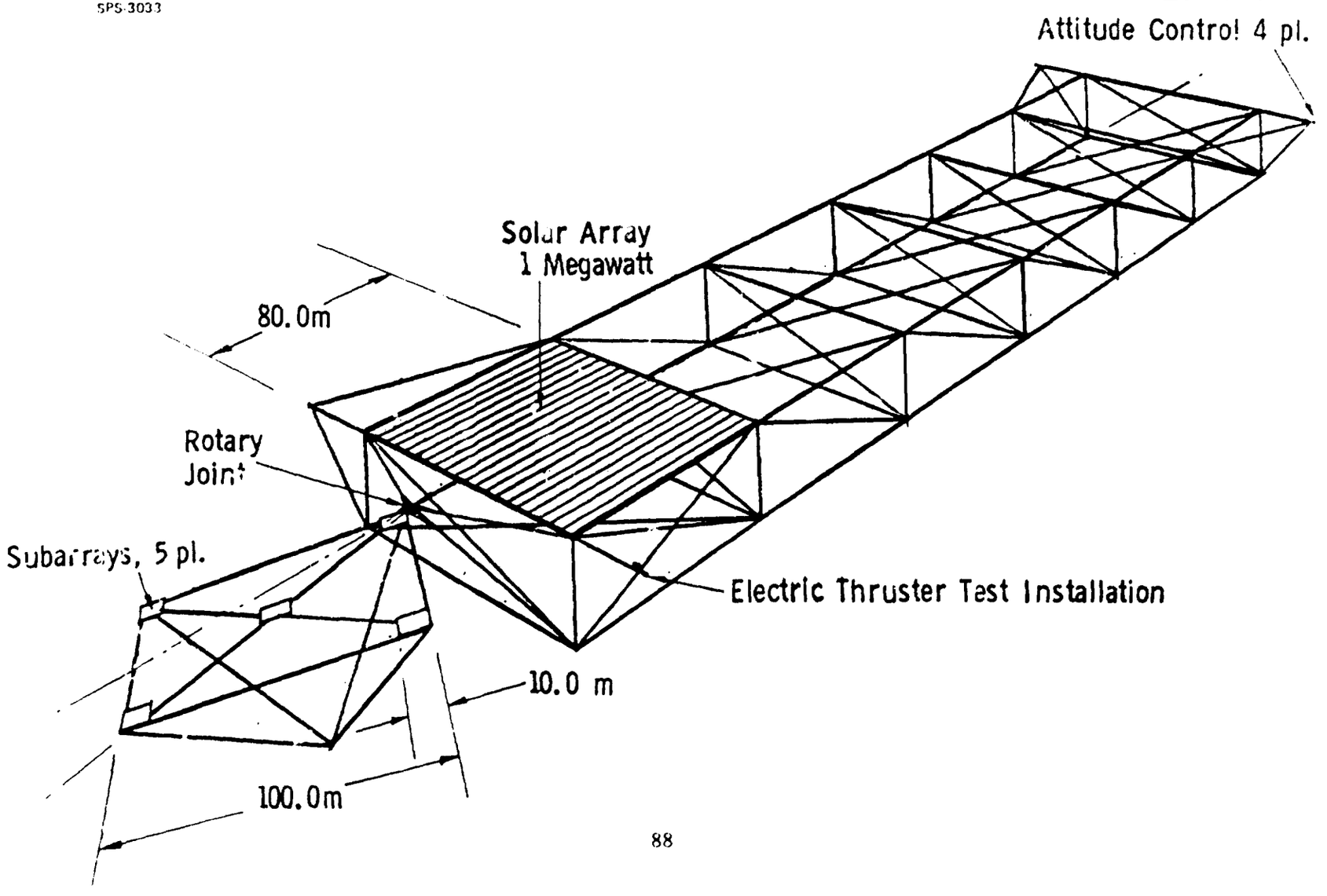
ENGINEERING VERIFICATION TEST ARTICLE CONCEPT

This Engineering Verification Test Article concept was based on the following major requirements:

- Test a solar array similar to that planned for SPS at LEO, intermediate altitudes and GEO.
- Fabricate and test a space structure large enough to demonstrate controllability and dynamic predictability by analysis.
- Test Power transmission elements at GEO.
- Test electric propulsion elements at LEO, GEO, and intermediate altitudes to ascertain plasma and magnetosphere interactions.

The estimated mass for this test article is 40 metric tons.

ENGINEERING VERIFICATION TEST ARTICLE CONCEPT



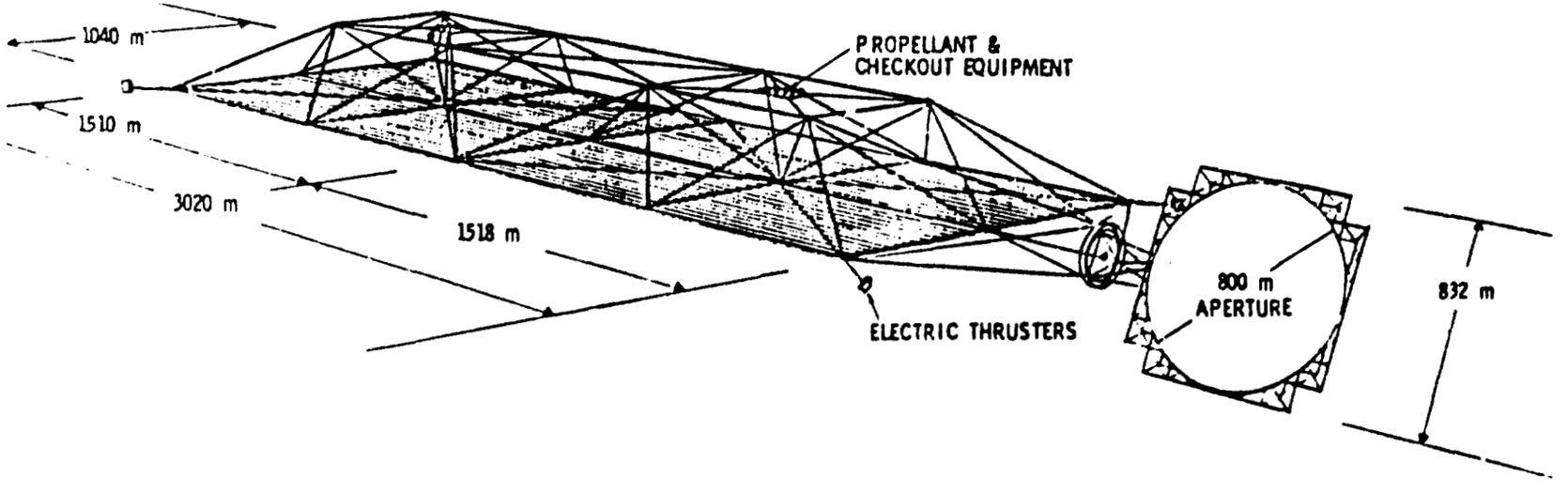
SPS DEMONSTRATION CONFIGURATION

The principal flight project for the demonstration phase is this pilot-plant-sized SPS. It would demonstrate space construction of large structures and power transmitter, EOTV operation, and power transmission from GEO to Earth. The power derived from the rectenna will be 100 to 200 megawatts depending on the rectenna area selected.

SPS DEMONSTRATION CONFIGURATION

SPS DEMONSTRATOR

- 300 MEGAWATTS RF POWER
- USES DUAL EOTV FOR ELECTRIC POWER & ORBIT TRANSFER
- 9280 TONS INCLUDING TRANSFER PROPELLANT



SPS TOTAL PROGRAM THRU #1

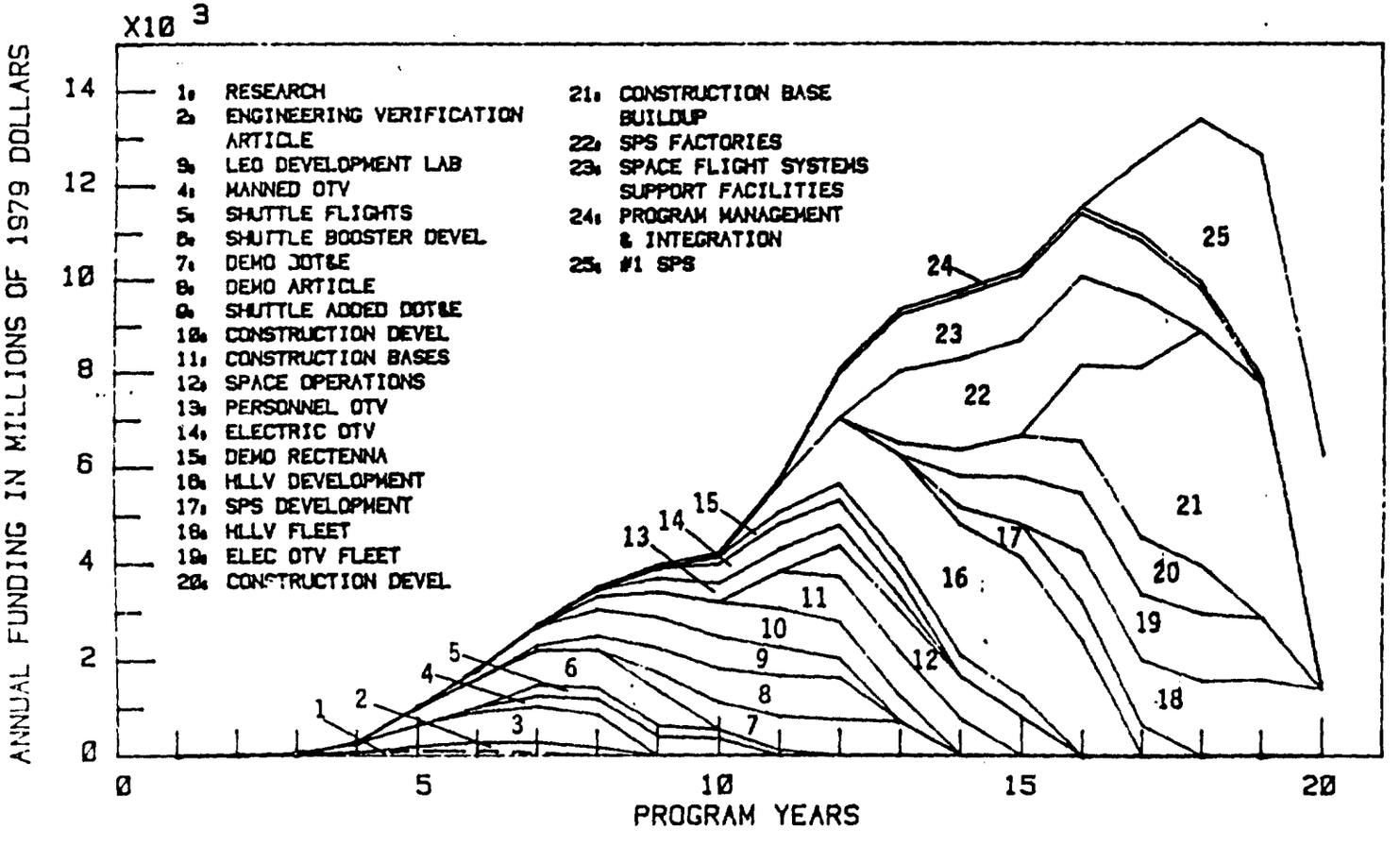
Cost estimates were made for each element of the program and time-phased to develop a funding projection. All elements identified were included, e.g., manned OTV, although many of the items may have application to other missions.

Items 2 through 6 comprise the engineering verification program. Items 7 through 15 comprise the demonstration program. Items 16 through 24 represent the investment necessary to achieve a production rate of 2 SPS's per year.

In the production phase, the total annual funding will be on the order of 25 billions per year.

The sum of all program element costs shown here including #1 SPS is 117.4 billions of 1979 dollars.

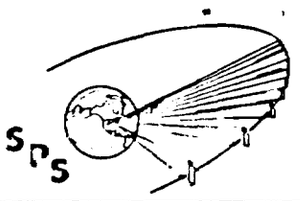
SPS TOTAL PROGRAM THRU #1



REASONS FOR INCREASED NON-RECURRING COST
(VALLUES IN BILLIONS)

At the conclusion of the 1977 SPS Systems Definition Study, the estimate of total non-revurring costs was 84 billions (1977 dollars). Tnis tabulation summarizes the principal differences in the estimates.

The most important increase elements are inflation and elements added to the program to reduce risk, i.e., the earlier program had no demonstration phase.



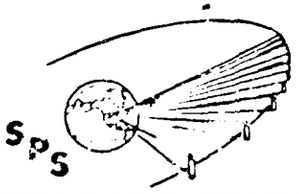
REASONS FOR INCREASED NON-RECURRING COST
(VALUES IN BILLIONS)

BOEING

1977 FIGURE	84	
INFLATION	13	
	97	
ADDED ITEMS	(25.7)	
LEO Development Lab	2.7	
Manned OTV	1.4	
Shuttle Booster & Shuttle HLLV	6.7	
SPS Demonstrator	8.1	
EOTV Fleet	6.8	
NEGLECTED ITEMS	(2.7)	
Personnel Module	1.0	
Propellant Production Facilities	1.7	
SMALLER FIRST SPS	-14	
TOTAL	111.4	
INCREASE	6	Mainly HLLV & Construction Bases
	117.4	

SPS HARDWARE MASS & COST SUMMARY

We now turn to the main results of the reference system update. Tabulated here are the mass and cost elements for the satellite.



SPS HARDWARE MASS & COST SUMMARY

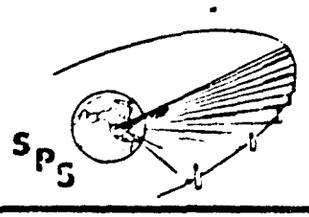
BOEING

	MASS	COST	$/KG
SPS TOTAL	50,984	4,945.9	
ENERGY CONVERSION	27,665.9	2,859.6	
STRUCTURE	4,654	448.2	96
SOLAR BLANKETS	21,144.9	1,987.8	94
POWER DISTRIBUTION	1,246	149.9	120
MAINTENANCE PROVISIONS	621	273.7	440
POWER TRANSMISSION	13,628.9	1,768.7	
STRUCTURE	324.3	25.6	79
SUBARRAYS	10,389.1	889	86
POWER PROC. & DISTR.	2,538.7	324.1	128
PHASE DISTR.	12.3	12.5	1016
MAINTENANCE PROVISIONS	230.2	503.9	2189
ANTENNA MECH POINTING	134.3	13.6	101
INFO MGMT & CONTROL	95.6	48.0	
COMPUTERS	4.5	30.7	6822
CABLING	91.1	17.3	190
ATTITUDE CONTROL & STA. KP.	212.1	160	
HARDWARE	142.1	160	1126
PROPELLANT	70	-	
COMMUNICATIONS	0.18	8	44,000
INTERFACE	235.6	101.6	431
GROWTH ALLOWANCE (22%)	9,146	Carried at Next Level	

SPS RECURRING COST SUMMARY
(1979 DOLLARS)

Average SPS recurring costs are summarized. The cost estimating method for satellite hardware implicitly includes amortization of factories and equipment, so an appropriate amount has been subtracted here, since these investments were identified as a discrete non-recurring cost/

Determination of the cost of an SPS to a utility requires specific definition of financial and management scenarios. A representative figure may be reached by adding back in the implicit amortization and adding 15% for financial costs such as interest during construction; the result is $14.8 billion or just under $3000/KWe in 1979 dollars.



SPS RECURRING COST SUMMARY

(1979 Dollars)

BOEING

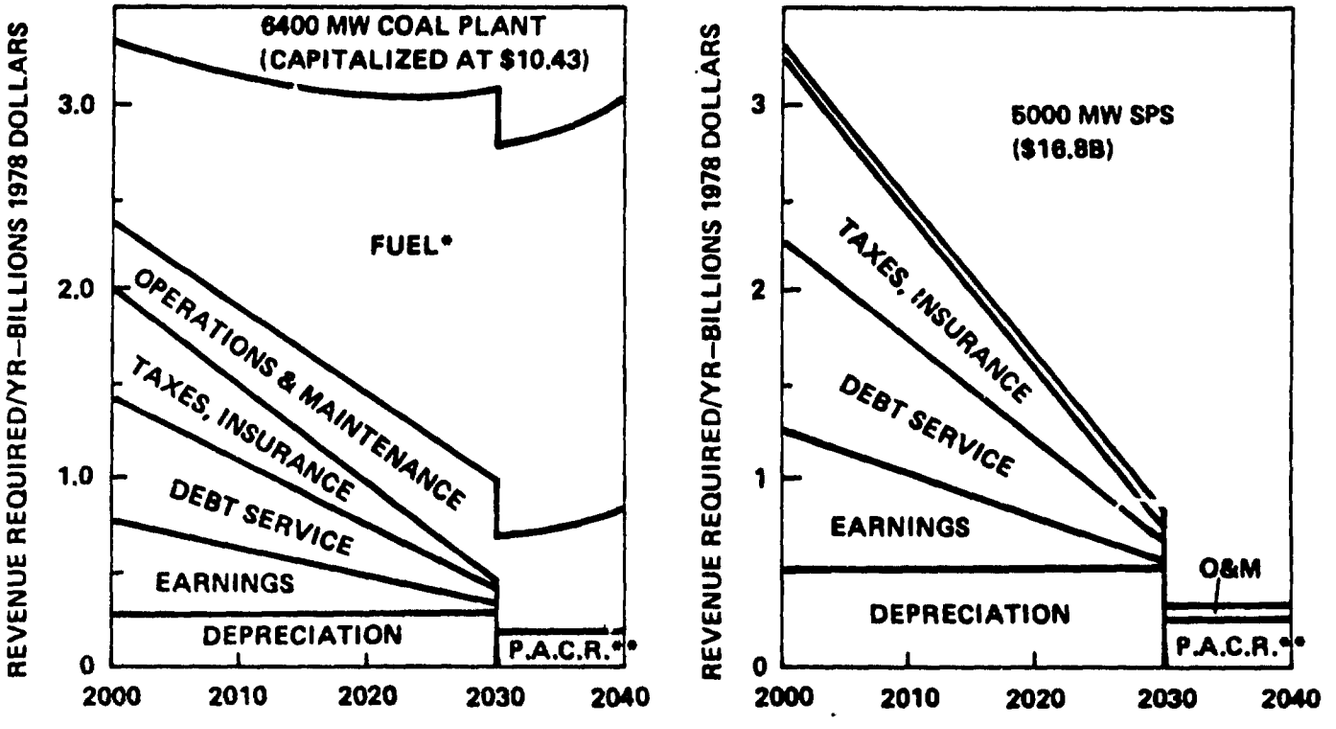
SPS HARDWARE AS COSTED	4946	
LESS IMPLICIT AMORTIZATION OF INVESTMENT	473 4473	(Half of 10.61% per annum on 8924 M for factories and production equipment)
SPACE TRANSPORTATION	3120	Based on SPS mass with growth'
CONSTRUCTION OPERATIONS	961	Includes 10 support people on the ground per space worker as well as construction base spares
GROUND TRANSPORTATION	35	
RECTENNA	2578	
MISSION CONTROL	10	
PROGRAM MANAGEMENT & INTEGRATION	495	Equivalent to 14,000 direct people
COST ALLOWANCE FOR MASS GROWTH	760	17% of net SPS hardware cost
TOTAL DIRECT OUTLAY	12,432	

ANNUAL REVENUE REQUIREMENTS IN 1978 DOLLARS

SPS's are projected to have considerably higher capital costs than coal or nuclear alternative, but no fuel costs. The comparison shown here was developed on an IR&D comparative assessment. It is based on escalation of capital and fuel costs to expected values in the year 2000 and beyond, but expressed in 1978 dollars.

Shown are the estimated annual revenue requirements for coal and SPS plants based on conventional electric utility accounting. The difference in installed capacity reflects on expected difference in plant factor. The SPS, a largely passive and highly redundant system, is projected to provide a plant factor of about 0.92; the equivalent coal plant capacity was based on a historical coal plant factor of 0.72.

Annual Revenue Requirements in 1978 Dollars



*FUEL PRICE ESCALATING AT 6%/YEAR IN 1978, DROPS LINEARLY TO 2%/YEAR BY 2020, STAYS AT 2%/YEAR THROUGH 2040

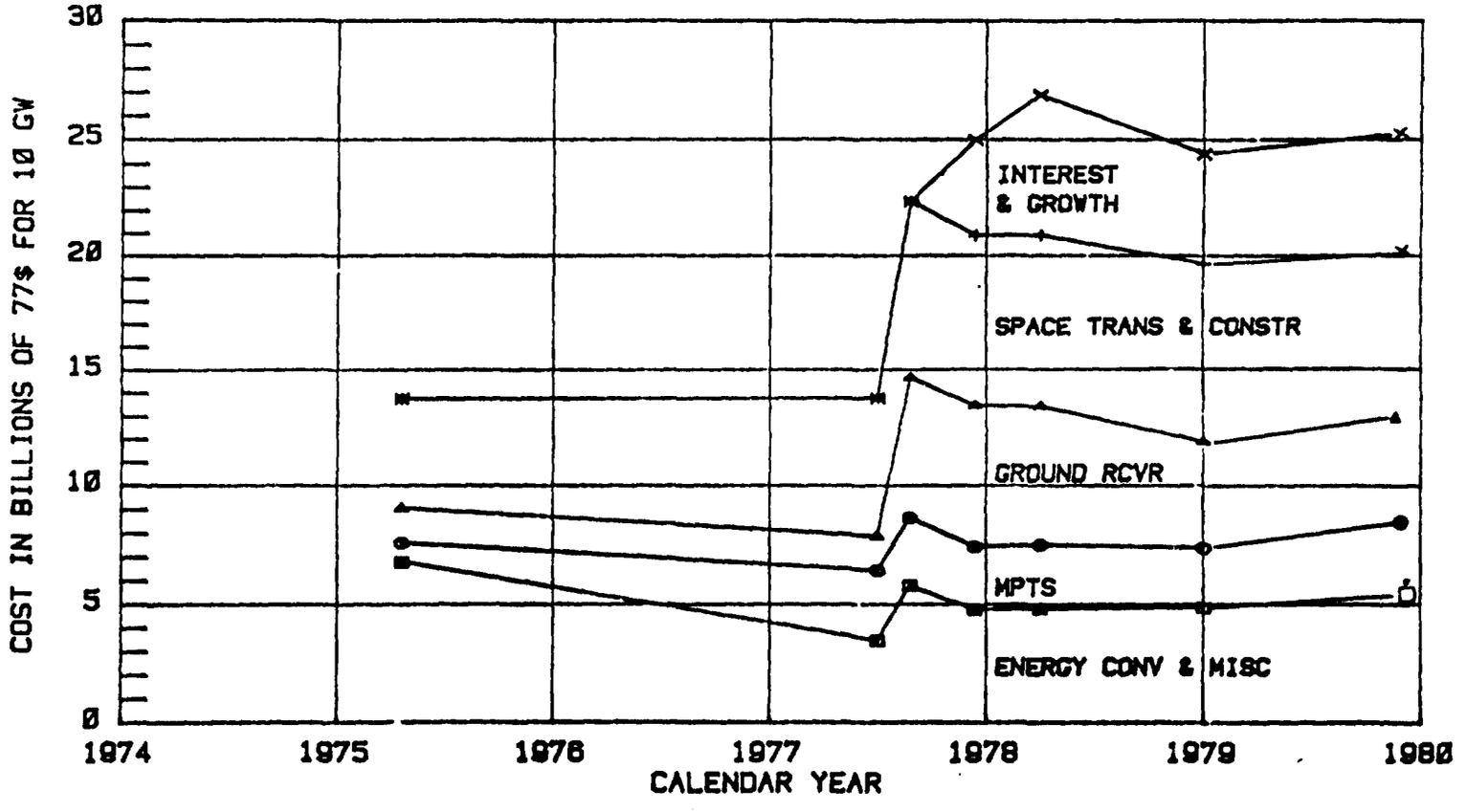
**POST AMORTIZATION CAPITAL RELATED
(EARNING, DEBT SERVICE, TAXES AND INSURANCE ON 10% OF CAPITAL INVESTMENT)

SPS RECURRING COST ESTIMATE HISTORY

The history of SPS cost estimates is shown here. Recent changes include a slight reduction in transportation costs and an increase in satellite costs, the latter due mostly to accounting of maintenance provisions as a part of satellite capital costs (formerly they were amortized in O&M costs).

SPS Recurring Cost Estimate History

SPS-2823



PHOTOVOLTAIC SPS MASS HISTORY

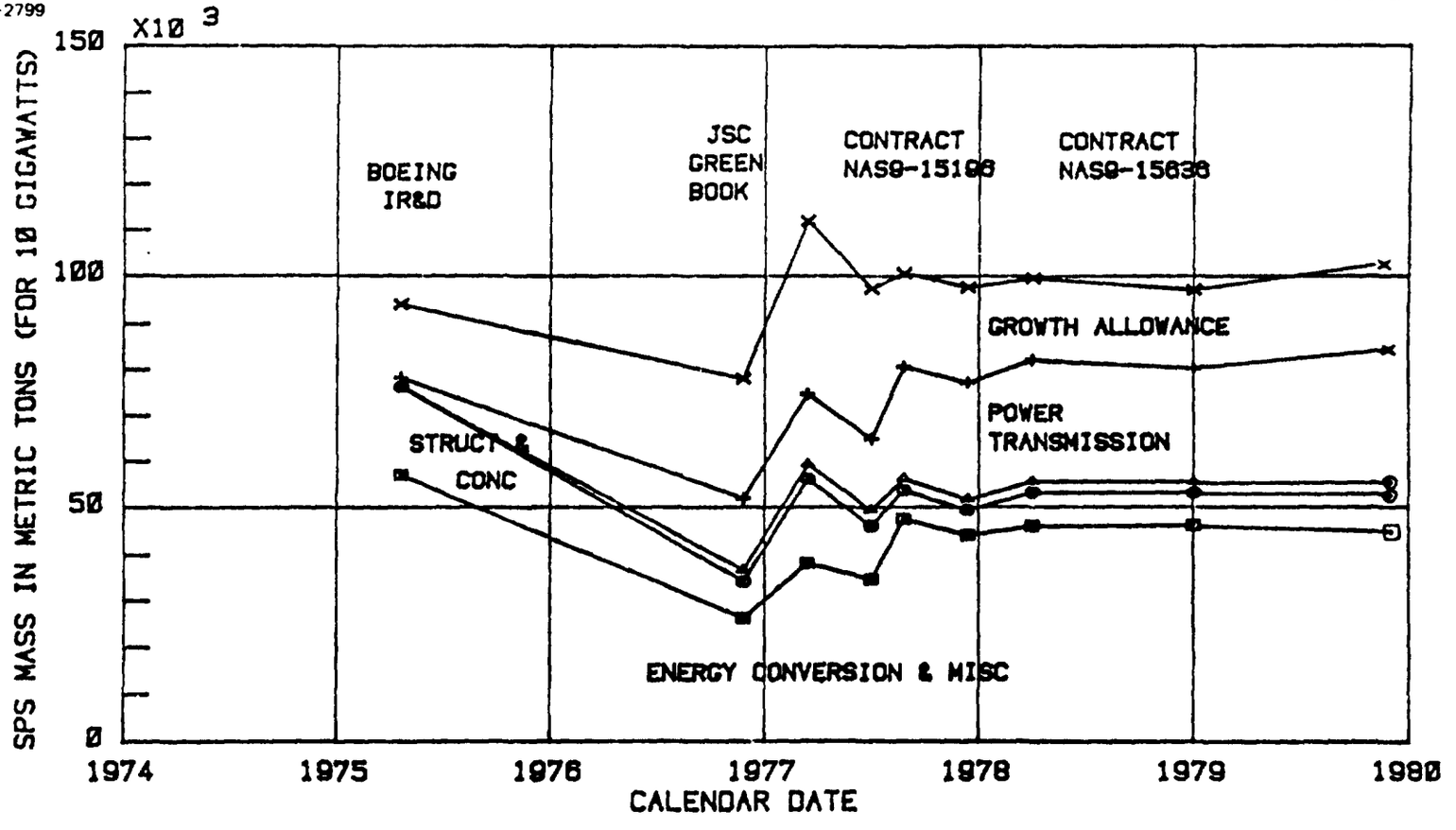
The history of SPS mass estimates since 1975 is traced here. Early fluctuations were due to changes in solar blanket definition, use of concentrators, and inadequate definition of the power transmitter. The present reference design was adopted in late 1977. The most recent mass estimate shows a slight increase due primarily to two items:

1) Change from plated plastic-matrix graphite composite waveguides to metal-matrix composites.

2) Better definition of maintenance provisions on the satellite.

Photovoltaic SPS Mass History

SPS-2799

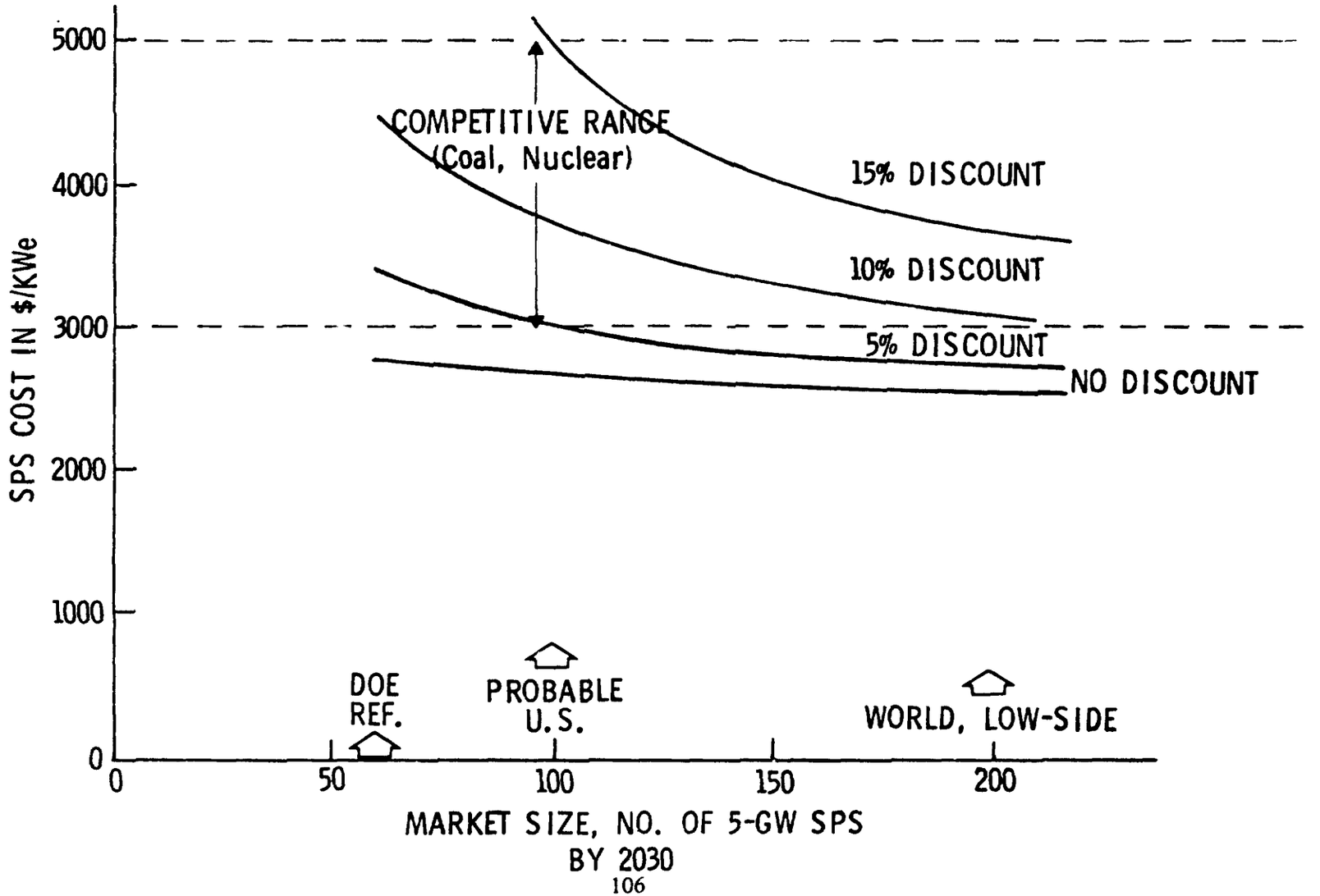


AMORTIZATION OF NONRECURRING COST

It is important to consider the economic significant of the SPS nonrecurring cost. A variety of economic judgements can be made, the most pessimistic being that the SPS production units should amortize the total nonrecurring cost, as illustrated here. In this constant (1979) dollar analysis, the most applicable discount rate is the real (without inflation) interest rate generally experienced, typically 3 to 5%. In the expected market range, amortization of nonrecurring cost does not have a major impact on SPS attractiveness. (The world market has been estimated as high as 2000 SPS's).

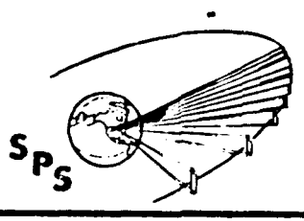
One can argue that the nonrecurring cost need not be amortized at all, on the ground that the expected U.S. market of 100 SPS's would return a trillion dollars in taxes over the book like (30 years) of the systems.

AMORTIZATION OF NONRECURRING COST



SPS MAJOR TECHNICAL ISSUES

The SPS systems studies have developed reference and alternate system designs in considerable detail and resolved many technical issues. Many more issues remain. A judgemental list of the most important is given here. Although additional systems study can shed light on two of the issues noted, the list is becoming dominated by issues that will require a ground-based exploratory development program for resolution.



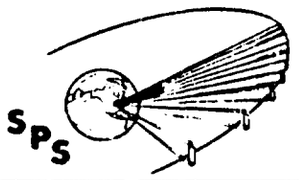
SPS MAJOR TECHNICAL ISSUES

BOEING

ISSUE	MEANS OF RESOLUTION
o HLLV Size and Trajectory Selection	o Analysis of Shuttle-derived and Shuttle-evolved HLLV's; additional trajectory & atmosphere effects analysis
o Array Degradation & Annealing	o Irradiation & Annealing Research (GBED)
o EOTV Performance & Degradation	o Analysis of integrated effects
o Phase Control & Ionosphere Effects	o GBED and satellite experiments
o Technology Selections (e.g., silicon vs GaAs)	o GBED
o Cost Confidence	o GBED & Engineering Verification

CONCLUSIONS

A great many conclusions could be stated as results of the systems definition study. Those most important to future SPS study and research are stated here.



CONCLUSIONS

- REFERENCE SYSTEM DEFINITION ADEQUATE BASIS FOR GBED
- LOW LEVEL DEFINITION HAD LITTLE IMPACT ON MASS AND RECURRING COST ESTIMATES
- SOLID STATE IS ATTRACTIVE ALTERNATIVE
- LASER TRANSMISSION AND ALTERNATIVE ORBIT TRANSFER OPTIONS MERIT STUDY
- SMALLER HLLV WOULD REDUCE NON-RECURRING COST
- SPS IS ECONOMICALLY ATTRACTIVE AS BASELOAD ELECTRIC POWER SOURCE--EVEN WITHOUT TECHNOLOGY IMPROVEMENTS BEYOND REFERENCE DESIGN

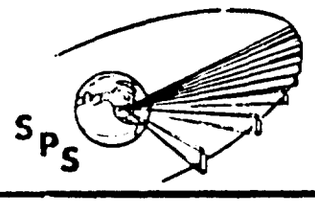
SPS RESEARCH, ENGINEERING VERIFICATION, DEMONSTRATION, AND INVESTMENT

This section describes results of the investigation of SPS research, development, and demonstration program requirements.

SPS
RESEARCH,
ENGINEERING VERIFICATION,
DEMONSTRATION,
AND
INVESTMENT

FIVE PHASES OF SPS

One of the most important results was the definition of the candidate five-phase program as noted on this chart, repeated from the executive summary.

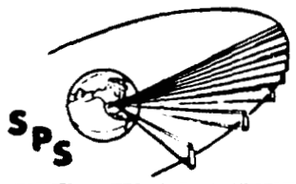


FIVE PHASES OF SPS

PHASE	OBJECTIVE
Research	o Evaluate and Select SPS Technologies o Resolve Technical, Environmental and Socio-economic Issues
Engineering Verification	o Demonstrate Conversion of SPS Technologies into Practical Engineering Hardware
Demonstration	o Demonstrate End-to-End Operational Suitability of SPS as a Baseload Electric Power Source
Investment	o Create the Industrial Base to Produce SPS Generating Capacity at 10,000 Megawatts/Yr.
Commercial Production	o Install and Maintain 300,000 Megawatts of SPS Generation Capacity over 30-Year Period.

RESEARCH PLANNING PROCESS

The principal steps in developing the research plan are tabulated on the facing page.

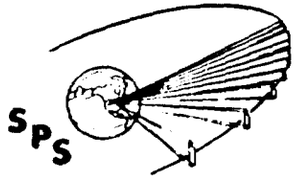


Research Planning Process

- IDENTIFY RESEARCH ISSUES & OBJECTIVES
- DEFINE RESEARCH TASKS
- REVIEW WITH JSC
- UPDATE
- DEFINE TASK INTERRELATIONSHIPS
- PERFORM NETWORK ANALYSIS
- GENERATE SCHEDULE (NO FUNDING CONSTRAINTS)
- ASSIGN RESOURCES (MANPOWER) BY SKILL
- CONDUCT COST ANALYSIS
- PERFORM COST-CONTROLLED SCHEDULING

TECHNICAL AREAS

The research plan is divided into the ten technical areas tabulated on the facing page. In addition, the research plan includes certain systems study and flight research activities.



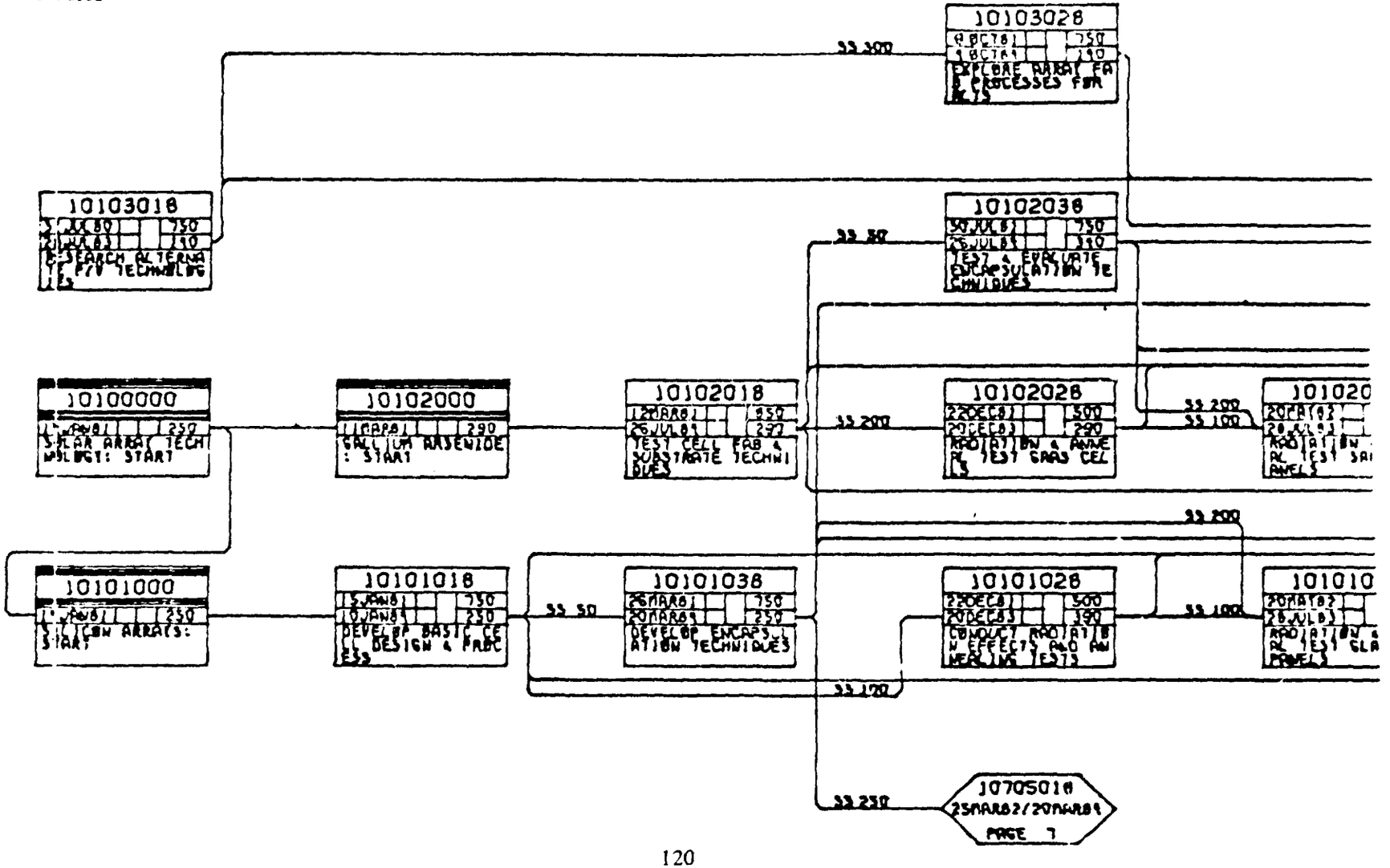
Technical Areas

- SOLAR ARRAYS
- THERMAL ENGINES & SYSTEMS
- POWER TRANSMISSION
- STRUCTURES
- MATERIALS
- FLIGHT & SYSTEM CONTROL
- SPACE CONSTRUCTION
- SPACE TRANSPORTATION
- POWER DISTRIBUTION & PROCESSING
- SPACE ENVIRONMENT EFFECTS

NETWORK EXAMPLE

The data from the research planning worksheets were input to an automated network analysis. One of the useful outputs of this analysis was a plot of the event logic network for each research area. A segment of a network is illustrated here.

Example Task Network (Solar Arrays)



SEGMENT OF SCHEDULE

Schedules as illustrated were developed for each of the technical areas.

Segment of Schedule


```
                                  SOLAR POWER SATELLITE

RJN DATE 30MAY79 1540HRS           W O R K I N G    S C H E D U L E                    PROJECT START 15JAN80

PROJECT  GBER      RESEARCH, DEVELOPMENT, & EVALUATION                                BASE COMPLETION 23JUL87

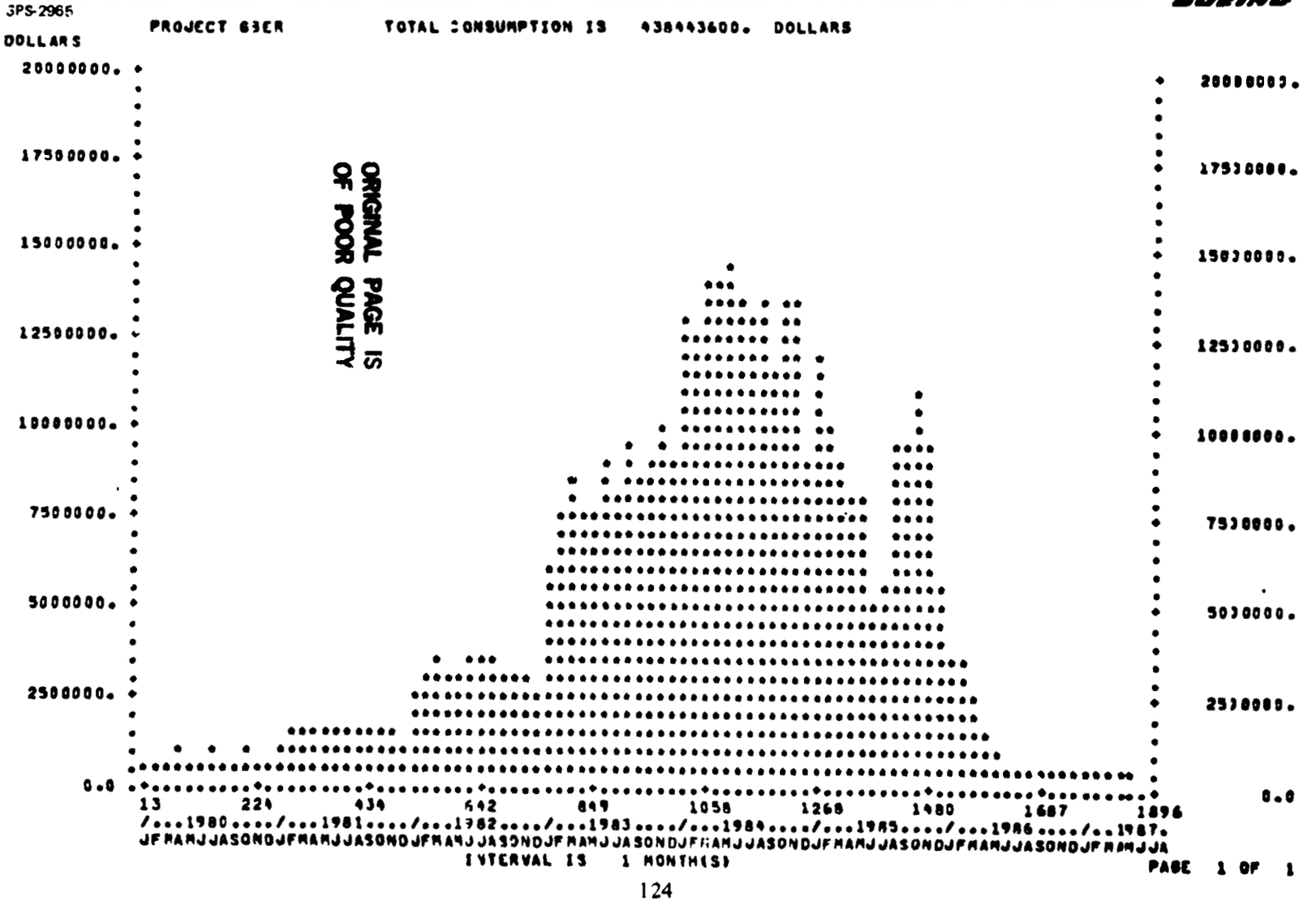
CODE         1  SOLAR ARRAYS                          SORT   CODES  23                                 PAGE  1
-------------------------------------------------------------------------------------------------------------
                                        MODE=0/FR    /...1980..../...1981..../...1982..../...1983..../...1984..../1985.
  ACTIVITY  D E S C R I P T I O N                    JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJ
-----------------------------------------------------I---------I---------I---------I---------I---------I----
                                                     I    I    I    I    I    I    I    I    I    I    I    I    I    I
SOLAR ARRAY TECHNOLOGY: START                        M
  10100000                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
SILICON ARRAYS: START                                M
  10101000                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
DEVELOP BASIC CELL DESIGN & PROCESS                              XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  10101018                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
CONDUCT RADIATION EFFECTS AND ANNEALING TESTS                                XXXXXXXXXXXXXXXXXXXXXXXX
  10101028                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
DEVELOP ENCAPSULATION TECHNIQUES                                             XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  10101038                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
RADIATION & ANNEAL TEST GLASSED PANELS                                                   XXXXXXXXXXXXXXX
  10101048                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
TEST & EVALUATE CELL/BLKT PROD PROCESSES                                                      XXXXXXXXXXXXXXXXXXXXXXXXX
  10101058                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
TEST & EVALUATE SAMPLE PRODUCTION PANELS
  10101068                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
GALLIUM ARSENIDE: START                              M
  10102000                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
TEST CELL FAB & SUBSTRATE TECHNIQUES                             XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  10102018                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
RADIATION & ANNEAL TEST GAAS CELLS                                           XXXXXXXXXXXXXXXXXXXXXXXX
  10102028                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
TEST & EVALUATE ENCAPSULATION TECHNIQUES                                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  10102038                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
RADIATION & ANNEAL TEST SAMPLE PANELS                                                    XXXXXXXXXXXXXXX
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TEST & EVALUATE CELL/BLKT PROD PROCESSES                                                      XXXXXXXXXXXXXXXXXXXXXXXXX
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TEST & EVALUATE SAMPLE PRODUCTION PANELS
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TEST & DEMONSTRATE GALLIUM RECOVERY                                                      XXXXXXXXXXXXXXXXXXXX
  10102078                                           I    I    I    I    I    I    I    I    I    I    I    I    I    I
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TOTAL RESEARCH PROGRAM NOMINAL COSTS

The nominal (resource-constrained schedule) total program costs are exhibited here, showing completion in 1987 and a total cost over the period slightly less than 440 million dollars.

Total Research Program: Nominal Costs

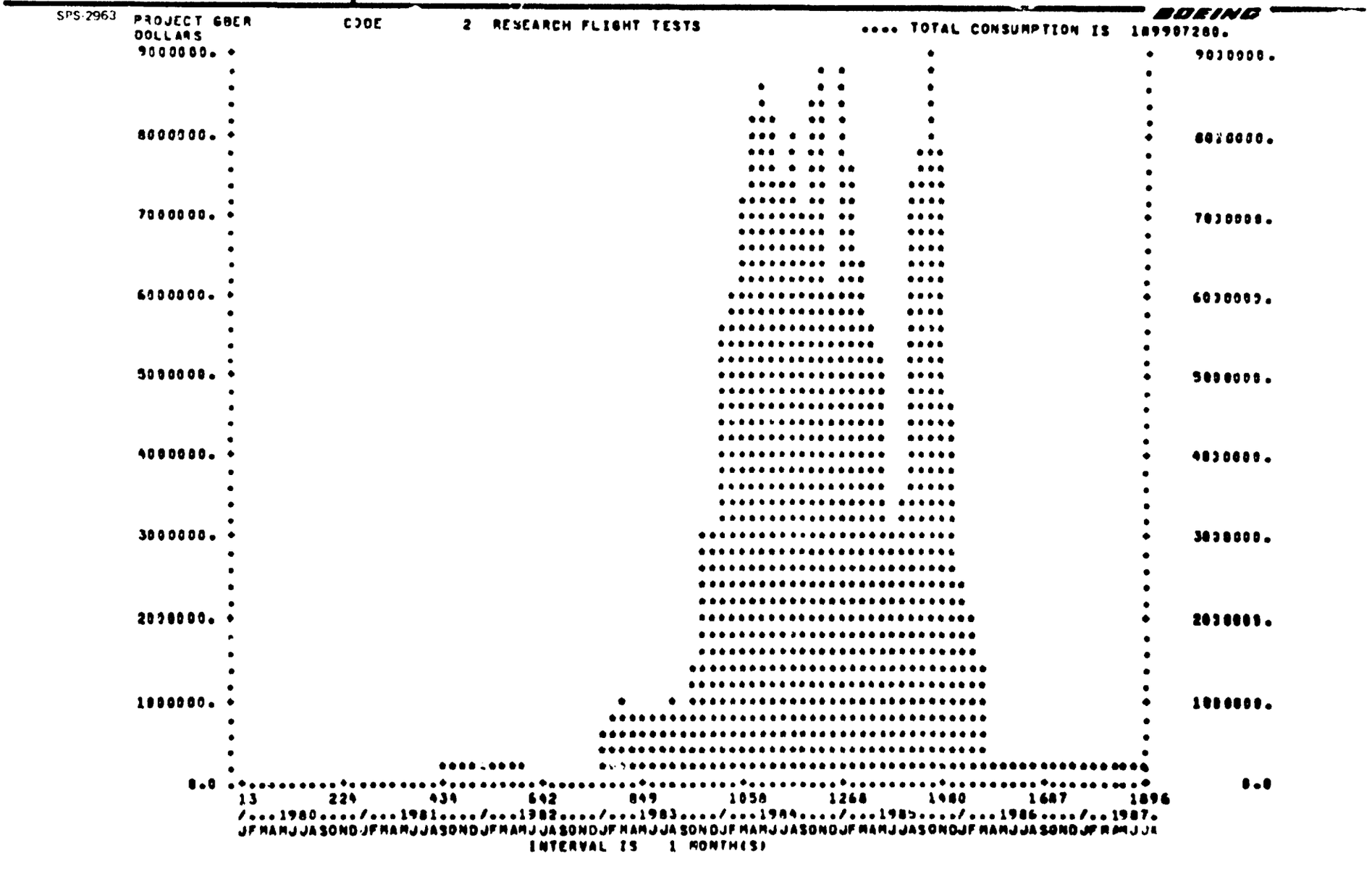
BOEING



FLIGHT RESEARCH NOMINAL COST

Certain of the elements of the research program required flight tests to acquire the necessary data. The total costs for flight program were roughly 190 million 1979 dollars.

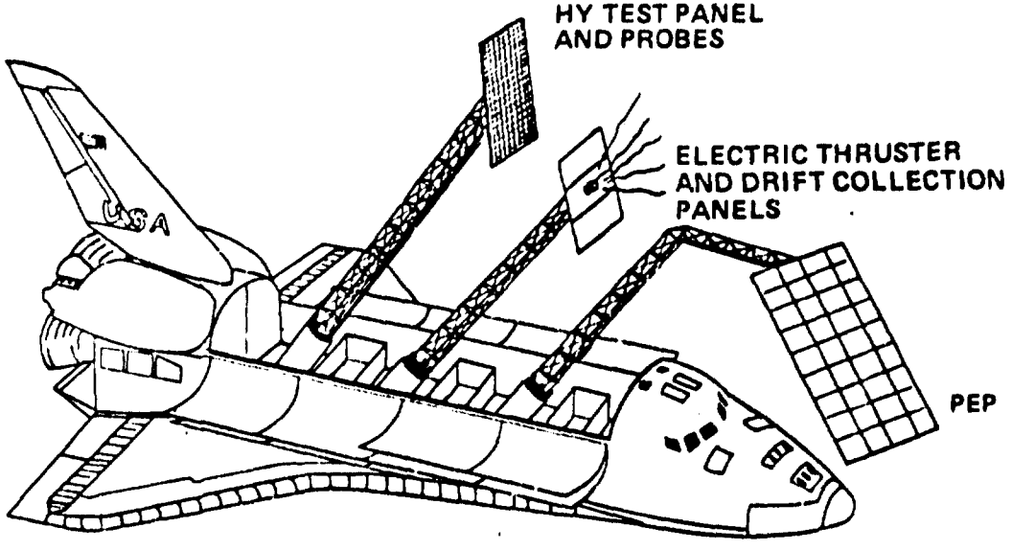
Flight Research: Nominal Costs

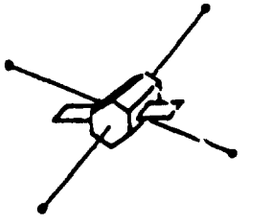


PLASMA EFFECTS SORTIE

A preliminary experimental investigation of plasma effects can be conducted in low earth orbit even though the environment there is significantly different than that at GEO. Further, the effects being investigated are important to the operation of electric orbit transfer vehicles in low earth orbit.

Plasma Effects Sorte





PROBE
SUBSATELLITE
(IF REQUIRED)

RESEARCH OBJECTIVES

- BREAKDOWN, ARC-THRU, & PLASMA CURRENTS FOR HV SOLAR ARRAYS IN LEO
- HV ARRAY-THRUSTER INTERACTIONS
- THRUSTER PLASMA EFFECTS ON IONOSPHERE & MAGNETOSPHERE

TIMING 1984-1985

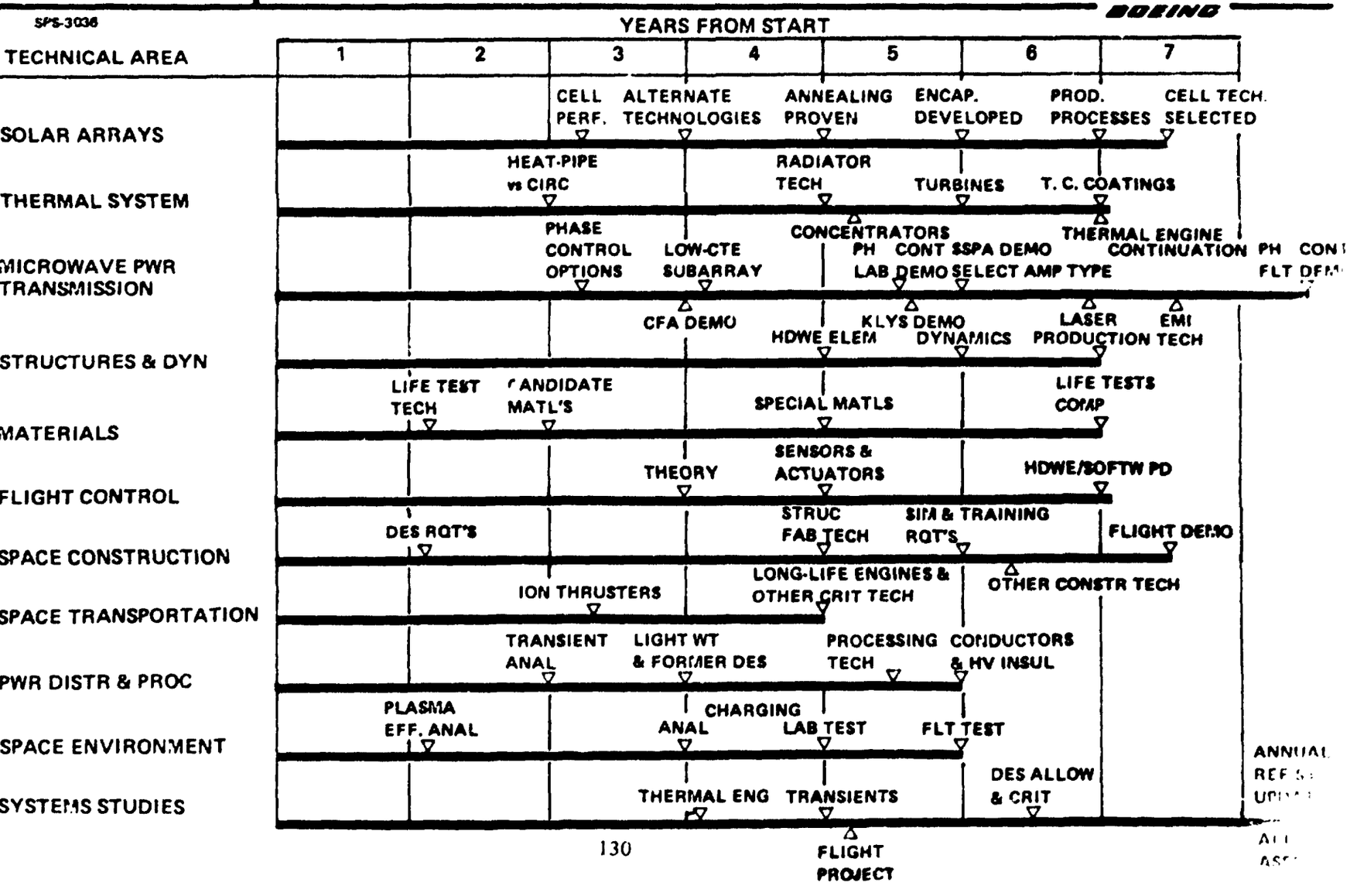
RESEARCH PROGRAM DECISION SCHEDULE

From the detailed research program schedule, the principal technology decisions were scheduled to provide a key as to when elements of the engineering verification program could begin.

Research Program Decision Schedule

SPS-3036

BOEING



REPRESENTATIVE ENGINEERING VERIFICATION ACTIVITIES

The engineering verification program plan was developed employing an issue-oriented task analysis as was done for the research program. This and the following six charts summarize the ground and flight test elements of the engineering verification program.

REPRESENTATIVE ENGINEERING VERIFICATION ACTIVITIES

	ISSUE	TASK	DURATION (YR)	FACILITIES REQUIRED
1-1	Solar array $ cost, quality	Develop and operate pilot production line	6	Production equipment (to be developed) and floor space = 1000 M^2
1-2	Solar array packaging and development	Develop packaging and deployment systems; flight test 1-MW array*	5 (2 flight)	LEO Development Lab; Shuttle
1-3	HV solar array operation and degradation at GEO; annealing	o Test array panels at GEO	5	Shuttle; manned OTV
		o Return samples to LEO and anneal	2	Manned OTV and LEO Development Lab
1-4	Solar array design criteria	Analyze results and prepare criteria and specifications	2	None
2-1	Fluid and thermal systems			
	o Heat rejection, - reflectivity	o Lab test prototype hardware elements	4	Existing
	o Fluid containment	o Flight test same	3	Shuttle, LEO Development Lab, Manned OTV
	o Degradation			

* Array to power #3-1 in addition.

(continued)

REPRESENTATIVE ENGINEERING VERIFICATION ACTIVITIES

	ISSUE	TASK	DURATION (YR)	FACILITIES REQUIRED
3-1	Microwave equipment performance and life at GEO	o Design and build proto-flight test hardware	4	Existing
		o Flight test at GEO	4	o LEO Development Lab (test) article assy) o Manned OTV (Transport to GEO and support)
3-2	Microwave/laser equipment cost in production	o Adopt proto-flight designs from #3-1 to production o Amplifies o Phase control circuitry o Phase distribution systems	2	None/Existing
		o Develop and operate pilot production lines	5	Equipment to be developed and floor space (1000 - 2000 M^2)
3-3	Specifications and design criteria	Analyze results of 3-1 and 3-2 and prepare specs and criteria	2	None

TABLE 1 (continued)

REPRESENTATIVE ENGINEERING VERIFICATION ACTIVITIES

	ISSUE	TASK	DURATION (YR)	FACILITIES REQUIRED
4-1	Predictability of large space structures dynamics	o Design test large space structure (= 100 x 1000 M)	1	None
		o Conduct dynamics analysis	1	None
		o Fab in space and test	3	Shuttle and LEO Development Lab
4-2	Structural systems' production cost	Develop and test structural elements pilot production live	3	Equipment to be developed and = 200 M^2 floor space
5-1	Materials degradation in actual environment	Test materials in GEO environment	5	Shuttle, LEO Development Lab and manned OTV
5-2	Materials production economics	Develop and test pilot production lives for cost-critical materials	4	Equipment to be developed and floor space = 2000 M^2
5-1	Controllability of large structures	Analyze results of 4-1 and develop control hardware	2	None
5-2	Electric thruster/plasma/ magnetic interactions and control influences	o Build and test experiment system at LEO and GEO (combine with 1-2, 3-1, and 4-1)	4 (design and dev.) 2 (flight test)	Space shuttle, LEO Development Lab Manned OTV
		o Analyze control influences	2	None
5-3	Software/hardware QC, QA, redundancy and production cost	Analyze software/hardware and select most economic overall approach	2	None

(continued)

REPRESENTATIVE ENGINEERING VERIFICATION ACTIVITIES

	ISSUE	TASK	DURATION (YR)	FACILITIES REQUIRED
7-1	Crew and equipment productivity	o Examine and test equipment and procedural options during 1-2, 3-1, 4-1, and 6-2. Note that this will increase cost of those programs as necessary to try different things	Per related tasks	Same as related tasks
		o Analyze results and develop appropriate criteria	2	None
7-2	Construction problems	Review problems encountered during 7-1 and modify SPS design to ameliorate	2	None
7-3	Actual construction costs	Perform cost analysis based on 7-1 and 7-2	1	None
8-1	Space transportation costs	Analyze shuttle experience and project to HLLV hardware designs and operational environments	2	None
8-2	Electric thruster clustering and plasma drift currents	Conduct cluster test at LEO	4 (Design and dev.) 1 (Test)	Shuttle and LEO Development Lab

(continued)

REPRESENTATIVE ENGINEERING VERIFICATION ACTIVITIES

	ISSUE	TASK	DURATION (YR)	FACILITIES REQUIRED
8-3	Booster engine costs	Breadboard booster engine	4	Engine test facility similar to old F-1 stands
8-4	Crew provisions and cabin designs for large numbers of passengers	o Design and build mockups	2	
		o Conduct simulations	1	Simulation lab (ground-based)
		o Analyze results and develop design criteria		
9-1	Power processor and circuit breaker performance, mass, life, and cost	o Design and test proto-flight power processors and circuit breakers	3	Electric power lab
		o Estimate costs in production environment	1	
9-2	Space environment effects on cable insulation materials	o Conduct thermal/VAC/UV chamber tests	2	Thermal-VAC combined environment lab
		o Conduct tests at GEO in conjunction with 5-1	5	Shuttle, manned, OTV

(continued)

REPRESENTATIVE ENGINEERING VERIFICATION ACTIVITIES

	ISSUE	TASK	DURATION (YR)	FACILITIES REQUIRED
9-3	Plasma and breakdown design criteria	o Conduct lab tests of conductors, insulators, and standoff	4	Combined environments
		o Conduct LEO/GEO tests of proto-flight hardware with 1-2, 3-1, etc.	4	Shuttle, LEO Development Lab, and Manned OTV
10-1	Electric Thruster plasma effects of magnetosphere	o Conduct thruster tests at selected altitudes	1	Shuttle and manned OTV
10-2	Solar array degradation during transfer	o Conduct array tests at selected altitudes	1	Shuttle and manned OTV
10-3	Shuttle/OTV/HLLV effect on upper atmosphere and ionosphere	o Observe and analyze effects of shuttle and OTV burns and extend by analysis to HLLV levels	2	None (no special flights required)
10-4	Environment-related design criteria	Analyze space environment results and develop criteria	Level of effort during this phase	None

(continued)

REPRESENTATIVE ENGINEERING VERIFICATION ACTIVITIES

	ISSUE	TASK	DURATION (YR)	FACILITIES REQUIRED
11-1	Integrated estimate of production SPS design and cost	Analyze all results, update and maintain design and cost data	Level of effort during this phase	None
11-2	Final plans and specs for demonstration system	o Phase A demonstration	1	None
		o Phase B/C demonstrator and support systems	3	Office Space
		o Conduct SR&T as required to support design decisions	3	Office and lab space

ENGINEERING VERIFICATION TEST ARTICLE CONCEPT

Many of the flight test needs described in the previous table were embodied in this engineering verification test article.

Highlights:

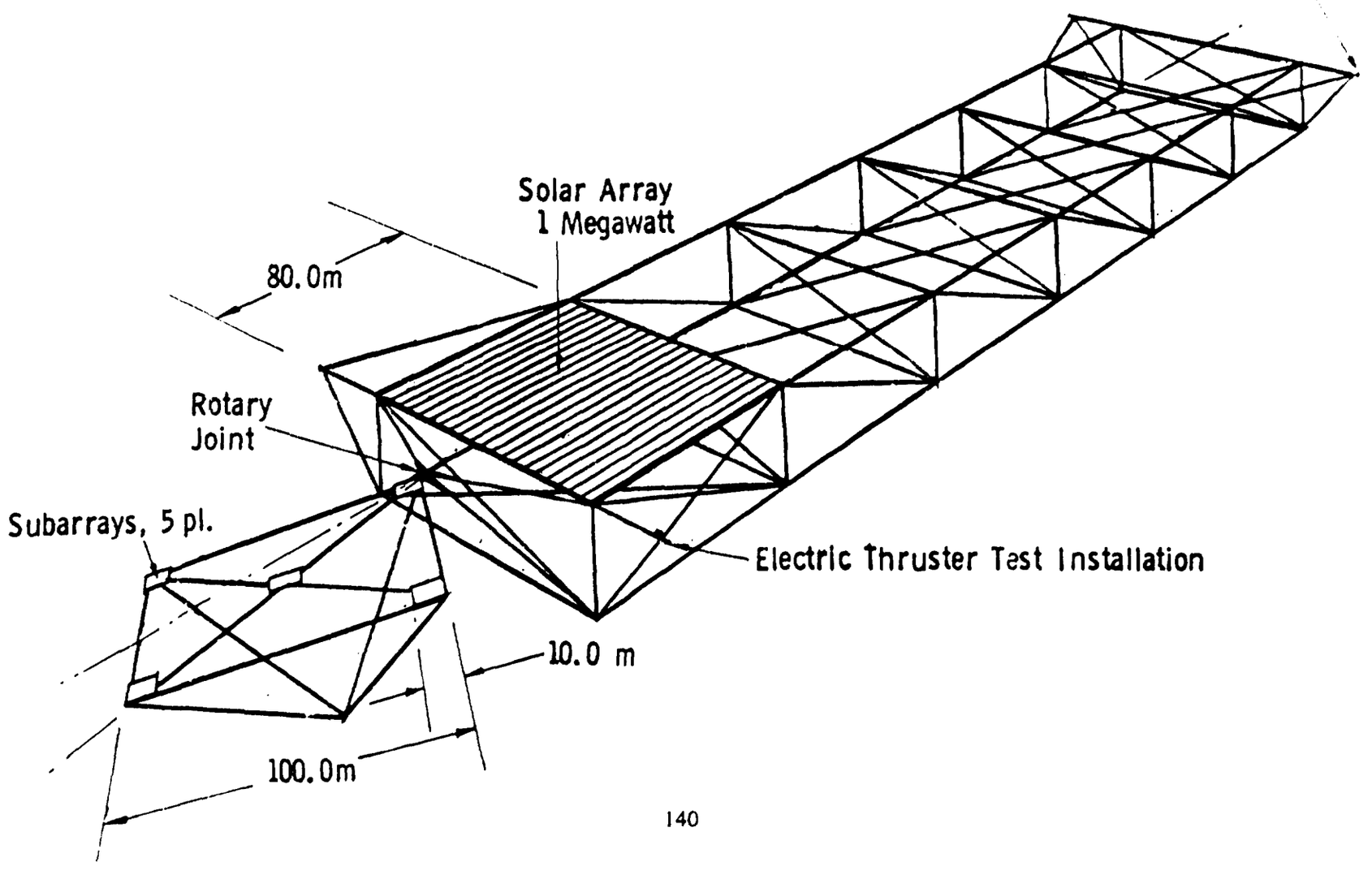
(1) A 1-megawatt solar array will allow testing of array deployment, tensioning, operation, and plasma interactions. Using 5 x 5 cm cells, it could generate about 1500 V. Switching to higher voltages may be desirable for plasma effects tests in higher orbits. The power is sufficient to drive several SPS-size klystrons or electric thrusters.

(2) Structure large enough to confirm dynamics and control predictability based on analytical models.

(3) SPS-type (subscale) subarrays with SPS-type klystrons, control circuits, and feed and radiating waveguides.

(4) Cluster of several 100-cm argon electric thrusters for thruster plasma-solar array and magnetosphere interaction tests.

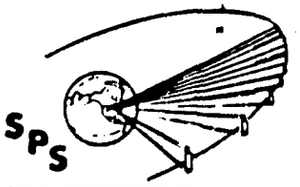
ENGINEERING VERIFICATION TEST ARTICLE CONCEPT



ENGINEERING VERIFICATION TEST ARTICLE
ROM MASS ESTIMATE

This mass estimate was prepared, scaled from mass data for SPS elements. The total mass represents about two shuttle flights. The structure employs tri-beams like the 1½-meter beams presently under development. Power distribution and processing estimates assume full power processing for the klystron test units and the electric propulsion test units and that these processing systems are independent.

The electric propulsion test unit is not relied upon for attitude control--a separate storable-propellant system is provided. The electric propulsion system will provide roughtly 16 newtons of thrust at 7500 sec Isp, enough to accelerate the EVTA at 4×10^{-4} m/sec. The electric propulsion system is not to be used for orbit transfer--a chemical orbit transfer vehicle will deliver the system to GEO after LEO and intermediate-altitude tests.



ENGINEERING VERIFICATION TEST ARTICLE ROM MASS ESTIMATE

BOEING

EVTA TOTAL	40	(Metric Tons)
ENERGY CONVERSION	17	
STRUCTURE		10
ARRAY		6
POWER DISTRIBUTION & SWITCHGEAR		1
POWER TRANSMISSION	7.2	
STRUCTURE		1.4
SUBARRAYS		1.5
POWER DISTR. & PROCESSING		4
PHASE DISTRIBUTION		0.1
MECHANICAL POINTING		0.2
INFO. MGMT. & CONTROL	0.4	
ATTITUDE CONTROL & STATION KEEPING	7	
ELECTRIC PROPULSION TEST UNIT		5
ATTITUDE CONTROL UNITS (STORABLE)		2
COMMUNICATIONS	0.2	
INTERFACE	2	
MECHANICAL		1
ELECTRICAL		1
GROWTH ALLOWANCE (20%)	6.6	

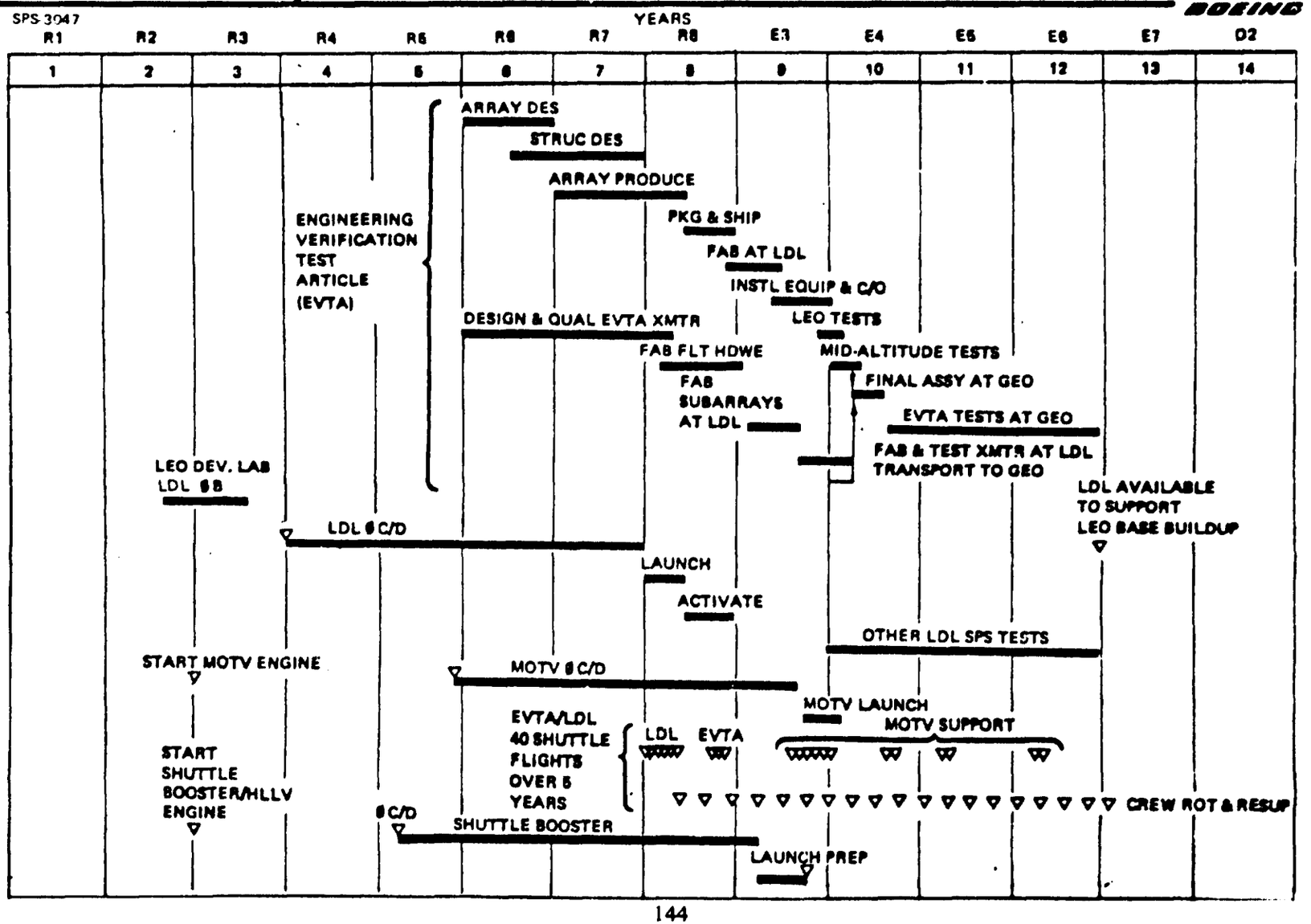
ENGINEERING VERIFICATION PROGRAM SCHEDULE

The engineering verification test program, and developmental activities to support it, are scheduled here. Promiment support systems are:

- A manned development laboratory in low Earth orbit with a crew of 8.
- A manned OTV for manned access to GEO to support GEO EVTA tests, and, operating in an unmanned mode, to deliver the EVTA to GEO after its construction and preliminary tests at LEO.
- A new shuttle booster to support the MOTV. This element could be postponed, but will reduce recurring cost of MOTV operations if developed as scheduled here.

Scheduling of the beginning of design and development of the EVTA was keyed to research program decisions (Note: research program years $1, $1, etc.). Scheduling of support systems development was then keyed to required availability.

ENGINEERING VERIFICATION PROGRAM SCHEDULE



DEMONSTRATION ISSUES

The present SPS program concept presumes that the development phase of SPS would be followed by a demonstration phase with the objective of demonstrating operational suitability of SPS for commercial use. Demonstration concepts for SPS have been studied over the past several years. A number of flight vehicle configurations have been developed. The facing tabulation synopsizes some of the principal issues that have surfaced and provides a present judgment as to the objectives of a demonstration system.

Demonstration Issues

- PREVIOUS STUDIES HAVE POSTULATED DEMONSTRATION SPS'S FROM 15 TO 10,000 MEGAWATTS
- SUCCESSFUL COMPLETION OF THE RESEARCH AND DEVELOPMENT PHASES OF SPS SHOULD PROVIDE UNPRECEDENTED TECHNICAL AND COST CONFIDENCE
- IF A UTILITY COMPANY ACQUIRES AN EXPENSIVE POWERPLANT THAT FAILS AND CANNOT BE READILY RESTORED TO SERVICE, THE FINANCIAL CONSEQUENCES ARE SEVERE.
- THE DEMONSTRATION SYSTEM SHOULD DEMONSTRATE OPERATIONAL SUITABILITY OF SPS: GRID COMPATIBILITY, AVAILABILITY, AND REPAIRABILITY. ENHANCEMENT OF COST AND TECHNICAL CONFIDENCE WILL ALSO RESULT.

PAST AND FUTURE ELECTRIC POWER ALTERNATIVES USE PILOT PLANTS

The history of development of new electrical generation technology shows a consistent pattern of graduating from test facilities to pilot plants to commercial demonstrators. Several examples are tabulated on the facing page.

Past and Future Electric Power Alternatives Use "Pilot" Plants

(1976 DATA)

PAST: PROGRESSION TO THE COMMERCIAL LIGHT WATER REACTOR

• EXPERIMENTAL REACTORS,	
• DEMO REACTOR,	SHIPPINGPORT, PA
• PROTOTYPE PLANT,	OYSTER CREEK, NJ

FUTURE: GROUND SOLAR POWER (TOWER TOP TYPE)

• TEST FACILITY	(5 MW_t) ALBUQUERQUE, NM
• PILOT PLANT	(10 MW_e) BARSTOW, CA
• COMMERCIAL DEMONSTRATOR	(100 MW_e)

BREEDER REACTOR (LIQUID METAL FAST BREEDER)

• FAST FLUX TEST FACILITY	400 MW_t
• CLINCH RIVER BREEDER	380 MW_e
• PROTOTYPE COMMERCIAL BREEDER	1,200 MW_e

FUSION (MAGNETIC)

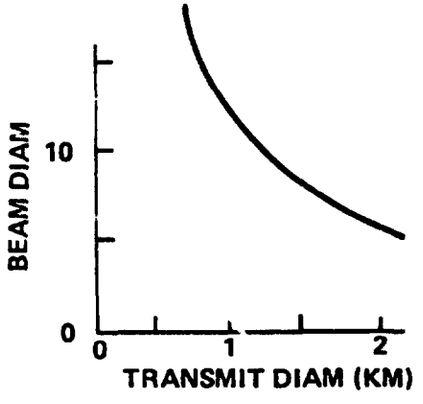
- EXPERIMENTAL POWER REACTOR 1 (20-50 MW_e)
- EXPERIMENTAL POWER REACTOR 2 ($>$ 100 MW_e)
- DEMONSTRATION REACTOR ($>$ 500 MW_e)

DEMONSTRATOR CONSIDERATIONS

The increasing definition of SPS hardware elements by the ongoing system definition studies has led to the considerations listed on the facing page. Of particular importance is the minimum power density achievable with the reference system design. It seems appropriate for demonstrator system to consider a uniform antenna illumination since the relatively higher sidelobes of the uniform illumination will still be considerably less in intensity than the side lobes of the operating SPS. It is also clear that a large transmit aperture is needed in order to provide a beam diameter at the ground commensurate with a reasonable of rectenna size.

Demonstrator Considerations

- LARGE ANTENNA APERTURES ARE REQUIRED TO ACHIEVE REASONABLE BEAM FOOTPRINT
- WITH REFERENCE SPS KLYSTRONS AND SUBARRAY SIZE 650 W/M^2 IS MINIMUM POWER DENSITY. (1 KLYSTRON PER SUBARRAY)
- SOLID-STATE OPTIONS LESS CLEAR, BUT COMPARABLE
- DESIRE $\approx$ 1 MW/CM^2 TO DRIVE RECTENNA
- LEADS TO 300-600 MEGAWATTS RF POWER AS MINIMUM; ROUGHLY SIZE OF REFERENCE EOTV



DEMONSTRATOR PROVISIONAL REQUIREMENTS

Based on the preceding considerations a set of provisional requirements for an SPS demonstrator have been developed. First, it must operate at geosynchronous orbit. This is important because the ionizing radiation and plasma environment in geosynchronous orbit is significantly different from that at low earth orbit. Also, a geosynchronous location is essential in order to provide continuous operation with a ground receiving station.

Secondly, meaningful power must be provided to a utility grid in order to demonstrate operational suitability for baseload service.

A conclusive demonstration of reliable control of the power beam and its sidelobes is important to a final demonstration of environmental acceptability as well as showing suitability for continuous service.

The SPS demonstrator should show the capability of an SPS to deliver a high plant factor in the range of 0.8 to 0.9 or better. Achievement of a high plant factor is critical to the economic acceptability of a high capital cost, low fuel cost, renewable energy system.

It is clear that reliable and repeatable startup and shutdown is important. In the process of demonstrating this and the other objectives, SPS hardware and operations can be qualified for commercial service.

Finally, in order to demonstrate the ability of an SPS to provide a high plant factor over a long period of time, maintainability and repairability of the SPS should be included in the demonstration program.

Demonstrator Provisional Requirements

- OPERATE AT GEO
- PROVIDE MEANINGFUL POWER TO A UTILITY GRID (TENS TO HUNDREDS OF MEGAWATTS)
- DEMONSTRATE RELIABLE CONTROL OF POWER BEAM AND ITS SIDELOBES
- DEMONSTRATE PLANT FACTOR CAPABILITY
- DEMONSTRATE RELIABLE, REPEATABLE STARTUP AND SHUTDOWN
- QUALIFY SPS HARDWARE AND OPERATIONS
- DEMONSTRATE MAINTAINABILITY AND REPAIRABILITY

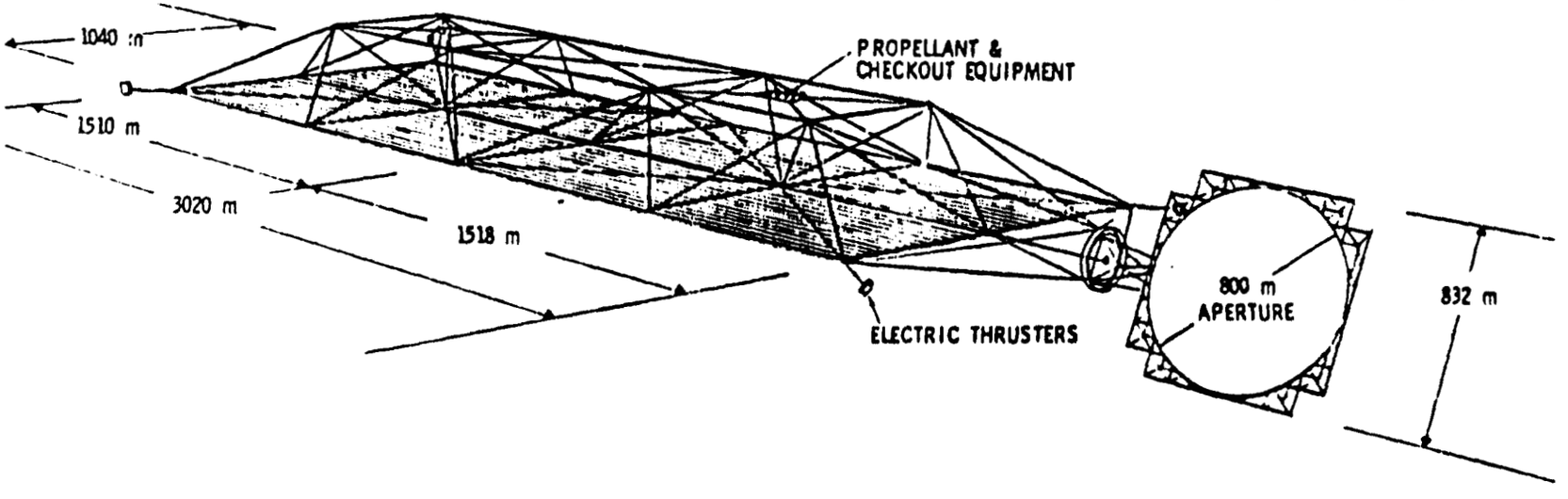
SPS DEMONSTRATION CONFIGURATION

The demonstrator design shown here takes advantage of size commonality with the EOTV, which also must be developed at about this point in the program to support buildup of the GEO construction base and to provide time for EOTV fleet buildup. It is essentially two EOTV's coupled together, providing power for an 800-m transmitter. The transmitter illumination is constant, with one SPS klystron per 10.4 x 10.4 m subarray. 4,650 subarrays fill the aperture. The power beam maximum intensity is about 1 mw/cm^2, with maximum sidelobes of 2 microwatts/cm^2. A rectenna somewhat smaller than the reference design can deliver 100 to 150 megawatts of electric power to a power grid.

SPS DEMONSTRATION CONFIGURATION

SPS-3094

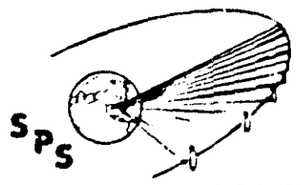
SPS DEMONSTRATOR
- 300 MEGAWATTS RF POWER
- USES DUAL EOTV FOR ELECTRIC POWER & ORBIT TRANSFER
- 9280 TONS INCLUDING TRANSFER PROPELLANT



SPS DEMONSTRATOR MASS ESTIMATE

The mass estimate here was factored from SPS and EOTV estimates. Full power processing is assumed, but reconfiguration of the EOTV array might allow testing of direct power to the klystrons from the array. The propellant load includes sufficient propellant for orbit transfer.

This vehicle would deliver as payload (not included in the mass statement) one or two 8-meter habitats and test and checkout equipment to support demonstrator test operations at GEO.



SPS DEMONSTRATOR MASS ESTIMATE

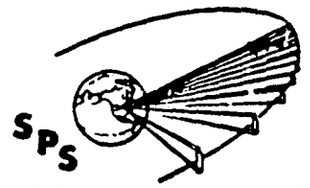
BOEING

	MASS	REMARKS
TOTAL	9,281	
ENERGY CONVERSION	1,993	
Structure	293	2 EOTV + 20%
Array	1,560	2 EOTV
Distribution	126	2 EOTV + 50%
Storage	14	
ELECTRIC PROPULSION	992	2 EOTV
AUXILIARY SYSTEMS	15	2 EOTV
TRANSMITTER	3,271	60% of SPS
Other	226	60% of SPS
Prim. Structure	98	64% of SPS
Sec. Structure	109	64% of SPS
Subarrays	1,998	One klystron per subarray/4650 subarrays
Power Processing	840	Full processing @ 2 Kg/KWe
INFO MGMT & CONTROL	32	1/3 SPS
INTERFACE	142	60% of SPS
GROWTH	1,289	20% of above
PROPELLANT	1,547	20% of above, this includes transfer propellant

SPS DEMONSTRATION AND COMMERCIALIZATION SCHEDULE

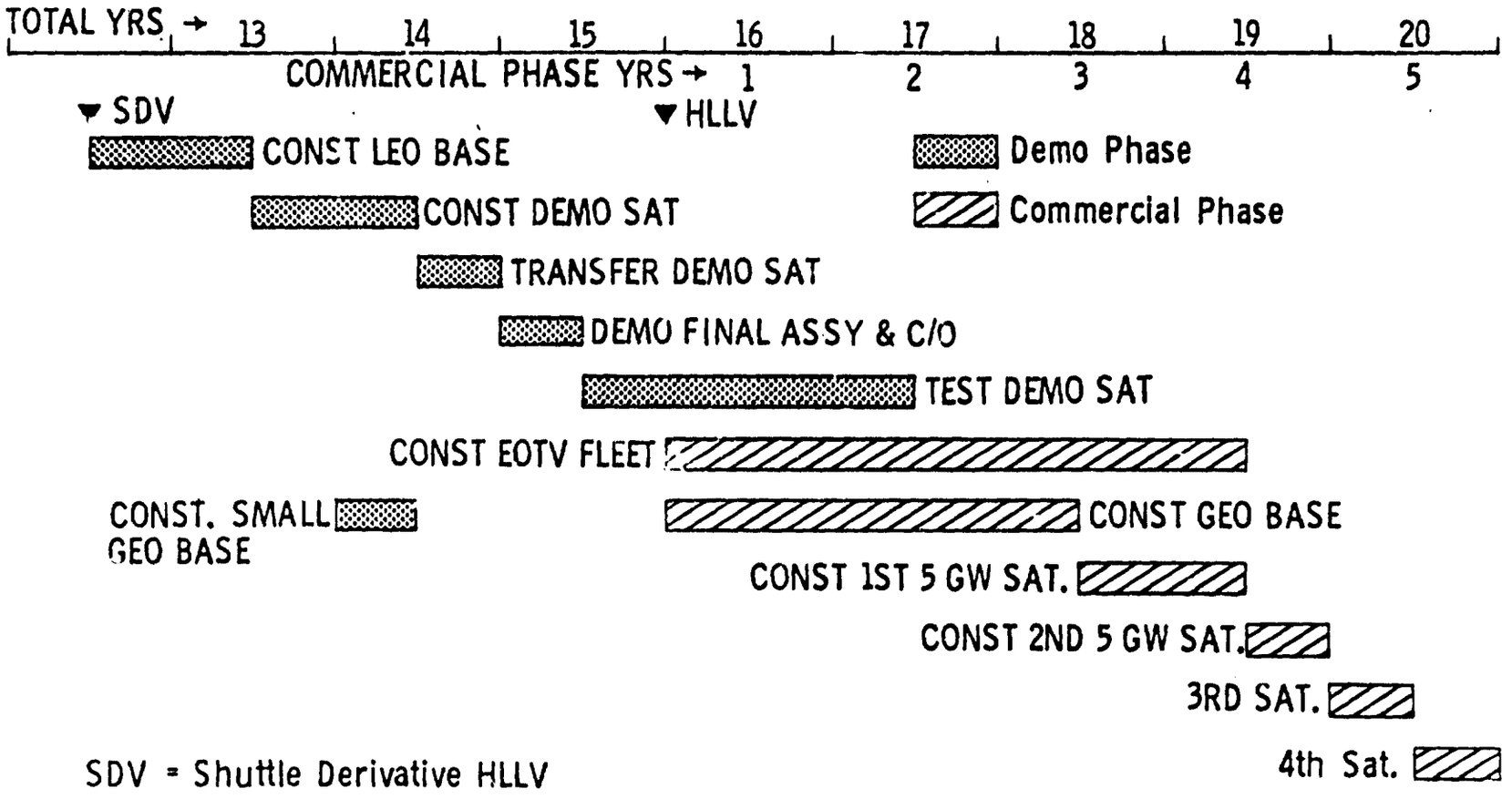
The estimated schedule for the demonstration and investment plans, and initial parts of the commercialization phase is shown here.

SPS DEMONSTRATION AND COMMERCIALIZATION SCHEDULE



BOEING

SPS-3087



SDV = Shuttle Derivative HLLV

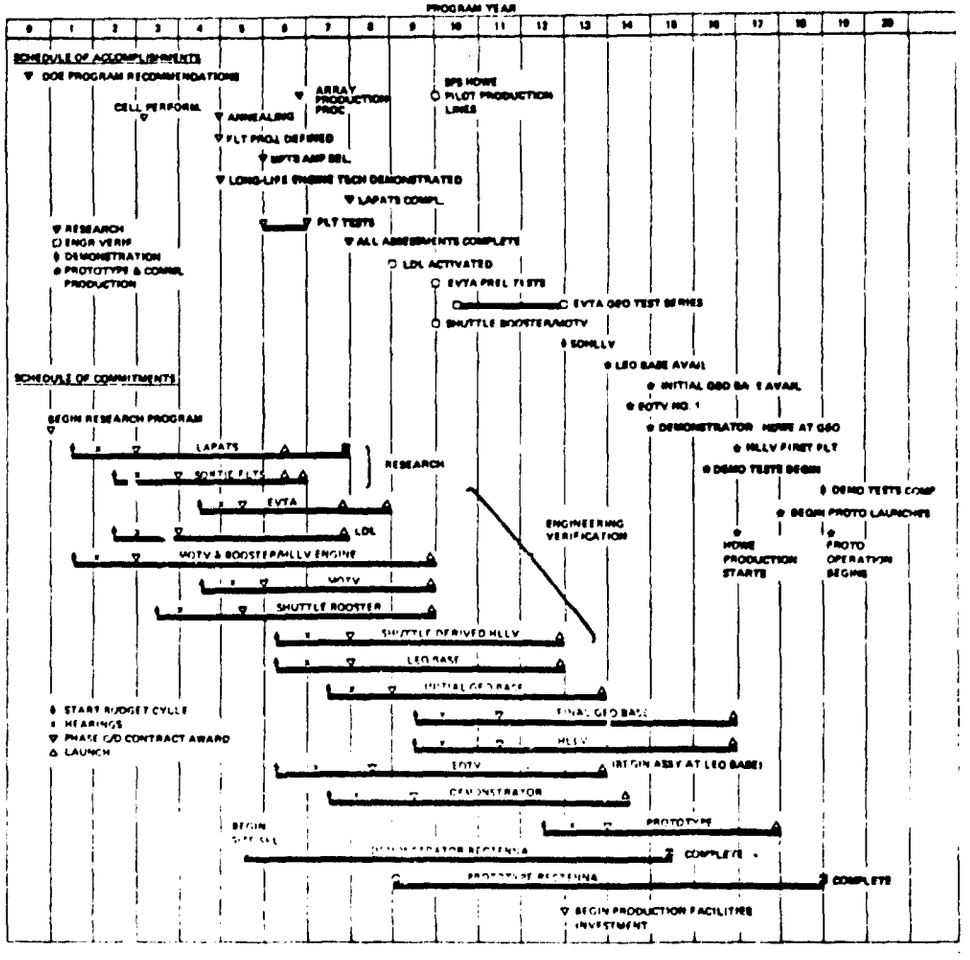
ACCOMPLISHMENTS AND DECISIONS

The preceding schedules were merged into a total program schedule. Shown here are accomplishment milestones superimposed on a development and commitment schedule. Two important findings are revealed on this chart:

(1) Budget considerations of long-lead items for the engineering verification phase must begin in the second year of the research program to support an SPS-by-2000 timetable.

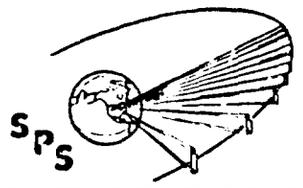
(2) Developmental decision requirements will provide a basis for yearly review of SPS program status through the critical first ten years of the program.

ACCOMPLISHMENTS AND DECISIONS



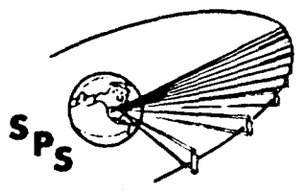
SPS PROGRAM NON-RECURRING COST

The candidate integrated SPS program plan described on previous pages provided a basis for and end-to-end nonrecurring cost estimate. This page and the following eight pages present the estimate and rationale.



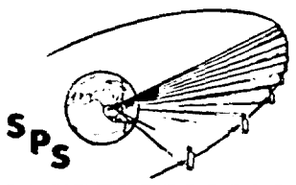
SPS PROGRAM NON-RECURRING COST

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Research		430	
GBED	Ground-Based Exploratory Development	240	Detailed Estimate Reported in Planning Document
Flight Research	Microwave Propagation and Phase Control Experiment Satellite + Shuttle Sorties	190	(Same)
Engineering Verification		9145	
SPS-Related	Subsystems Devel. & Test	421	Sub-Allocation of SPS DDT&E
EVTA Hardware	Engineering Verification Test Article: 1-Megawatt Array Plus Microwave and Electric Propulsion Experiments	240	Sub-Allocation of SPS Hardware Cost



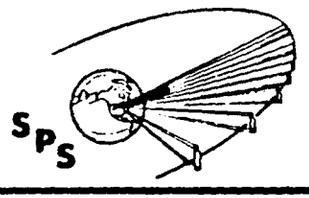
SPS PROGRAM NON-RECURRING COST - Cont.

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Engineering Verification			
LEO Development Labs	8-Man Test & Space Support Facility	2700	JSC Estimate
Manned OTV	All-Prolpulsive or aero-braking OTV with 2- to 4-man capability	1430	800 for OTV from OTV studies. 500 guess for manned module DDT&E plus one unit at 80 + 50
Shuttle Flights	LEO Dev. Lab & MOTV Support plus EVTA Launch	1000	40 flights total
Shuttle Booster	Liquid Flyback Booster for Shuttle	3284	DDT&E plus one extra flight unit. Provides shuttle payload increase to support MOTV.
Program Mgmt & Integration	Integration, Coordination, and Management support to tie program elements together.	70	200 people for 5 years



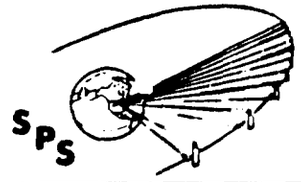
SPS PROGRAM NON-RECURRING COST - Cont.

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Demonstration Program		26349	
Demonstrator DDT&E	Development of the Demonstrator Subsystems and Integrated Configuration	3134	Sub-allocation of SPS DDT&E
Pilot Production Facilities	Pilot Lines for Arrays, Klystrons, Power Pro-processors, etc.	460	Sub-allocation of SPS Investment
Demonstrator	Hardware for Demonstrator	2922	Sub-allocation of SPS Hardware Cost
Shuttle DDT&E & Fleet	2 Boosters, 2 Orbiters, 25 ET's, Development of Pod-Type HLLV	3403	Boosters: 310; Orbiters: 1265; ET's: 115; Tooling: 173; GSE:50; HLLV DDT&E 1490



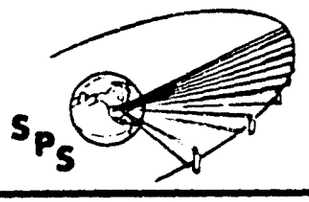
SPS PROGRAM NON-RECURRING COST - Cont.

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Demonstration Program			
Construction DDT&E	Leo Base: 8-meter Habitat & Full Work Support Facility GEO Base: Habitat Delta for Shielding & 10% WSF	3586	Based on 8-meter habitat DDT&E 1135 & Unit 136, scaled from 17-meter habitat
Construction Base Cost	LEO Base: 4 Habitats & Full WSF GEO Base: 1 Habitat & 10% WSF	3421	Scaled from 17-meter habitat
Space Operations	4 Years Operations: Construct Bases & Demonstrator	3200	130 HLLV flights @ 12:1560 24 PLV flights @ 15:360 Crew salaries & resupply based on 100 crew = 1/6 of operational SPS: 1280



SPS PROGRAM NON-RECURRING COST - Cont.

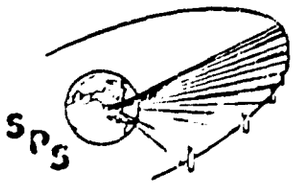
ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Demonstration Program			
POTV DDT&E Plus one extra unit	Personnel OTV with Passenger Module	1986	From DDT&E estimate with MOTV credits: Engine - 355 Avionics- 55 ECLS - 30
EOTV DDT&E	Electric OTV Development Only (supports Demo Article)	2041	From DDT&E estimate with 543 credit for commonality with Demo Article (no flight test unit)
Demonstrator Rectenna	8 x 11 km	2021	Scaled from operational rectenna + $250 M DDT&E
Program Mgmt & Integration		175	500 people for 5 years



SPS PROGRAM NON-REQURRING COST - Cont.

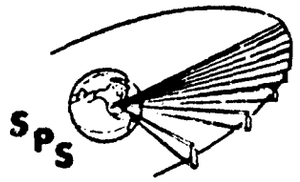
SPS-3063

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Investment		66363	
HLLV Development	2-Stage Fully Reusable	12100	From DDT&E estimate with booster engine credit 800
SPS DDT&E	Upgrading Demo Subsystems & Integration of Configuration	2473	Sub-allocation of SPS DDT&E
HLLV Fleet	6 Boosters, 7 Orbiters, Tooling and GSE	6983	From detailed estimate
EOTV Fleet	21 Vehicles	6858	From detailed estimate
Construction DDT&E	Delta DDT&E to Upgrade Bases to Operational Capability	4900	New 17-meter habitat & work module plus GEO Base work support facilities



SPS PROGRAM NON-RECURRING COST - Cont.

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
First SPS		15090	
SPS Hardware	Flight Hardware Ready to Ship	4473	Detailed estimate less amortization
Space Transportation	All Space Transport, Hardware + Crew	4192	Delta flights due to 1-year construction time EOTV 1.3 POTV 12 HLLV 54 PLV 29
Ground Transportation	Factory to Launch	35	ADL estimate
Packaging Equipment	Launch Packaging	200	5% of SPS Hardware Packaging is Reusable
First Year Full Base Ops	Crew Salaries & Spares & Support	1922	Detailed estimate
Rectenna	9 x 13 km	2578	GE estimate in 79$



SPS PROGRAM NON-RECURRING COST - Cont.

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
First SPS			
Mission Ops		20	TRW Estimate
Sustaining DDT&E	Development Support to Prototype	495	3500 people 2 years
Program Mgmt & Integration		495	3500 people 2 years
Cost Growth		680	17% on SPS Hardware
TOTAL THROUGH #1 SPS		117377	

SPS TOTAL PROGRAM THRU #1

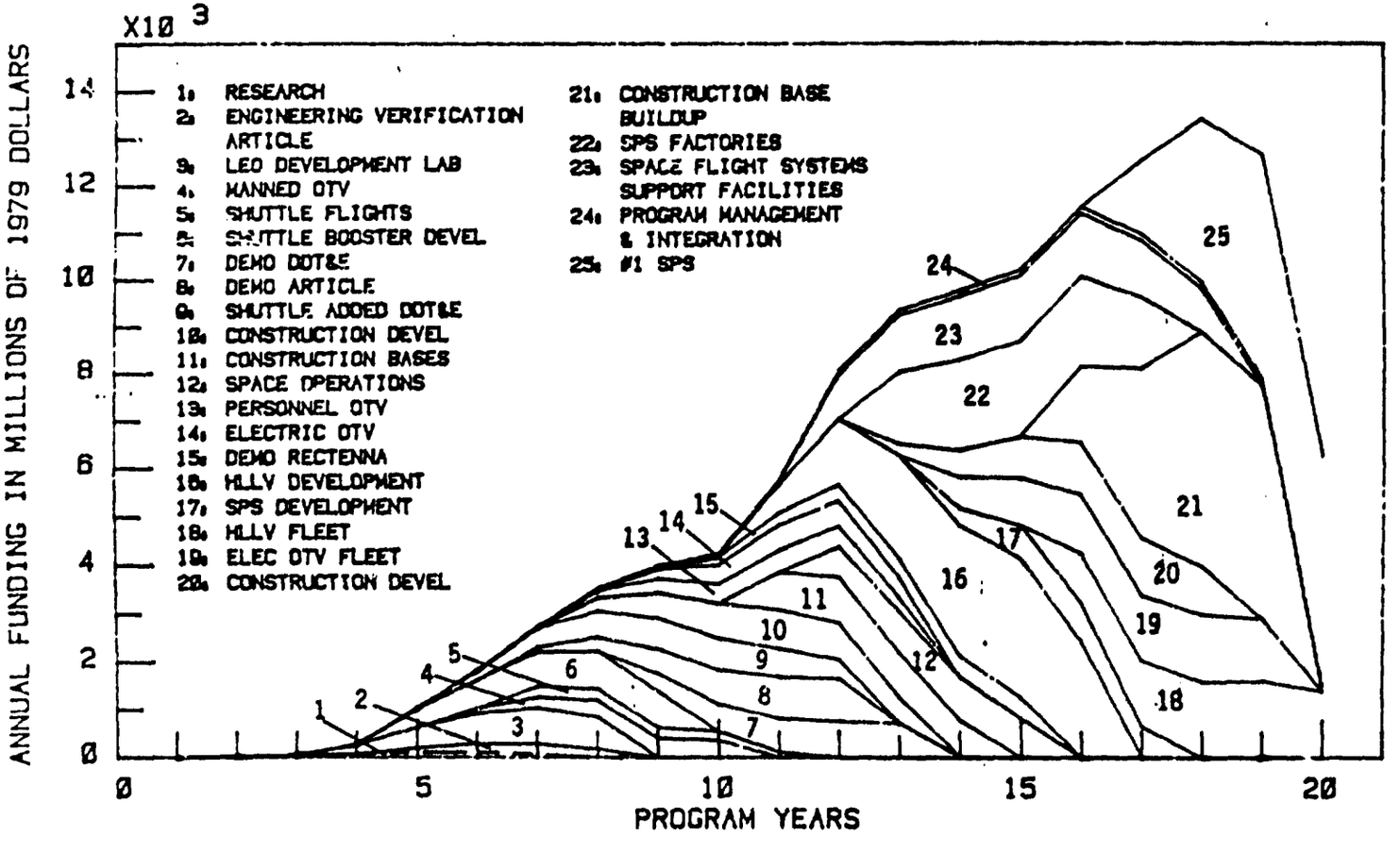
Cost estimates were made for each element of the program and time-phased to develop a funding projection. All elements identified were included, e.g., manned OTV, although many of the items may have application to other missions.

Items 2 through 6 comprise the engineering verification program. Items 7 through 15 comprise the demonstration program. Items 16 through 24 represent the investment necessary to achieve a production rate of 2 SPS's per year.

In the production phase, the total annual funding will be on the order of 25 billions per year.

The sum of all program element costs shown here including #1 SPS is 117.4 billions of 1979 dollars.

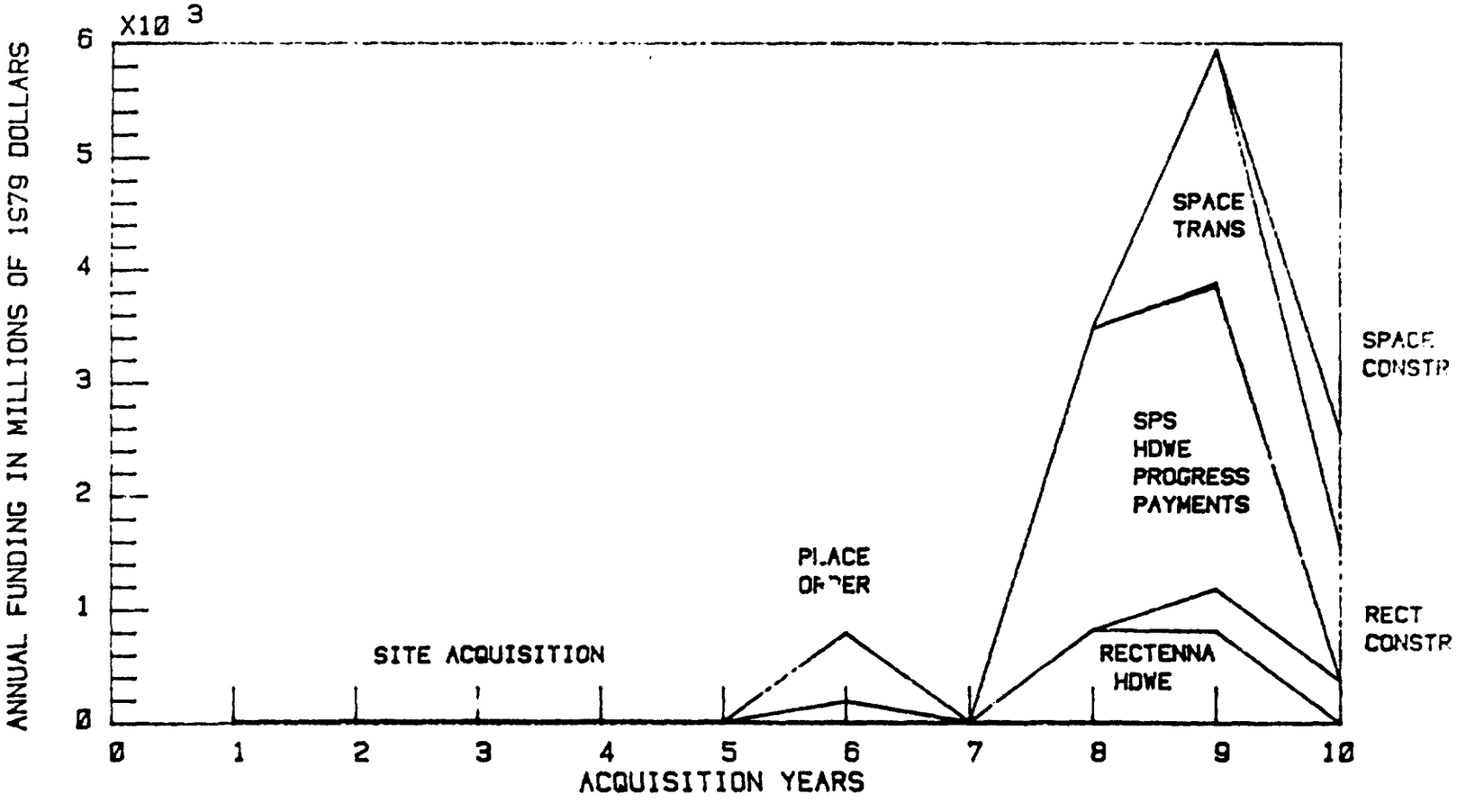
SPS TOTAL PROGRAM THRU #1



SPS ACQUISITION FUNDING

Presented here is an estimate of the funding schedule required for a production (recurring) SPS.

SPS ACQUISITION FUNDING



SOLAR POWER SATELLITE SYSTEM DEFINITION STUDY

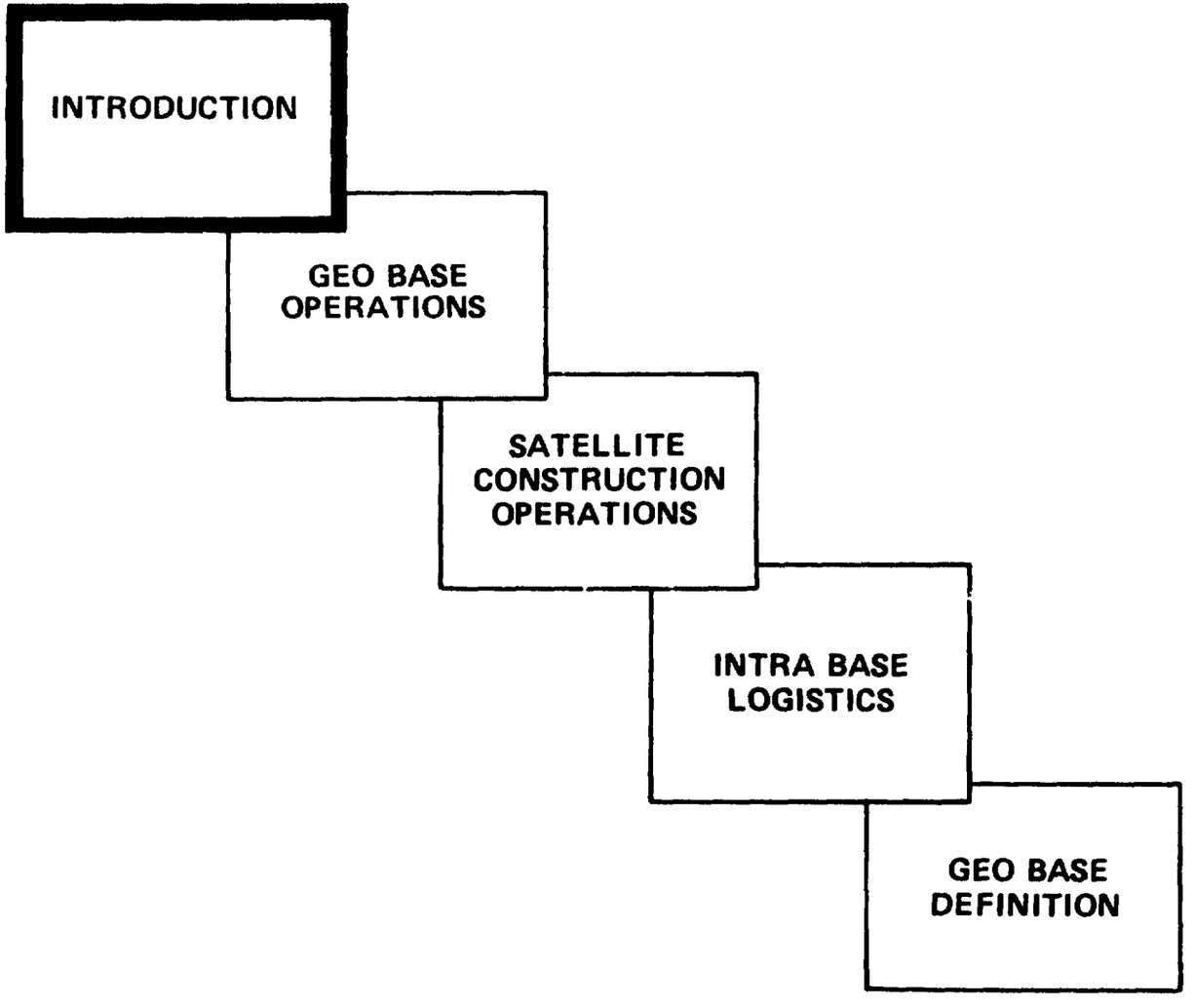
final briefing — phase 2

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Boeing Aerospace Company
P.O. Box 3999
Seattle, Washington 98124

under contract no. N520080-9114
Contracting Study Manager Gordon Woodcock

prepared for
Grumman Aerospace Corporation
Bethpage, New York 11714

report no. NSS-SPS-B-RP016


INTRODUCTION
GEO BASE OPERATIONS
SATELLITE CONSTRUCTION OPERATIONS
INTRA BASE LOGISTICS
GEO BASE DEFINITION
GRUMMAN

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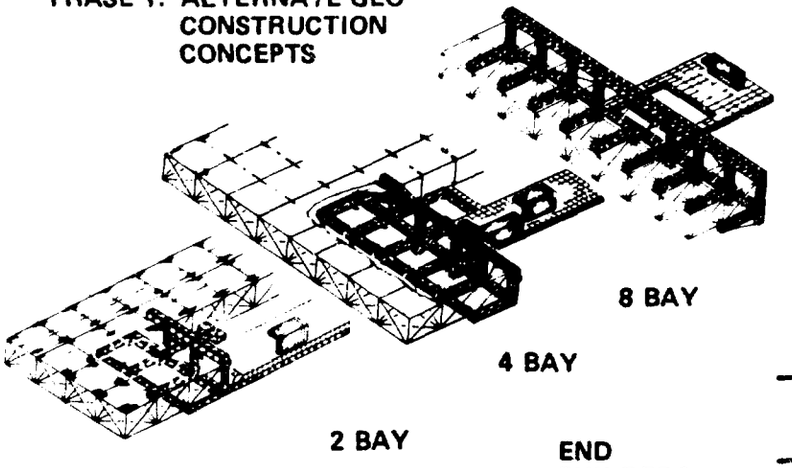
SPS SYSTEM DEFINITION STUDY FOR BOEING/JSC

Different methods for constructing the 5000 MW reference satellite in GEO were investigated during Phase 1 by a joint Boeing/Grumman team. Alternate end builder construction concepts were developed by Grumman for direct comparison with a single-deck construction platform concept. These construction options are shown on the facing page.

Ground rules for preliminary analysis of the platform type and end builder construction concepts were to use a common antenna construction facility, and to constrain SPS final assembly and checkout to one satellite every six months. All options were evaluated in terms of cost, performance, complexity, risk, etc. The 8 bay wide end builder exhibited the highest unit cost and was not able to fully utilize its production capability. The comparison of the multi-pass end builder and the single-deck platform concepts was nearly even. The 4 bay end builder was selected, however, for additional definition work in Phase 2 because of its greater production rate growth capability.

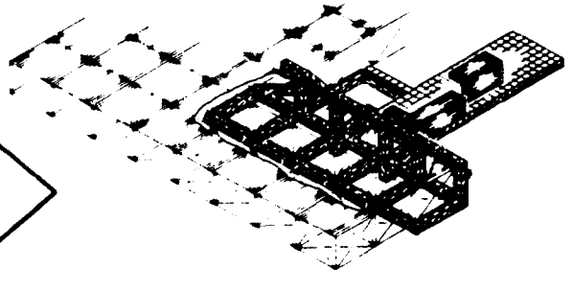
SPS SYSTEM DEFINITION STUDY FOR BOEING/JSC

PHASE 1: ALTERNATE GEO CONSTRUCTION CONCEPTS



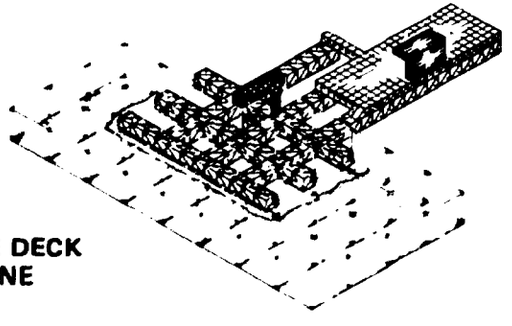
END BUILDERS

PHASE 2: CONSTRUCTION BASE OPERATIONS & DEFINITION



4 BAY END BUILDER

VS



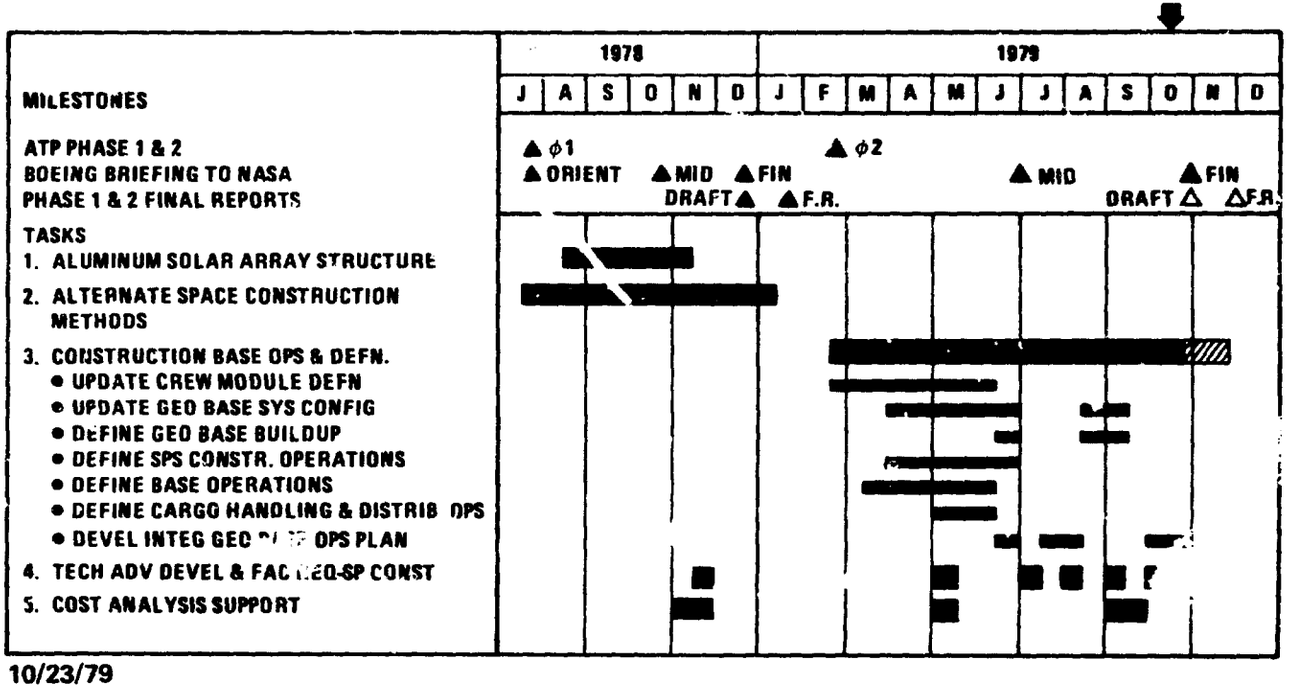
SINGLE DECK BASELINE

1079-006D

GRUMMAN SPS SYSTEM DEFINITION STUDY SCHEDULE

Grumman's Phase 2 effort for Boeing is focused on further defining the operations and systems elements of the 4 Bay End Builder. The major operations tasks include the analysis and definition of GEO Base Operations, SPS Construction Operations and intra-base cargo handling and distribution operations. Analysis of these functional areas helped to establish system feasibility and provide a basis for subsequent design updating. It also served as a tool for identifying technology issues which require further study and/or near-term technical development.

GRUMMAN SPS SYSTEM DEFINITION STUDY – SCHEDULE



10/23/79

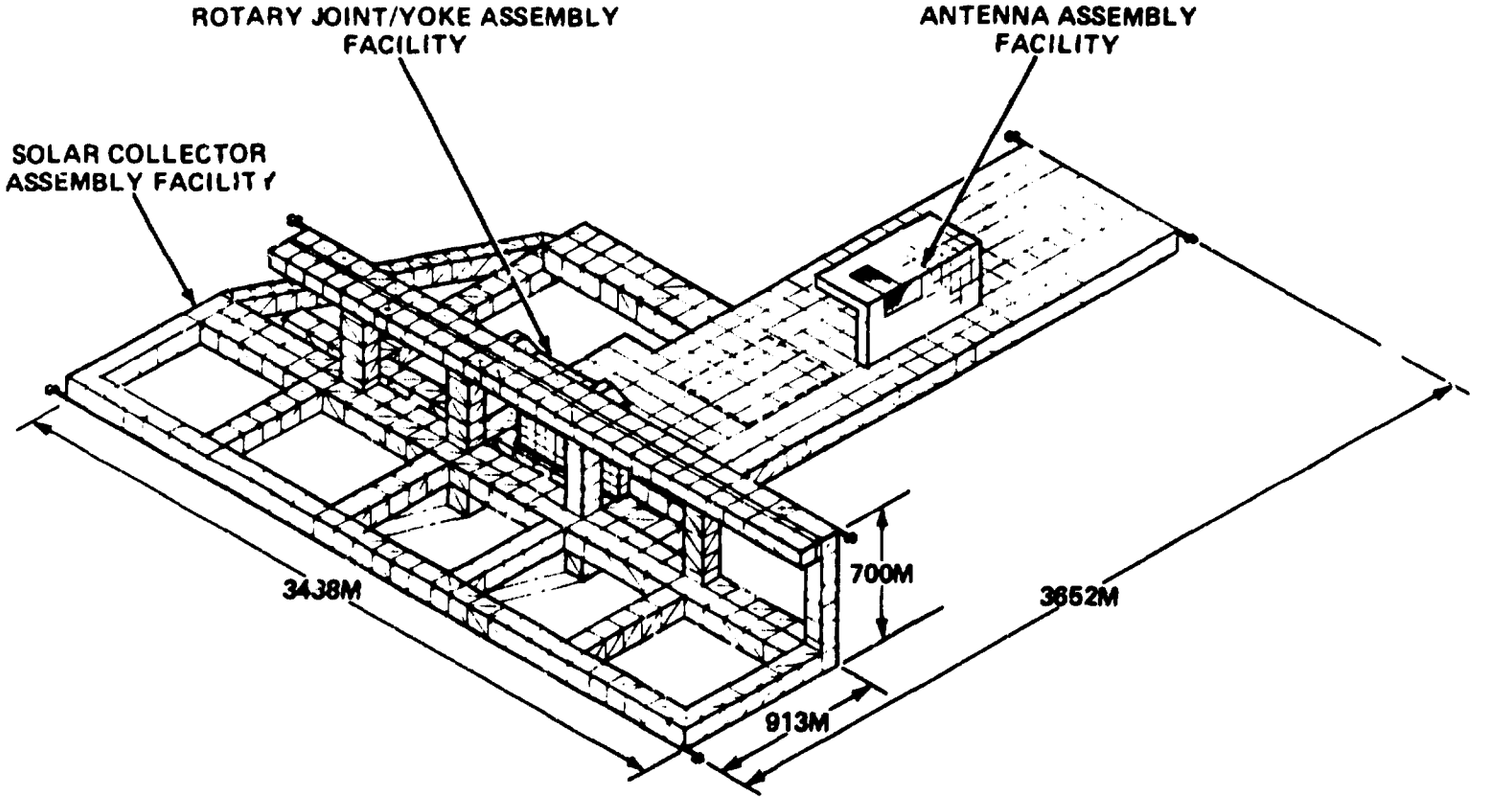
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4 BAY END BUILDER CONSTRUCTION BASE -- UPDATE

The GEO base structure supports the emerging satellite during all phases of construction. The SPS energy conversion system is assembled during two successive passes by the L-shaped framework shown. The width of this framework (3.44 km) encompasses a 5-bay segment of the energy conversion structure to provide a one bay overlap for lateral and longitudinal indexing operations. The 700 m high open truss is sufficient to house beam fabrication stations, solar blanket installation equipment, bus installation mechanisms, crew facilities, docking, storage, intra-base transport, etc. The other leg of the facility (913 m long) guides and supports the satellite until all systems are mated and checked out. The antenna assembly platform, which is located at the rear of the base, is arranged to facilitate the construction and attachment of the antenna and rotary joint interface. This open truss platform (2.74 km x 1.65 km) also supports the antenna/yoke assembly during the final lateral index and mating operations with the assembled 8 x 16 bay energy conversion system. The framework provided for the rotary joint facility, yoke assembly facility and antenna assembly facility is sufficient to house the construction equipment and machines as needed.

4 BAY END BUILDER CONSTRUCTION BASE – UPDATE



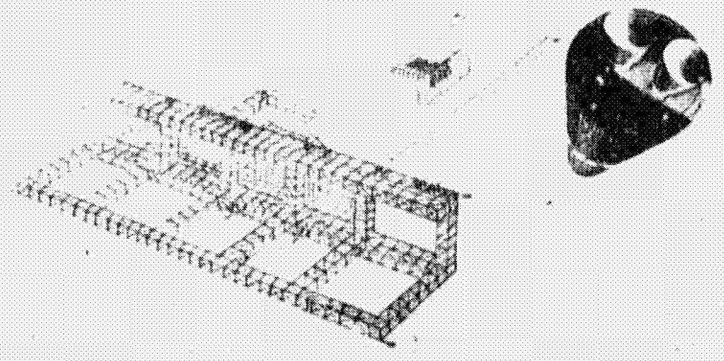
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4 BAY END BUILDER CONSTRUCTION OPERATION

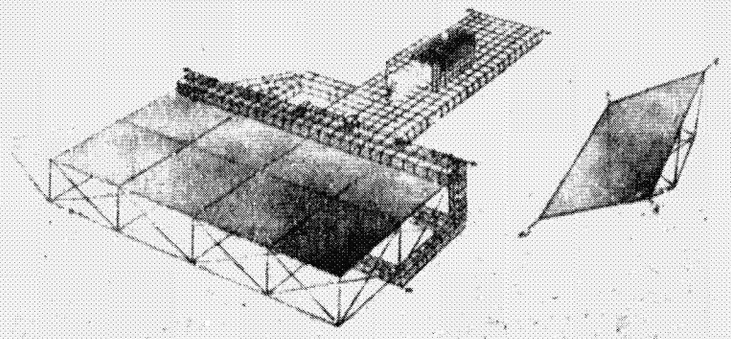
Construction of the 5000 MW reference satellite takes place in GEO. Consequently, the personnel needed to activate the 4 Bay End Builder Construction Base must travel first by means of the Shuttle to LEO and finally by means of an orbital transfer vehicle (OTV) which operates from the LEO base.

The 4 bay end builder assembles the SPS satellite in two successive passes as shown by the construction sequence illustrated on the facing page. During the first pass, the GEO construction base builds a 4 bay wide strip by 16 bays long. Construction of the satellite antenna is performed in parallel. When one-half of the satellite energy conversion system has been assembled, the base is indexed to the side and then back along the edge of the satellite. The base is realigned with the end frame of the satellite to start the second construction pass. The remaining 4 bay wide strip is attached directly to the assembled satellite systems as the base moves toward the other end. Large electric orbital transfer vehicles (EOTV) will deliver SPS materials and components throughout the assembly process. GEO base crews will also be rotated as needed. The satellite antenna is completed in parallel with the construction of the 8 x 16 bay energy conversion system. At the end of the second pass, the base is indexed sideward to mate the antenna with the centerline of the energy conversion system. Following the satellite final test and checkout, the base will be separated from the satellite and transferred to the next SPS GEO construction location.

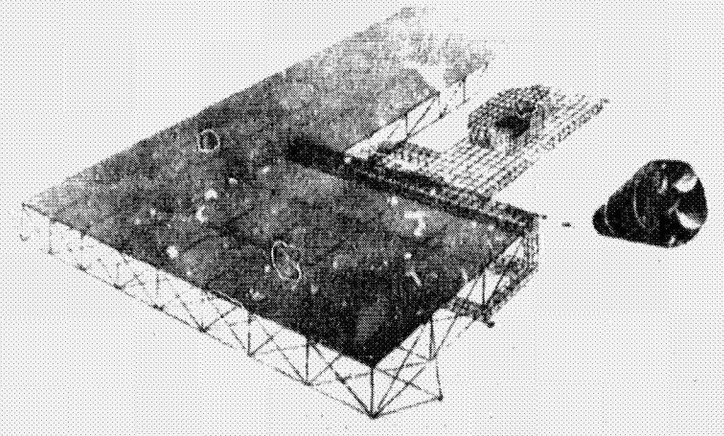
SPS — 4 BAY END BUILDER CONSTRUCTION



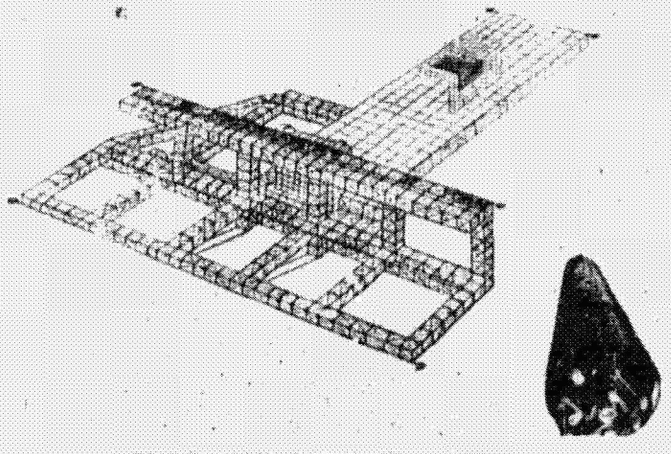
ACTIVATE GEO BASE



FIRST CONSTRUCTION PASS



SECOND CONSTRUCTION PASS



CHECKOUT SPS & TRANSFER BASE

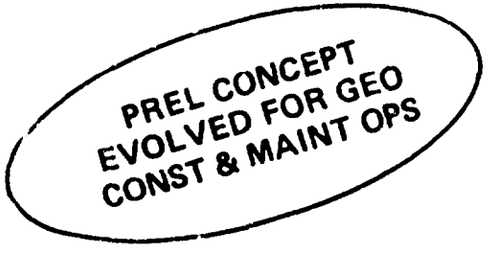
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SPS CONSTRUCTION BASE – PHASE I CONCLUSIONS



- 2 BAY & 4 BAY END BUILDERS PROVIDE HIGHER PRODUCTION CAPABILITY FOR EQUIVALENT COST AS SINGLE DECK
- 8 BAY WIDE BASE NOT COST EFFECTIVE FOR 6 MONTH CONSTRUCTION CYCLE
- COUPLING SOLAR ARRAY DEPLOYMENT WITH LONGITUDINAL BEAM FABRICATION FACILITATES FASTER CONSTRUCTION
- SYNCHRONIZED OPERATION OF MULTIPLE BEAM BUILDERS CAN BE IMPLEMENTED WITH S-C-A FEEDBACK CONTROL TECHNIQUES
- ALUMINUM SOLAR ARRAY STRUCTURE FEASIBLE

SPS GEO CONSTRUCTION BASE – PHASE 2 CONCLUSIONS



- GEO CONSTRUCTION OPERATIONS FEASIBLE CONSIDERING
  - SATELLITE ASSEMBLY STEPS
  - CREW OPERATIONS SUPPORT
  - MAJOR BASE SUBSYSTEMS
  - INTRA-BASE LOGISTICS
  - GEO BASE BUILD UP
- ADD ON SPS MAINTENANCE SUPPORT FACILITIES FEASIBLE ON GEO CONSTRUCTION BASE

SPS GEO CONSTRUCTION BASE – RECOMMENDATIONS FOR FURTHER EFFORT

- CONTINUE SPS CONSTRUCTION TECHNOLOGY ANALYSIS
  - RE-EXAMINE ANTENNA CONSTR CONCEPT (KLYSTRON & SOLID STATE)
  - INVESTIGATE ALUMINUM STRUCTURE FOR SOLID STATE ANTENNA
  - UPDATE & ADD SUBSYS INSTALLATION METHODS AS DESIGN MATURES

  DEVELOP COMPARATIVE CONSTRUCTION METHODS FOR EVALUATING ALTERNATE SPS CONCEPTS (e.g. LASERS)

- FURTHER EXPAND GEO BASE SYSTEM MASS & COST DATA
  - UPDATE STRUCT, CONSTR EQUIP, CARGO HDLG SYS, & SUBASSY FACTORY DEFIN
  - DEFINE BASE MAINT, TEST & C/O, AND C & C FACILITY CONCEPTS
  - DEFINE GEO RADIATION SHIELDING METHODS
  - RE-EXAMINE BASE FLIGHT CONTROL & ELECTRICAL POWER SUBSYSTEMS

  INVESTIGATE TRANSPORTATION PAYLOAD CONSTRAINTS ON CREW MODULE & CONSTR EQUIP DES

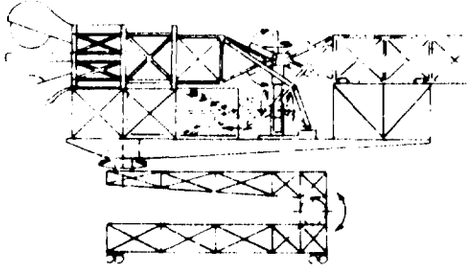
- FURTHER DEFINE GEO BASE BUILD UP CONCEPT

- FOCUS SPS EARLY TECHNOLOGY DEVELOPMENT ON PARALLEL CONSTR ISSUES
  - STRUCTURAL FAB & ASSY
  - CONSTRUCTION SUPT OPERATIONS
  - SUBSYS ASSEMBLY METHODS

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SPS STRUCTURAL FAB & ASSY – EARLY TECHNOLOGY DEVMT OBJECTIVES

- DESIGN & DEVELOP TECHNOLOGY FOR SPS BEAM BUILDER SUBSTATIONS
  - ENERGY CONVERSION
  - ANTENNA
  - INTERFACE
    - DEVELOP SUBSCALE PROTOTYPE BEAM BUILDERS TO DEMO
      - AUTO FAB DIMENSIONAL CTL & PRODUCIBILITY (AL & COMP MATLS)
      - CONTINUOUS AUTO FAB WITH OPEN & CLOSED CAP MEMBERS
      - CONTINUOUS CAP FAB WITH AUTO FAB BATTENS
      - SEGMENTED BEAM FAB WITH END FITTINGS
      - CONTINUOUS BEAM FAB WITH ATTACHMENT FRAMES
      - MULTI BEAM FAB SYNCHRONIZATION
      - AUTO BEAM FAB WITH MAINT. RAILS
      - AUTO BEAM FAB WITH DATA BUS/CABLES
      - AUTO BEAM FAB WITH ACQUISITION BUS



7.5 m BEAM BUILDER SUBSTATION

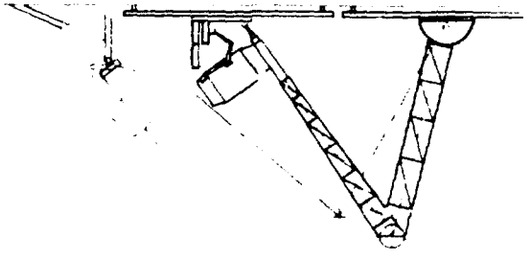
- INVESTIGATE ALTERNATE STRUCTURAL JOINTS
- CONDUCT GRND SIMULATIONS & FLT EXPMTS USING SPS STRUCTURAL ASSY METHODS

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1622-056W

SPS CONSTRUCTION SUPPORT OPERATIONS – EARLY TECHNOLOGY DEVMT OBJECTIVES

- DESIGN & DEVEL TECH FOR SPS BEAM HANDLING, SUBSYS ASSY & MOVEMENT OF LSS
- DEVELOP PROTOTYPE HDWR TO COMPARE EVA, CLOSED CHERRY PICKER & REMOTE CRANE TURRET METHODS FOR ASSEMBLING SUB SCALE BEAMS
- DEVEL SIMULATION TECHNIQUES & PROTOTYPE HDWR TO DEMO SUBSCALE SPS CONSTRUCTION METHODS & SUPPORTING OPERATIONS
  - 7.5 m & 12.7 m BEAM HANDLING & JOINING
  - SOLAR ARRAY BLANKET INSTALLATION SUPT
  - POWER BUS INSTALLATION SUPT
  - ANTENNA SUBARRAY INSTALLATION SUPT
  - OTHER SUBSYS ASSY OPERATIONS
  - CARGO HANDLING & DELIVERY
  - BASE SUBSYS/EQUIP SERVICING
  - HANDLING & MATING LARGE SYSTEM ELEMENTS

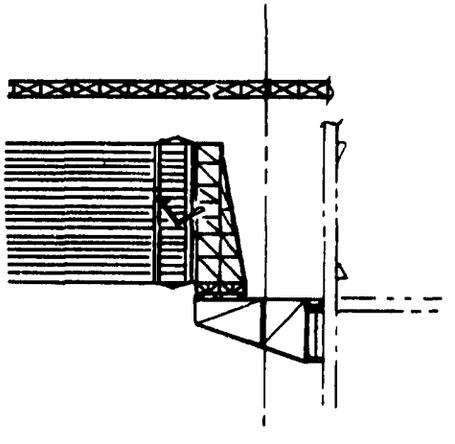


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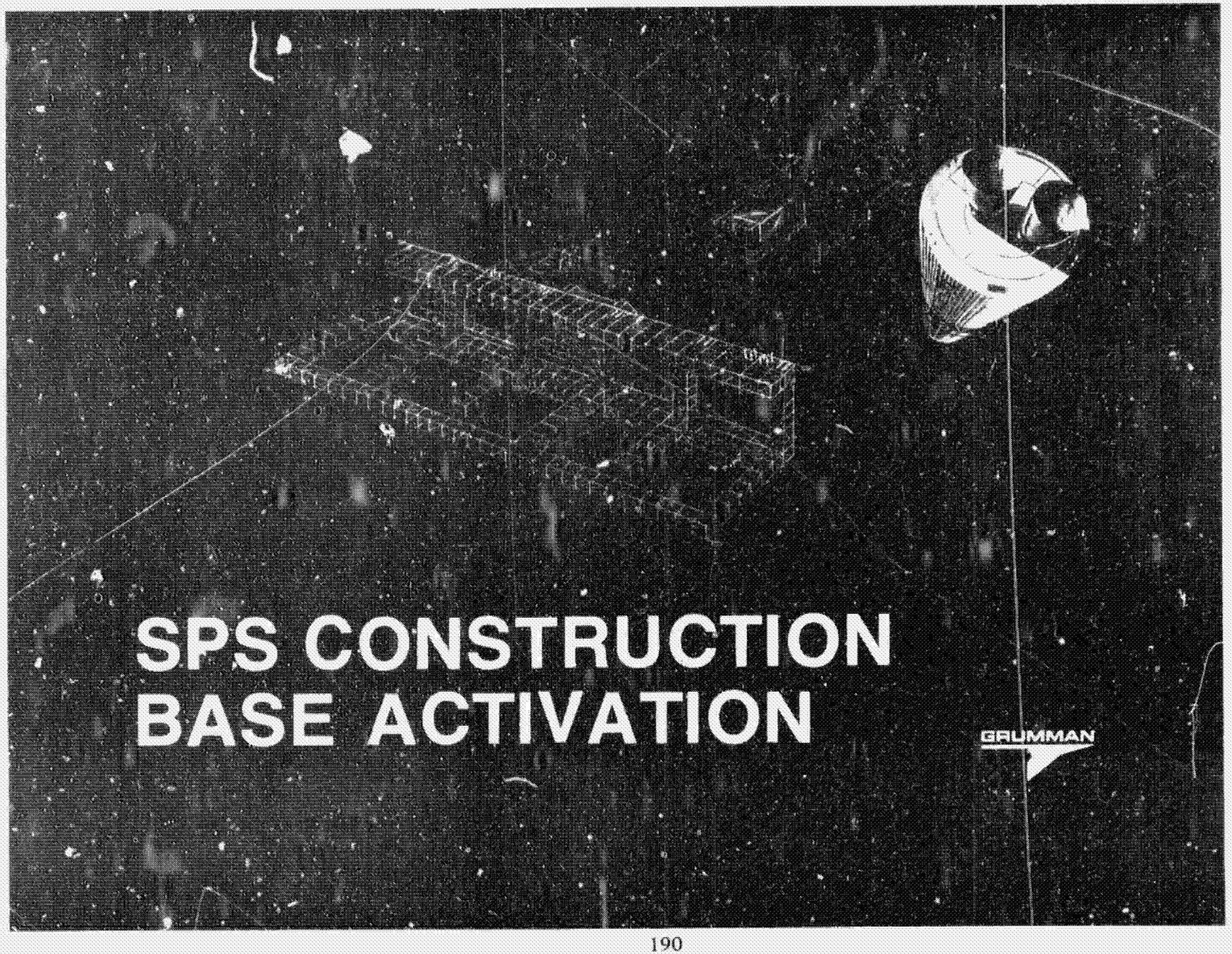
SPS SUBSYSTEM ASSEMBLY METHODS – EARLY TECHNOLOGY DEVMT OBJECTIVES

- DESIGN & DEVELOP TECHNOLOGY FOR DEPLOYMENT & INSTALLATION OF SPS SUBSYS
- DEVELOP PROTOTYPE HDWR TO DEMO SUBSCALE TECHNIQUES FOR PACKAGING & INSTALLATION OF LARGE SUBSYSTEM ELEMENTS
  - SOLAR ARRAY BLANKET DISPENSERS
  - POWER BUS DISPENSERS
  - ATTITUDE THRUSTERS & PROPELLANT STORAGE FIXTURES
  - ANTENNA SUBARRAY INSTALLERS
  - ANTENNA ROTARY/GIMBALLED INTERFACE FIXTURES
    DATA BUS DISPENSERS
  - OTHER SUBSYSTEM INSTALLATIONS

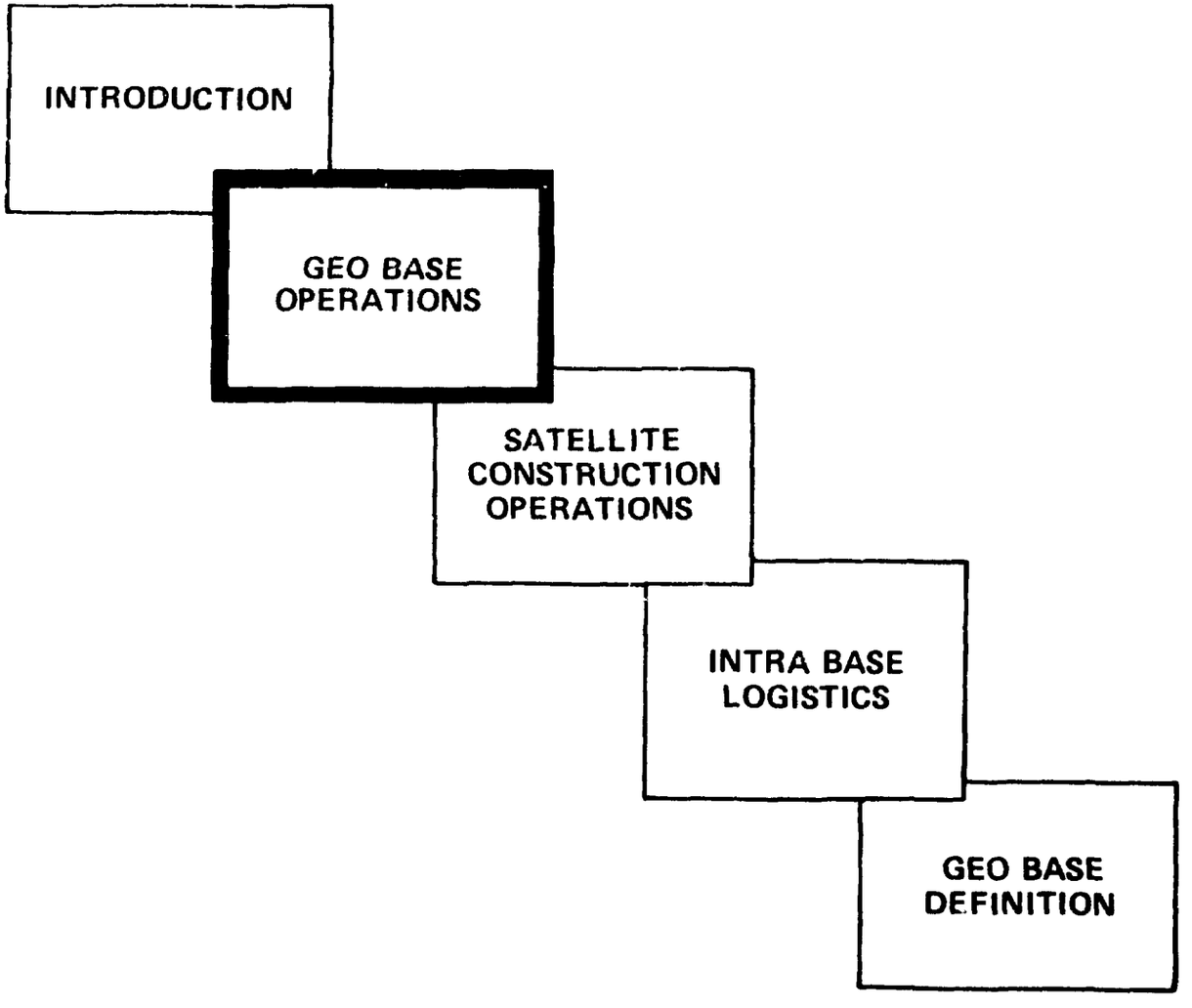


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SPS GEO BASE OPERATIONS REQUIREMENTS & ISSUES

The SPS GEO construction base is used to build and commission two 5 GW reference satellites per year for 30 years. The GEO base is also required to support the maintenance activities on operational Solar Power Satellites and to service supporting elements of the SPS space transportation system (i.e., OTVs and EOTVs). The crew jobs and organizations for constructing and maintaining the SPS in GEO are defined in the Phase I Final Report Reference System Description (Volume III, D180-25037-3) and the Phase II Second Monthly Report (April 1979), respectively. The GEO construction facility includes many functions related to the operation of construction equipment, operation of base systems, and the support of crew operations. As the SPS reference system matures, all aspects of GEO base operations must be examined to verify system feasibility and identify areas needing further development. Several technology issues related to GEO base operations are listed on the facing page. While most of these issues are beyond the scope of the study, they include further analysis of required base functions, degree of automation, related crew functions and type of organization needed. Control of the diverse base functions is addressed below but it requires further study to size and cost preliminary command and control systems. Other areas which require further study include: the impact of frequent crew rotation and related training requirements to maintain high productivity; crew habitability requirements for zero gravity versus artificial gravity plus related health, safety and rescue operational requirements for SPS construction; and operational limitations for IVA and EVA with required protection from ionizing radiation and other GEO environmental effects. In addition, base attitude control and required operational interfaces need further study.

SPS GEO BASE OPERATIONS REQUIREMENTS & ISSUES

- CONSTRUCT TWO 5GW SATELLITES PER YEAR FOR 30 YEARS
- SUPPORT OPERATIONAL SATELLITE MAINTENANCE
- SERVICE FLIGHT TRANSPORTATION VEHICLES
- GEO BASE PHASE 1 CREW JOBS & ORGANIZATION (D180-25037-3)
- SPS MAINTENANCE ORGANIZATION (APR '79 MPR NO. 2)
- GEO BASE OPERATIONS ISSUES
  - CREW FUNCTIONS & ORGANIZATION
  - COMMAND & CONTROL CONCEPT
  - CREW ROTATION & TRAINING POLICY
  - CREW HABITABILITY & HEALTH
  - CREW SAFETY & RESCUE
  - RADIATION PROTECTION & OTHER ENVIROMENTAL CONSTRAINTS
  - BASE ATTITUDE CONTROL
  - OPERATIONAL INTERFACES

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GEO BASE OPERATIONAL FUNCTIONS

The GEO Base performs three main functions:

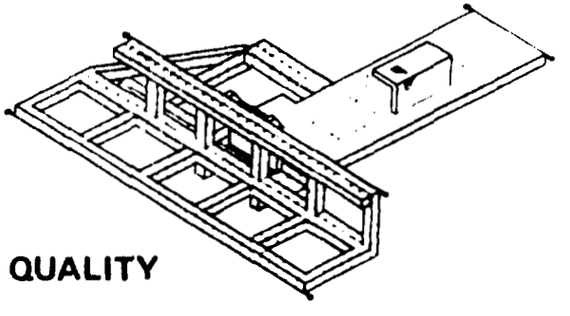
- Construct solar power satellites (SPS)
- Service and maintain operational SPS
- Service flight logistic vehicles.

In order to accomplish these functions a number of others are imposed. The base must be capable of docking transportation vehicles, unloading them and then transporting supplies and personnel via a railroad system to work areas. Space workers require habitats that function in a manner similar to hotels, as well as pressurized enclosures that consist of control centers, cherry pickers and transportation vehicles. The construction and base equipment must be maintained and personnel health services must be provided. Because SPS construction will continue for many years, requirements exist for a continuing supply of new space workers. Therefore, training facilities must be provided. All of these functions are to be integrated into the Command and Control Organization.

GEO BASE OPERATIONAL FUNCTIONS

DIVERSE FUNCTIONS TO BE INTEGRATED

CONSTRUCT SOLAR POWER SATELLITES
SUPPORT OPERATIONAL SPS MAINTENANCE
SERVICE FLIGHT TRANSPORTATION VEHICLES
CONTROL EXTERNAL LOGISTIC VEHICLES
DIRECT BASE TRANSPORTATION
MANEUVER BASE
CONTROL BASE SUBSYSTEMS
ASSURE CONSTRUCTION & MAINTENANCE QUALITY
OPERATE HABITATS
ASSURE CREW HEALTH & SAFETY
MAINTAIN BASE EQUIPMENT
PROVIDE COMMUNICATIONS & DATA
TRAIN CREW



SPS GEO BASE OPERATIONAL INTERFACES

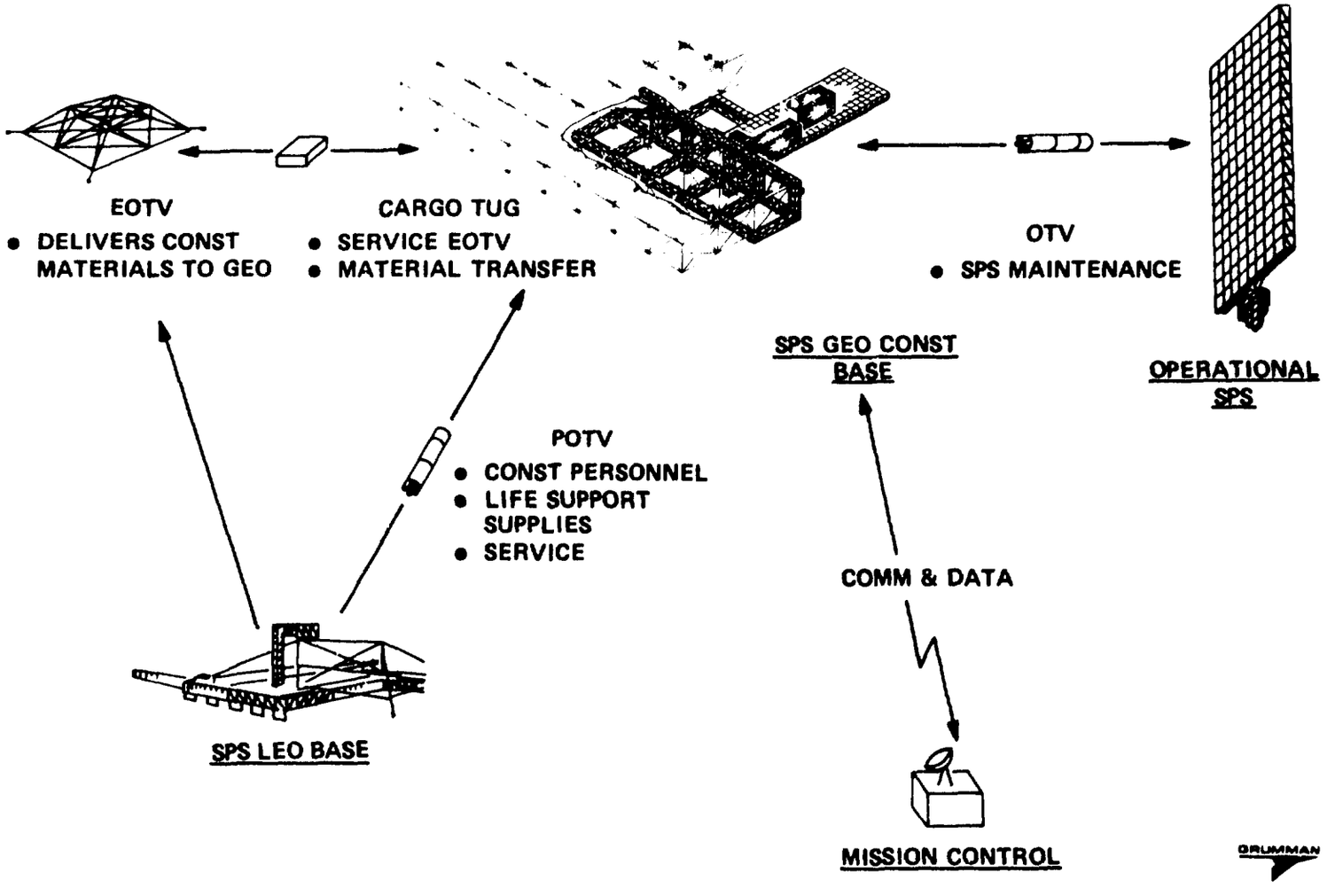
The illustration shows the GEO Base external operational interfaces. Earth mission control coordinates all aspects of SPS construction and operation. This includes all the ground and orbital elements. Construction progress, material and personnel needs are reported daily to earth mission control.

The GEO Base receives construction material via Electric Orbit Transfer Vehicles (EOTV). These vehicles are loaded at the LEO base, rendezvous with the GEO Base, and stationkeep while Cargo Tugs transfer material pallets. EOTV terminal rendezvous is coordinated by the GEO base. Cargo Tugs require docking stations, cargo handling equipment and distribution/warehouses. Service & maintenance crews transfer to the EOTV to perform solar array annealing operations.

Personnel and life support supplies are also shipped from the LEO Base utilizing Personnel Orbit Transfer Vehicles (POTV). These vehicles dock to the GEO Base, then crew transportation modules are attached for personnel unloading. Unloading equipment removes life support supplies and the POTV is serviced for return to LEO Base.

The GEO Base also prepares Orbit Transfer Vehicles (OTV) for the trip to service operational SPS. The GEO Base control center directs OTV departures and when the OTV's return, terminal control & docking are also coordinated by the GEO base. Base loading and unloading equipment, plus the necessary transportation/warehousing facilities, are required.

SPS GEO BASE OPERATIONAL INTERFACES



1079-011D

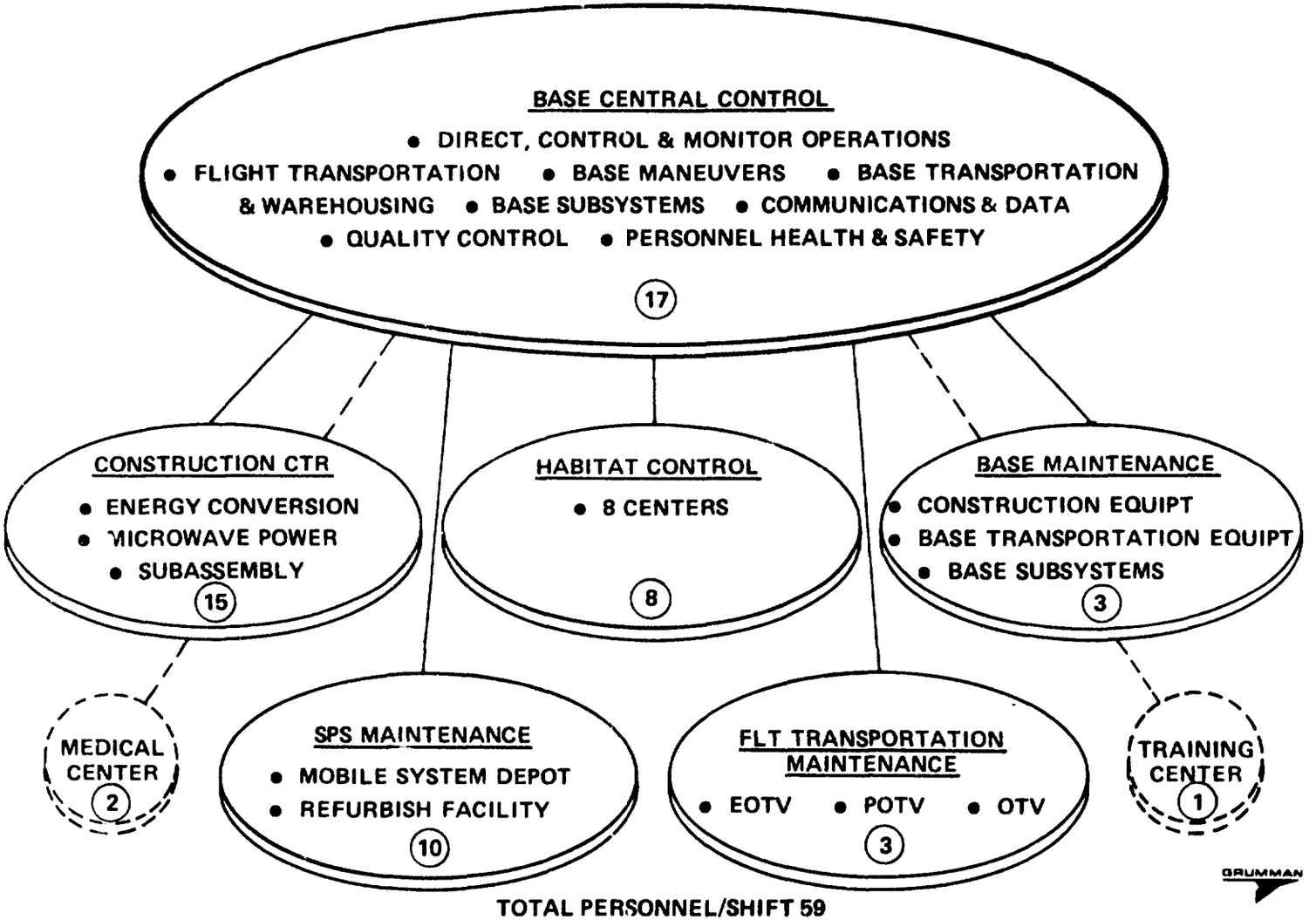
GEO BASE OPERATIONS CONTROL

The Base Central Control is where the Base Director, Construction Manager, Base Operation Manager and Base Support Manager are located. They direct and control all related GEO base operations and are supported by staff personnel who assist in planning, scheduling and monitoring base functions. Certain functions such as orbital control of the base, control of external and internal traffic, communications, data and base subsystems are handled directly from the Central Control Center. Other operational functions receive directions from the Central Control Center, but the interface for these functions (construction, habitat, base maintenance, SPS maintenance and flight transportation maintenance) could be performed at other locations.

The medical center is required for personnel well-being and is available should accidents or sickness occur. It is shown reporting directly to the Base Central Control and illustrated in broken lines as it is not primary for daily operations.

Training functions are also not required for day-to-day operations but are necessary for the base long term continuous operation.

GEO BASE OPERATIONS CONTROL



TOTAL PERSONNEL/SHIFT 59

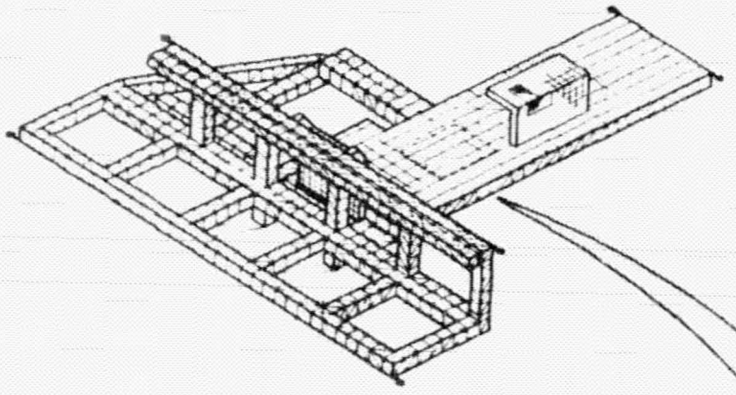
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GEO BASE CREW OPERATIONS

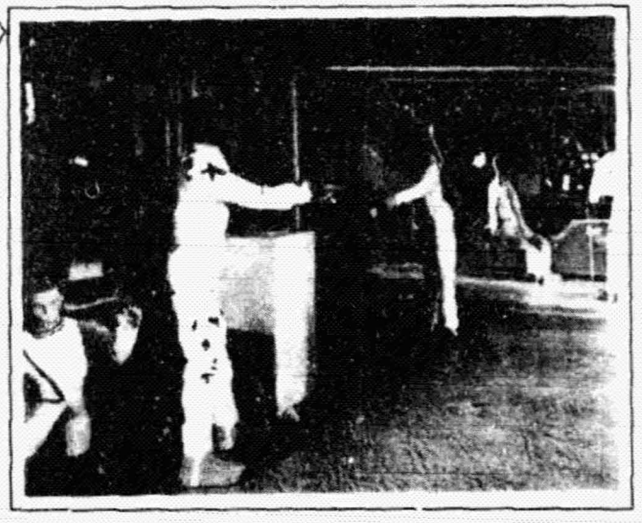
A new vocation, that of space worker, will be open to men and women of the U.S., and to a lesser extent, other nationalities in the near future. In some respects it will be similar to the life of a sailor, travelling for approximately three (3) months then home for about the same length of time. This type of employment could continue for years, with upward advancement in the organization expected, paralleling terrestrial enterprizes.

Current projections are in excess of 450 people involved in the construction and maintenance of the Solar Power Satellite (SPS). This imposes the requirement for a comprehensive training program that includes a spectrum of construction and support activities. Training facilities will be needed early in the SPS program. A continuing need for SPS training facilities equipment and instructors is expected as the demand for space workers increases with time. Training schedules must meet the needs of crew rotation requirements. Although most training can be accomplished in terrestrial simulators, verification of space adaptation to perform tasks is required in an orbital facility. A training facility in low earth orbit may be a practical solution because a staging depot will likely exist and minimizes travel distance for instructors and supporting personnel. A close-in facility makes sense if students were to be exposed to the space environment prior to completion of training.

GEO BASE CREW OPERATIONS



CONTROL CENTER FOR SPS CONSTRUCTION



- BASE CREW ~ 450 TO 1600 (30 YR)
- 2 SHIFT WORK SCHEDULE
- NOMINAL 10 HR/DAY – 6 DAYS/WEEK
- 90 DAY TOUR OF DUTY
- COMPREHENSIVE GROUND TRAINING
- LEO SPACE ACCLIMATION & TRAINING VERIFICATION

ORIGINAL PAGE IS OF POOR QUALITY

NUMBER OF BASE PERSONNEL

Personnel requirements established by Boeing for operational SPS maintenance and flight transportation vehicles maintenance are added to the GEO Base construction crew. When 20 to 60 satellites are being maintained the total personnel complement varies from 827 to 1593 people. The maximum number of personnel on one shift has been totaled at 648. There are times when the personnel on duty could be considerably less, i.e., during the construction crew's time off.

NUMBER OF BASE PERSONNEL

DISCIPLINE	TOTAL CREW	ONE SHIFT CREW
SPS CONSTRUCTION	(417)	(199)
BASE MANAGEMENT	17	17
CONSTRUCTION	262	131
BASE SUPPORT & OPERATIONS	120	45
OPERATIONS SAFETY	18	6
FLIGHT TRANSPORTATION MAINT	(27)	(14)
EOTV SUPPORT	8	4
OTV SERVICING	19	10
SUBTOTAL	444	213
SPS MAINTENANCE (20 TO 60 SATELLITES)	(383 TO 1149)	(145 TO 435)
REPAIR EQUIPMENT	260 TO 780	130 TO 390
MOBILE MAINTENANCE	83 TO 249	NA
CREW SUPPORT	40 TO 120	15 TO 45
TOTALS	827 TO 1593	358 TO 648

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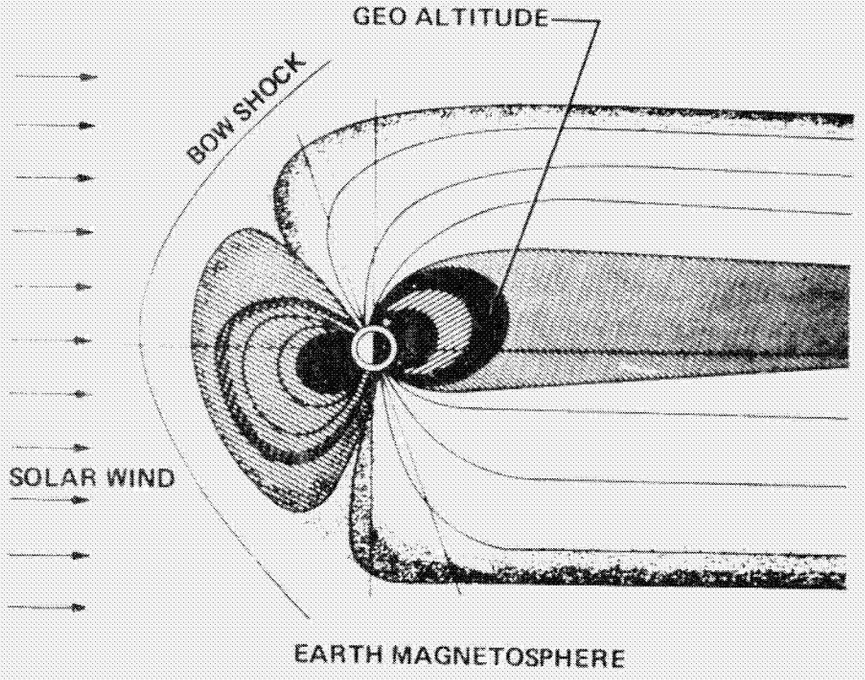
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SPS GEO RADIATION SOURCES

This illustration shows the magnetosphere and the radiation sources to which SPS systems and the assembly and maintenance crew will be subjected.

- The major sources of radiation at GEO orbit are the geomagnetically trapped electrons and protons, galactic cosmic rays and solar flare event particles.
- The trapped radiation particles undergo large temporal fluctuations (diurnal and during magnetic storm activity).
- Types of ionizing radiation important to SPS operations:
  - Electrons and secondary radiation: bremsstrahlung (with variation of factor of two due to parking longitude location)
  - Protons (flux from solar flare protons dominates) and secondary radiation protons, neutrons
  - Heavy ions (HZE), secondary radiation: protons, neutrons and lighter nuclei.
- Other sources
  - Onboard nuclear powered payloads and equipment
  - X-Ray equipment
  - Possible nuclear weapon detonations.

SPS GEO RADIATION SOURCES



- TRAPPED ELECTRONS & PROTONS
- GALACTIC COSMIC PARTICLES
- SOLAR FLARES
- OTHER SOURCES

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1079-050D

RADIATION EXPOSURE LIMITS & CONSTRAINTS (REMS)

This chart lists the current astronaut radiation exposure limits as defined by the National Academy of Science/Radiobiological Advisory Panel/Committee on Space Medicine in 1970. These astronaut radiation exposure limits are based upon a 5-year career and are presently included in the STS Payload Safety Guidelines Handbook. These limits are, of course, intended to cover all forms of ionizing radiation (natural and induced). Comparable radiation exposure limits are also shown for industrial workers, as defined by the Department of Labor OSHA regulations. The low OSHA limits are also contrasted with the maximum radiation limit allowed for each Apollo mission.

It is interesting to note that the average skin dose experienced by the Apollo astronauts was very low (about 1 rem), since no solar event occurred. Nevertheless the maximum limit for Apollo was established for a program of national importance that included less than one hundred volunteer astronauts. The OSHA standards, of course, apply to millions of industrial workers. The SPS construction base is presently estimated to have approximately 800 workers on board, which equates to a 10,000 man work force over a 30-year period. Hence, allowable SPS radiation limits may have to be established with respect to societal considerations.

RADIATION EXPOSURE LIMITS & CONSTRAINTS (REMS)

SHOULD INDUSTRIAL LIMITS APPLY TO SPS GEO SPACE WORK FORCE?

	ASTRONAUT*			INDUSTRIAL WORKER**	APOLLO MAX LIMIT
	SKIN (0.1mm)	EYES (3mm)	BONE MARROW (5cm)	BFO & EYES	BFO & SKIN
1 YR AVG DAILY RATE	.6	.3	.2		
30-DAY MAXIMUM	75	37	25		65 & 520*** PER MISSION
QUARTERLY MAXIMUM	105	52	35	3	
YEARLY MAXIMUM	225	112	75	5	
CAREER	1200 (5 yr)	600	400	235 (@ 65)	

* SPACE TRANSPORTATION SYSTEM PAYLOAD SAFETY GUIDELINES HDBK NASA/JSC - JSC 11123, JULY 1976

** FEDERAL REGULATIONS - LABOR PART 1910 OSHA - 1 JULY 1978

***APOLLO MISSIONS 7 TO 17 ONLY HAD ~ 1 REM AVG SKIN CREW DOSE- SINCE NO MAJOR SOLAR PARTICLE EVENTS OCCURRED

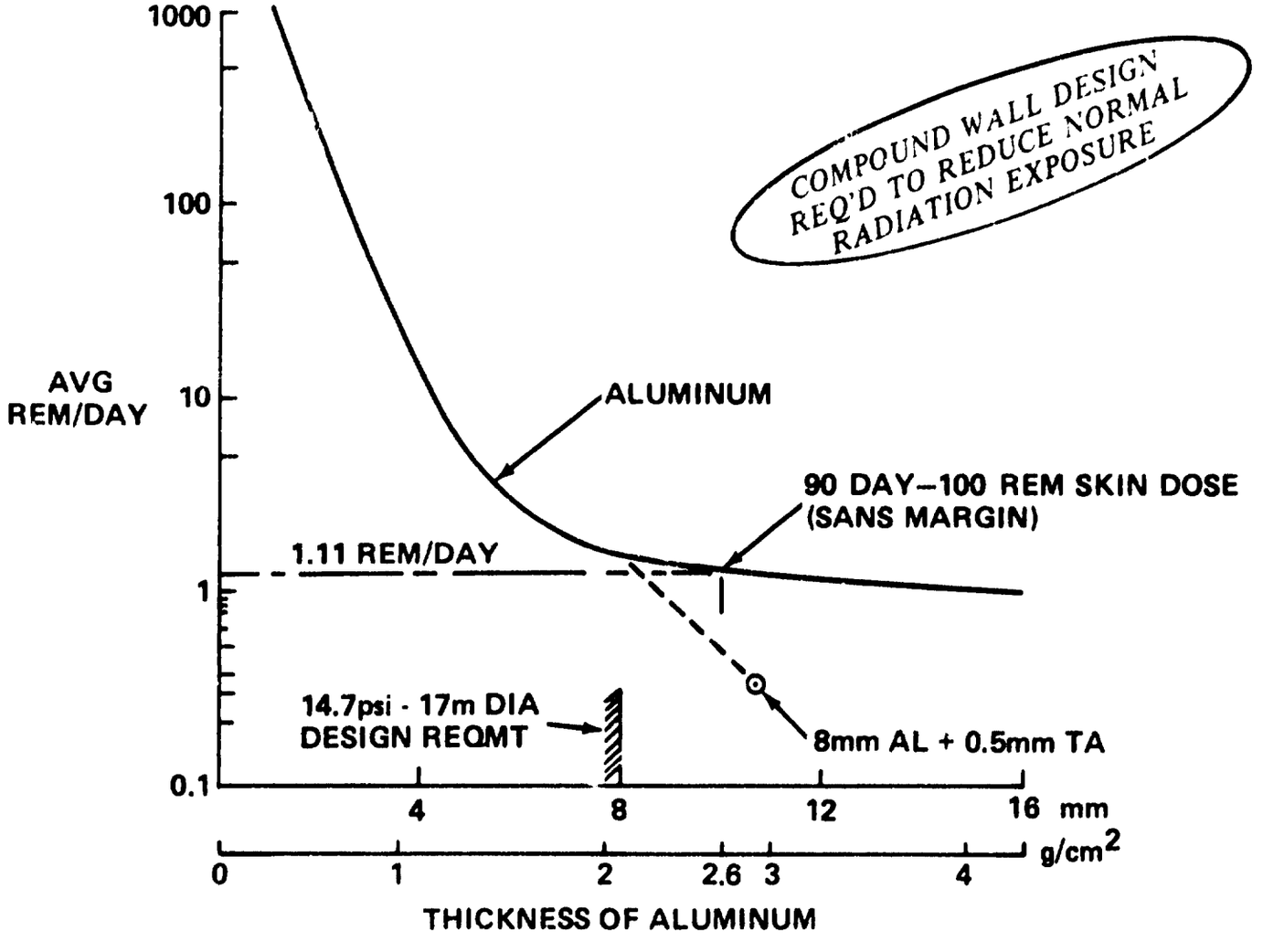
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SHIELDING THICKNESS FOR GEO TRAPPED ELECTRONS PLUS BREMSSTRAHLUNG

The average REMs that a crew member will experience each day in geosynchronous orbit is plotted as a function of equivalent aluminum cabin wall thickness, as shown on the facing page. In order to reduce the skin dose to 1.11 REMs per day for the maximum quarterly exposure limit (i.e., 105 REMs less 5 REMs for OTV LEO/GEO transit) at least 10 mm of aluminum should be provided. Aluminum is not a very effective shield for this level of radiation due to Bremsstrahlung (secondary radiation) effects. However, by adding a thin inner layer of tantalum, the cabin radiation level can be lowered to provide a margin for other unscheduled radiation conditions (e.g., x-ray inspection, etc.). The use of compound wall design techniques is an effective way of coping with Bremsstrahlung which provides increased radiation protection for minimum shield thickness and weight. Practical shielding designs that can reduce the daily dose rate to OSHA levels require further study and remain as a technology issue.

SHIELDING THICKNESS FOR GEO TRAPPED ELECTRONS
PLUS BREMSSTRAHLUNG (270° EAST LONGITUDE)



IRAD
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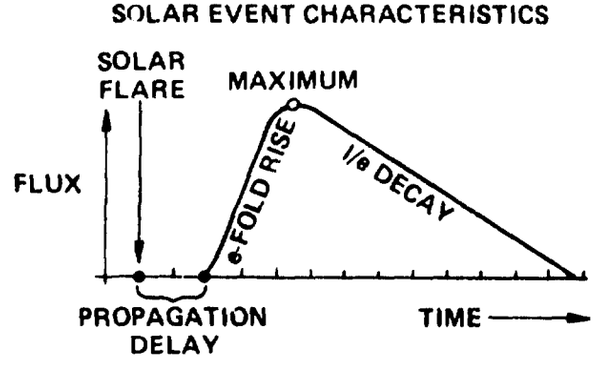
SOLAR FLARE RADIATION PROTECTION REQUIREMENTS

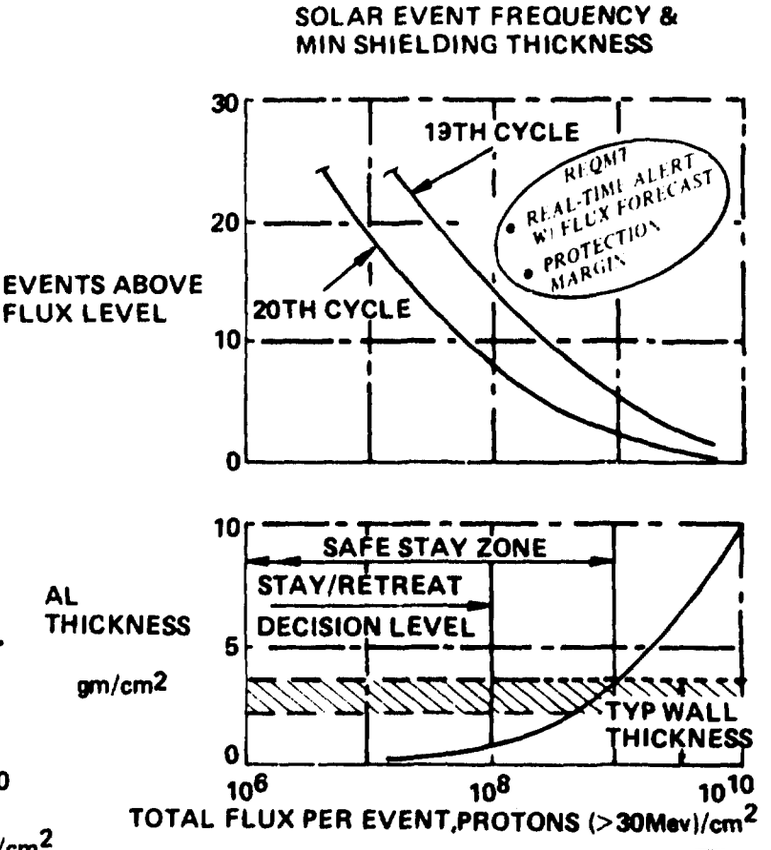
The GEO base solar flare radiation protection system must be able to provide timely warning of a high energy solar event, so that the crew can safely reach a radiation shelter to ride out the storm. The characteristics of a typical solar event are shown on the facing page, together with related data on the severity and duration of prior solar events. Minimum aluminum shielding thickness requirements are provided.

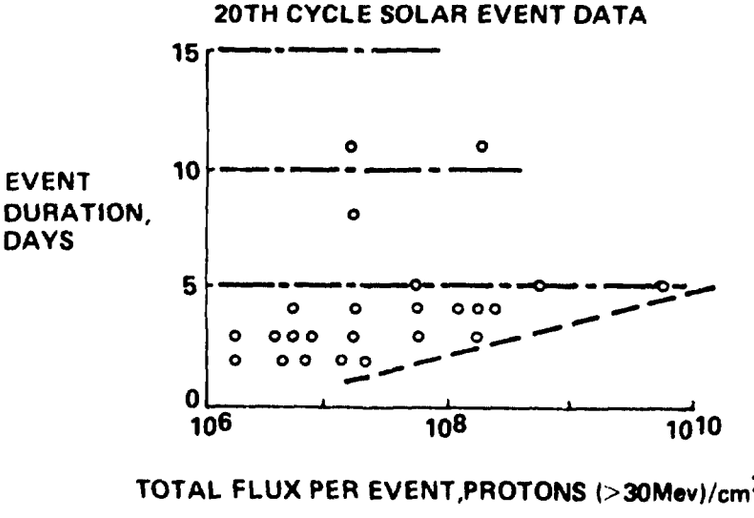
Once a solar flare is observed, a 20 to 30 minute delay occurs in particle propagation before an increase in the background energy level is detected. From the onset of increased radiation, the maximum flux level may be attained within 15 minutes to a few hours according to T. Wilson et al (NASA TND 8290, 1976). However, recent communication with G. Heckman at the Boulder NOAA, Space Environment Laboratory indicates that maximum flux rise time occurs less rapidly, from 2 to 100 hours. The corresponding time delay for the first particle to arrive is about 1/3 to 1/2 of the time to reach peak intensity. The peak intensity, in turn, may last only intermittently or for a few hours and the subsequent decay period may be over in a matter of hours or days. Data from the 20th solar cycle shows that the highest energy event recorded lasted for five days and that a few lower energy events lasted 10 days. Hence, the radiation storm shelter must be able to support the crew life support functions for several days.

In the upper right part of the chart, the frequency of solar events is plotted as a function of the severity of the event (protons/cm^2). Smoothed historical data are shown for the two most recent solar cycles. Cycle 21 is now underway and resembles cycle 19 rather than cycle 20. The lower righthand part of the figure shows the cabin wall thickness necessary to protect against this range of event sizes. A typical cabin wall thickness needed for shielding trapped electrons in GEO is also shown at 2.6 to 4 gm/cm^2 (i.e. 1.0 to 1.5 cm of aluminum). A 4 gm/cm^2 shield gives protection for any event up to 1 x 10^9 p/cm^2 flux, however, a minimum thickness of 10 gm/cm^2 is needed for a major solar event (Aug 1972) provided the crew is also equipped with personal shielding for the eyes and testes during peak exposure. Development of a real time solar flare alert system with flux forecast is needed. If the alert system can be triggered at predetermined energy levels below the nominal wall radiation protection level, then a built-in margin for error in forecasting accuracy could be achieved.

SOLAR FLARE RADIATION PROTECTION REQUIREMENTS







IRAD
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1622-007W

SPS GEO BASE RADIATION DESIGN CONSIDERATIONS

The allowable crew dose for the SPS GEO construction base remains to be established. Total accumulated dose limits are required for the entire mission profile, that is, time in LEO, LEO/GEO transit and the GEO base. How much margin should be provided for unscheduled exposure and whether the astronaut allowed radiation levels are applicable to SPS are areas for further study.

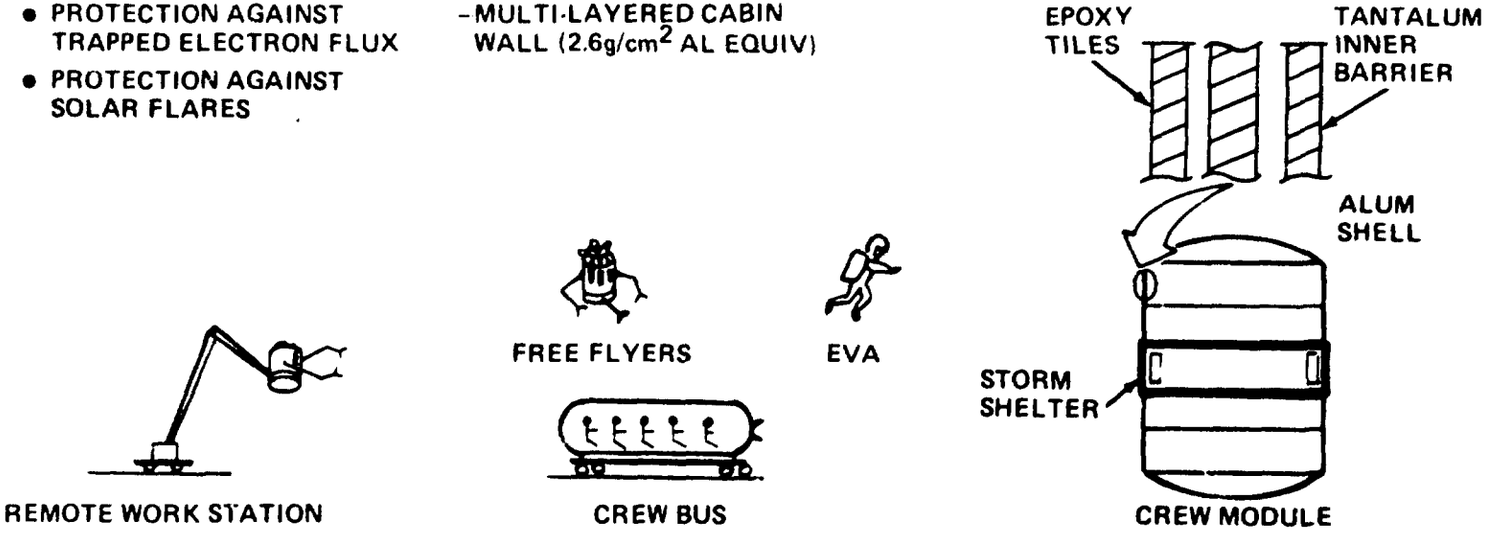
Protection against trapped electron flux in geosynchronous orbit must be factored in all aspects of GEO base operations and design, which include IVA assignments in remote work stations, free fliers, crew bases and crew habitation modules. We propose a multilayered cabin wall of 2.6 gm/cm^2 aluminim equivalent for the crew module as shown in the figure. The other IVA crew stations could be designed with lighter shielding provided that the total allowable dose is not exceeded. In addition, if EVA operations are needed they should be conducted near local midnight to minimize normal belt radiation exposure. However, EVA should be avoided during large scale fluctuations due to geomagnetic disturbances. The present SPS suit must be upgraded to provide added protection for GEO EVA (i.e., between 1.5 and 4 mm equivalent aluminum.)

Protection against solar flares requires an adequate flare alert warning system that will allow all GEO base workers on remote IVA or EVA assignments to retreat to the nearest storm shelter. Means for protecting stranded workers at these remote locations need to be considered together with the systems required to implement their rescue. The storm shelter is provided with 20 gm/cm^2 of multilayered aluminum equivalent thickness. Additional shielding benefits can be attained by placing internal equipment arrangements against the outer wall.

Protection against high energy heavy ions (HZE) requires further study. Although the dose from these HZE particles is small it is important because of possible biological effects.

SPS GEO BASE RADIATION DESIGN CONSIDERATIONS

- ALLOWABLE CREW DOSE – 60% ASTRONAUT LEVEL?
- PROTECTION AGAINST TRAPPED ELECTRON FLUX – MULTI-LAYERED CABIN WALL (2.6g/cm^2 AL EQUIV)
- PROTECTION AGAINST SOLAR FLARES



ALERT — FLUX FORECAST — SHELTER

- HZE BIOLOGICAL EFFECTS/PROTECTION?

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1622-008W

BASE/SATELLITE CONSTRUCTION ATTITUDE REQUIREMENTS

Only two of the nine requirements opposite appear to be significant when selecting the most desirable orbital attitude for the GEO Base. These are sun angle and EOTV unloading location. Both are discussed on subsequent charts.

The propulsion system penalty for attitude control in GEO is small and structural loading due to mass offset during construction appears lower than baseline design limits. Since maneuver capability is required for the base, SPS operational attitude and orbitkeeping do not affect construction attitude. Base stability for docking presents no problem since the GEO orbital rate is low. Location of communication antennas does not constrain attitude, as they can easily be located on the base open structure once other attitude requirements are imposed.

BASE SATELLITE CONSTRUCTION ATTITUDE REQUIREMENTS

- BASE ATTITUDE CONTROL (GRAVITY & SOLAR PRESS TORQUE)
- √ SUN ANGLE
  - CONSTRUCTION LIGHTING
  - SPS SOLAR ARRAY DEPLOYMENT
  - BASE SOLAR ARRAY
- SPS OPERATIONAL ATTITUDE
- BASE MANEUVERS TO NEXT CONSTRUCTION SITE
- BASE STABILITY FOR DOCKING
- √ EOTV UNLOADING LOCATION
- COMMUNICATION ANTENNA LOCATION
- STRUCTURAL LOADING
- ORBITKEEPING

CANDIDATE GEO BASE SPS CONSTRUCTION ATTITUDES

If the SPS solar arrays are deployed in sunlight, high voltage is generated as the solar arrays are exposed to sunlight. Shorting cables could be used to terminate the solar array output, however, the method of handling these and the safety issues involved require study. Another approach to solving the problem is to orient the active side of the solar array from the sun. This issue also affects maintenance on an operational SPS.

Two GEO base construction attitudes can provide the off-sun attitude during construction and then revert to on-sun attitude for final checkout and separation. The SPS solar arrays can be positioned with it's longitudinal axis perpendicular to the orbit plane (POP), as the operational SPS, or be positioned in an earth pointed mode. Both attitudes minimize light impingement during construction and rely on longitudinal roll maneuvers to acquire on-sun conditions. Other variations of the two attitudes shown opposite do not appear to offer any advantage.

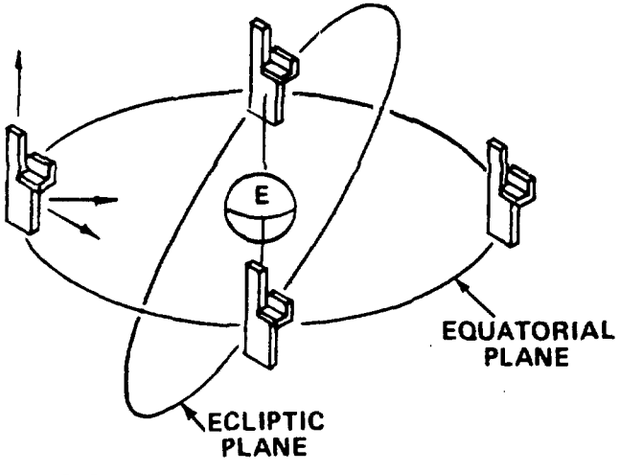
CANDIDATE GEO BASE/SPS CONSTRUCTION ATTITUDES

PH2 EMPHASIS

- BOTH METHODS ALLOW OFF-SUN CONSTR
- FURTHER STUDY NEEDED TO OPTIMIZE BASE SYS & OPS

SPS ARRAYS – LONG. AXIS POP
(SPS OPS. REF)



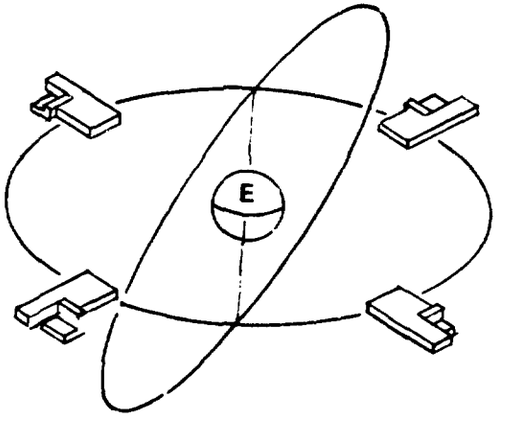


24 HR ORBIT

- CONSTANT ILLUMINATION & HEATING
- VARYING GRAVITY GRADIENT LOADS

SPS ARRAYS – IN ORBIT PLANE
(EARTH ORIENT.)





VARYING ILLUMINATION & HEATING
CONSTANT GRAVITY GRADIENT LOADS

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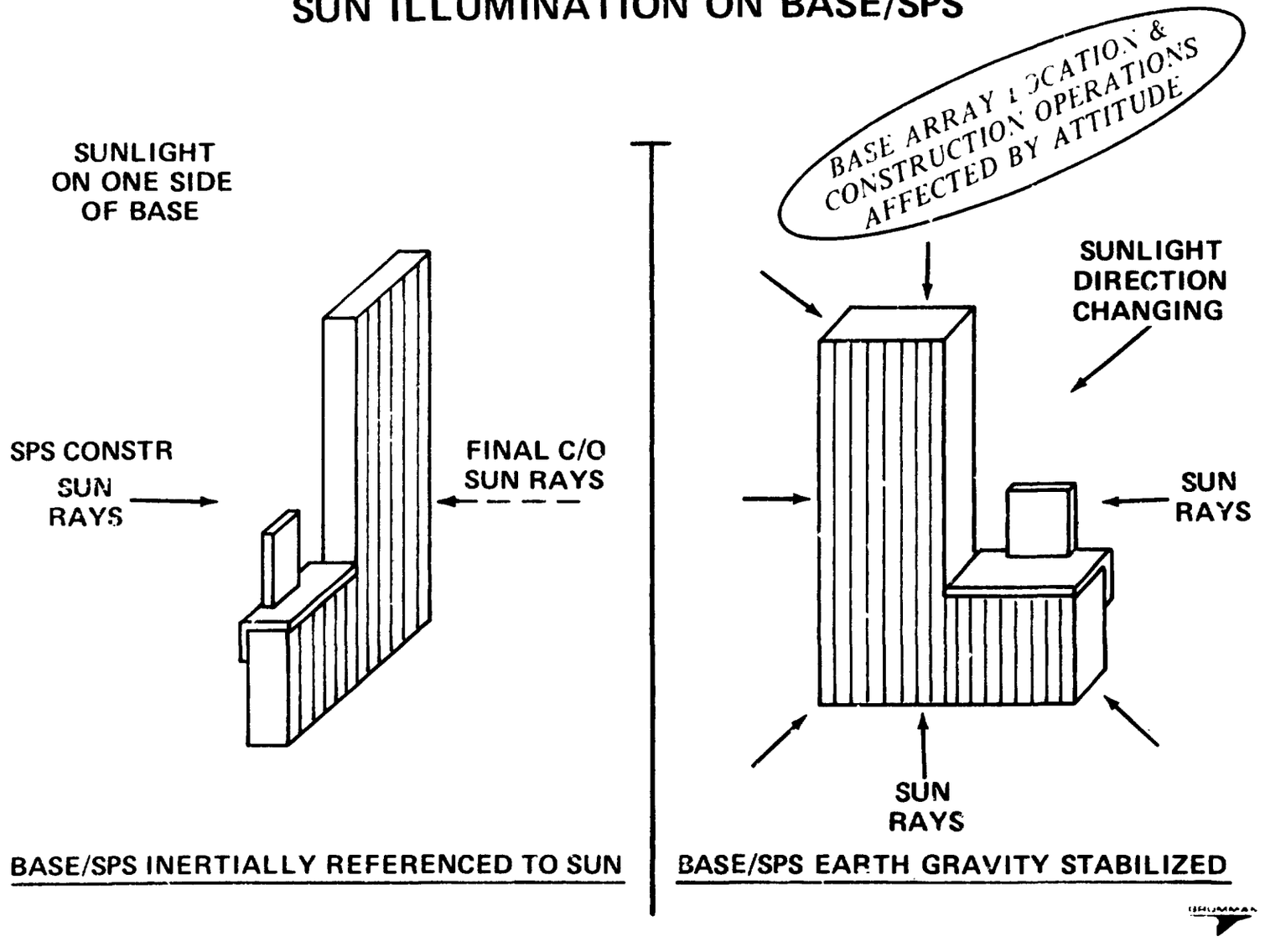
SUN ILLUMINATION ON BASE/SPS

The direction of sun illumination affects crew visibility during daily operations and placement of solar arrays on the Base.

The crew should not face the sun during construction or docking operations. Over-the-shoulder illumination is best. Construction operations require at least 1.5 MW of electrical power. Fixed solar arrays are less complicated than gimbal type.

The left-hand illustration opposite shows the Base/SPS inertially reference to sun, simplifying the selected location of fixed solar arrays, docking approach and construction illumination constraints. The right-hand illustration shows a more complex illumination situation as the sunlight direction varies on the gravity-reference Base/SPS. These factors are pertinent to the selection of the GEO Base construction attitude.

SUN ILLUMINATION ON BASE/SPS



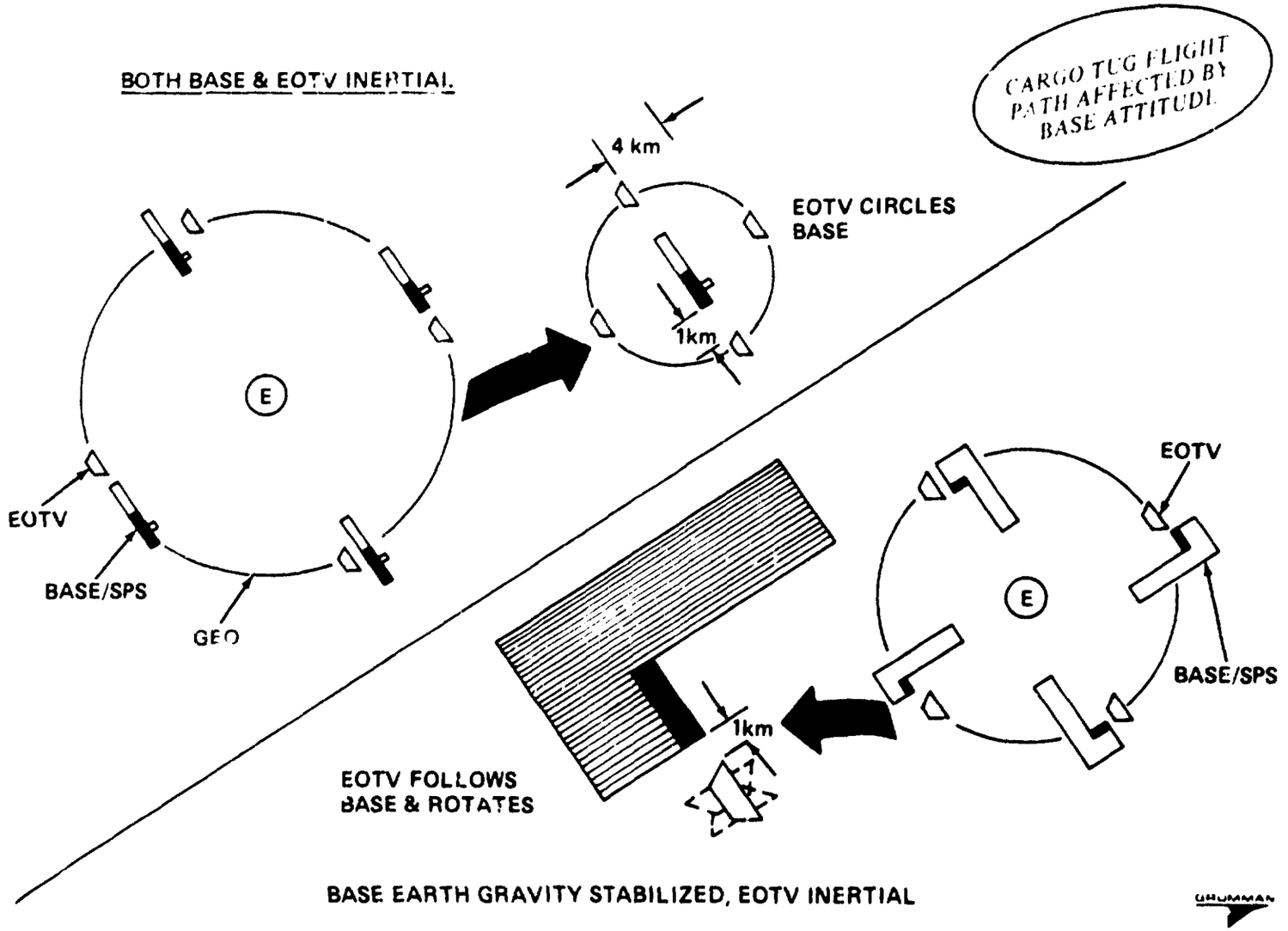
EOTV CARGO UNLOADING CONSIDERATIONS

The EOTV location as it stationkeeps with the Base affects the flight path of Cargo Tugs (CT) as they unload the EOTV, the distance the CTs must travel to docking ports, and EOTV stationkeeping propulsion requirements. If the EOTV is not in the same orbital path as the GCB then propulsion requirements are increased. Ideally, the EOTV should be located alongside of the dock ports at minimum distance consistent with safety requirements. Attitude requirements of the Base and EOTV and orbital mechanics may dictate a changing relationship between these two vehicles in GEO orbit and separation distances greater than 1 km (baseline).

The baseline operational attitude for the SPS is a candidate for construction operations. The illustration opposite shows this attitude with the EOTV stationkeeping during a 24 hour period. Both spacecraft are in the same orbital path with their solar arrays perpendicular to the sun. Note that the change in relative attitudes of the two vehicles during an orbit makes it appear that the EOTV is circling the Base/SPS. If this is the operating condition, then the two vehicles are separated by approximately 4 km at times and the CT flight paths are continually changing – an obvious impact on CT propulsion and control requirements. One solution is to maneuver between the two vehicles only when they are in the most favorable geometric location.

If the Base is earth gravity stabilized as shown, then the relative location of the Base and the EOTV remains fixed. The EOTV, however, rotates 360° every 24 hours with respect to the Base. Hence, CT flight paths will also be constrained to the most favorable geometric arrangement.

EOTV CARGO UNLOADING CONSIDERATIONS



1622-011W

GEO BASE FLIGHT CONTROL REQUIREMENTS & ENVIRONMENTAL DISTURBANCES

The facing page lists the basic requirements used to analyze the GEO base flight control system. The POP mode was emphasized for the SPS off-sun solar array construction requirements, since previous SPS feasibility studies show low propellant requirements for all GEO flight attitudes The POP attitude permits base solar arrays to be fixed on the structure and also allows construction operations to be conducted under constant lighting and solar heating conditions.

The major environmental disturbances considered in this analysis for attitude control and station keeping functions are also listed.

GEO BASE FLIGHT CONTROL REQUIREMENTS & ENVIRONMENTAL DISTURBANCES

REQUIREMENTS

- CONSTRUCT SPS ARRAYS OFF-SUN (POP)
- FINAL SPS C/O IN POP ATTITUDE (ON-SUN)
- MAINTAIN SPS/BASE AT DESIRED ORBITAL POSITION WITHIN $\pm$ 1°
- SEPARATE SPS/BASE AT DESIRED GEO LONGITUDE (I.E. 90°W TO 150°W)
- TRANSFER BASE TO NEXT ORBITAL CONSTRUCTION SITE (~ 10°)
- PROVIDE BASE ONLY THRUSTER CONTROL

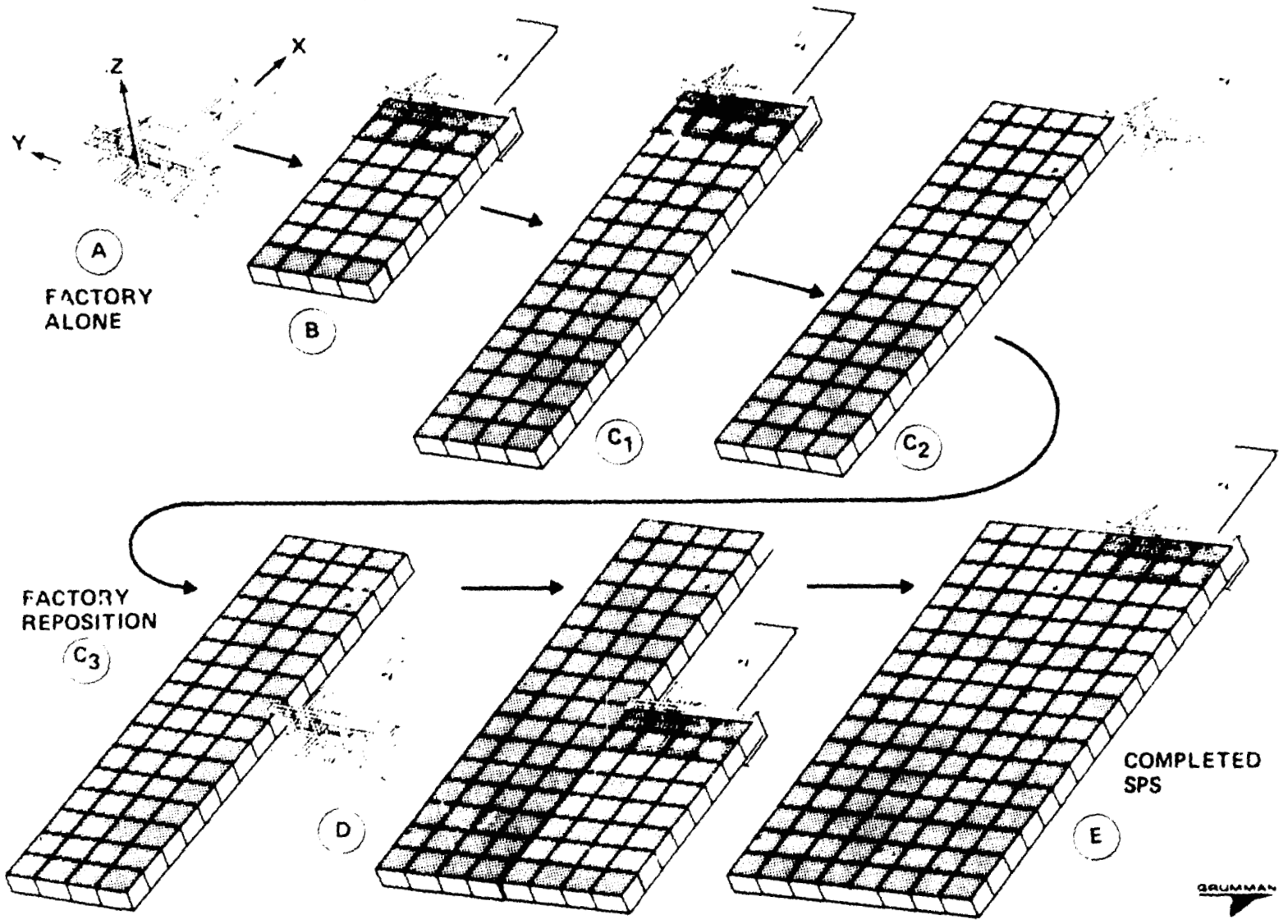
ENVIRONMENTAL DISTURBANCES

- ATTITUDE CONTROL FORCES
  - GRAVITY GRADIENT
  - SOLAR PRESSURE
- STATIONKEEPING FORCES
  - SUN & MOON GRAVITATIONAL INFLUENCE
  - SOLAR PRESSURE
  - ELLIPTICITY OF EARTH EQUATORIAL PLANE

SPS CONSTRUCTION PHASES

Seven significant phases of the 6 month GEO base/SPS construction operation are shown on the facing page. Each configuration represents a significant increase in mass and/or a significant shift in center of pressure and center of gravity. The selected body axis system is also identified on the first configuration.

SPS CONSTRUCTION PHASES

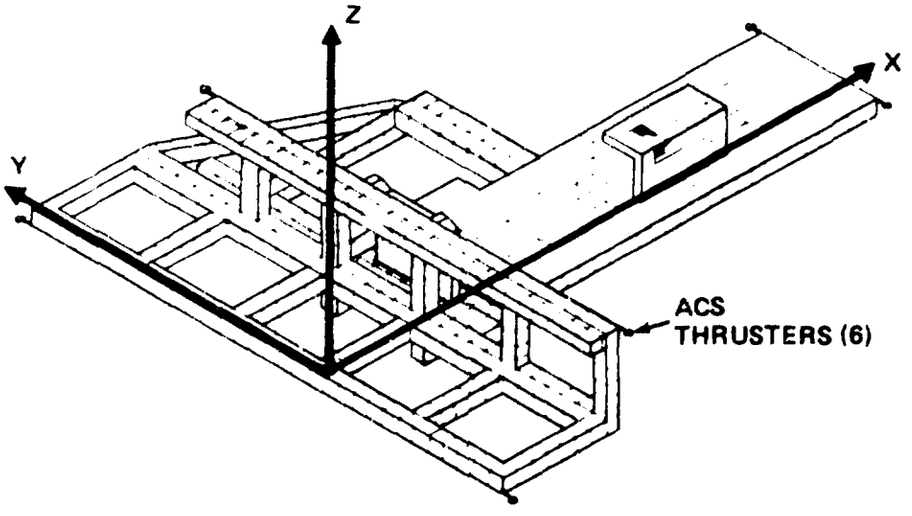


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GEO BASE FLIGHT CONTROL THRUSTERS

The GEO Base flight control system uses six electric ion propulsion modules, which are common with the EOTV attitude control system, to maintain the emerging satellite in an off-sun POP orientation. These modules are located at the outer corners of the antenna platform (level C), solar-collector facility legs (level B) and the top decks (level J). Each module consists of a gimbal, yoke, thruster panel, propellant tanks, and thermal control. The gimballed modules are inhibited from firing either toward the base or any part of the constructed satellite. Chemical propulsion is also provided on each module to control the satellite/base attitude during occultation periods, during the on-sun roll maneuver, and subsequent operations for satellite test and checkout.

GEO BASE FLIGHT CONTROL THRUSTERS



- LOW PROPELLANT ION THRUSTERS-COMMON TO SPS/EOTV EMPHASIZED
- GIMBALLED ION THRUSTER CTL FIRES AWAY FROM SPS & BASE
- CHEM PROPULSION USED FOR OCCULTATION & ON-SUN ROLL MANEUVER

MISSION PHASE	PEAK TORQUE*			ION THRUSTER PANEL TORQUE *					
				SPS-150N @ 20000 SEC			EOTV-838N @ 8000 SEC		
	X	Y	Z	X	Y	Z	Z	Y	Z
A	1	16	3	540	1080	1080	3020	6035	6035
B	77	155	12	540		1080			
C	119-602	589-41	31-2120	540		1080		PREFERRED	
D	739	219	224	540		1080			
E	1070	889	1800	540	1080	1080	3020	6035	6035

*10^3N-m

INSUFFICIENT CONTROL

1622 023W

GEO BASE FLIGHT CONTROL PROPELLANT REQUIREMENTS & AREAS FOR FUTURE STUDY

The propellant requirements for operating the GEO base in the SPS off sun POP flight mode are summarized on the facing page. Almost 100MT of propellant is required each year for GEO base attitude control, station keeping, and base transfer functions.

Recommended areas for future study are also listed.

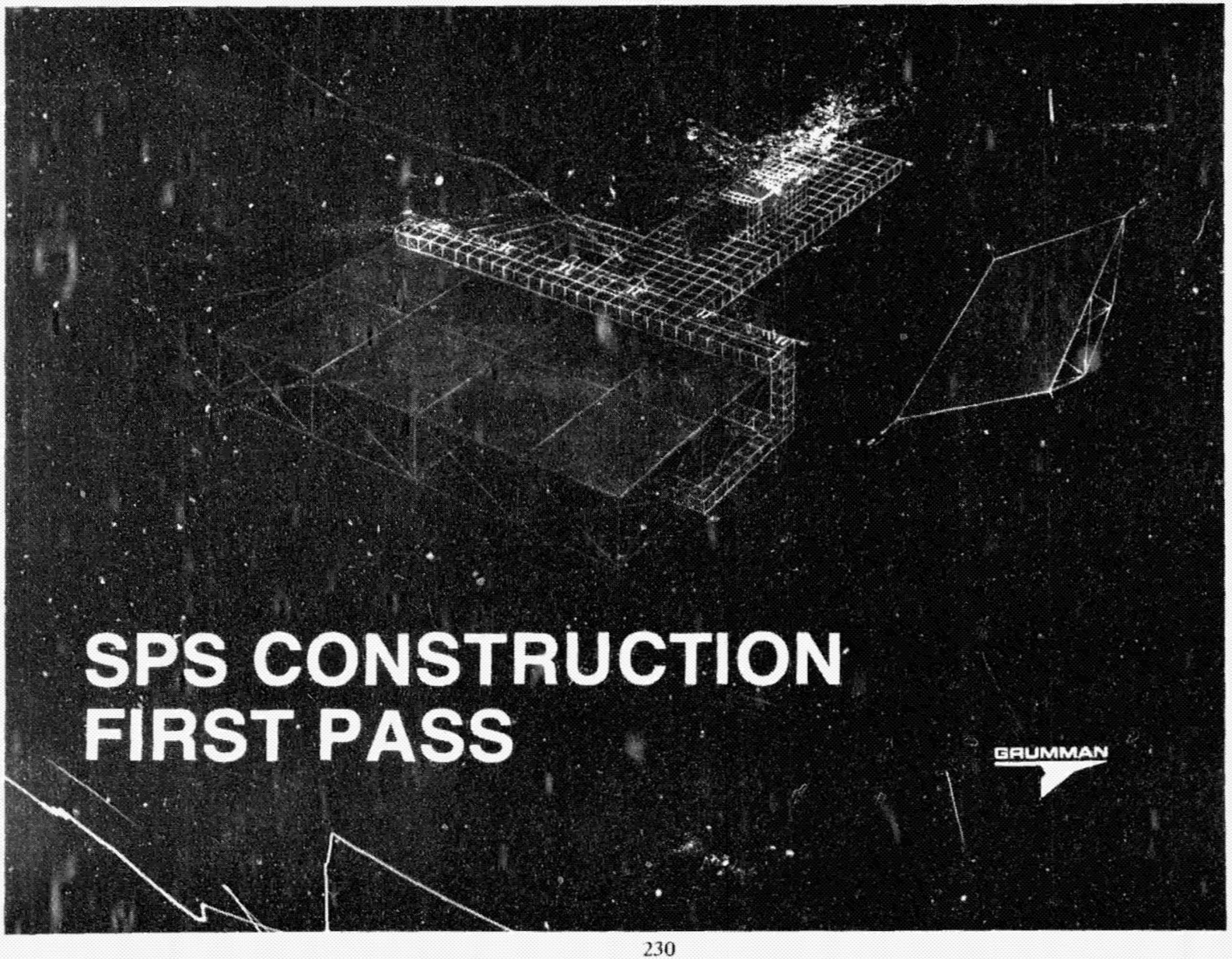
GEO BASE FLIGHT CONTROL PROPELLANT REQUIREMENTS & AREAS FOR FUTURE STUDY

6 MO. CONSTRUCT CYCLE REQMT	MASS (KG)
ATTITUDE CONTROL	37030
STATION KEEPING	6850
• SUN & MOON PLANE CHANGE	(2300)
• SOLAR PRESSURE	(3800)
• EARTH ELLIPTICITY	(1750)
BASE TRANSFER	1000
CONTINGENCY (10%)	4488
TOTAL	49370 KG

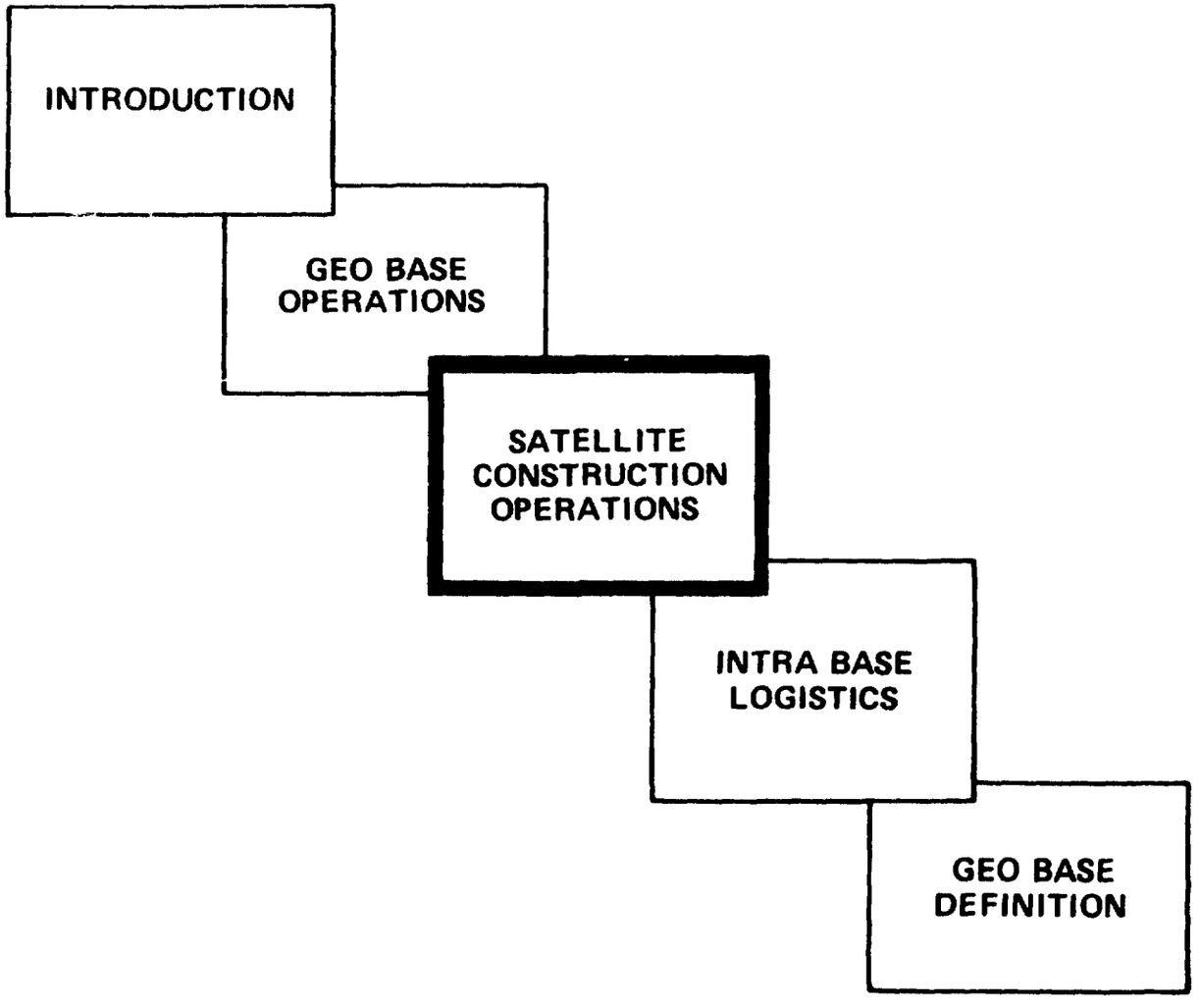
RECOMMENDATIONS FOR FUTURE STUDY

- ANALYZE & COMPARE CHEMICAL VS ELECTRIC PROPULSION SYSTEMS
- EVALUATE ATTITUDE STEERING TECHNIQUES & ALTERNATE FLIGHT ATTITUDES
- EXAMINE ATTITUDE CONTROL EFFECTS DUE TO BASE/SPS STRUCTURAL FLEXIBILITY & MOMENTUM TRANSFER INTERACTIONS

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INTRODUCTION
GEO BASE OPERATIONS
SATELLITE CONSTRUCTION OPERATIONS
INTRA BASE LOGISTICS
GEO BASE DEFINITION

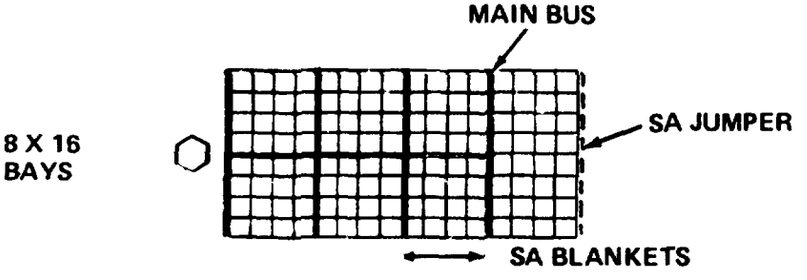
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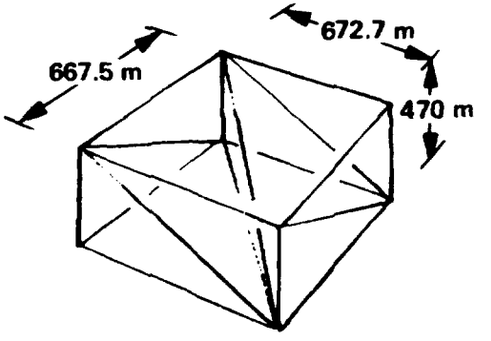
SPS PHASE 2 CONSTRUCTION REQUIREMENTS AND ISSUES

The 5000 MW reference solar power satellite is to be constructed entirely in GEO and is to be fully assembled in 6 months. The reference satellite has a single antenna located at one end of a large photovoltaic energy conversion system as shown on the facing page. The 8 x 16 bay energy conversion system features a hexahedral braced structure, longitudinal solar array blanket installation and multiple power buses. The satellite construction approach includes the 2 pass longitudinal buildup of the energy conversion system and the 16 row lateral buildup of the power transmission antenna as defined in Boeing's Phase I final report (Volume III, D180-25037-3). The GEO construction operation is to rely upon normal IVA assembly methods. A broad range of technology issues (many of which are beyond the scope of this study) must be addressed to cover all aspects of the SPS construction process. As the reference system matures, the satellite construction approach must be reexamined for the energy conversion, power transmission and interface systems. In addition the structural assembly methods should be well understood to the level of beam fabrication, handling and joining. Techniques for installing the major subsystems (i.e., solar arrays, buses and subarrays) must be further developed and the requirements for construction equipments need further refinement. In addition, the structural dynamic, thermodynamic and control interactions between the base and the satellite should be investigated and defined. Other areas to be examined include methods for berthing or mating of large system elements, techniques for in-process inspection and repair, and concepts for implementing satellite final test and checkout.

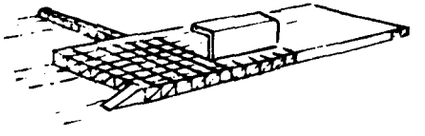
SPS PHASE 2 CONSTRUCTION REQUIREMENTS & ISSUES

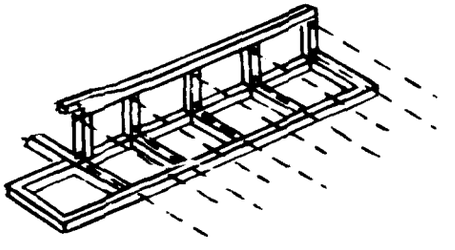
- ASSEMBLE BASELINE 5 GW SATELLITE IN 6 MONTHS





- 4 BAY END BUILDER (PH-1, REF S/S DESC D180-25037-3)
  - 2 PASS LONG. ENERGY CONV ASSY
  - 11 ROW LATERAL ANTENNA ASSY
- *IVA ASSEMBLY METHODS - EVA EMERGENCY LIMITED*
- SPS CONSTRUCTION ISSUES
  - SATELLITE CONSTRUCTION APPROACH
  - STRUCTURAL ASSEMBLY METHODS
  - SUBSYSTEM INSTALLATION TECHNIQUES
  - CONSTRUCTION EQUIPMENT REQMTS
  - SATELLITE SUPPORT & BASE INTERACTIONS
  - HANDLING & MATING LARGE SYSTEM ELEMENTS
  - IN PROCESS INSPECTION & REPAIR
  - FINAL TEST & CHECKOUT





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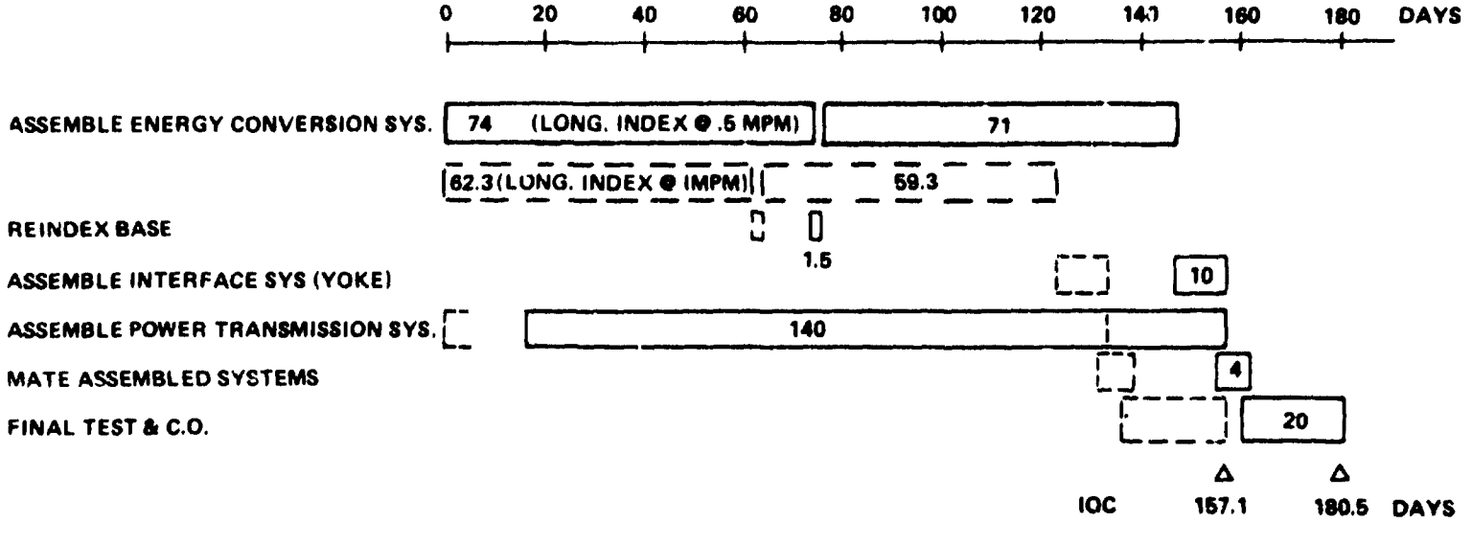
4 BAY END BUILDER TIMELINE

SPS assembly operations commence with the construction of the energy conversion system, as shown on the facing page. Assembly of the energy conversion system is timed for simultaneous completion and mating with the interface system and power transmission system. The 5GW monolithic satellite is constructed and checked out in GEO in six months.

The 4 bay end builder uses two passes to construct the 8 x 16 bay energy conversion system; each pass provides a 4 x 16 bay module which contains the appropriate subsystems (i.e., structure, solar blanket; power distribution and control, attitude control, etc.). The main power bus is installed during the first pass in parallel with the fabrication of continuous longitudinal beams. The second construction pass is somewhat shorter since one side of the structure is already built, and therefore less vertical and diagonal support beams are required.

The interface system is constructed separately and then joined to the power transmission system. The satellite is fully assembled, when these systems are mated with the energy conversion system.

4 BAY END BUILDER TIMELINE



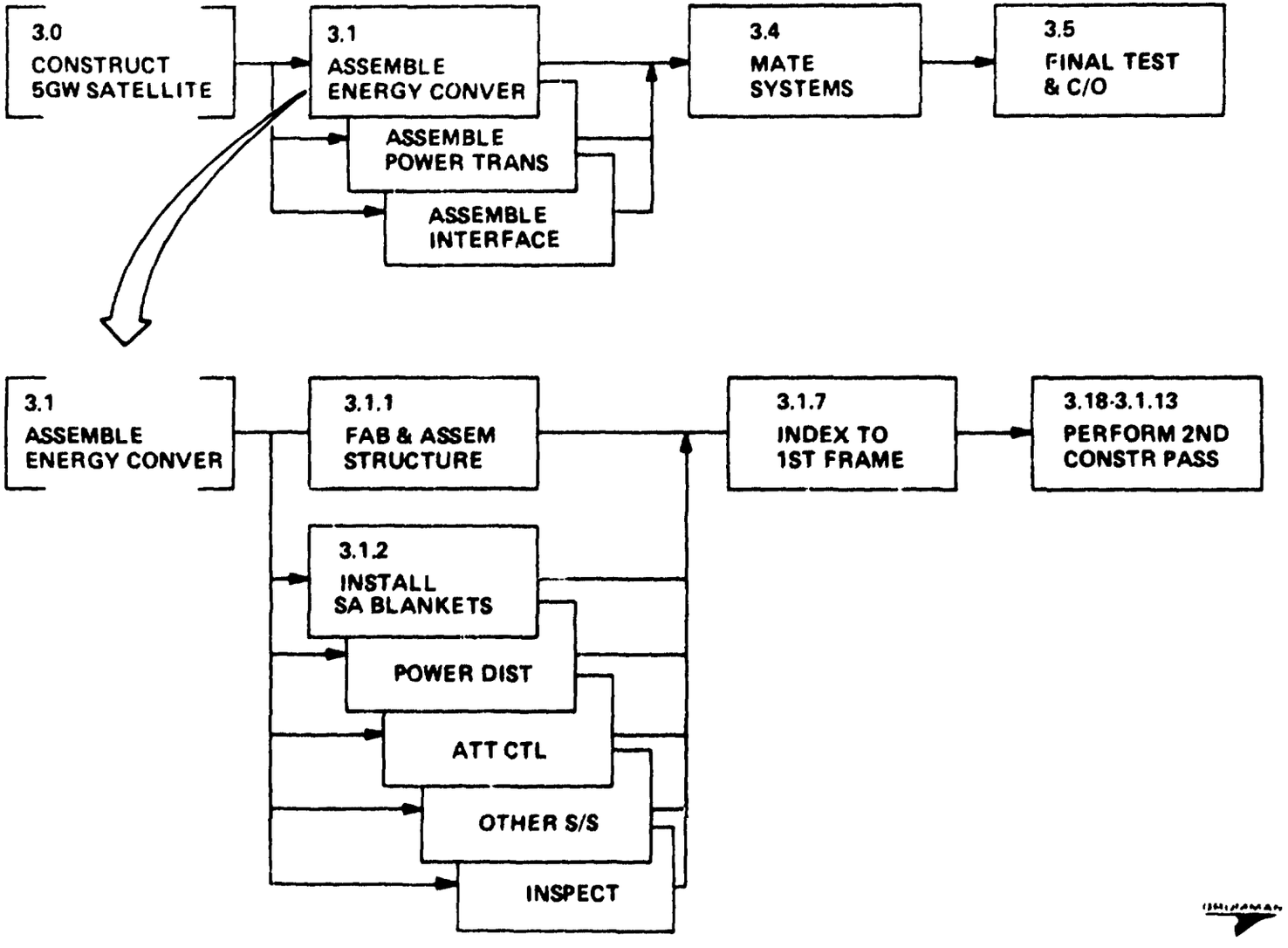
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SATELLITE CONSTRUCTION OPERATIONS ANALYSIS

SPS construction operations are analyzed from the top down, by defining the required steps at each level of the construction sequence. As shown in the facing page, construction of the reference satellite systems includes parallel assembly of energy conversion, power transmission and interface elements. When these system elements are fully assembled, they will be mated and integrated to form the complete solar power satellite. The construction process ends with final test and checkout of SPS systems.

A further breakdown of the assembly operations for the energy conversion systems is shown by the abbreviated flow in the lower half of the chart. This assembly activity includes the fabrication and assembly of the structure for the first construction pass (3.1.1) and the parallel installation and inspection of required subsystems (e.g. solar array blankets, power distribution, etc.). When the first half of the satellite energy conversion system has been constructed, the base will be indexed back along the side of the satellite structure to a position adjacent to the first frame (3.1.7). The second construction pass begins from that point and includes the fabrication and assembly of the remaining structure together with the parallel installation of other subsystems.

SATELLITE CONSTRUCTION OPERATIONS ANALYSIS

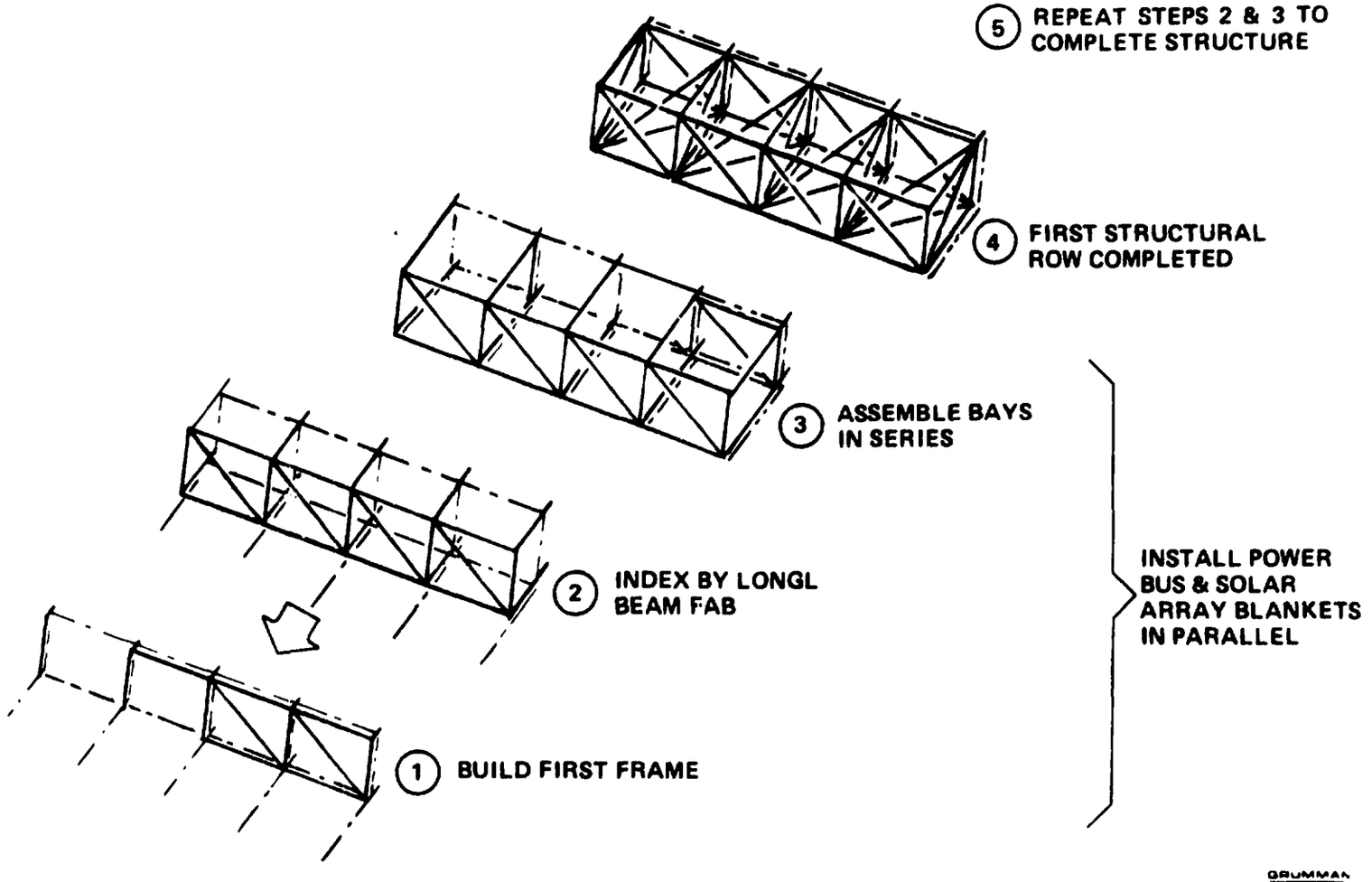


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END BUILDER STRUCTURAL ASSEMBLY SEQUENCE

The end builder construction system is tailored to the structural cross section of the satellite and uses ten (10) dedicated semi-fixed beam machines to automatically fabricate continuous longitudinal members. Lateral and diagonal members of the structural assembly are fabricated by three (3) mobile beam machines. The assembly sequence as illustrated begins with Step 1, the assembly of the first frame and its attachment to the longitudinal members. The structural members of the frame are fabricated by three mobile beam machines that travel from one position to the next. The upper lateral beam is fabricated and then positioned for assembly. As this member is being joined, the mobile beam machines fabricate the other members of the frame needed to complete the assembly. Step 2 indexes the frame for one bay length by fabricating the continuous longitudinal beams from the dedicated beam machines. In Step 3, the next frame is built as in Step 1. During these three steps, power busses and solar array blankets are installed in parallel. The solar array blankets are deployed in the direction of build, are attached to the upper lateral beams and are fed out of cannisters as the structure indexes. Longitudinal busses are installed "on the fly" as the structure is indexed; lateral busses are installed before a bay is indexed. In Step 4 the bay structure diagonal beams are fabricated and assembled to complete the bay. This bay is then indexed, as in Step 2, and the entire sequence repeated until the energy conversion structure is built.

END BUILDER STRUCTURAL ASSEMBLY SEQUENCE

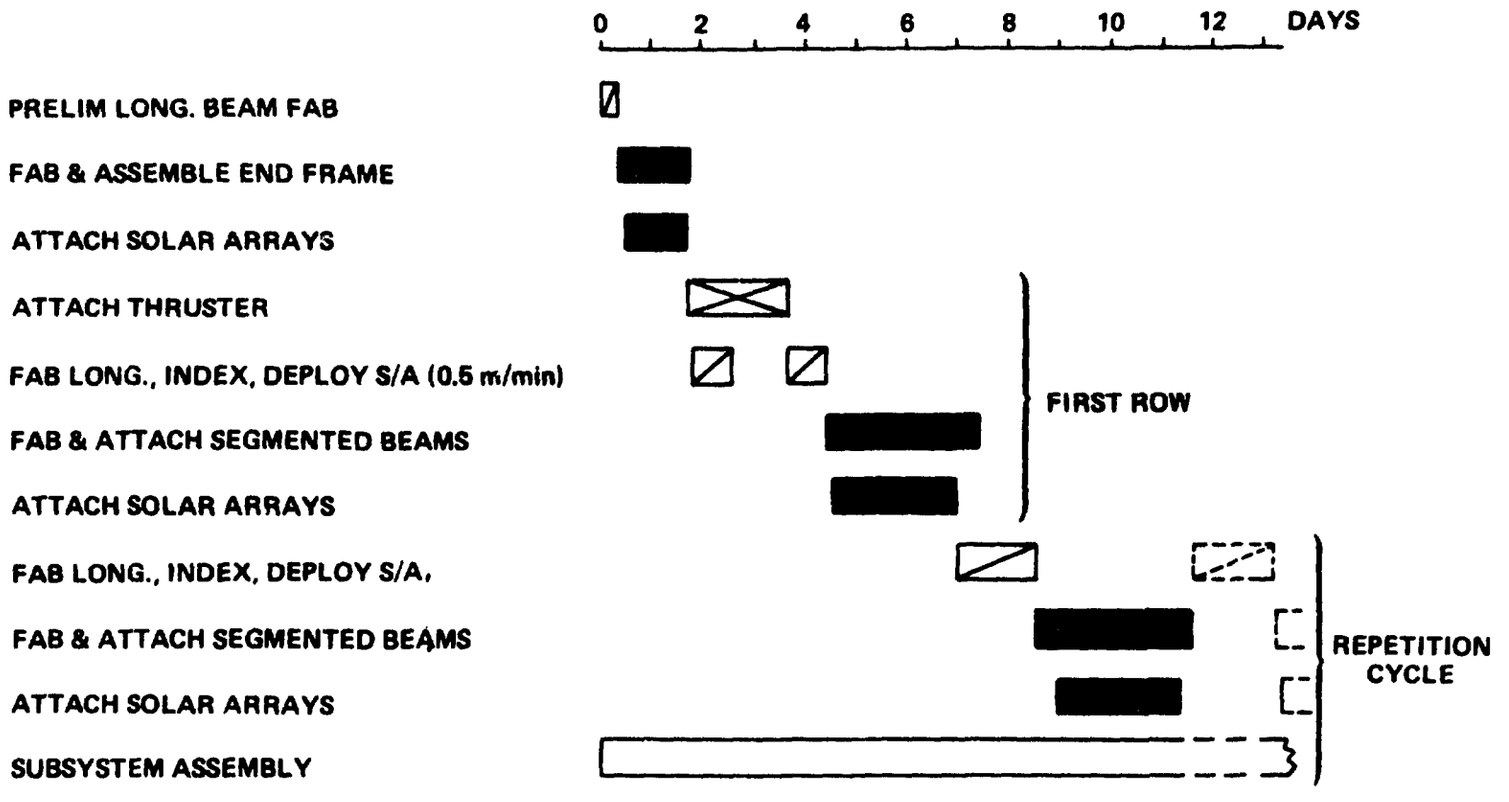


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ENERGY CONVERSION SYSTEM ASSEMBLY OPERATIONS TIMELINE – UPDATE

As a result of the Phase II analysis, the 4 Bay End Builder construction operations timeline has been updated to include the preliminary fabrication of longitudinal beams required to allow the assembly of the first end frame. The beam fabrication operations have also been updated to include the installation of beam end fittings and related space frames on the continuous longitudinal beams. Moreover, the assembly of the attitude control thrusters and its effect on the fabrication of the continuous longitudinal beams for the first structural row has also been considered, as shown on the facing page. The impact of this update has only added two days to the construction of the energy conversion system.

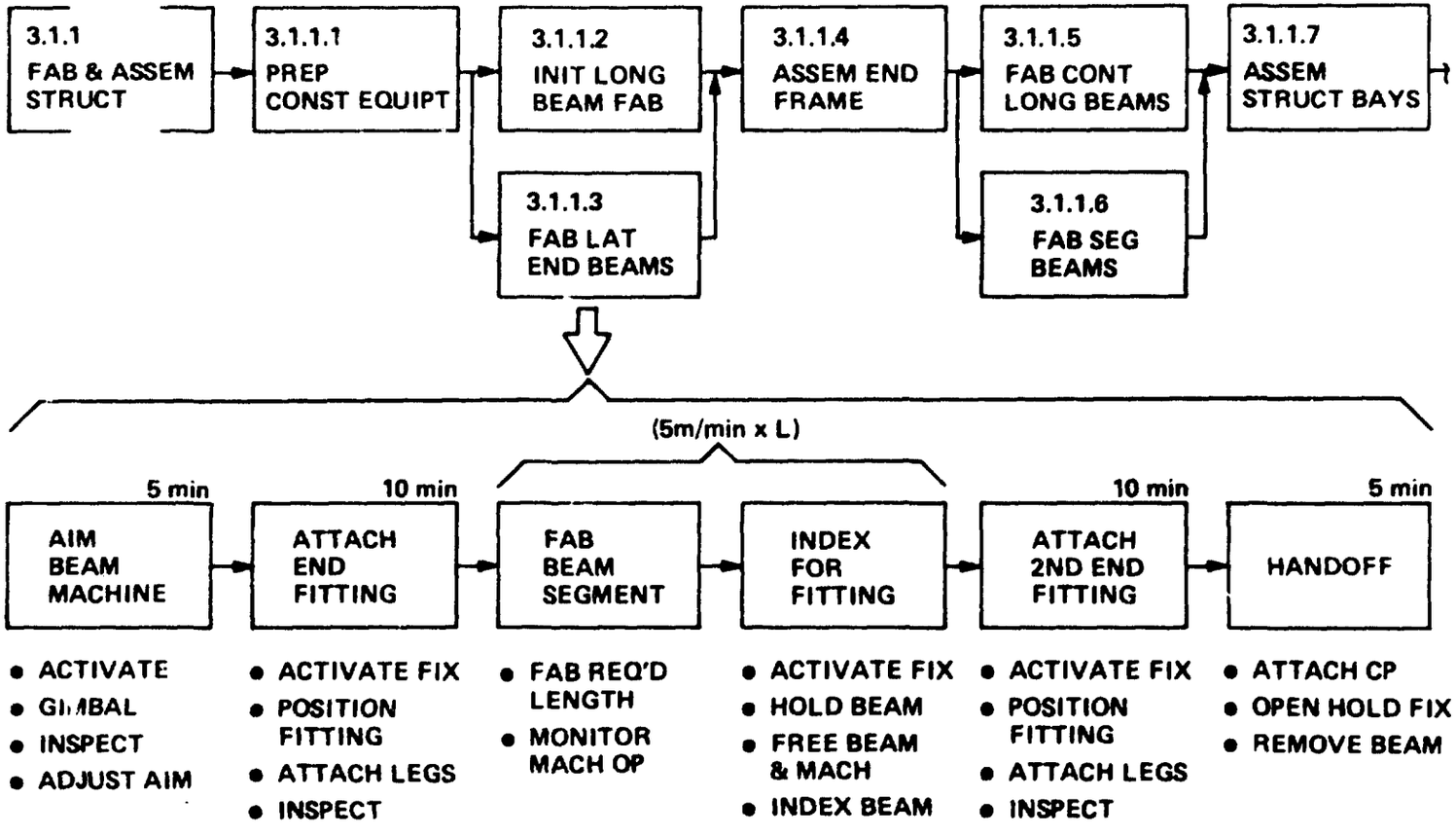
ENERGY CONVERSION SYSTEM ASSEMBLY TIMELINE–UPDATE



ENERGY CONVERSION STRUCTURE FABRICATION & ASSEMBLY FLOW

A further breakdown of the SPS structure fabrication and assembly operations is shown on the facing page. This functional flow defines the beam fabrication requirements leading to the assembly of the first 4 bay wide end frame for the energy conversion structure. It also defines the beam fabrication requirements which permit the assembly of structural bays (16 rows) for the first construction pass. The major functional blocks, such as 3.1.1.3-fabricate lateral end beams, are defined to the level of detail illustrated by the flow in the lower half of the chart. Times are estimated for each of the functions which comprise the fabrication of segmented lateral beam for subsequent attachment to the continuous longitudinal beams. The attachment of beam end fittings is defined for both ends of the beam as it emerges from an automatic beam machine. The need for an indexing beam holder is also identified as a prerequisite to the attachment of the second end fitting.

ENERGY CONVERSION STRUCTURE FABRICATION & ASSEMBLY FLOW



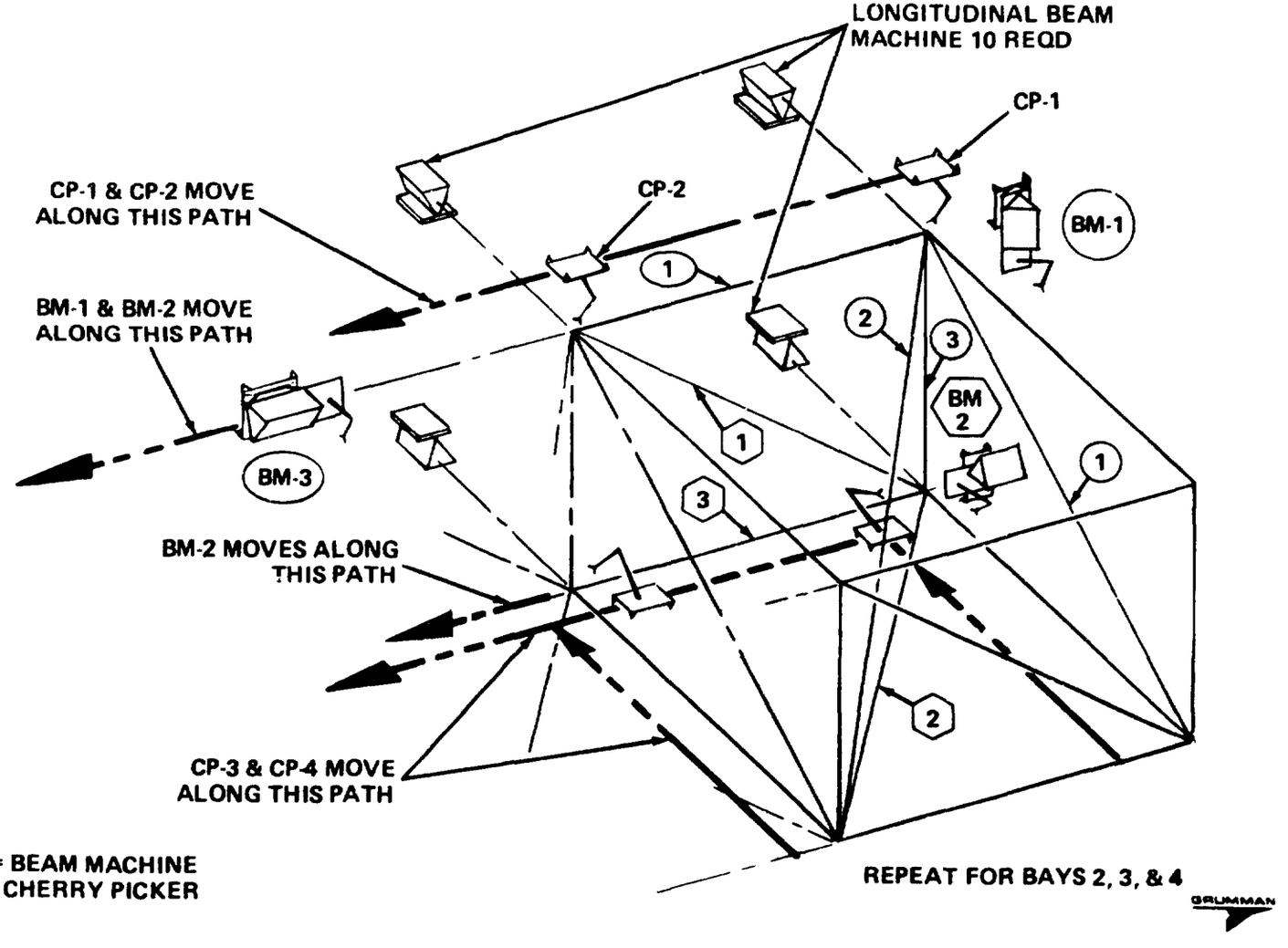
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ENERGY CONVERSION STRUCTURE ASSEMBLY EQUIPMENT & SEQUENCE – 1ST BAY

This illustration identifies the assembly equipment and construction sequence required to assemble the structural bays of the energy conversion module. The first bay of the four-bay pass is shown requiring the use of longitudinal beam machines (semi-fixed), three (3) mobile beam machines and four (4) cherrypickers. The operating paths of the mobile beam machine and cherrypickers are also defined along with the fabricating sequence of each of the mobile beam machines. This sequence is then repeated for bays 2, 3 and 4.

ENERGY CONVERSION STRUCTURE - ASSEMBLY EQUIPMENT & SEQUENCE - 1ST BAY



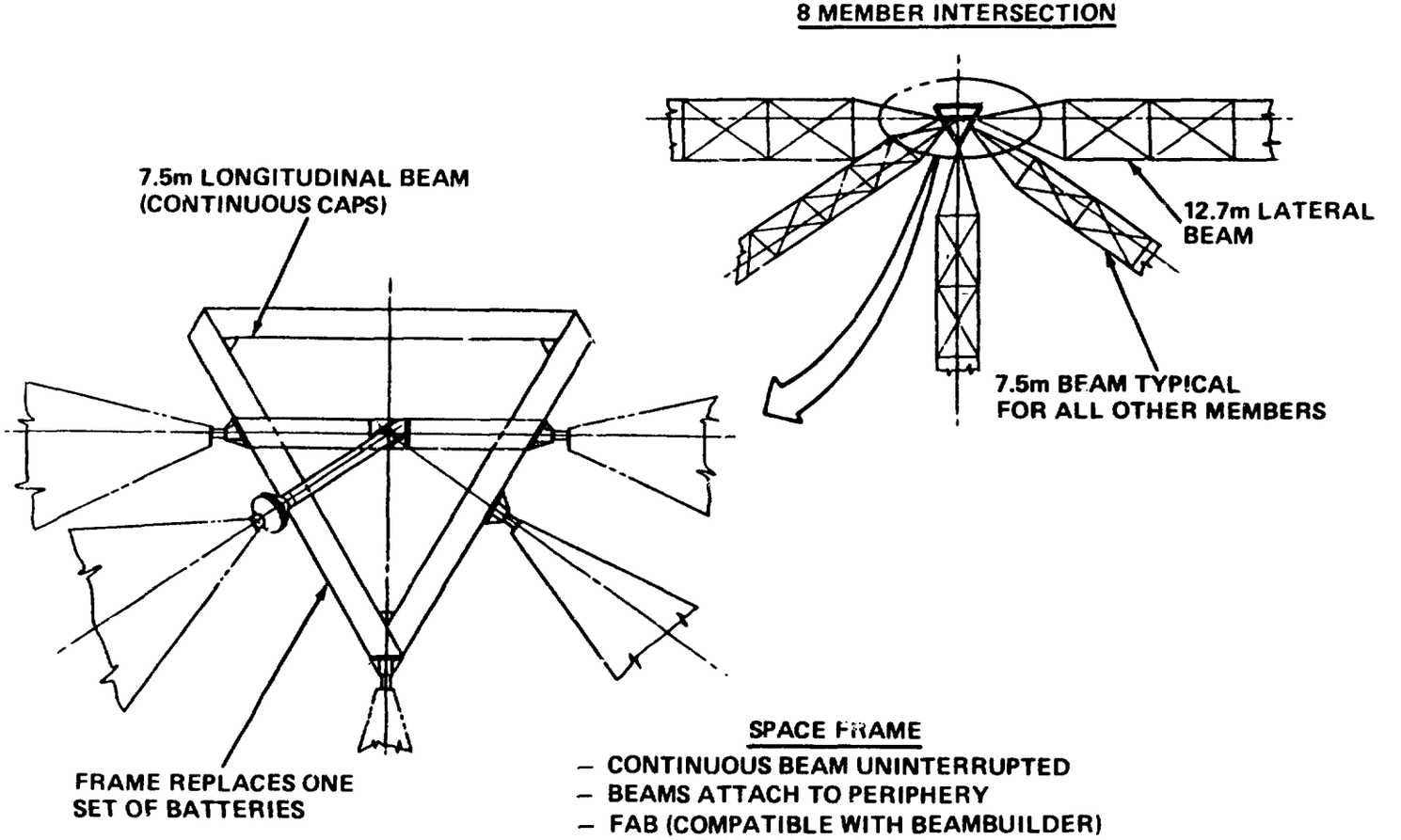
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STRUCTURAL JOINT DESIGN COMPATIBLE WITH END BUILDING CONSTRUCTION

A space frame is used in the assembly of the multi-member structural joints of the energy conversion structure. As shown the frame replaces one set of battens of the longitudinal beam and does not interrupt the continuous chords (caps) of the beam. Pickup points are provided on the periphery of the frame, enhancing access required for the attachment of the lateral, vertical and diagonal bracing beams. These pickup points are located so that the end load in each attaching beam is aligned with the centroid of the continuous longitudinal beam. These frames are also compatible with beam machine fabrication and could be space fabricated or ground fabricated in segments and space assembled. The frame segments are loaded into beam machine supply canisters and the frame assembly becomes an integral operation of the beam machine.

Although the space frame seems attractive at this time, further study is required to determine the effects of introducing torsion in the continuous beam which will result from the eccentricities or misalignment of the attaching beams. Additionally, designs of hybrid nodal spider-type fittings for the joints should be pursued.

STRUCTURAL JOINT DESIGN COMPATIBLE WITH CONTINUOUS LONGITUDINAL BEAM CONSTRUCTION



SPACE FRAME

- CONTINUOUS BEAM UNINTERRUPTED
- BEAMS ATTACH TO PERIPHERY
- FAB (COMPATIBLE WITH BEAMBUILDER) OR ASSEMBLED IN SPACE

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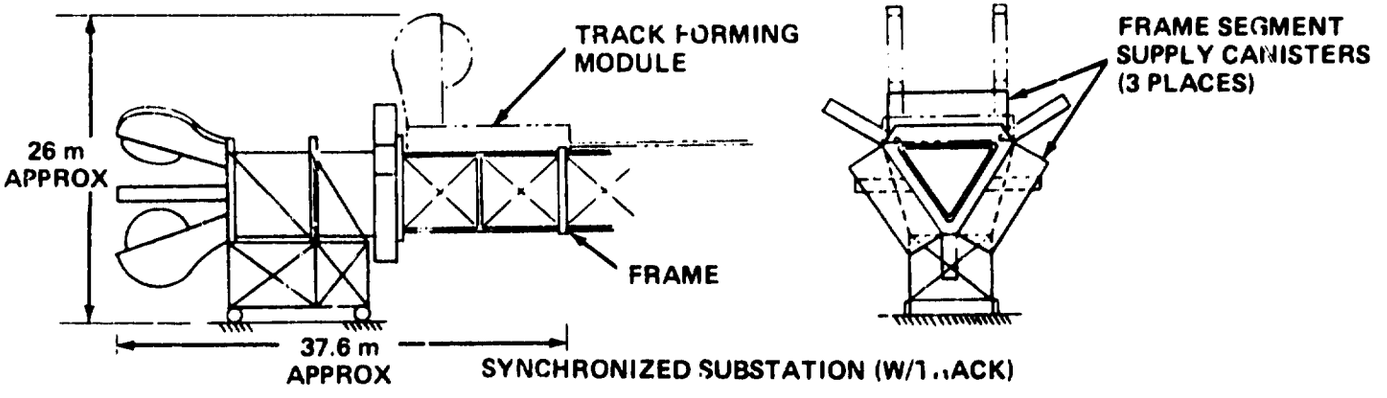
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7.5 m BEAM BUILDER SUBSTATIONS

The 7.5 m synchronized substation includes a beam machine equipped with frame-making features as shown. Frame segment supply canisters are mounted at each beam face at cross member attaching stations. Since current maintenance track concepts call for supports at each cross member, track attachment will occur after the completed cross members emerge from the beam machine. This requirement dictates the location of the track forming module as shown.

The 7.5 m mobile substation uses a beam machine provided with end fitting attachment features. A column mounted end fitting support fixture with movable gripping fingers can rotate to place fittings on either end of a beam. The column swings down as required to clear the emerging beam or pick up an end fitting from the supply canister. The grip is capable of extending to secure and withdraw a fitting from the supply canister. An automatic arm attaches the end fittings to the beam on either end as required. An accessory platform is equipped with holding devices which index the completed beam and position it for installation of the end fitting after it has emerged from the beam machine. The entire platform with beam machine and accessories is capable of 360° swiveling and can be rotated perpendicular to the carriage to provide any required orientation.

7.5 m BEAM BUILDER SUBSTATIONS



7.5 m MOBILE SUBSTATION

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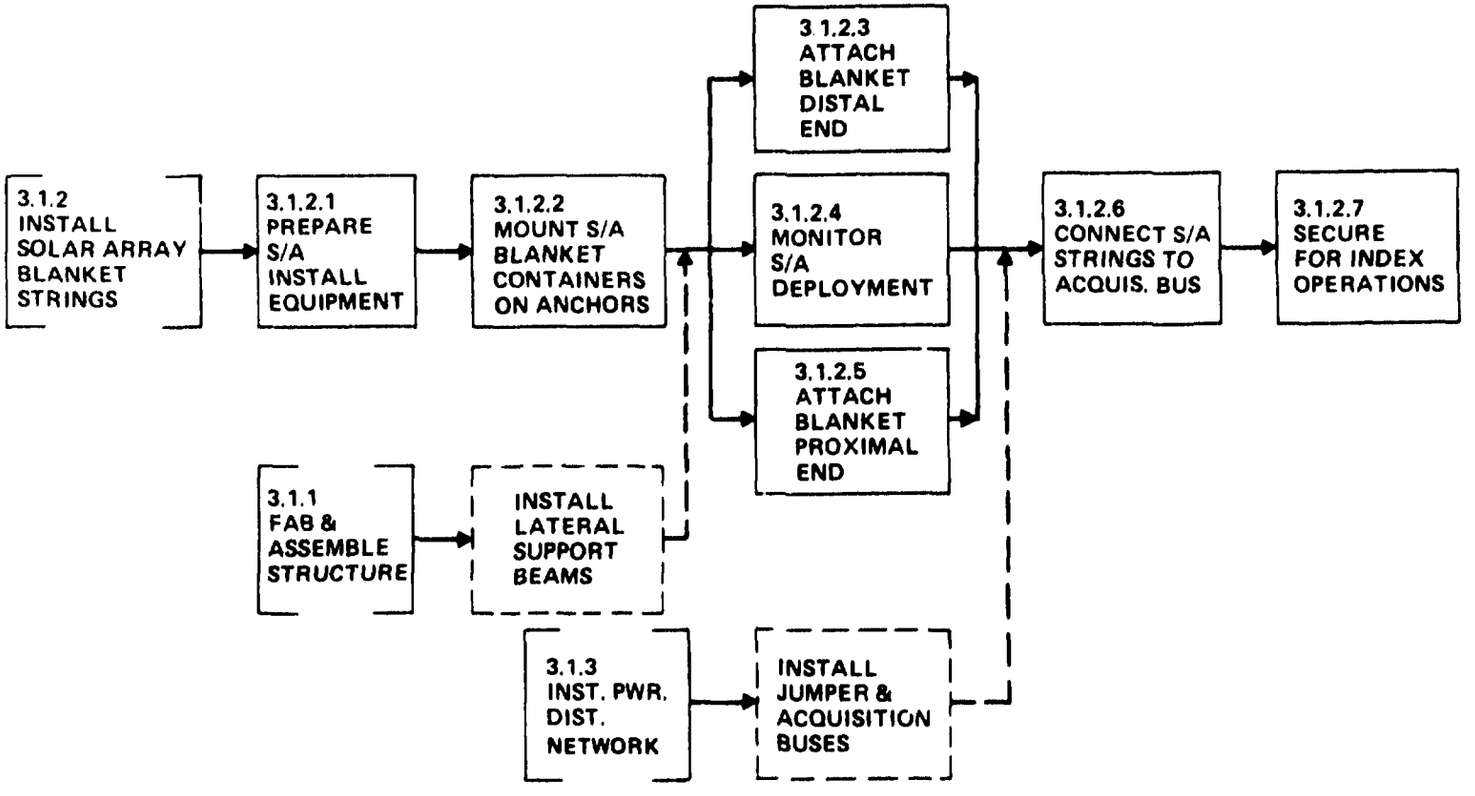
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ENERGY CONVERSION SYSTEM SOLAR ARRAY INSTALLATION FLOW

The facing page illustrates the generic sequence used for the assembly of the solar array blanket strings for the energy conversion system of the SPS. The assembly flow includes the preparation of the solar array blanket installation equipment (Block 3.1.2.1), the installation and deployment of the solar array blankets (Blocks 3.1.2.2 through 3.1.2.5), and the connection of the solar array blanket strings to the acquisition bus (Block 3.1.2.6). The final operation is to secure the solar array installation equipment in preparation for index operations (Block 3.1.2.7).

In performing the solar array blanket installation operations, 2 cherry pickers and an unmanned supply cart operate together as an installation team. Two installation teams operating simultaneously install the 44 solar array blankets in each of the 4 bays of any row of the energy conversion system structure. Each team installs 22 blankets in its own zone of responsibility, which consists of one-half of the 660m bay width.

ENERGY CONVERSION SYSTEM SOLAR ARRAY INSTALLATION FLOW



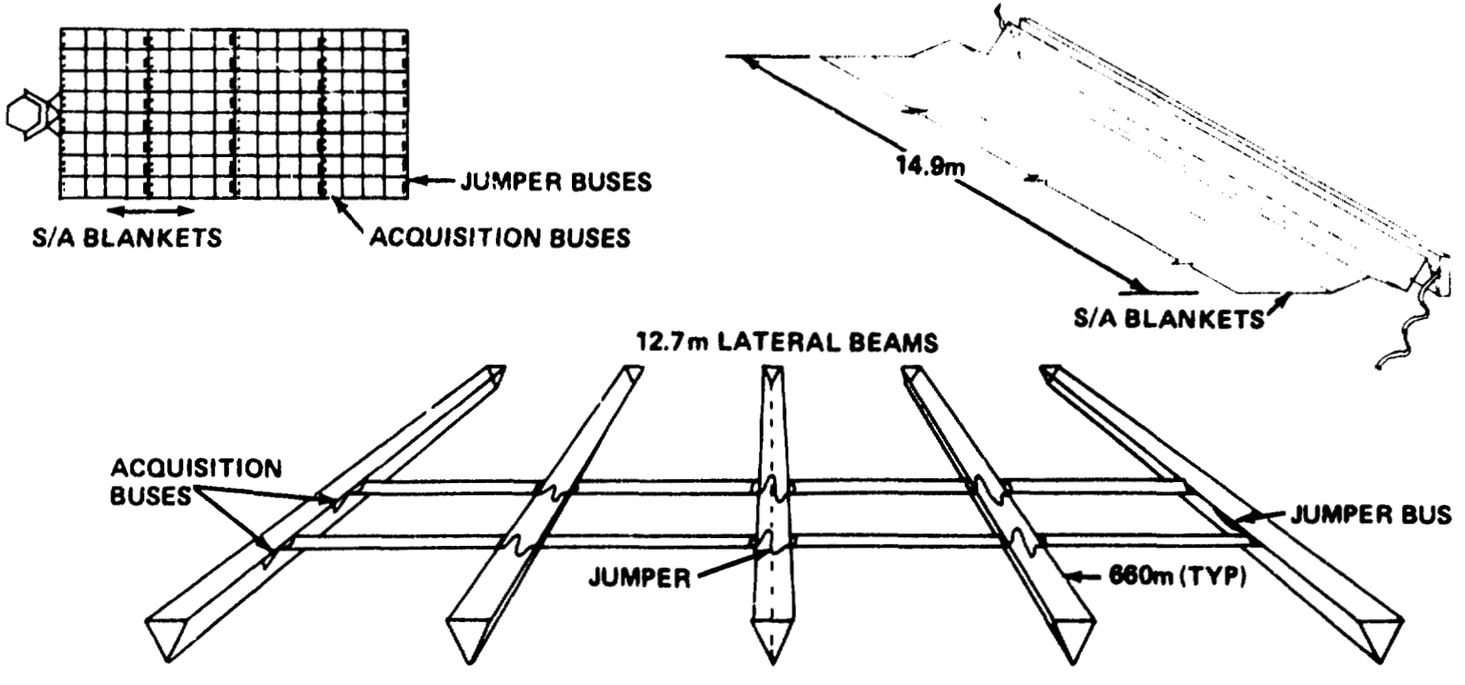
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SOLAR ARRAY INSTALLATION REQUIREMENTS

SPS solar array blankets are installed in strings which requires 8 blankets to be connected in series between the first and fifth upper lateral beams, or every 4 bays. Inter bay jumpers connect 4 blankets in series which in turn is connected to a parallel 4 blanket string through a turn around jumper bus. Opposite ends of these 4 bay folded strings are attached to positive and negative acquisition buses located at the 5th, 9th, 13th and 17th frames as shown on the facing page. Accordion folded solar array blankets, 14.9m wide by 660m deployed, are installed on the 12.7m lateral beams. Fourty-four blankets are installed within each bay of the satellite and each blanket is preloaded to 61.5N.

SOLAR ARRAY INSTALLATION REQUIREMENTS



8 · BLANKET S/A STRING

- ACCORDIAN FOLDED SOLAR ARRAY BLANKETS
  - ATTACHED CONCURRENT W/SEGMENTED BEAM FAB
  - DEPLOYED CONCURRENT W/LONG. BEAM FAB
- 44 BLANKETS/BAY, EACH TENSIONED @ 61.5N
- BLANKETS JOINED BY JUMPERS & JUMPER BUSES
- 8-BLANKET STRINGS CONNECTED TO ACQUISITION BUSES

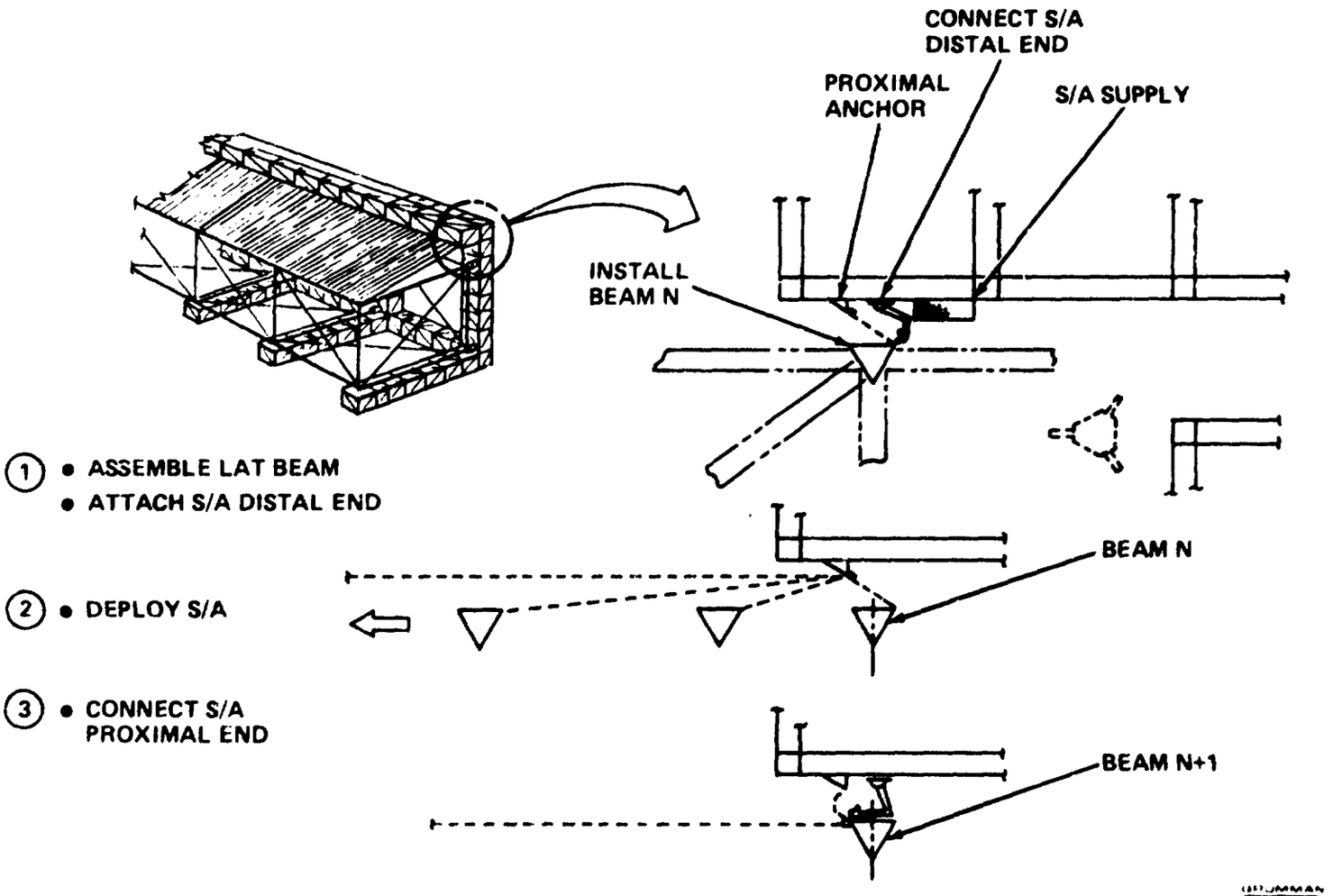
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COUPLED FRAME ASSEMBLY/SOLAR ARRAY DEPLOYMENT

The installation of solar arrays occurs at the same work station in the base as the assembly of in-plane structural frame elements, to obtain maximum time-line benefits from parallel activities.

Subsequent to the installation of a 12.7 m solar array support beam, the cherry picker removes an SA box from the supply crib shown and fastens it to the proximal anchor. The distal-end of the blanket is then connected to the beam. When the frame has been indexed one bay away, the blankets are fully deployed and the box is removed from its anchor support fittings and fastened to the next 12.7 m support beam to complete the cycle.

COUPLED FRAME ASSEMBLY/SOLAR ARRAY DEPLOYMENT



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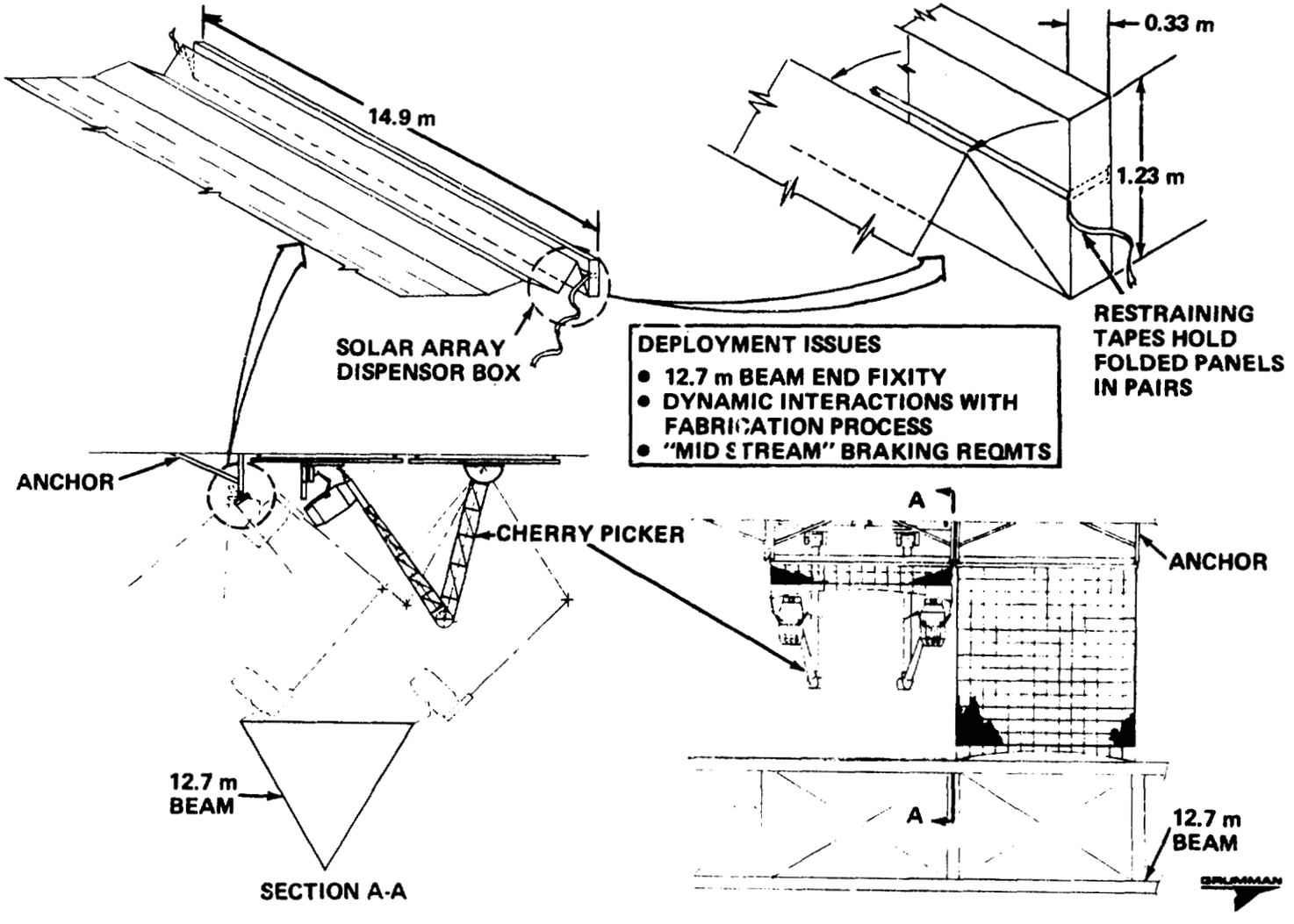
SOLAR ARRAY HANDLING & DEPLOYMENT

A pair of track mounted, mobile cherrypickers perform all solar array handling and deployment functions in the concept shown. Working in unison, the two cherrypickers move the solar array dispensor box from a supply cart to the base mounted anchors, and secure the box in place. The cherrypickers then move the solar array blanket distal end down to the 12.7m beam and secure it to the beam.

In the dispensor box, panel segments are held in folded pairs by thin tapes from one end of the box to the other. The tapes, with a calibrated breaking strength, help reduce panel spillage. However, as construction proceeds, tension loads in the deployed portion of the panel increases until the load reaches the breaking point of the tape and a folded pair of panel segments is released, relieving the load. This repeated cycle causes periodic variations in panel tension. If planned or emergency factors require construction shutdown, braking loads may be sufficient to cause spillage of the stowed panel even with restraining tape. Future studies should investigate alternative dispensing concepts, for example, reel or drum mounted panels which could be controlled using established methods of braking etc.

The present 12.7m lateral beam design was sized for an earlier solar array deployment concept which was not coupled to the fabrication of continuous longitudinal beams. Each beam was allowed to rotate about its nodal end fitting to relieve solar blanket preload bending. The rotating beam concept is not compatible with the end builder coupled solar array/structure deployment operations since it makes solar array blanket tensioning very difficult. It is also not compatible with the installation of solar array maintenance track, particularly with respect to the lateral end members and the numerous track cross-over connections. It is recommended that further study be devoted to alternate beam design concepts with different end fixities.

SOLAR ARRAY HANDLING & DEPLOYMENT

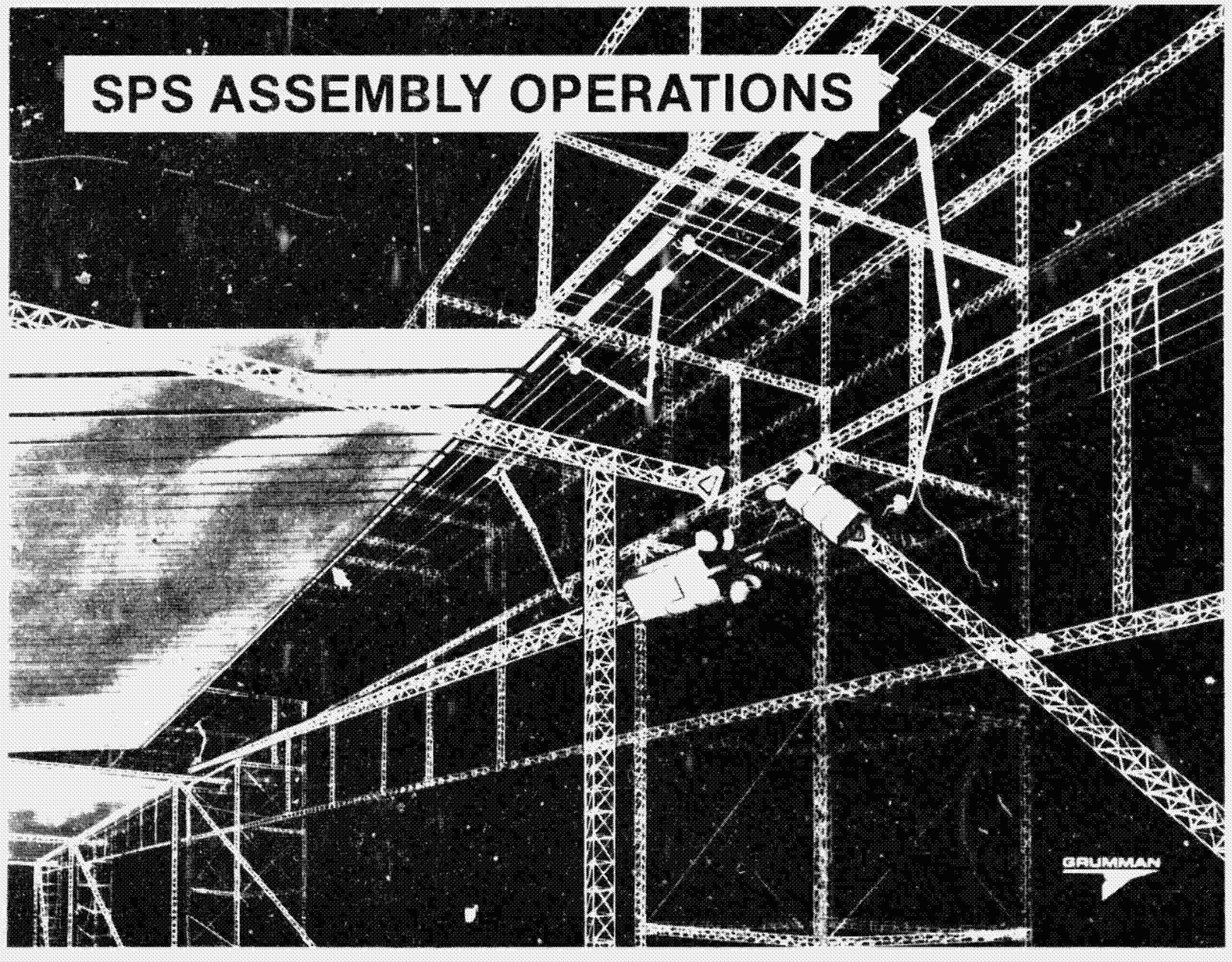


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SPS ASSEMBLY OPERATIONS

The facing page rendering depicts the construction activities at levels F, G, and H of the energy conversion construction facility. These levels are utilized in the construction of the upper surface of the energy conversion module. Shown nestled in the facility structure is the 7.5 m longitudinal beam machine (semi-fixed), and operating from a horizontally mounted track system are two mobile beam machines. One beam machine is shown fabricating the 7.5 m bracing beam and the other the 12.7 m lateral (solar array support) beams. Located overhead on the facility overhang and operating from a track system, cherrypickers are used to maneuver and attach the completed beams. The complex operations of these two cherrypickers in the maneuvering, handing-off and installation of beam lengths of approximately 600 to 1000 meters requires further study.

Solar array blanket deployment and installation is coupled with the end builder structural assembly sequence. Shown are the blanket installers operating from a track system mounted on the facility overhang. The solar array blankets are deployed from canisters mounted on the overhang. Replacement canisters are shown being moved into place and installed at their deployment station by a mobile flatbed cherrypicker.



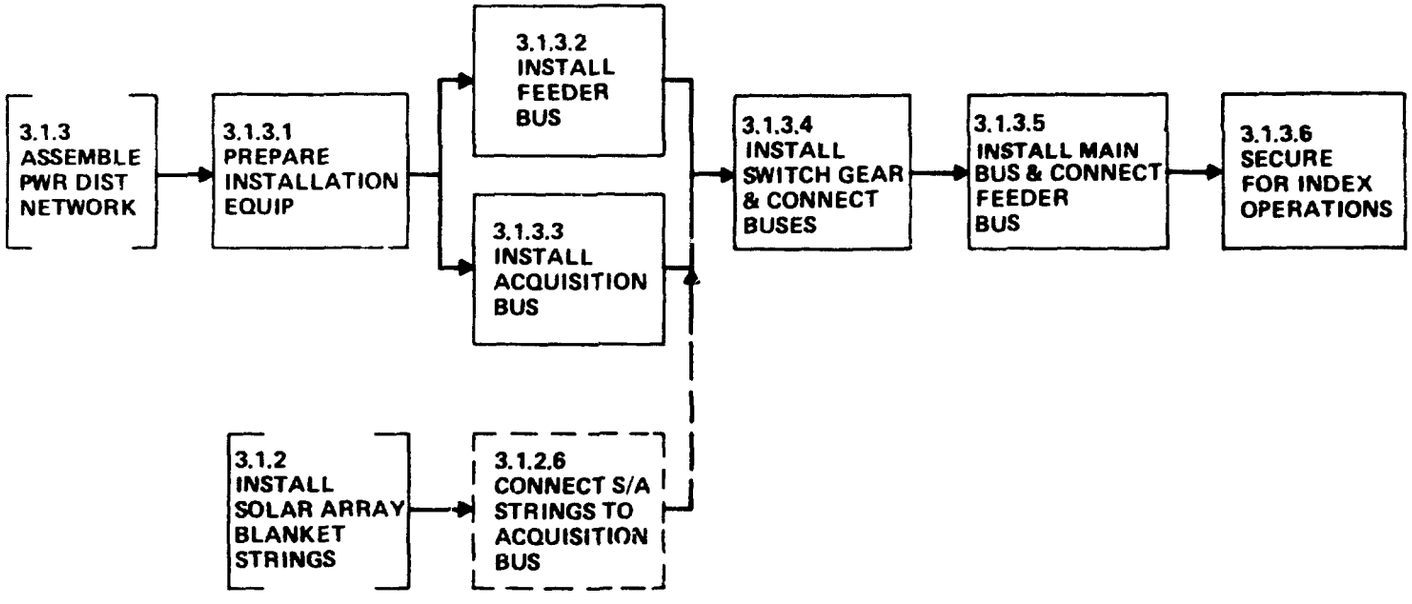
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ENERGY CONVERSION SYSTEM POWER DISTRIBUTION NETWORK ASSEMBLY FLOW

The power distribution network of the energy conversion system includes the cables, switch gear and power buses necessary to transmit electrical energy from the acquisition buses (located on the lateral beams at energy conversion system frames 1, 5, 9 & 13) to the rotary joint. The generic sequence of operations for the assembly of the power distribution network is shown on the facing page.

The assembly of the power distribution network begins with the preparation of the installation equipment in Block 3.1.3.1. The two phase coupled assembly approach used for the end builder concept requires that the acquisition & feeder buses and the switch gear be installed on the structure in Blocks 3.1.3.2 through 3.1.3 4 and be electrically connected to the solar array strings, while the lateral and diagonal structural beam segments are being fabricated and installed (Block 3.1.1.7). Conversely, the main bus is installed in Block 3.1.3.5, while the longitudinal beams are being fabricated (Block 3.1.1.5). The final operation is the preparation of the installation equipment for the indexing operations in Block 3.1.3.6.

ENERGY CONVERSION SYSTEM POWER DISTRIBUTION NETWORK ASSEMBLY FLOW



POWER DISTRIBUTION SYSTEM INSTALLATION REQUIREMENTS

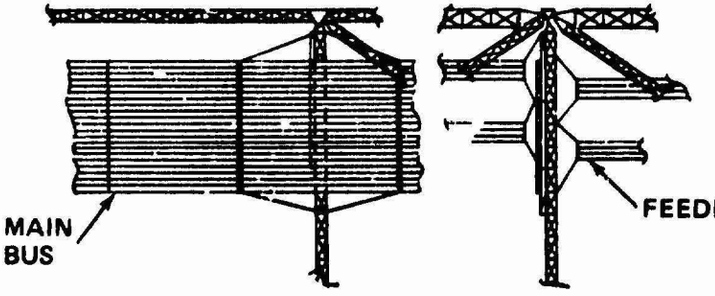
The power distribution system installation requirements are comprised of the main and feeder buses and their interface with the power collection system together with the associated maintenance track system.

The main and feeder buses are supported next to the satellite vertical beams beneath any intersecting diagonal or cross bracing structure. Support of the bus arrays is achieved using cables tensioned to compensate for thermal variations and provide preload to maintain the natural frequency of the bus array above that of the satellite.

The acquisition and jumper buses are attached to opposite sides of the beam just below the cap members. The switch gear assemblies are supported on platforms attached to the lower cap member and braced with additional members from the upper cap members. Connections are made from the acquisition bus to the switch gear. Installation of the switch gear assemblies takes place after the beam is completed.

The maintenance concept shown provides a separate maintenance track beam underneath the solar arrays which parallels the main and feeder bus locations. This track provides a working base for bus maintenance equipment to travel upon. The requirement for a dedicated maintenance track can also be satisfied by expanding upon the updated beam builder substation concept which installs solar array maintenance track during the beam fabrication process.

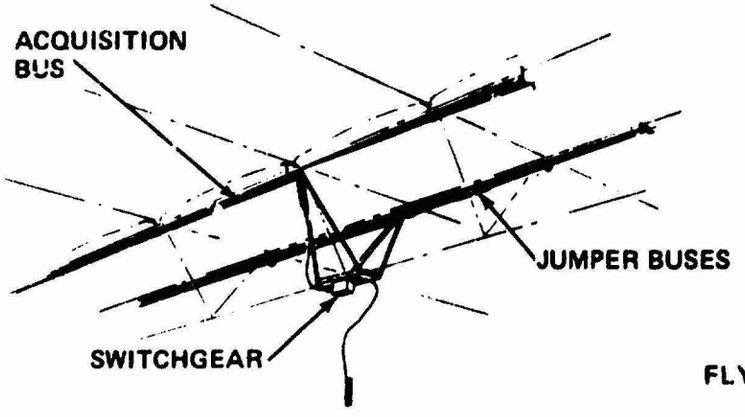
POWER DISTRIBUTION SYSTEM INSTALLATION REQUIREMENTS



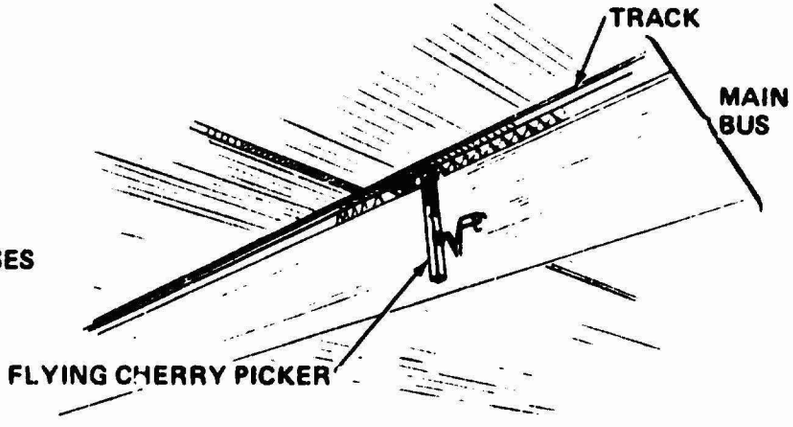
MAIN & FEEDER BUS

- TENSION PRELOAD
- COORDINATE WITH CONSTRUCTION PROCESS

POWER COLLECTION/DISTRIBUTION



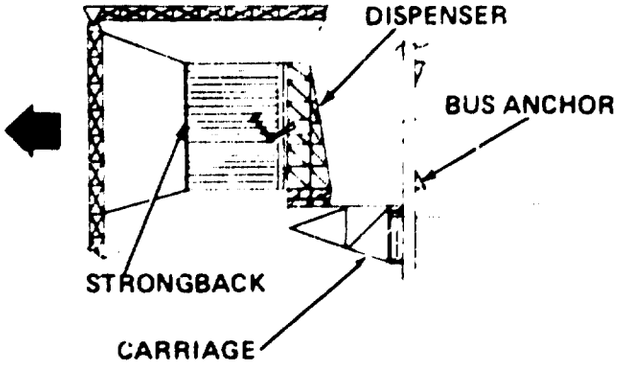
BUS MAINTENANCE TRACK



MAIN BUS INSTALLATION SEQUENCE

The main bus installation sequence shown on the next two pages depicts the primary steps in the main bus installation procedure which occurs during the first construction pass. These steps are essentially the same for the feeder bus installation with the exception of the "hand-off" requirement. The sequence shown repeats for 4 bay lengths. At the end of every fourth bay, the main bus installation is interrupted and the feeder bus installation is accomplished. Main bus installation is then resumed for another 4 bays. The supply of main and feeder bus strips must be programmed to supply the correct selection of A and B power bus strips of the appropriate size and type.

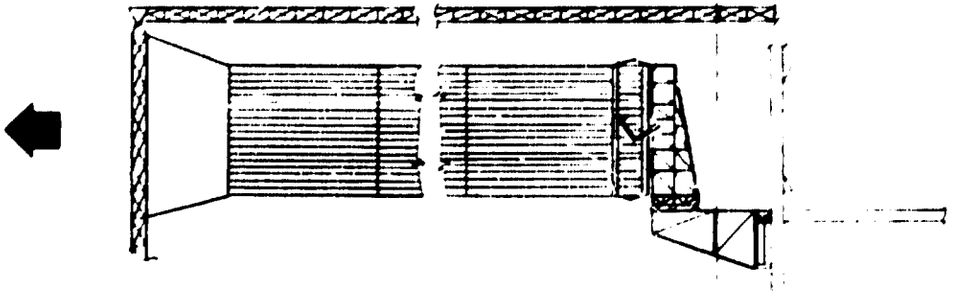
MAIN BUS INSTALLATION SEQUENCE



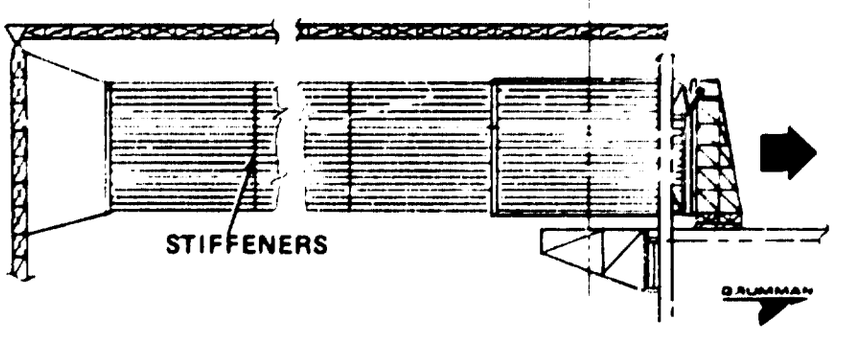
1.
- ATTACH SUPPORT CABLES TO STRUCTURE & STRONGBACK
- BEGIN BUS DEPLOY

2.
- DISPENSE BUS WITH STIFFENERS
- ATTACH NEXT STRONGBACK & BEGIN CABLE DEPLOY

FRAME STATION

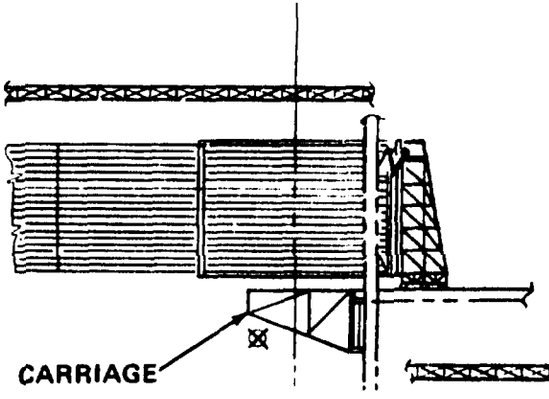


3.
- RETRACT BUS DISPENSER
- INSTALL STRONGBACK
- DISPENSE FLEX LOOP
- HAND OFF CABLES AND BUS TO BUS ANCHORS ON BASE

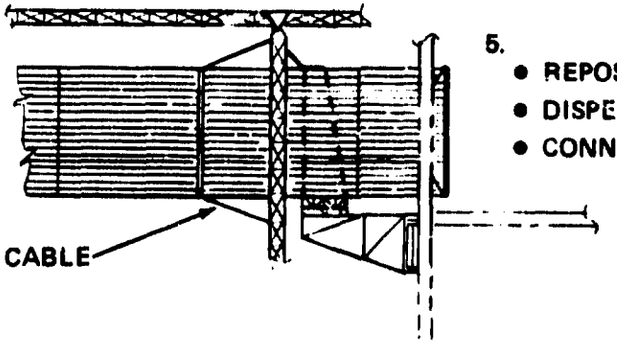


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MAIN BUS INSTALLATION SEQUENCE (CONTINUED)

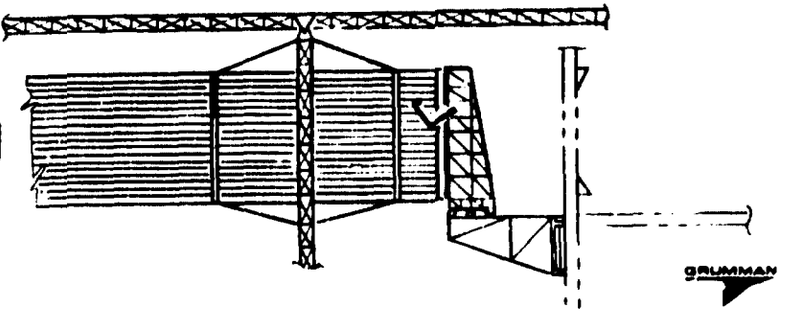


4.
- INDEX CARRIAGE LATERALLY
- CUT DISPENSER/BUS FREE AT ANCHOR SUPPORT



5.
- REPOSITION DISPENSER ON CARRIAGE
- DISPENSE FEEDER BUS WHEN REQD
- CONNECT SUPT CABLES TO FRAME

6.
- RECONNECT DISPENSER TO ANCHORED BUS
- FORM FLEX LOOP
- ATTACH REMAINING SUPT CABLES
- RESUME BUS DISPENSING



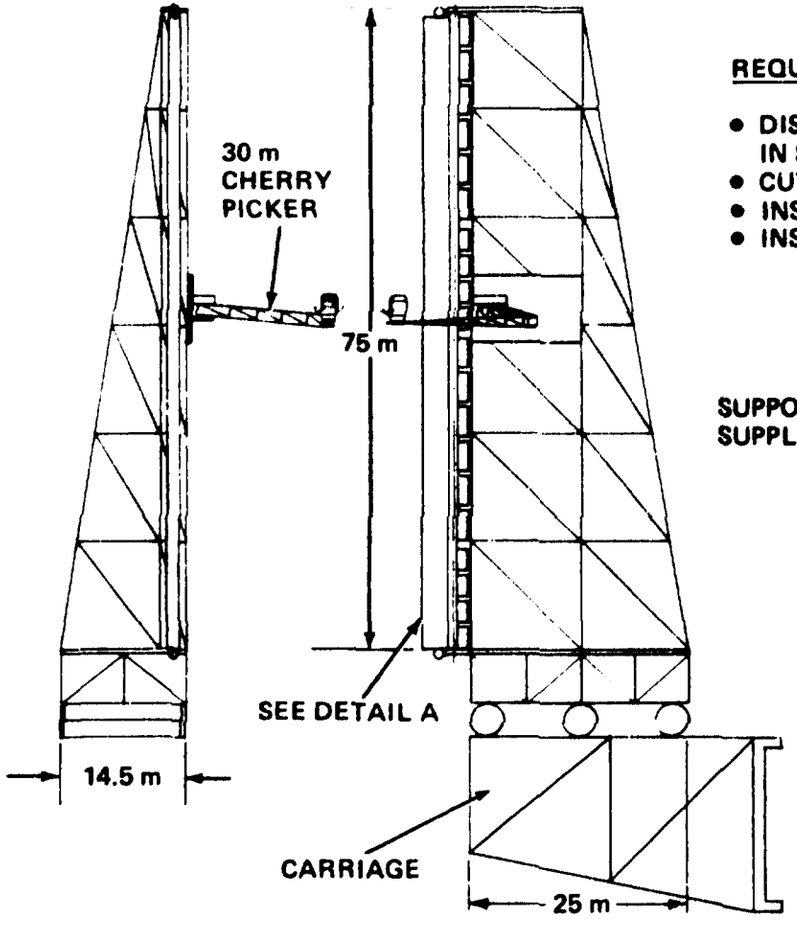
MOBILE POWER BUS DISPENSING STATION

The power bus dispensing station dispenses both main and feeder buses and installs the bus support cables. Individual bus strips are supplied by specific supply cannisters mounted at the back of the dispensing unit. The support cables are supplied by drums mounted on the top and bottom of the dispensing unit. The entire dispensing module pivots to dispense either feeder or main bus as required. The dispensing unit is supported on a base which travels on the main carriage. The main carriage moves the entire assembly from one end of the construction base to the other during feeder bus dispensing.

Aided by a dedicated, mobile cherrypicker, the bus dispensing station installs and preloads the support cables on the bus array as part of the dispensing operation. The support strongbacks and intermediate stiffeners are installed while the bus array is still secured by the dispensor. The dispensing station provides the correct mix of bus array elements to meet main and feeder bus requirements in the correct sequence in the construction process. The dispensing station can cut and splice bus material as required.

During main bus dispensing operations, the dispensing station is positioned at one end of the construction base.

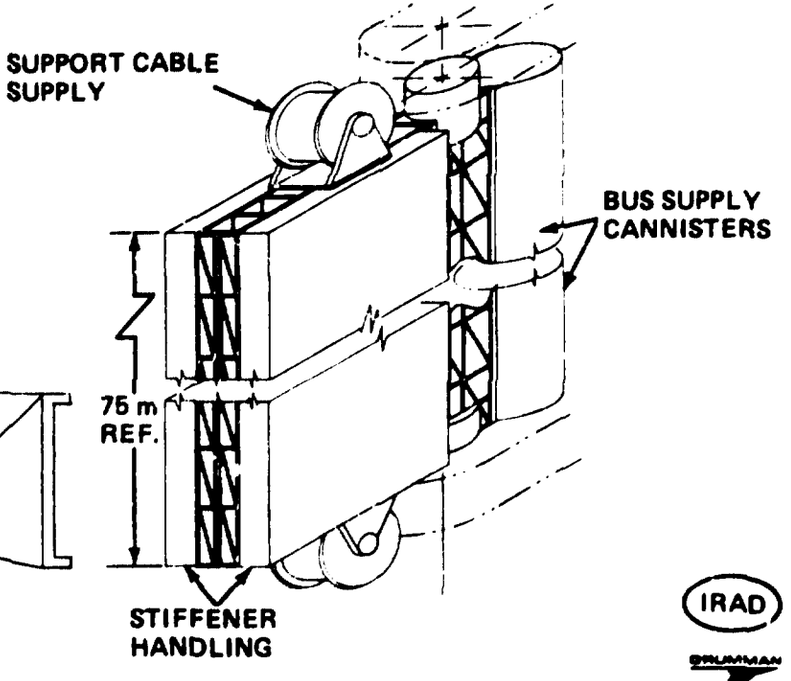
MOBILE POWER BUS DISPENSING STATION



REQUIREMENTS

- DISPENSE MAIN & FEEDER BUSES IN SEQUENCE
- CUT AND SPLICE BUS MATERIAL
- INSTALL STIFFENERS & STRONGBACKS
- INSTALL AND PRELOAD CABLES

DISPENSER DETAIL A



IRAD

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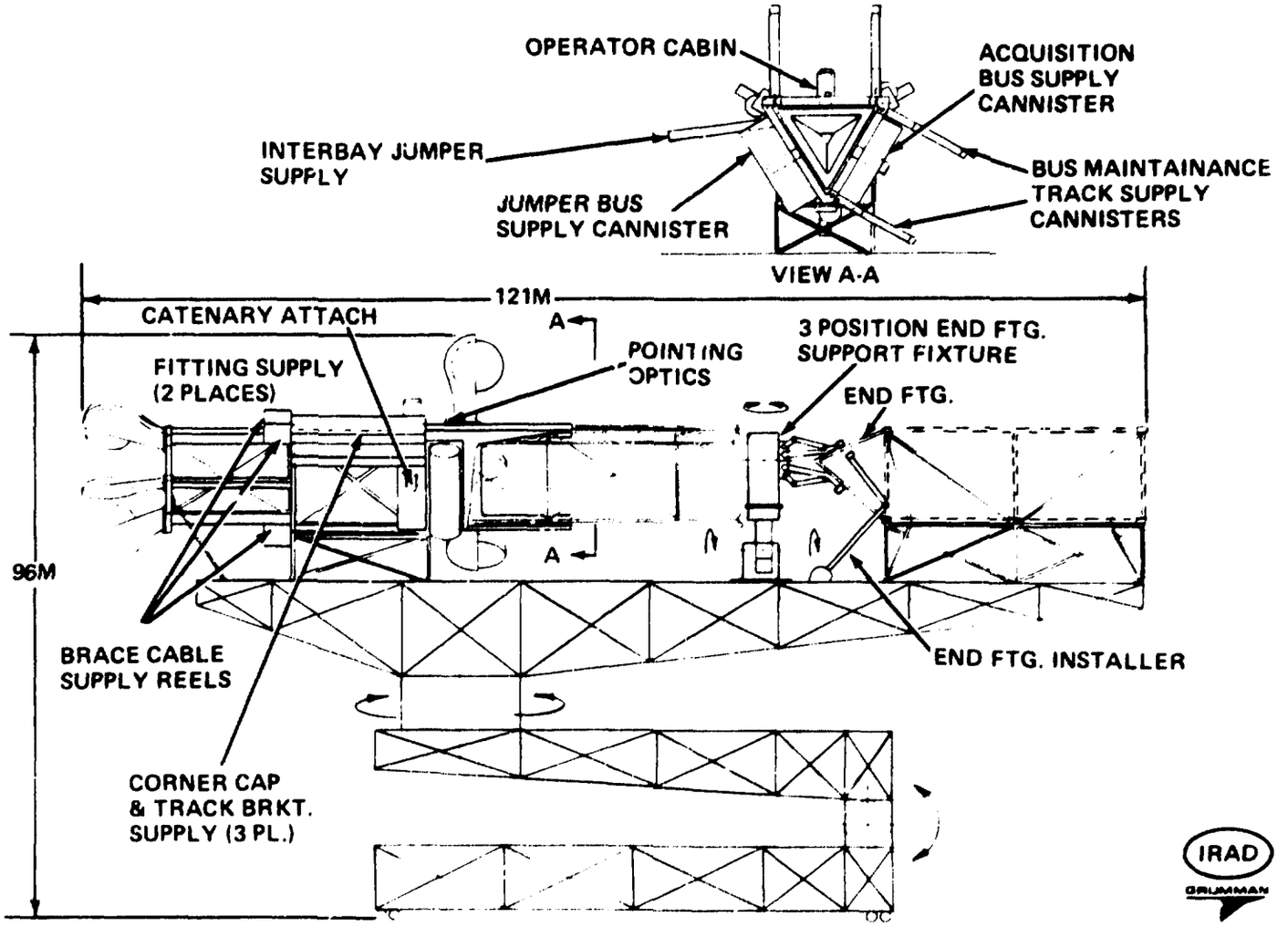
1622-062W

12.7m BEAM BUILDER/ACQUISITION BUS SUB-STATION

The 12.7m beam builder concept shown has multiple functions in addition to the basic beam fabrication:

- The entire sub-station platform can be oriented to direct the fabricated beam as required.
- Maintenance tracks are installed on the beam top and one side during beam fabrication.
- An end fitting fixture can take pre-fabbed end fittings from a supply cannister and install them on either end of the beam with the aid of the end fitting installer.
- Acquisition and jumper buses are installed during beam fabrication as needed.
- Catenary attach fittings and S/A interbay jumpers are installed during beam fabrication.
- A support platform equipped with indexers holds the beam to maintain alignment during fabrication and end fitting installation and aids in positioning the completed beam.

12.7 m BEAM BUILDER/ACQUISITION BUS SUBSTATION

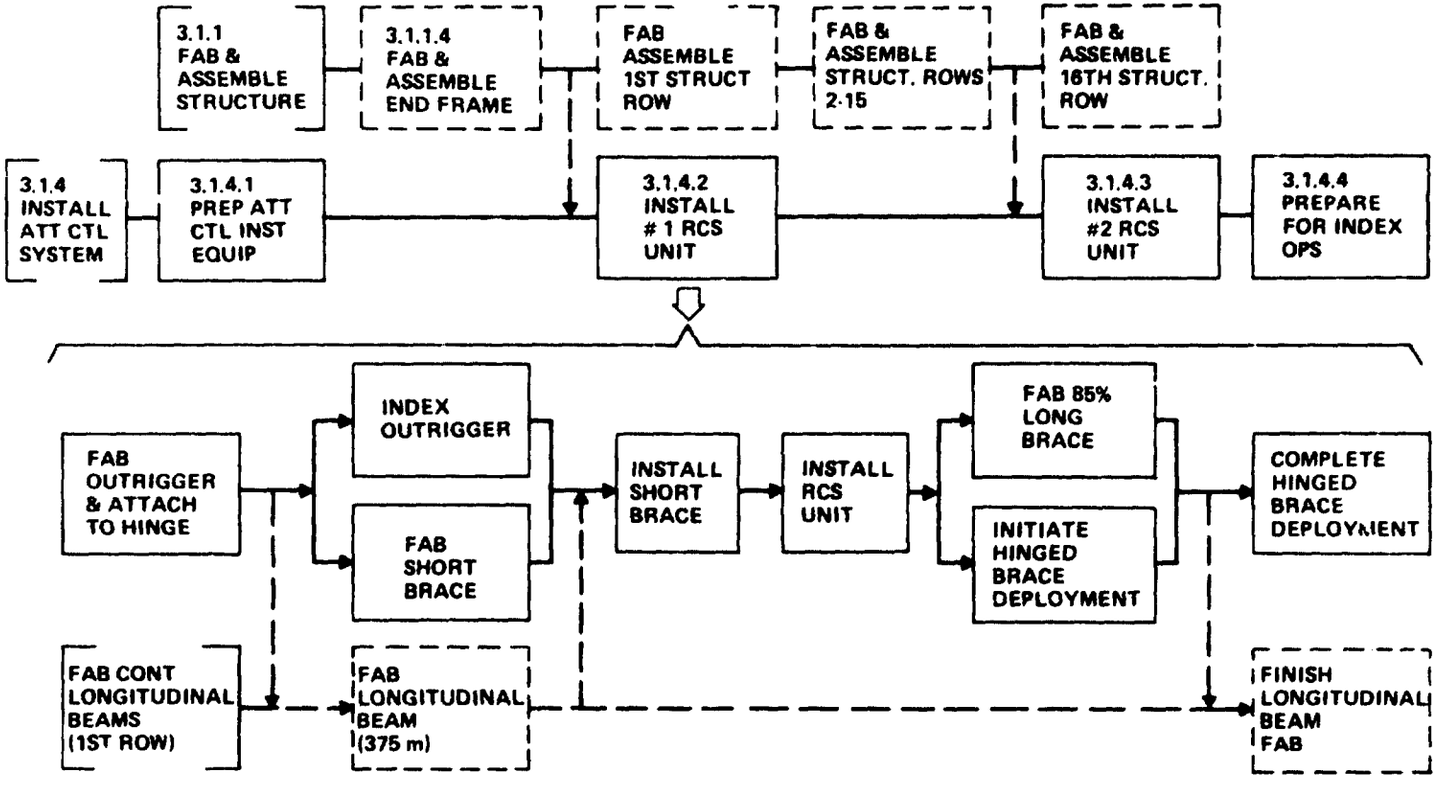


1622-040W

SPS ATTITUDE CONTROL SYSTEM ASSEMBLY FLOW

The attitude control thrusters are assembled and installed in parallel with the fabrication and assembly of the first and last structural row of the energy conversion system, as shown on the facing page. The sequence of assembly operations, shown at the bottom of the page are identical for the installation of all four thrusters.

SPS ATTITUDE CONTROL SYSTEM ASSEMBLY FLOW



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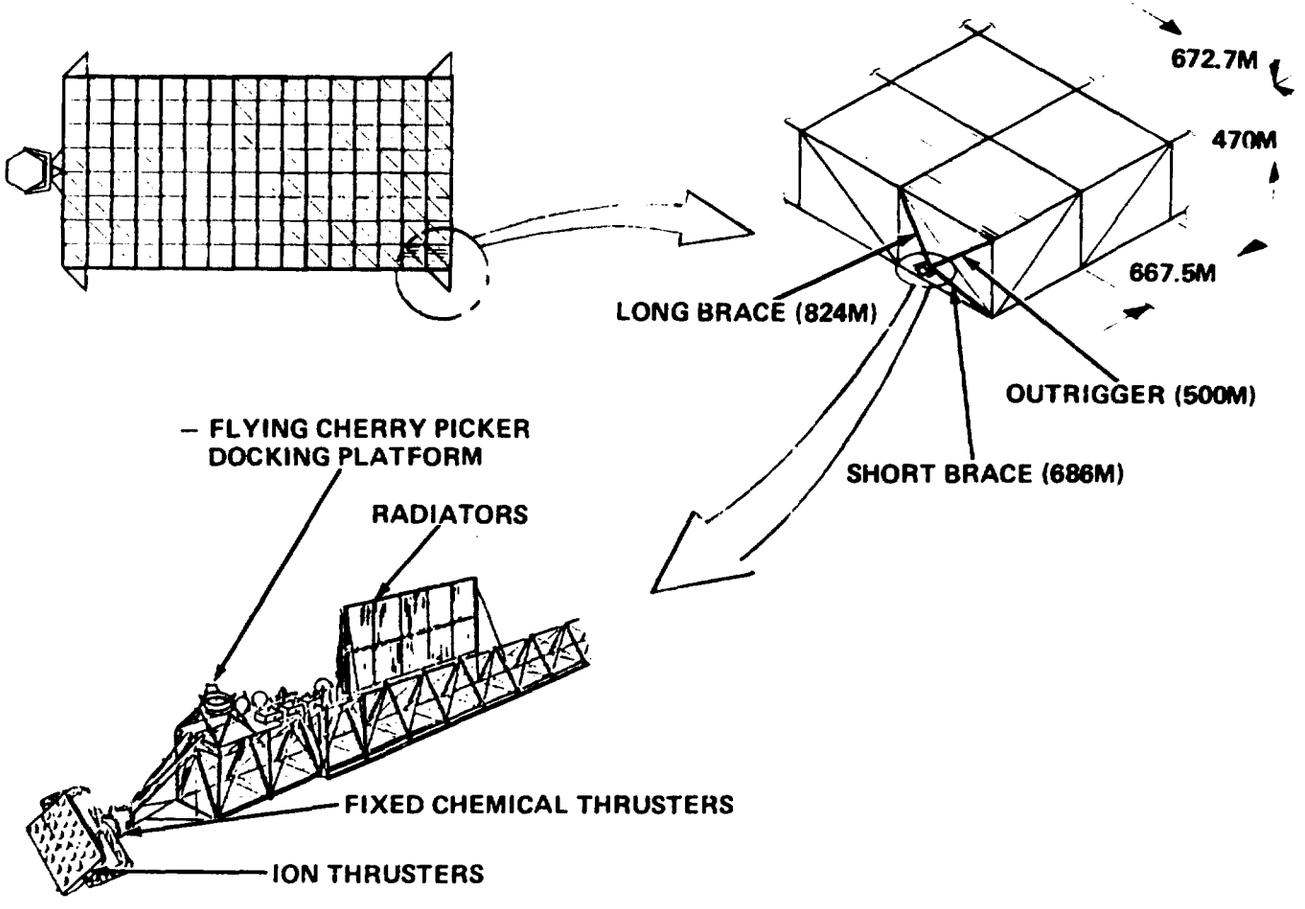
1622-015

SPS ATTITUDE CONTROL SUPPORT REQUIREMENTS

The attitude control system includes all operational elements and software required to establish attitude control of the operational SPS satellite upon release from the GEO construction base and to maintain proper attitude and orbit station keeping during the operational life of the satellite. As shown on the facing page, this includes an ion thruster (with a chemical propulsion backup system for control during equinoctal occultation or unexpected loss of electric power) at each corner of the satellite.

Each thruster is mounted on a 500m *outrigger* that is positioned as an extension of a 12.7m lateral beam of the energy conversion system structure. The outrigger is supported by a 686m *short brace* from the lower continuous longitudinal beam and an 824m *long brace* located in the plane of the upper surface of the structure.

SPS ATTITUDE CONTROL SUPPORT REQUIREMENTS



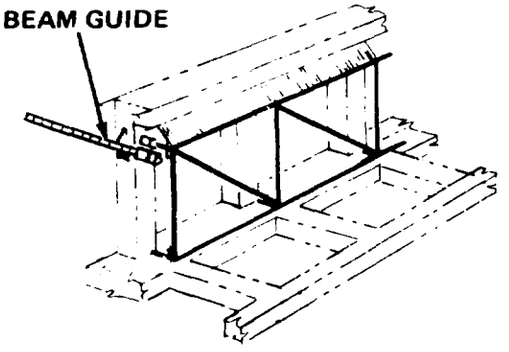
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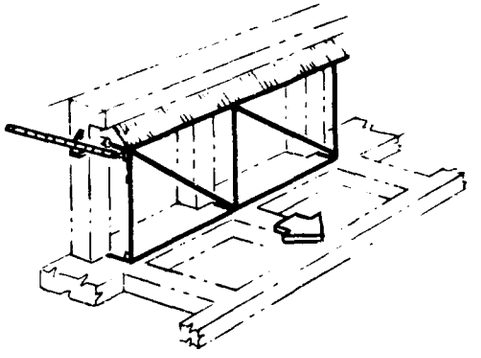
ATTITUDE CONTROL THRUSTER ASSEMBLY – INSTALLATION

The braces, which support the attitude control thruster assembly, are all fabricated by the 7.5m upper mobile beam machine. As shown on the facing page, fabrication begins with the beam machine facing to the rear of the construction base and fabricating the 500m outrigger. Upon completion of fabrication, the outrigger is attached to the end frame hinge. Subsequent fabrication of 350m of the continuous longitudinal beams will cause the outrigger to be indexed forward the same distance. After fabrication of the 686m short brace and its attachment to the end frame hinge and to the outrigger, the thruster assembly is installed on the rear 150m of the outrigger. After attaching the end fitting, protruding from the mobile beam machine, to the end of the outrigger, fabricating 85% of the long brace will cause the outrigger and short brace to swing outward, away from the structure. Completion of the 672.7m of the longitudinal beam fabrication and the long brace fabrication will complete the outward swing of the outrigger. The final step is to detach the long brace from the beam machine and attach it to the longitudinal beam.

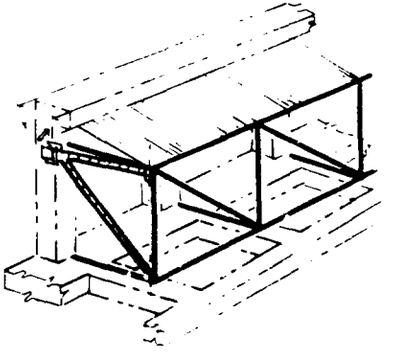
ATTITUDE CONTROL THRUSTER ASSEMBLY – INSTALLATION



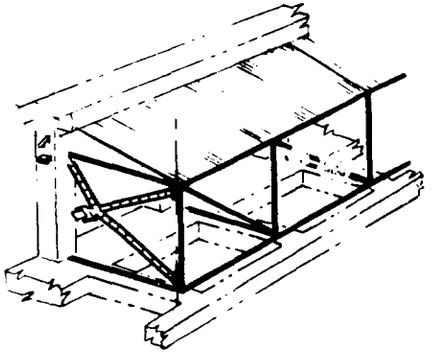
- FAB & GUIDE 500M OUTRIGGER BEAM



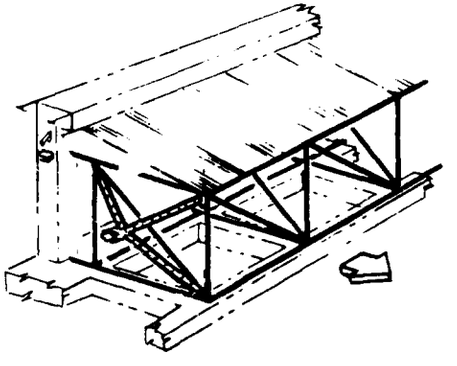
- ATTACH OUTRIGGER BEAM TO END FRAME HINGE FTG.
- FAB LONG'L BEAMS ~ 350M



- STOP LONG'L BEAM FAB
- FAB & HINGE 686M SHORT BRACE
- JOINED HINGED BEAMS INSTALL THRUSTER ASSEMBLY



- FAB LONG BRACE (PARTIAL-85%) & DEPLOY HINGED BEAMS



- COMPLETE LONG'L BEAM FAB (672.7M)
- COMPLETE LONG BRACE BEAM & ATTACH TO NEXT FRAME

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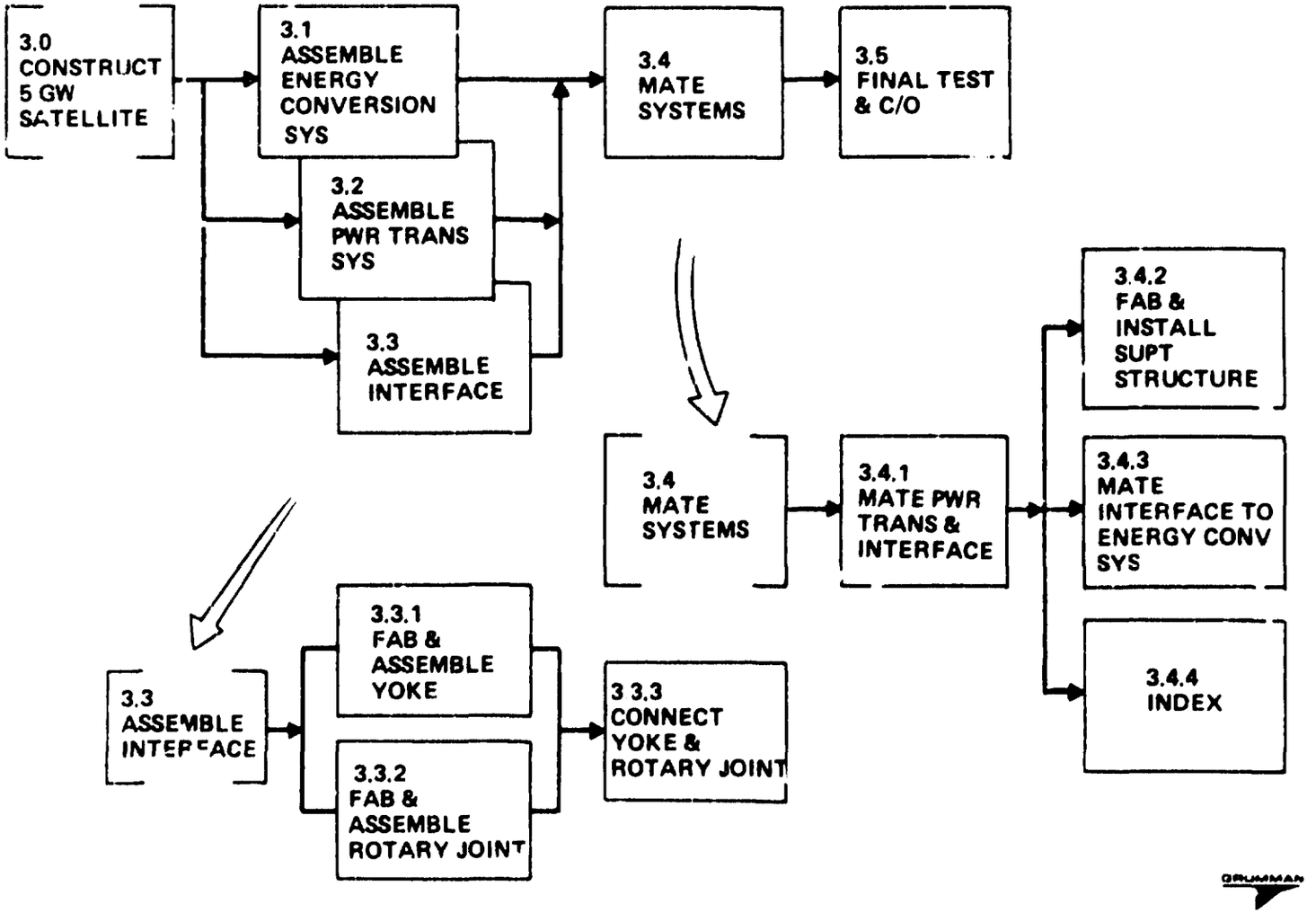
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INTERFACE ASSEMBLY & SYSTEMS MATING FLOW

SPS construction operations are analyzed from the top down, by defining the construction sequence at each level of operation. At the top level, construction of the 5-GW reference satellite includes parallel assembly of the energy conversion, power transmission and interface systems, followed by mating of the assembled systems and the final test and checkout of the complete solar power satellite. A further breakdown of the assembly operations for the interface system and the mating operations for the assembled systems is shown on the facing page.

The assembly of the interface (Block 3.3) includes the parallel fabrication and assembly of the yoke and rotary joint in Blocks 3.3.1 and 3.3.2 and their subsequent integration by the Block 3.3.3 operations. The completed interface system is then mated to the power transmission system in Block 3.4.1 and to the energy conversion system in Blocks 3.4.2 through 3.4.4, which include the fabrication and assembly of the yoke support structure and the concurrent lateral indexing operations.

INTERFACE ASSEMBLY & SYSTEMS MATING FLOW



1622 017W

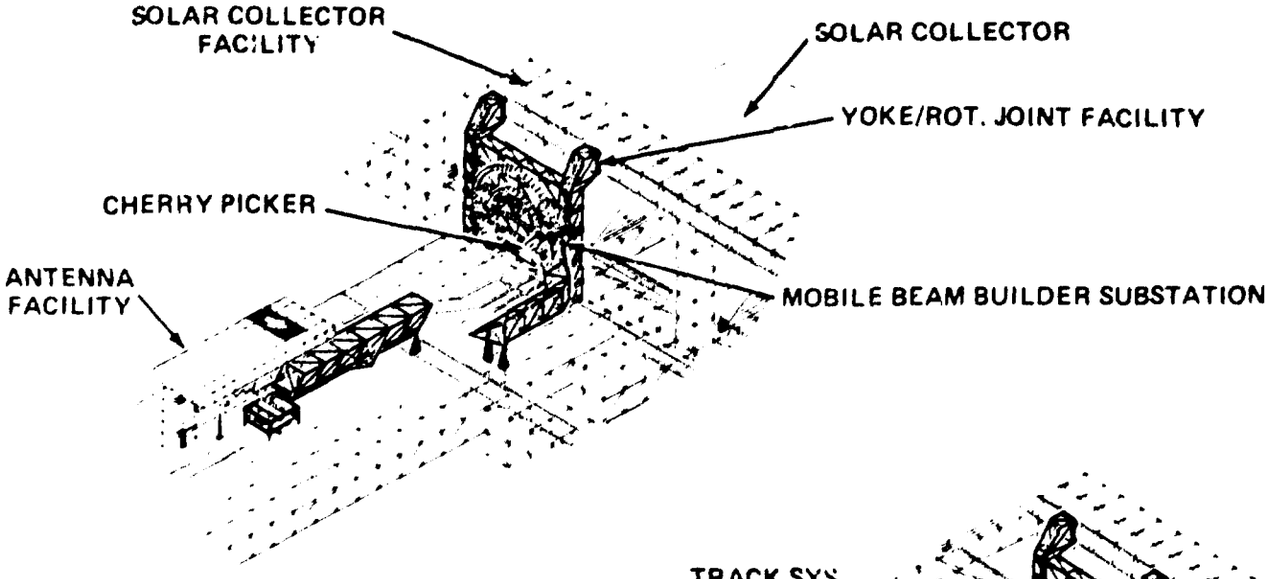
YOKE/ROTARY JOINT ASSEMBLY

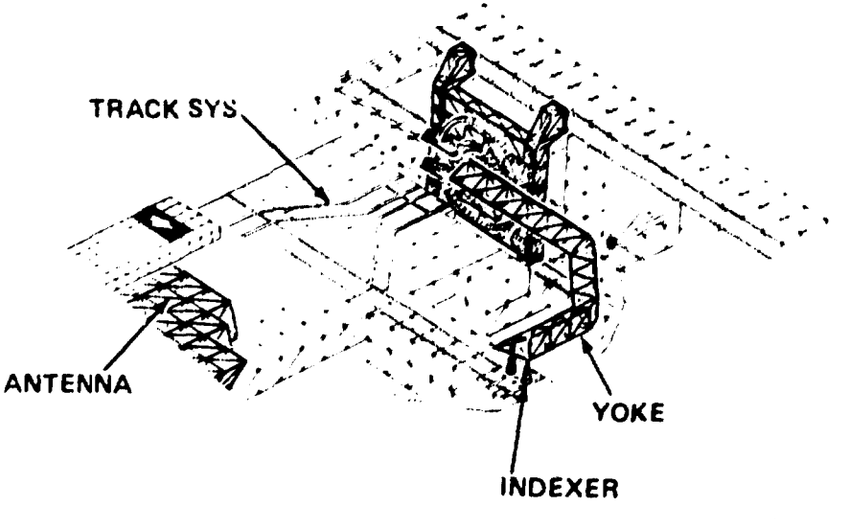
The antenna support yoke assembly sequence is shown on the next two facing pages. The same construction facility used for the rotary joint is used to fabricate and position the support yoke. The entire yoke is fabricated at the final installed level using tall indexers to support the completed sections during the fabrication process. The yoke structure is fabricated using 7.5m beam builder sub-stations mounted on the face of the construction facility. The structure is composed of individual beam elements. The beam handling is accomplished using cherry pickers on the face of the construction facility and on the antenna construction levels as required.

In the first view opposite, the indexer supports are shown moving the completed portion of the yoke along diagonal tracks as the first diagonal leg nears completion. The construction facility is indexed to the left and supports the yoke end where fabrication is in progress.

The second view shows the support indexers moving laterally as the construction facility moves to the right to position the completed yoke sections in their final location and fabrication of the main cross member proceeds. During this phase of fabrication, the main cross member is supported on the construction facility.

YOKE/ROTARY JOINT ASEMBLY





- START ANTENNA FAB
- FAB YOKE IN PARALLEL

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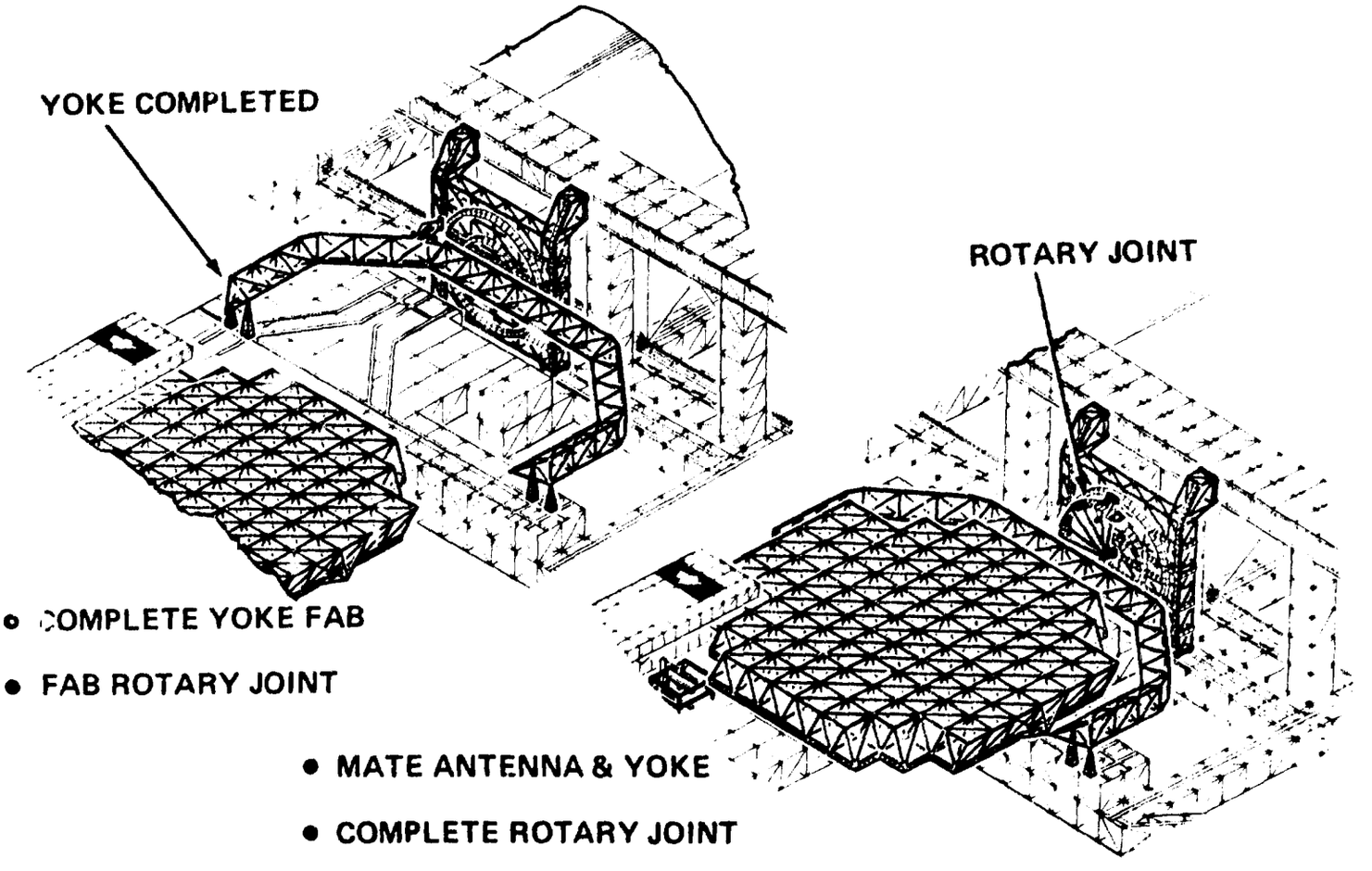
YOKE/ROTARY JOINT ASSEMBLY (CONTD)

The final stages of yoke/rotary joint construction are shown on the facing page.

In the first view opposite, the yoke is shown completed and positioned ready to receive the antenna. The construction facility was positioned to the left to complete fabrication of the remaining yoke sections.

In the second view the antenna and yoke have been mated and the yoke, supported entirely by the indexer supports has been separated from the construction facility. The facility is now free to begin fabrication of the rotary joint.

YOKE/ROTARY JOINT ASSEMBLY – CONTINUED

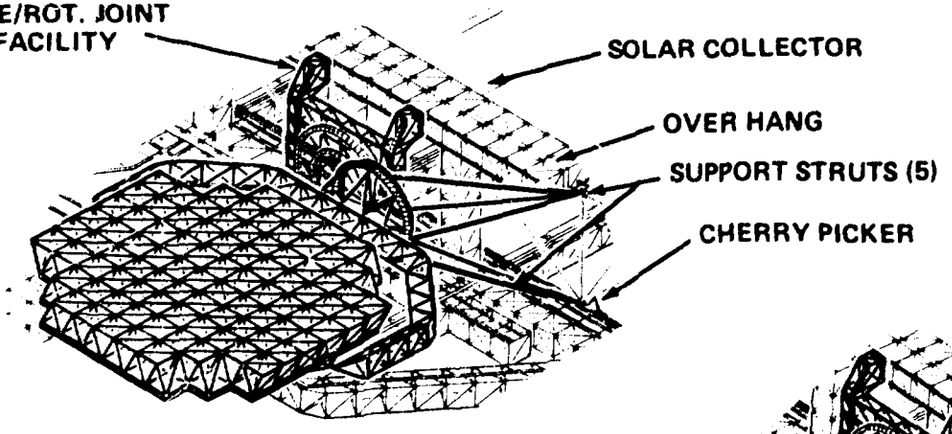


- COMPLETE YOKE FAB
- FAB ROTARY JOINT
- MATE ANTENNA & YOKE
- COMPLETE ROTARY JOINT
- FAB & INSTALL YOKE/ROT. JOINT STRUTS
- INSTALL BUS

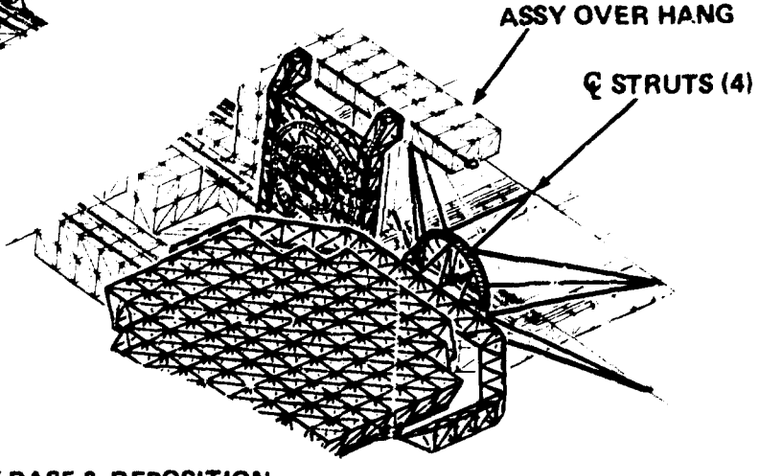
FINAL SYSTEM MATING

With the completion of both the antenna/yoke/rotary joint assembly and solar collector assembly the final mating of antenna and collector must be made. To accomplish this mating the following operations have been established. First the base is indexed to the solar collector antenna support strut pick-ups as shown in facing page illustration. Next the antenna assembly (antenna, yoke, rotary joint) is indexed to align with the collector, and the yoke facility is positioned. Two (2) mobile 7.5m beam builder sub-stations mounted on the yoke facility initiate the fabrication of the outboard support struts (5). These stations align the beam fabrication with the collector-pick up point areas where cherry pickers mounted on the collector facility wait to capture and attach the fabricated struts to the collector attach fittings. The yoke facility mobile cherry picker perform this same operation in attaching the strut end to the rotary joint pick-up fitting. This procedure is repeated until all five outboard struts are installed. Next the base is re-indexed and the yoke facility is repositioned to fabricate and install the four center line struts. After the struts have been installed the solar collector power buses are routed along and attached to these struts and final power bus hook-up is made between antenna and collector. With the power bus installation completed the base and yoke facility are again relocated to align with the five (5) remaining strut pickups and the operations are repeated for the fabrication and installation of these antenna support struts. The remaining operations are those for final satellite checkout.

FINAL SYSTEMS MATING

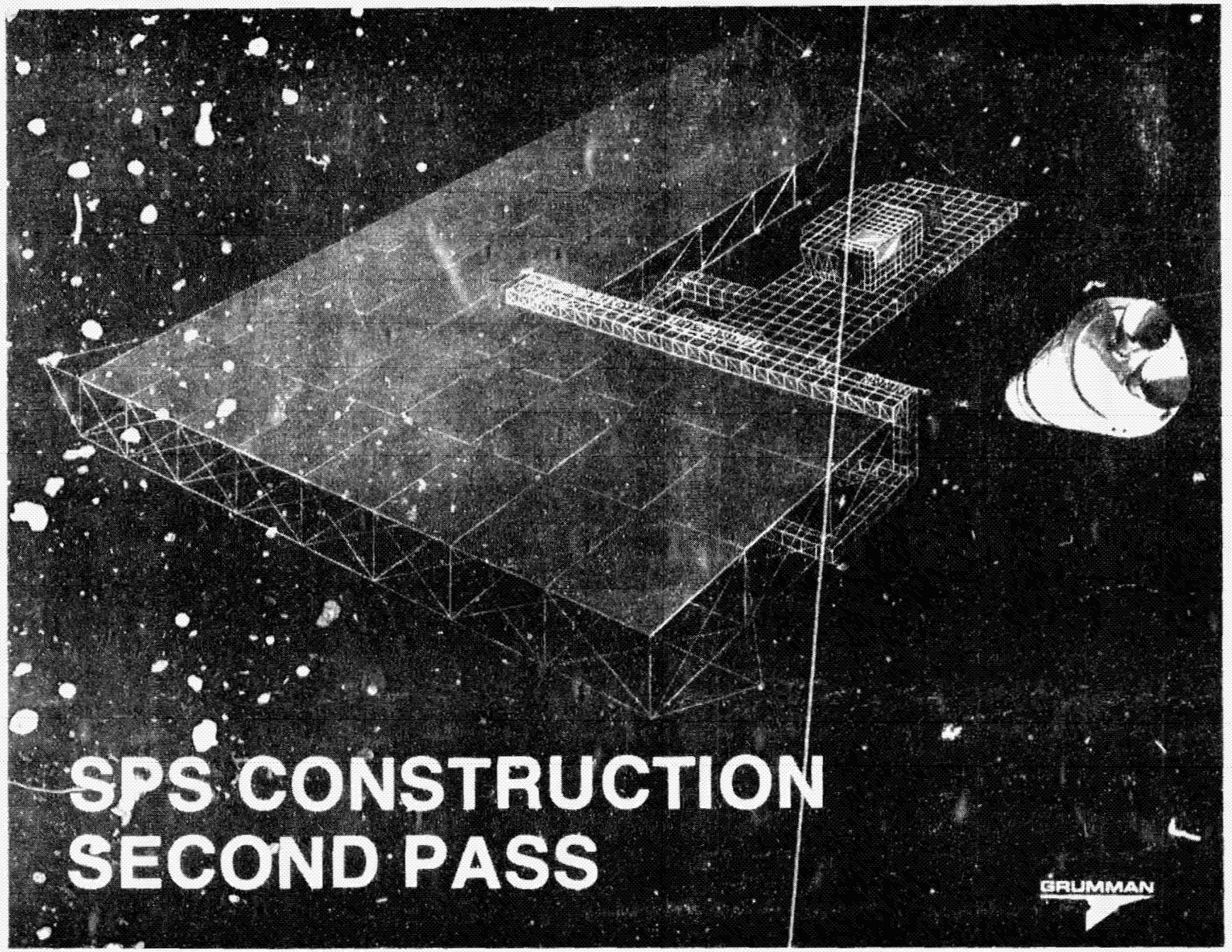


- INDEX BASE TO SOLAR COLLECTOR PICKUP
- INDEX ANTENNA TO ALIGN WITH COLLECTOR
- POSITION YOKE FACILITY TO FAB & INSTALL SUPPORT STRUTS

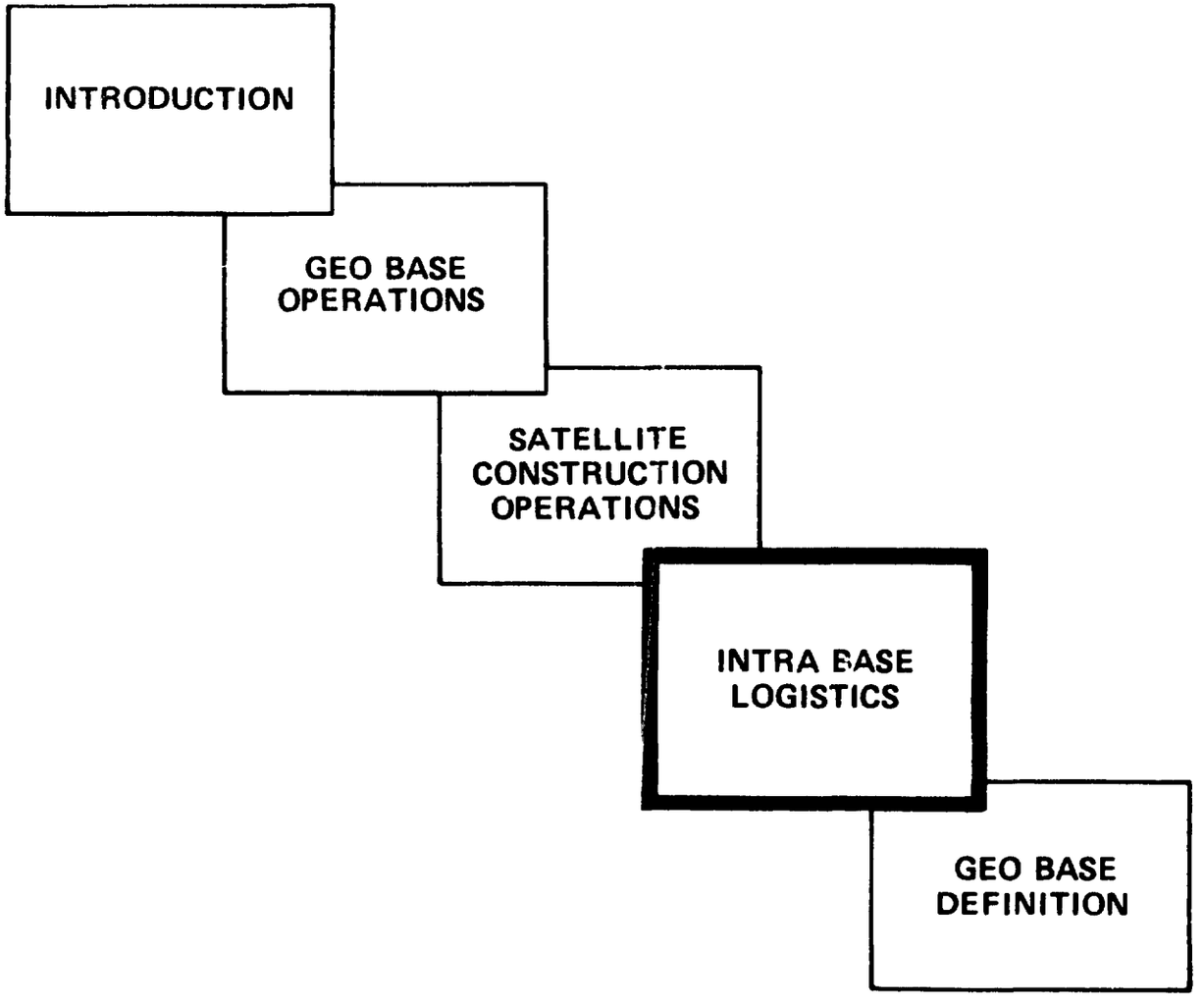


- RE-INDEX BASE & REPOSITION YOKE FACILITY TO FAB & INSTALL REMAINGING (9) SUPT. STRUTS
- INSTALL PWR BUS
- PREP FINAL C/O

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OF POOR QUALITY


INTRODUCTION
GEO BASE OPERATIONS
SATELLITE CONSTRUCTION OPERATIONS
INTRA BASE LOGISTICS
GEO BASE DEFINITION

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GEO BASE LOGISTIC SUPPORT REQUIREMENTS

The GEO Base, in addition to building the SPS, must fulfill strenuous logistic support requirements.

Every thirteen days an EOTV will arrive with large Cargo Pallets. A dedicated area must be available at the GEO Base to transfer this material on board in a quick and efficient manner. At the same time, empty pallets have to be removed from the base. As soon as the Cargo Pallets are landed, they have to be moved to an unloading/sorting area and processed through the subassembly factory. To accomplish this, an efficient transport system must be available. Level J, the top deck of the base, provides 6.1 Km of main line track and 5.1 Km of connecting spur lines.

The base has to rotate the 827-man crew at planned intervals. All these people have to be housed comfortably and transported to their assigned work stations each day. Each time a new crew is brought up, resupplies must also be provided.

The other function of the base is to serve as a home base for service of all outlying SPS stations. Defective material on the SPSs must be replaced, brought back to the base and reconditioned. The refurbished material is stored until needed as replacement parts on the next visit to the SPS stations.

GEO BASE LOGISTIC SUPPORT REQUIREMENTS

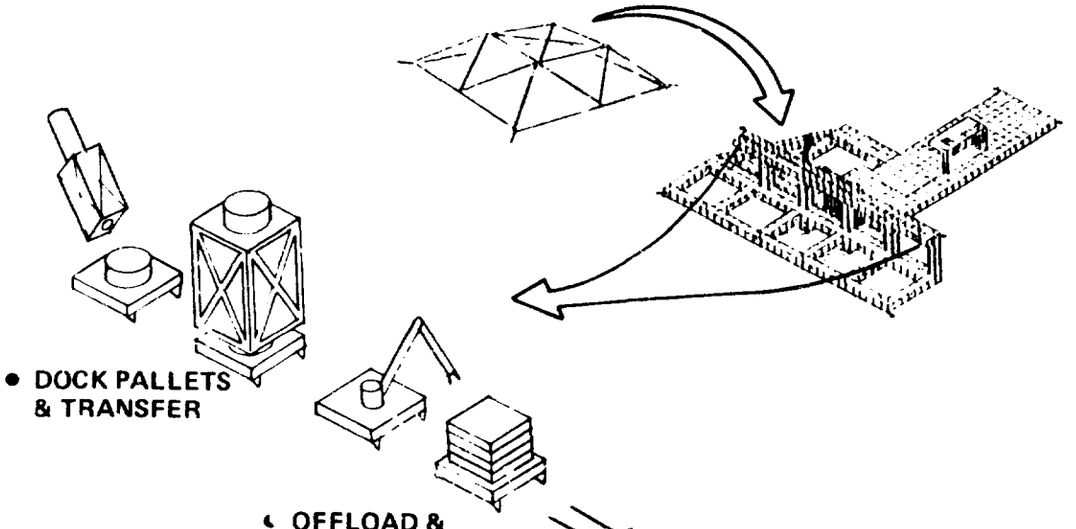
- EOTV CARGO DELIVERY
  - 4000 MT UP & 200 MT DOWN/FLIGHT - EVERY 13 DAYS
  - OPERATE & SERVICE 2 CARGO TRANSFER TUGS
  - DOCK & UNLOAD 10 TO 20 CARGO PALLETS
  - PROVIDE PALLET TRANSPORTERS
- POTV GEO CREW ROTATION
  - ROTATE UP TO 75-80 PEOPLE/FLIGHT @ 15-DAY INTERVALS
  - MAINTAIN TRANSIENT CREW QUARTERS
  - DOCK 4 POTVs & PROVIDE INTRA-BASE CREW BUSES
- SPS OPERATIONAL MAINTENANCE SUPPORT (PER 20 SATELLITES)
  - LOAD/UNLOAD SPS COMPONENT RACKS @ 4½-DAY INTERVALS
  - MAINTAIN RECONDITIONED & DEFECTIVE COMPONENT STORAGE
  - DOCK & SERVICE SPS MAINT FLEET (4 OTVs & 4 PAYLOADS)
  - MAINTAIN KTM/COMPONENT REFURB FACILITIES
  - PROVIDE CREW HABITATS

CARGO HANDLING & DISTRIBUTION FLOW

EOTV cargo is transferred to the GEO base by a dedicated cargo tug. A tug lifts a cargo or KTM pallet from the EOTV and flies it over to the base cargo docking area, as shown on the facing page. Construction materials, base supplies, OTV supplies and SPS maintenance parts are unloaded onto waiting railroad flat cars adjacent to the docking area. The loaded flat cars are moved onto mainline track to one of five (5) cargo staging areas. When required, the flat car, loaded with construction materials, is moved out of the staging area onto either forward or aft facing vertical elevators. The aft elevators move down to the interface and antenna construction level, whereas the forward elevators move down to energy conversion assembly substations. Other supplies would be moved directly to the appropriate area on level J.

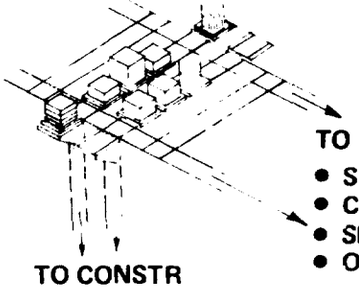
The docked cargo pallets are moved (on its docking pad) to the unloading area which is capable of storing 20 pallets. Mobile 40 meter MRWS cranes are located between each row of parked pallets; they are unloaded in the area onto the empty cargo pallets, are moved back to the docking area where a tug docks to the top of the pallet. The tug lifts the empty pallet off the railroad docking pad and flies it back to the parked EOTV.

GEO BASE CARGO HANDLING & DISTRIBUTION FLOW



- DOCK PALLETS & TRANSFER
- OFFLOAD & DISTRIBUTE
  - CONSTR MATL
  - BASE SUPPLIES
  - OTV SUPPLIES
  - SPS MAINT PARTS

CARGO STAGING AREA



TO
- SUBASSY FACTORY
- CREW OPERATIONS
- SPS MAINT SUPT
- OTV SERVICING

TO CONSTR SITES

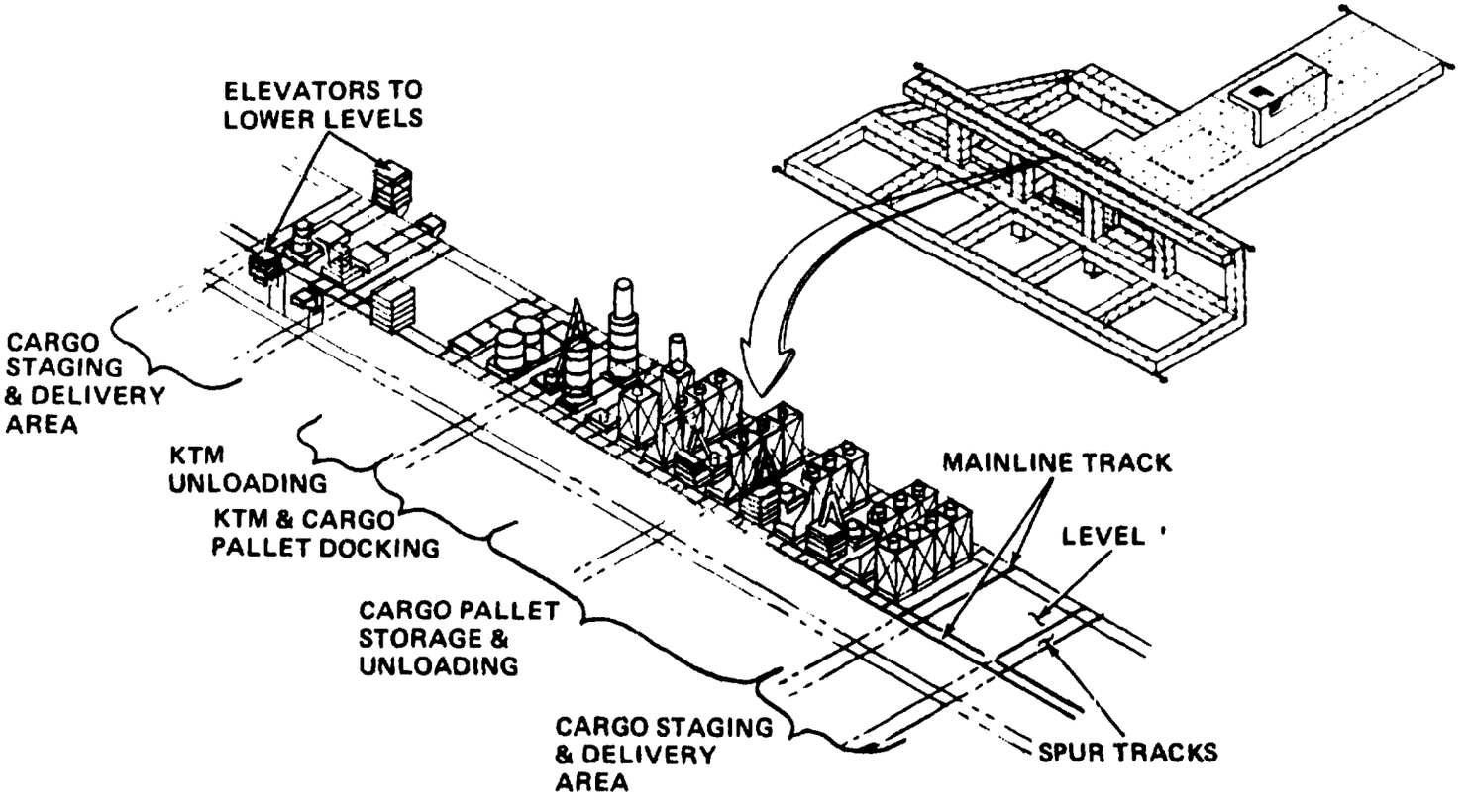
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LEVEL J CARGO DOCKING/UNLOADING/SORTING CENTER

The cargo brought from LEO via the EOTV is delivered to the area for storage and processing. KTM pallets and cargo pallets are flown from the EOTV by cargo tugs. Special railed flatcars with docking mechanism are located in the docking center. A four-man control center (not visible on sketch) is located between the six docking pads. Two are configured to dock KTM pallets, two for cargo pallets, one for a spare tug and the last one is a spare docking pad. After the KTM pallets are docked, they are unloaded with the 75 meter crane onto waiting railroad flat cars. From here they are moved to one of the three (3) staging areas for eventual delivery to antenna levels 'K' & 'L'. The cargo pallets remain on the docking pad and are railed to the unloading area. Five (5) rows (4 deep) provide storage for twenty (20) cargo pallets. Forty (40) meter MRWS cranes located between the rows of stored cargo pallets are used to unload the pallets onto waiting flatcars. These flatcars are moved either to one of the five (5) staging areas or to the sub-assembly factory. The loaded flatcars in the staging areas are eventually moved onto the vertical lift elevators for delivery to the lower construction levels.

The empty cargo pallets are moved back to the docking area. An unused tug docks to the cargo pallet and lifts it off level J base for return to the EOTV station keeping 4 to 5 Km away.

LEVEL "J" - CARGO DOCKING/UNLOADING/SORTING CENTER

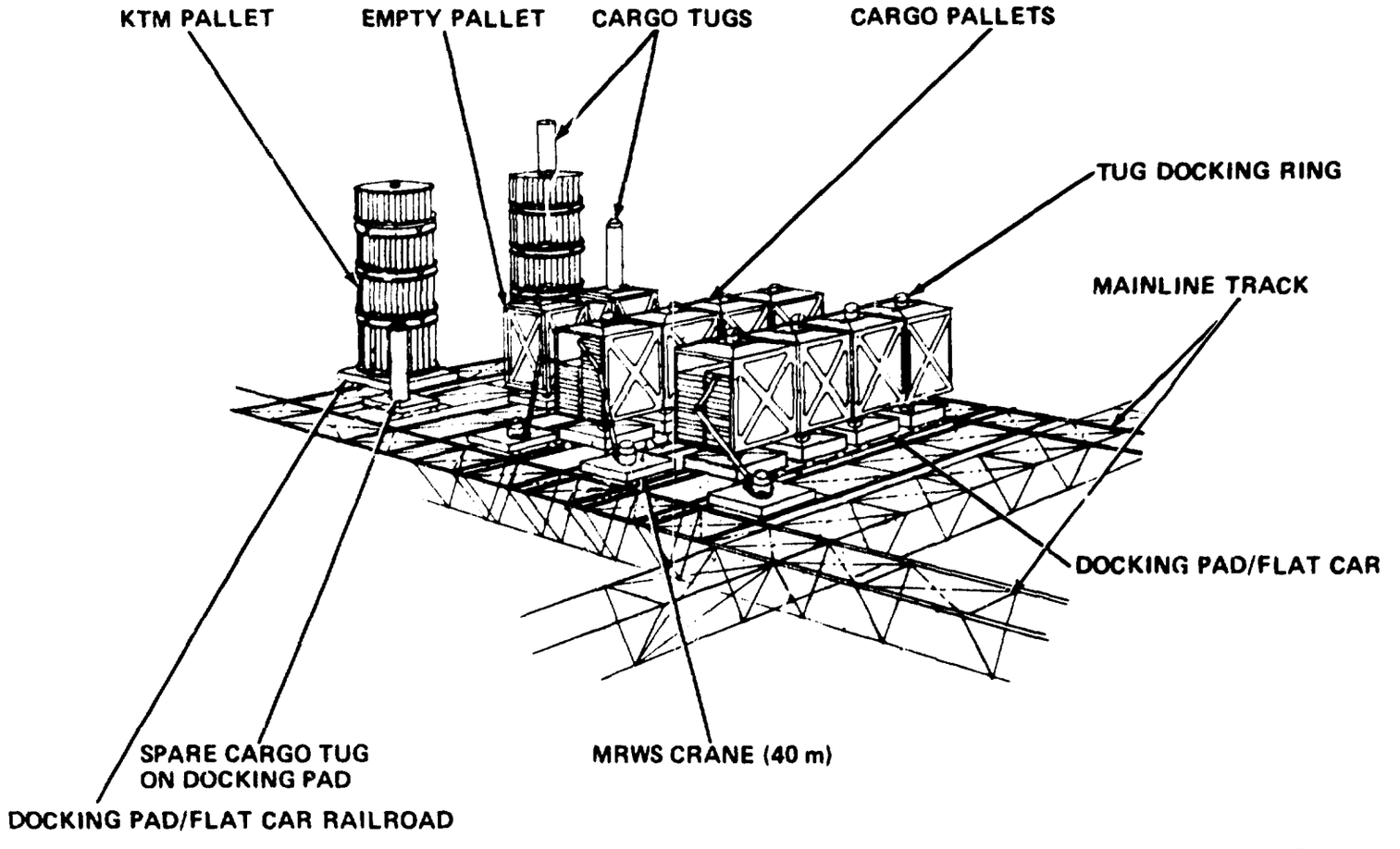


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CARGO UNLOADING & SORTING OPERATION

The facing page illustration depicts more detail presentation of the unloading and sorting activitiy described on the previous page.

CARGO UNLOADING & SORTING OPERATION



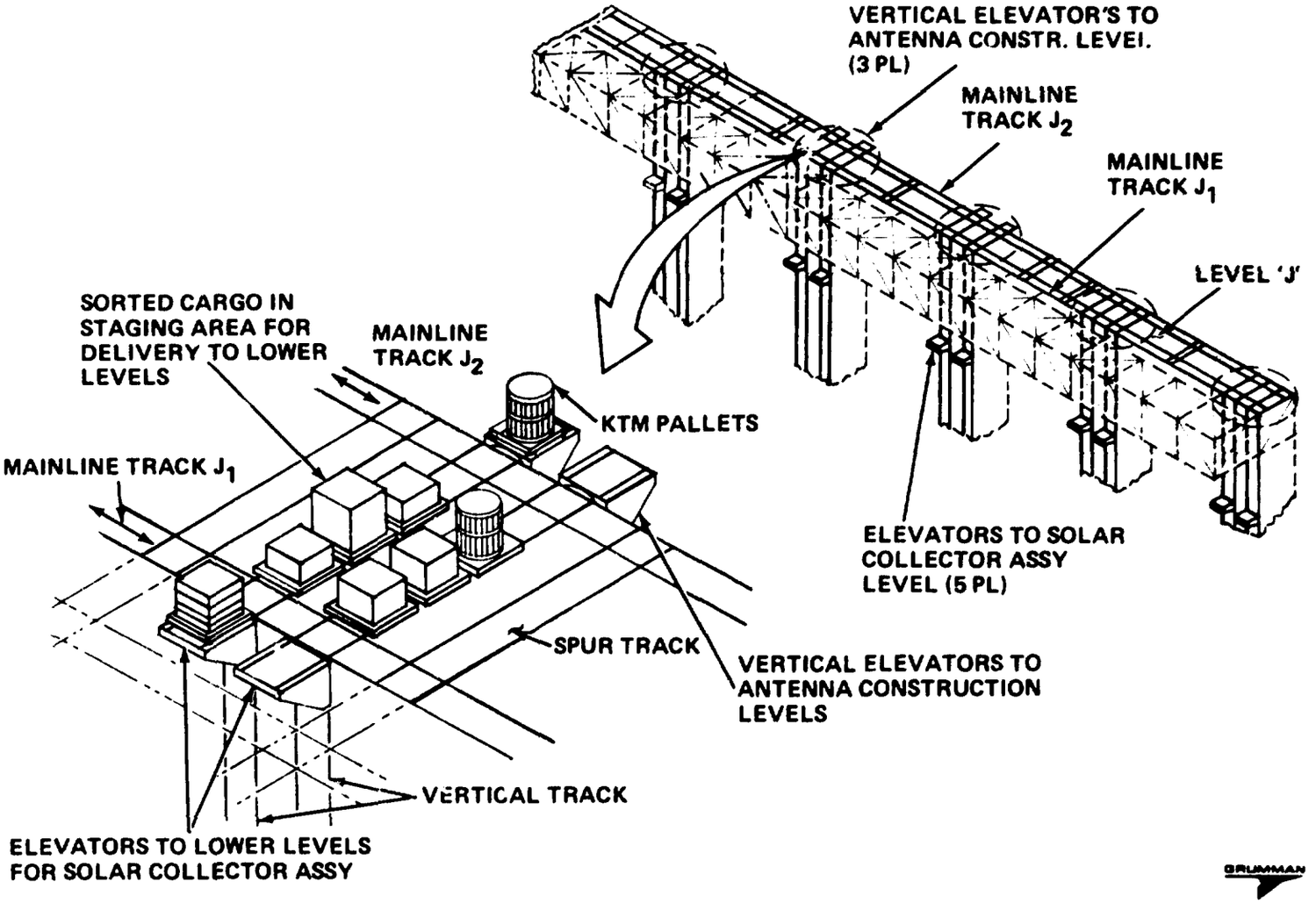
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CARGO STAGING & DISTRIBUTION SYSTEM

All material delivered from LEO is delivered to the cargo docking area. From there it is moved in its pallet to the unloading area. Waiting MRWS cranes unload the cargo onto waiting flatcar transporters. Those pieces of hardware requiring build up are moved into the subassembly factory. The sorted hardware and subassembled hardware are then moved to appropriate staging areas (5) and stored temporarily until required in the lower level factory levels. The loaded flatcars are moved out onto one of the vertical lift elevators (16 shown) and lowered to designated factory level. The sketches on the right show a loaded flatcar being delivered to Level "H". In this example, the railroad tracks are 180° to the Level "J" tracks. For this reason, the vertical lift elevator is mounted on a large rotary bearing. The whole loaded flatcar and elevator rotates 180° to put this unit into proper position with the Level "H" tracks. The loaded flatcar can now be moved onto the properly indexed tracks and proceed to designated area at this factory level. The same concept applies to the other lower levels of the factory.

CARGO STAGING & DISTRIBUTION SYSTEM



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GEO BASE PERSONNEL DISTRIBUTION AND TRANSFER CONCEPTS

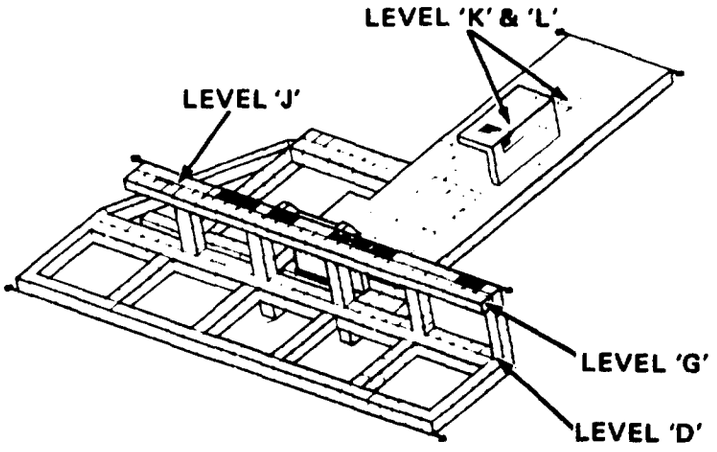
The accompanying sketch illustrates the distribution of personnel during a typical work shift. Approximately five (5) people are located in cherry pickers at Level "D" working on the Solar Collector. Another eleven (11) people are located in various assembly devices at Level "G", working on the collector assembly and energy conversion assemblies. Thirty (30) people are working on the antenna and are far away from the central home base. The remainder of the people are located throughout Level "J". Five hundred (500) people are located in the eight (8) Habitats. They are either off duty or working within these Habitats. Seventy-three (73) people are working in the Control Center; all facets of the GEO Base and SPS are controlled from this area. The Refurbishment Modules house one hundred forty-three (143) people.

Personnel can move about the GEO Base in three different modes of transportation. Quick and direct movement can be accomplished using a MRWS type of free flyer. This vehicle can carry two people and limited hardware to almost any location on the Base or Satellite. The crew can work at the site while in shirt sleeve attire inside the MRWS. Some work tasks will require that the crew get into close areas that are inaccessible by other means. In this mode the crew member will don a GEO EMU and MMU and traverse short distances to the work site.

For movement of personnel, a railed bus is used. The flatcar Bus Transporter operates on the 12.5 meter track system, providing movement of people and supplies. One Transporter shown is sized to move large numbers of people from the POTV to the Habitats while the other is sized to move a small amount to the various work stations each day.

The Bus Transporters can reach the berthing ports on all modules while moving on spur tracks between mainline J1 and J2 tracks.

GEO BASE PERSONNEL DISTRIBUTION & TRANSFER CONCEPTS



PERSONNEL TRANSFER MODES

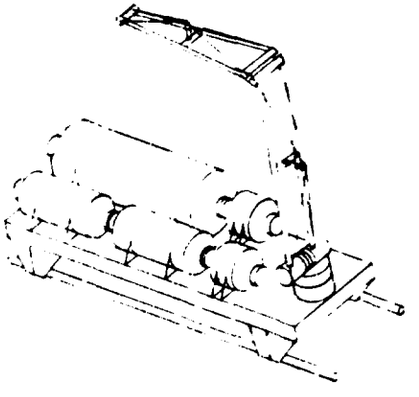


FREE FLYER



EVA

LEVEL 'J' ACTIVITY	PEOPLE/SHIFT
HABITATS & CONTROL CENTER	565
WORK AREAS	73
REFURBISHMENT MODULES	143
LEVEL 'K' & 'L' ACTIVITY	
• ANTENNA FACILITY	30
LEVEL 'G' ACTIVITY	
• ENERGY CONVER. ASSY	11
LEVEL 'D' ACTIVITY	
• COLLECTOR ASSY	5
TOTAL	827



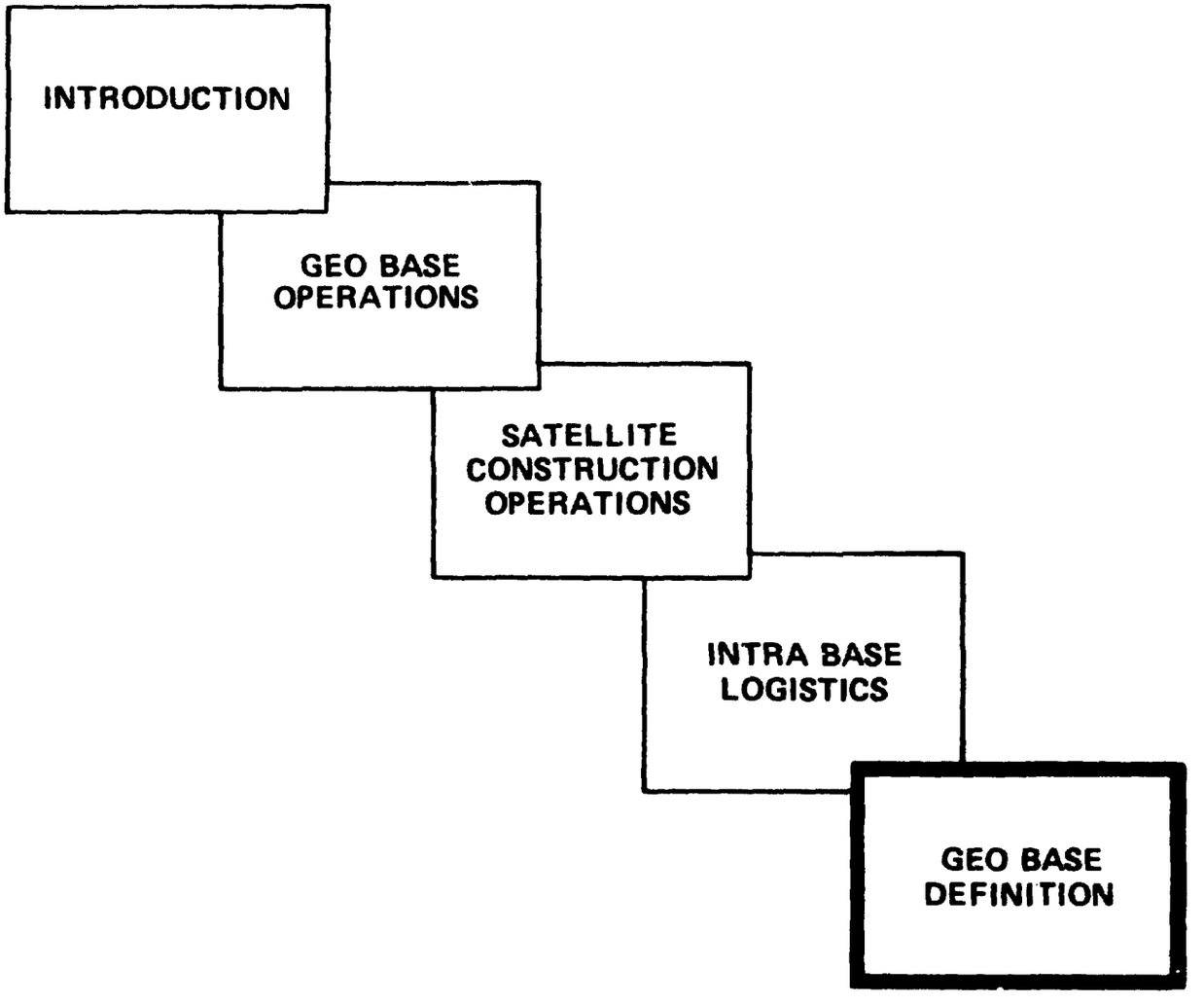
RAILED CREW BUS

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INTRODUCTION
GEO BASE OPERATIONS
SATELLITE CONSTRUCTION OPERATIONS
INTRA BASE LOGISTICS
GEO BASE DEFINITION

1079-005D

GEO BASE SYSTEM REQUIREMENTS

Top level requirements that established the design and operations of the SPS are shown opposite. These are extracted from Phase 1 of the study and guide the definition of all other requirements.

GEO BASE SYSTEM REQUIREMENTS

- CONSTRUCT ONE 5 GW SPS WITHIN 6 MONTHS ±5%
- ENERGY CONVERSION & MICROWAVE POWER CONSTRUCTION FACILITIES CONTIGUOUS
- CONSTRUCTION APPROACH:
  - ENERGY CONVERSION – TWO PASS LONGITUDINAL BUILDUP
  - MICROWAVE POWER – ELEVEN ROW LATERAL BUILDUP
- DESIGN LIFE: 30 + YEARS
- DOCKING & OFFLOADING SYSTEM FOR POTV, CARGO TUG & OTV
- OPERATIONAL AREAS FOR: COMMAND & CONTROL MODULES, CARGO WAREHOUSING, SUBASSEMBLY FACTORIES, CREW & WORK MODULES, BASE MAINTENANCE, OTV MAINTENANCE, EOTV MAINTENANCE, OPERATIONAL SPS MAINTENANCE & TRAINING
- BASE LOGISTIC VEHICLES & TRACK NETWORK
- CONSTRUCTION ACCURACY & QUALITY
- BASE ATTITUDE CONTROL, STATIONKEEPING, LONGITUDINAL TRANSFER CAPABILITY
- BASE ELECTRICAL POWER, COMMUNICATION & DATA MANAGEMENT CAPABILITIES

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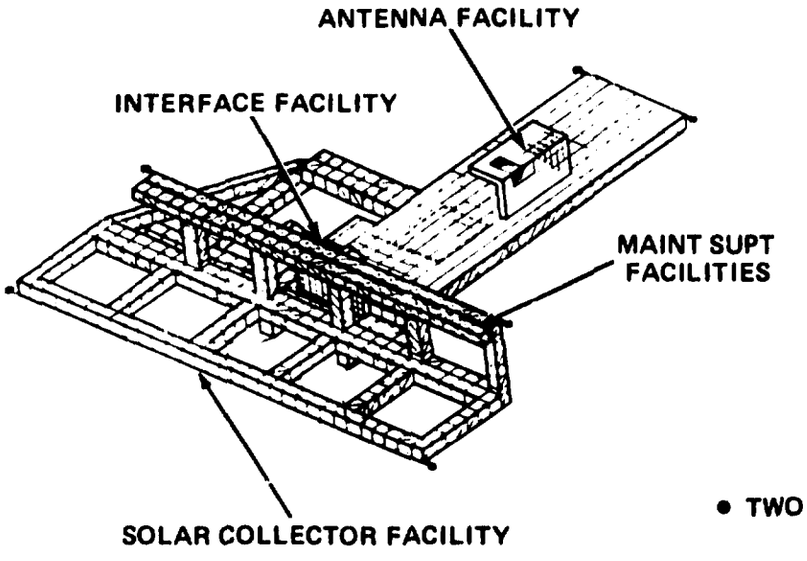
4 BAY END BUILDER GEO BASE FEATURES

The GEO base is staffed with 444 people to assemble and checkout one 5GW reference satellite every six months. The construction base operates on two 10 hour shifts per day for six days each week. The 4 bay wide construction base uses two passes to build the 8 x 16 bay energy conversion system; each pass provides a 4 x 16 bay module which contains the appropriate subsystems. Assembly of the energy conversion system is timed for simultaneous completion and mating with the power transmission system.

When SPS operational maintenance support is included, the GEO base crew complement will be increased to perform satellite component refurbishment and related crew support services. The number of personnel required for SPS maintenance and repair varies with the size of the operational fleet and the maintenance schedule adopted. It is presently planned that scheduled maintenance will be performed on each satellite twice a year, during the fall and spring seasons.

The cost and mass of the base construction facilities and the add-on maintenance support facilities is shown on the facing page.

4-BAY END BUILDER GEO BASE FEATURES



- TWO 5GW SPS ASSEMBLED & C/O PER YEAR

- BASE CONSTRUCTION FACILITIES
  - UNIT COST (1979 $) $ 8.48 B
  - MASS 6390 MT
  - TOTAL CREW 444

- ADD-ON MAINT. SUPT. FACILITIES
  - COST DELTA $ 3.21 to $9.63 B
  - ADD'L MASS 1326 TO 3979 MT
  - ADD'L CREW 383 TO 1149

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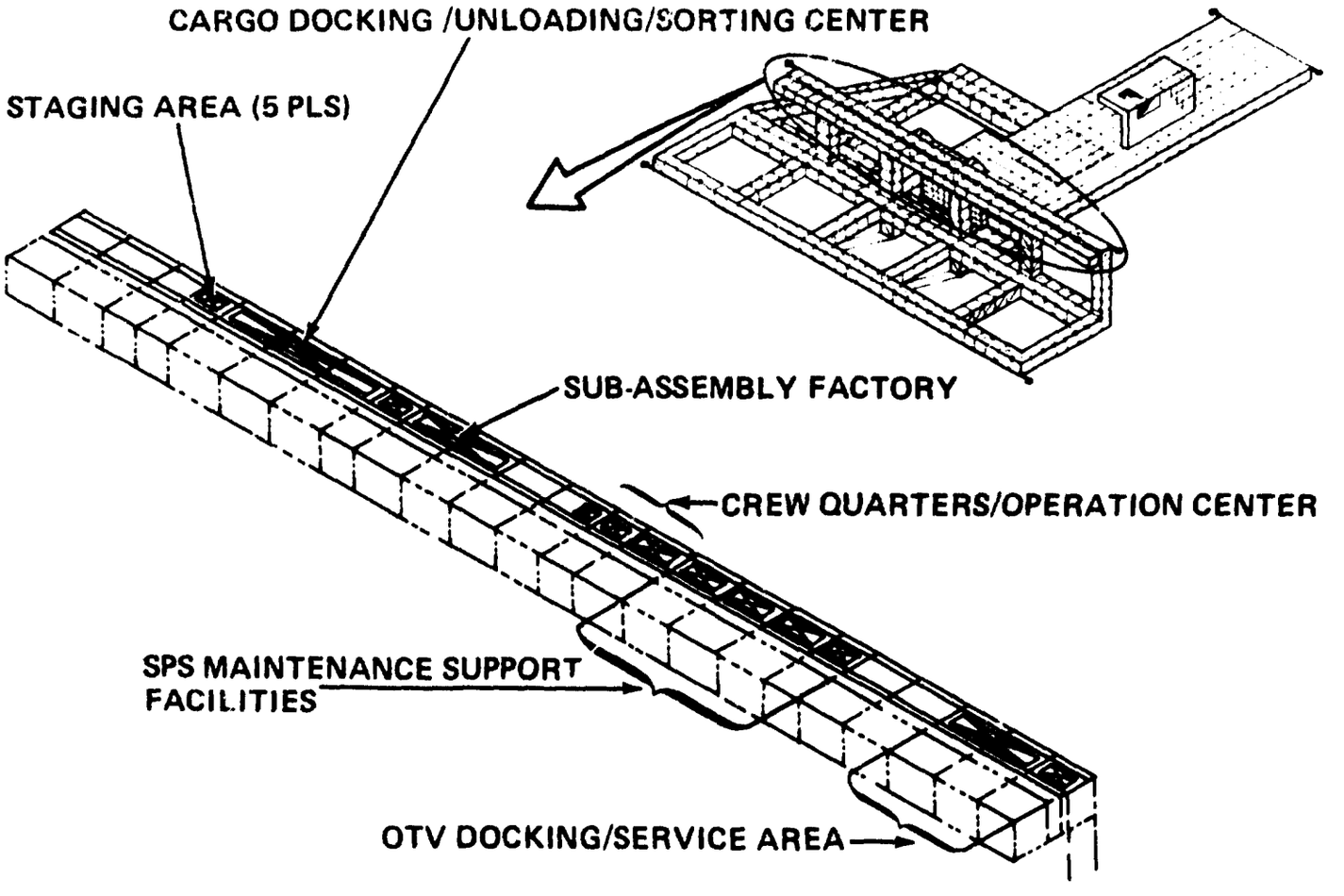
GEO BASE LEVEL 'J' FACILITIES ARRANGEMENT

The center of base activity occurs at the top deck, level 'J'. The material and personnel are brought to this level from the LEO base and the SPS service crew, with their materials, depart from here. In addition, numerous vertically moving transportation devices interface with supplies and personnel here for delivery to the lower levels.

Starting from the left, the following areas of activity are defined:

- Staging Area – This area is located over the vertical columns of the factory. The sorted and sub-assembled hardwares are stored here until required in the lower construction areas. The loaded flatcars are moved onto vertical lift elevators and then travel down to the appropriate lower construction level work site. The staging area is duplicated in five locations, as noted.
- Cargo Docking/Unloading/Sorting Center – The KTM modules and Cargo Pallets are landed here and unloaded onto railroad flatcars for delivery to their next station
- Subassembly Factory – The hardware in the Cargo Pallets is delivered to this area for subassembly work prior to its movement to the lower levels for installation
- Crew Quarters/Operations Center – This center includes the base habitats and areas for habitat growth.
  - Satellite Service Habitat Growth Area – This area has been reserved for growth when 40 satellites are being serviced. This area will be identical in configuration as the habitat area used for servicing 20 satellites.
  - Base Construction Habitats & Satellite Service Habitats – This area contains two functional complexes. One area consists of four (4) habitats, one (1) interim habitat and one (1) control center. The other area contains four (4) habitats and one (1) interim habitat. The first complex is used to house and control the base construction personnel and the other for satellite service personnel.
- SPS Maintenance Support Facilities – This complex includes satellite refurbishment factories and component storage
  - Reconditioned Component Storage – Those components which have been reconditioned and repaired in the KTM & Miscellaneous Component Refurbishment Factories are stored here until needed
  - KTM Refurbishment Factory – All defective klystrons from the outlying SPS stations are brought into this module for refurbishment
  - Miscellaneous Component Refurbishment Factory – This module has facilities within it for refurbishment of electrical, electronic and mechanical devices. Components are disassembled and assembled, as well as tested, in this area
  - Defective Component Storage – Those components which have to be reconditioned and repaired are stored here. When room and scheduling permits, they are transported from here to the Refurbishment Factories
- OTV/POTV Docking/Service Area – Sufficient docking pads are located here for the landing of POTVs and OTVs. Quantities of propellant for refueling the OTVs are also stored here.

GEO BASE LEVEL 'J' FACILITY ARRANGEMENT



OTV DOCKING & SPS MAINTENANCE SUPPORT

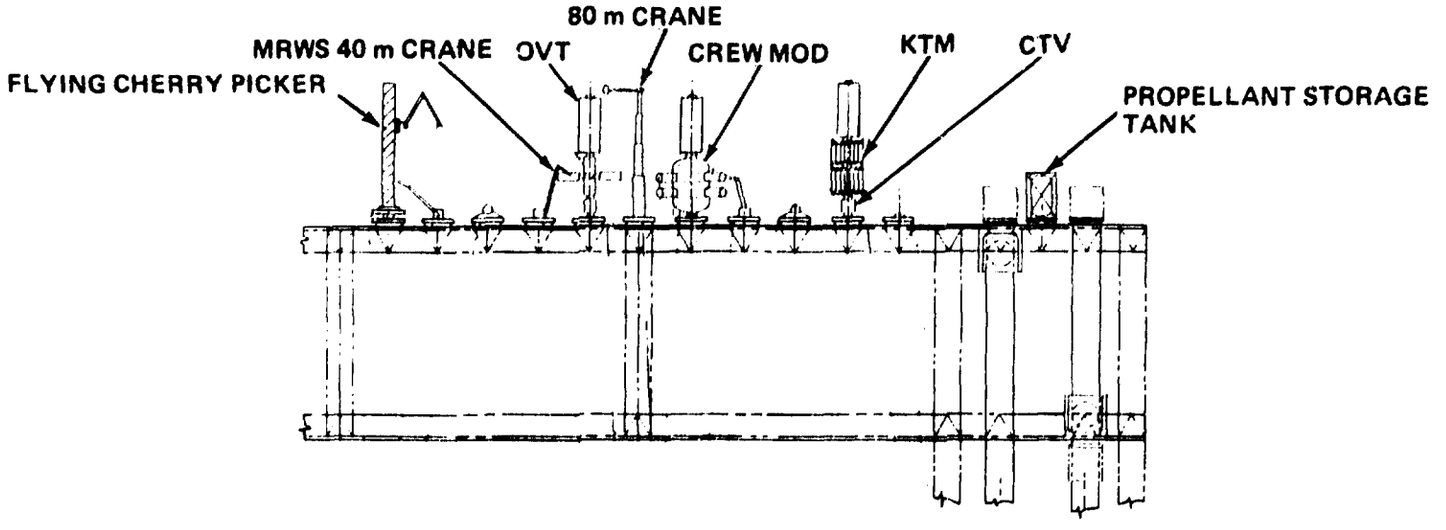
The OTV docking/service area has been located at the end of the base because of the high level of flight activity. Numerous flights to and from level 'J' dictate that its location be in one corner of the complex so its operation will not affect normal movement for base construction. Sixteen (16) spur line railroad tracks are placed between the mainline 'J'1 and 'J'2 tracks to enhance traffic flow.

A docking pad is provided for the flying cherry picker, a 40 meter MRWS crane located on an adjacent track services this unit. Two (2) docking pads are provided for the POTV's arriving from the LEO Base. Each POTV is sized to deliver 84 people with four (4) spacelab modules attached. These vehicles are serviced with a 80 meter crane, a 40 meter MRWS crane and bus transporter. A four (4) man control center is located between the complex of landing pads.

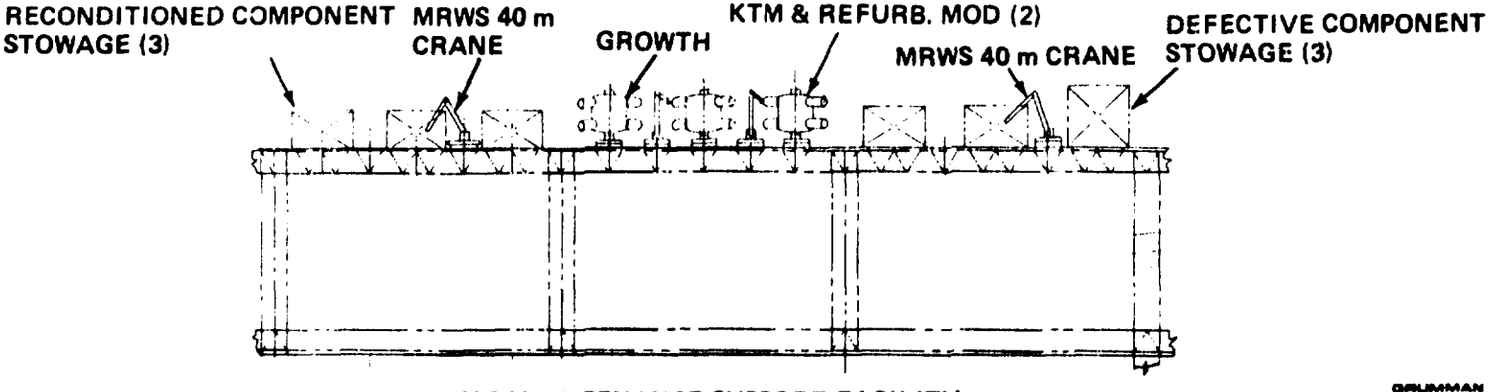
The other half of this complex contains five more docking pads, two (2) for SPS OTV's, two (2) for KTM pallets and one (1) for spare. The SPS OTV's contain a crew module for eighty (80) people, a two (2) man control transfer vehicle and eight (8) long spacelab modules filled with supplies for the thirty (30) day mission to service the operational satellites. The KTM vehicles are sized to return defective klystron assemblies to the refurbishment module. Reworked assemblies are loaded onto this vehicle with the one of the railed cranes in the area. A second control center is located between this grouping of landing pad. Three (3) propellent storage tanks are provided at the corner of the Level 'J' complex.

The SPS Maintenance Support Facility is adjacent to the OTV docking area and the Crew Quarters/Operations Center. The defective material brought back from the operational satellites is off loaded onto railroad flat cars and transported over to the defective component storage area. When scheduled, this material is moved into the KTM and component refurbishment modules where they are reconditioned. The reworked hardware is placed in the reconditioned component stowage area, for eventual return to the OTV docking area.

OTV DOCKING & SPS MAINTENANCE SUPPORT



OTV DOCKING/SERVICE AREA



SPS MAINTENANCE SUPPORT FACILITY

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CREW QUARTERS/OPERATIONS CENTER

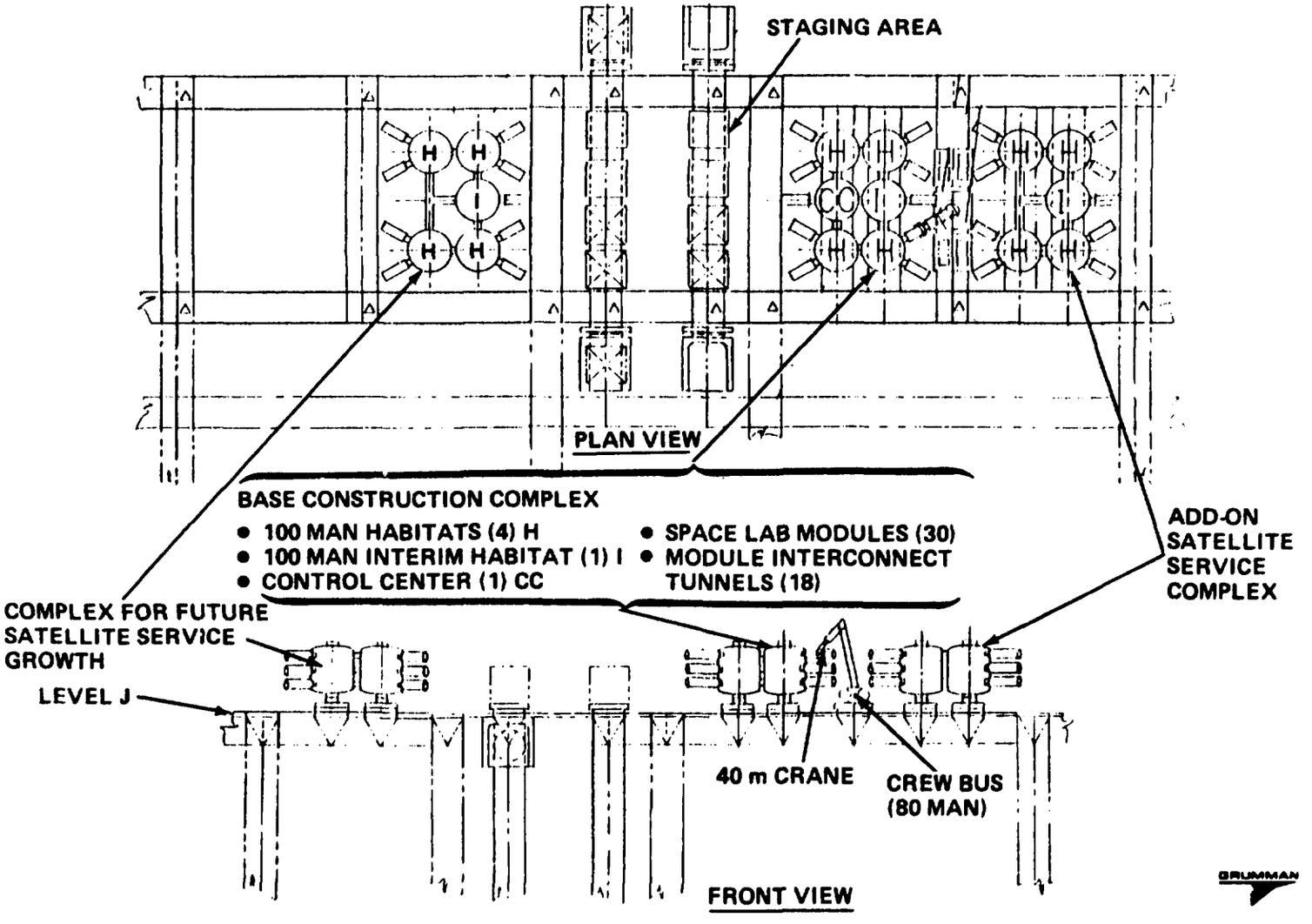
This area contains all the pressurized modules for crew living and control of the base complex. Six large modules are grouped together in a geometric pattern and interconnected with tunnels. Four of these modules are used for habitats for four hundred (400) persons. Two modules (identical in size) are situated between these habitats, one is used as a base operations control center and the other is used as an interim habitat for one hundred (100) transients. Berthing points (30) are located on these modules for attachment of spacelab modules such as airlock, resupply, waste disposal, expendables, passenger delivery, and vehicle transfer. Since these modules are all inter connected, transfer between modules can be accomplished in shirt sleeve attire. This grouping is used to house the personnel that are required to work and control the operations of the base construction complex.

Adjacent to this aforementioned complex, but not connected to, is another grouping of large modules. These five modules are used to house up to four hundred (400) people and one hundred (100) transients required to maintain and service twenty (20) satellites. Again, the modules are inter connected with tunnels and also have berthing ports for attachment of twenty-seven (27) spacelab modules.

An additional area has been established for the installation of five (5) more large modules. They are configured the same as the five (5) previously mentioned. This complex is added at some future date when forty (40) satellites are being serviced. When sixty (60) satellites are serviced the first group of habitats used for base construction can be used to house the additional personnel.

The habitat complexes are all bordered with spur line railroad tracks. In this manner operation buses with supplies and people can be interchanged with the 40 meter MRWS crane on the bus transporter.

CREW QUARTERS & OPERATION CENTER



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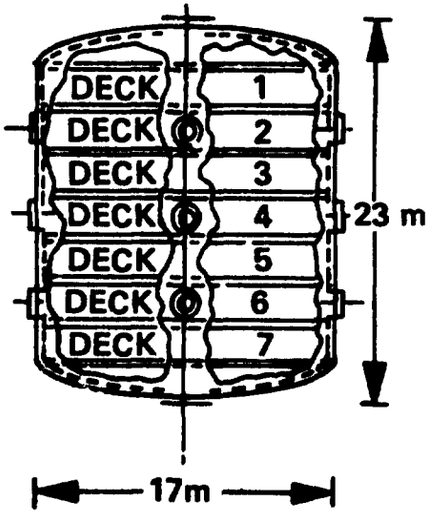
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CREW MODULE GENERAL REQUIREMENTS

Some of the more important requirements used to design the crew module are listed here. The first four requirements establish the size and interfaces of the crew modules. Interior accommodations obviously must be designed for zero g operation. However, to prevent crew disorientation, they should all be designed to a common reference. One-g was selected, as this facilitates ground operations and is satisfactory for space activities. Crew mix was based on the Navy projection for support ships.

CREW MODULE GENERAL REQUIREMENTS

- SIZE (17m DIA X 23m LONG) COMPATIBLE WITH HLLV
- ACCOMMODATIONS FOR 100 PEOPLE
- DESIGN LIFE: 30 + YEARS
- BERTHING/DOCKING/AIR LOCK COMPATIBLE WITH CREW BUS & LOGISTICS & MODULE
- STRUCTURAL ATTACHMENT TO BASE
- DESIGN FOR ZERO G OPERATIONS
- INTERIOR LAYOUT ONE G
- CREW 75% MALE, 25% FEMALE
- METEOROID & SOLAR STORM RADIATION PROTECTION



CREW MODULE

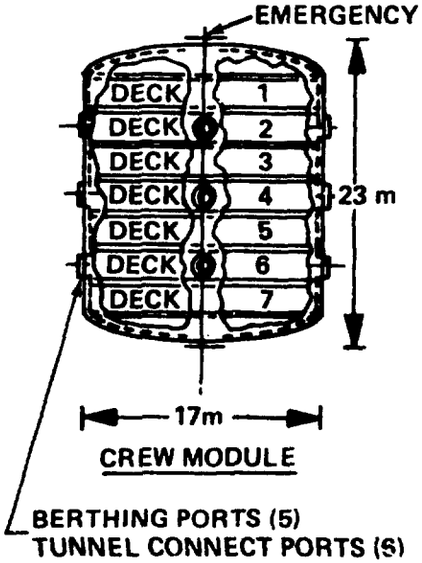
GEO CONSTRUCTION BASE – 100 MAN HABITAT UPDATE

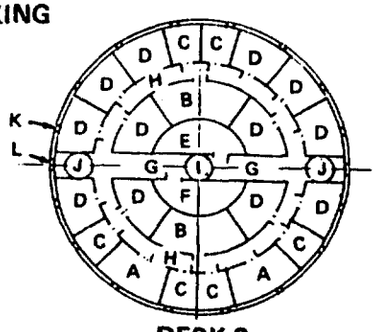
This illustration depicts a domed end cylinder housing 100 crew members with dedicated work stations. The pressure shell diameter is 16.5 m and the external diameter is 17.0 m. A nominal 0.25 m has been tentatively allotted for thermal insulation, radiation protection and radiator wraparound functions. The pressure vessel is 23.0 m long. Seven decks have been provided, each having a 2.2 m floor to ceiling height. The structure between each deck is 0.3 m thick, providing volume for installation of wiring, ducting, lighting, insulation, etc. Decks 2 and 6 have two (2) berthing ports located 90° to each other, while Deck 4 has only one (1) port. These berthing rings are configured to mate with berthing ports on Spacelab-type modules. The attached Spacelab modules provide the services and re-supplies to keep the modules operational. Larger diameter berthing or docking rings are located at each dome end for mating with the base structure, another module or the transportation delivery vehicles (HLLV or EOTV). Each deck contains 16 to 18 viewing windows around its periphery.

One possible arrangement for accommodating the SPS GEO Base 400-man construction crew is shown by the crew habitat complex on the following pages. Adjacent modules are interconnected with flexible tunnels mated to the berthing hatches on Decks 2, 4 & 6. In this manner, there are at least six ways in and out of each module (total of 6 tunnels). Deck 2 has a short Spacelab-type module affixed to it for use as a 4-6 man airlock. Another short Spacelab is provided for use as a transfer vessel from the large volume habitat to the smaller volume closed cherry picker, bus, free flyer or crane. Deck 4 has one berthing ring for attachment of a long Spacelab module. This module can provide a 90 day food supply for 100 persons. Deck 6 has two berthing rings for attachment of two short Spacelabs. One module contains tankage to re-supply the expendables, while the second module is configured to accept waste material which is compacted into 26-inch cubes. The four large berthing rings on the bottom mate with facilities on the space base. The four large berthing rings at the top of the dome end can be used for emergency docking of HLLV, PLV or OTVs, if needed.

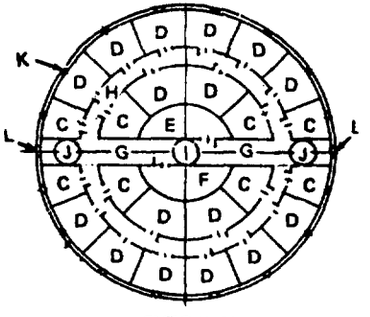
Decks 1, 3 and 7 have been allotted for the living quarters for 100 crew members, both male and female. Deck 1 is configured to house the management-type personnel in 16 various sized one and two men staterooms for a total of 24 people. A large waste management compartment and personal hygiene compartment are provided to handle the occupants on this deck. Deck 3 has four staterooms and 18 crew quarters to house 36 persons. It also contains a W/M and personal hygiene compartment. Deck 7 has 24 crew quarters, a W/M and personal hygiene compartment to accommodate 40 people. The density factor of each deck is varied according to job title on board the space base. Providing for more than 100 people in this size module is not recommended.

GEO CONSTRUCTION BASE – 100 MAN HABITAT – UPDATE

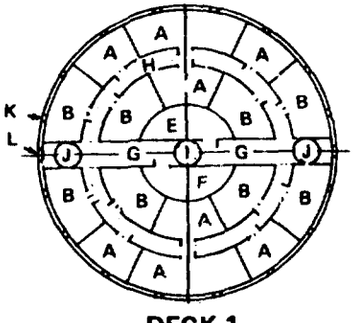




DECK 3
CREW QUARTERS



DECK 7
CREW QUARTERS



DECK 1
CREW QUARTERS

HABITAT AREAS:

- A. ONE-PERSON STATEROOM
- B. TWO-PERSON STATEROOM
- C. ONE-PERSON CREW QUARTER
- D. TWO-PERSON CREW QUARTER
- E. WASTE MANAGEMENT
- F. PERSONAL HYGIENE
- G. CENTRAL PASSAGEWAY
- H. TORUS AISLEWAY
- I. THRU-DECK ACCESS
- J. INTERDECK ACCESS
- K. CABIN WINDOWS
- L. VIEW WINDOWS

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GEO CONSTRUCTION BASE – 100 MAN HABITAT – UPDATE (CONT'D)

Deck 2 contains a control center. A total of 25.44 square meters of displays and controls has been provided to monitor space base and module parameters. The controls need not be duplicated in each of the four modules, but should be overlapped. In the event of a module shutdown, control of the base should still be possible by virtue of the instrumentation remaining in the other three modules. A large room is provided for all facets of EVA hardware.

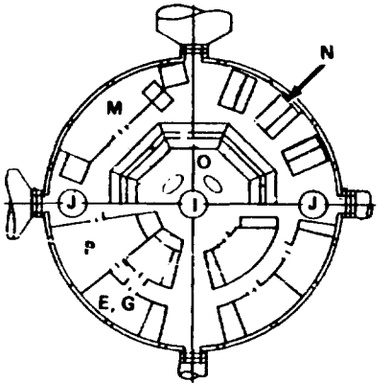
Deck 4 has been arranged to accommodate dining facilities for 56 people at one setting. The food serving center contains combination hot air/convection/resistance ovens for heating food, and is the area where the food is dispensed to the diners, cafeteria style. The return rack is the area where used dishes and food are placed. Compactors and dishwashers are located here. Up to 100 people can also be accommodated in Deck 4, when used as a radiation shelter.

Deck 5 is recreational/physical fitness/services area. The central area is 6 m in diameter and serves as a lounge area. From this lounge, access can be obtained to the snack bar, barber shop, post office, chapel, theatre, library, gym and recreation area, and sick bay/dentist areas.

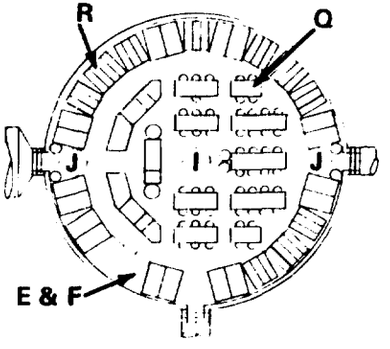
Deck 6 contains tanks for storage of expendables and three large rooms for subsystem equipment and hardware. The fourth quadrant contains storage for waste bales and an area for agricultural study.

Each deck is accessible to the adjacent deck via three (3) 1.5 m diameter openings. In general, the decks have a 1.5 m wide central asile passageway and a torus aisleway 1.0 m wide.

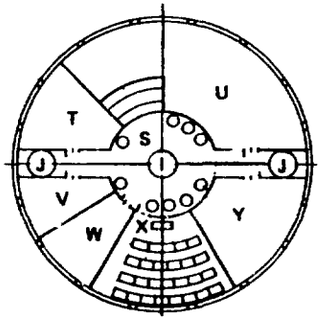
GEO CONSTRUCTION BASE – 100 MAN HABITAT – UPDATE (CONT'D)



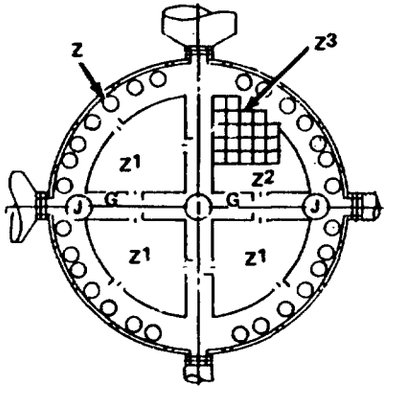
DECK 2
CONTROL CENTER/SUBSYSTEMS



DECK 4
GALLEY/DINING AREA/STORM SHELTER



DECK 5
RECREATION/PHYSICAL FITNESS/SERVICES



DECK 6
EXPENDABLES/SUBSYSTEMS

HABITAT AREAS:

- M. EMU/EVA PREP ROOM
- N. COMPUTER RACKS
- O. CONTROL CENTER
- P. CONFERENCE ROOM
- Q. DINING AREA (56 PERSONS)
- R. FOOD STORAGE
- S. LOUNGE
- T. LAUNDRY/SUPPLIES
- U. RECREATION/GYMN
- V. BARBER SHOP/POST OFFICE
- W. LIBRARY/STUDY
- X. THEATER/CHAPEL
- Y. SICK BAY/DENTIST
- Z. EXPENDABLES
- Z1. SUBSYSTEMS
- Z2. AGRICULTURAL STUDY
- Z3. COMPACTED WASTE

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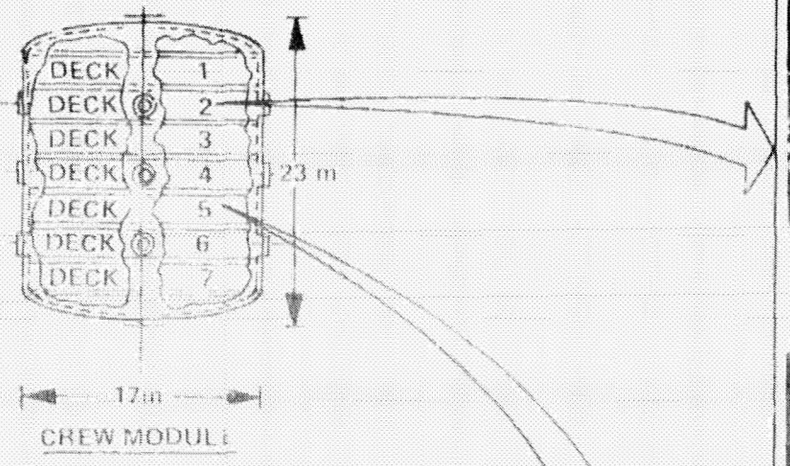
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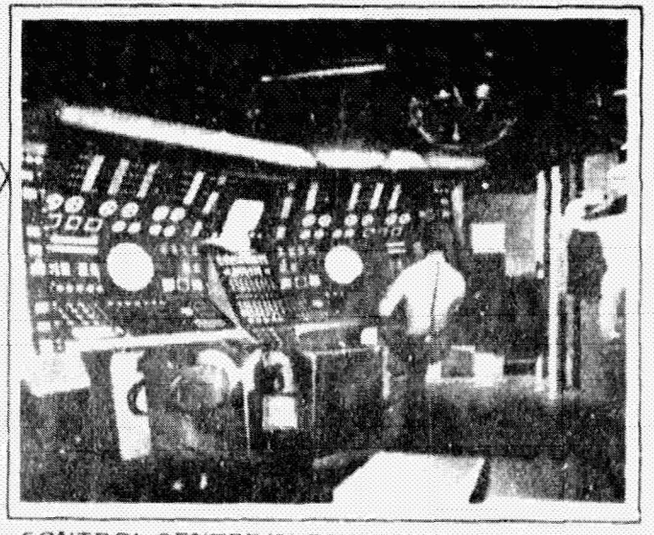
100 MAN HABITAT – TYPICAL INTERIORS

The Phase 2 crew module design effort consisted of a superficial investigation of compartmental partitioning of the habitat using estimated volumetric data for the equipments and its arrangement. The habitat galley arrangement and sizing was the only detail design effort afforded in the habitat preliminary design. Here the weight and volume of the food and its storage arrangement was looked at in some detail, since the galley provides crew dining and 100 man storm shelter accommodations.

The opposite page photos are of some typical interiors which were established in an earlier Grumman study and may be used as examples of what a future SPS habitat interior might resemble.

100 MAIN HABITAT – TYPICAL INTERIORS





CONTROL CENTER/SUBSYSTEMS – DECK NO. 2



LOUNGE AREA IN CENTRAL PORTION OF DECK NO. 5

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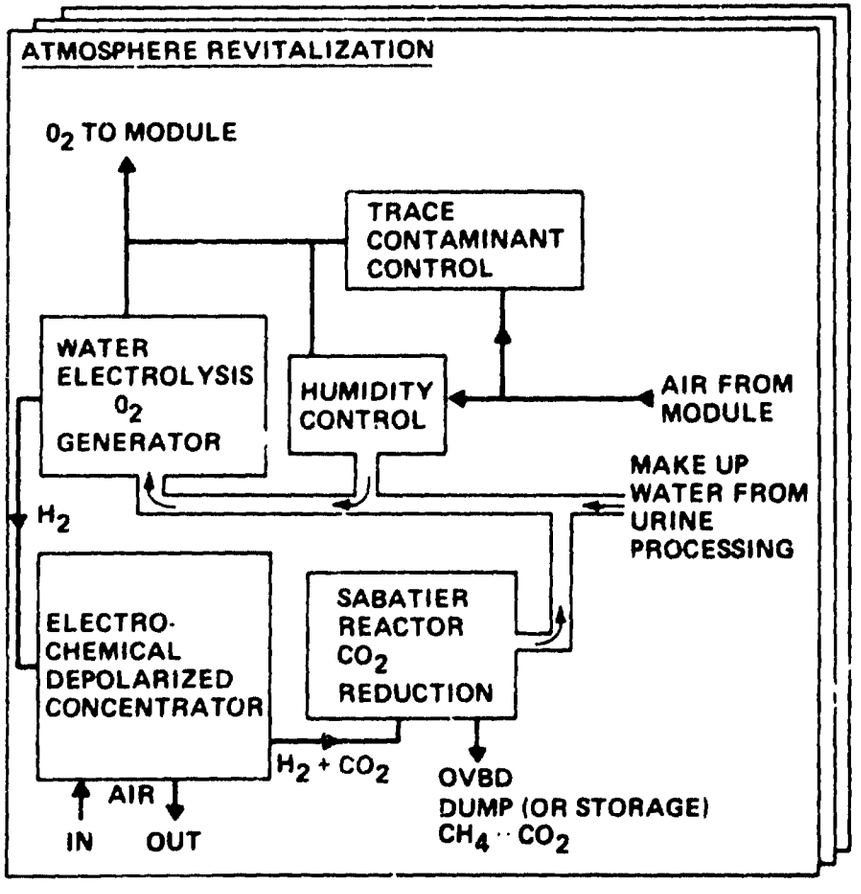
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ENVIRONMENTAL CONTROL/LIFE SUPPORT SUBSYSTEM – 100 MAN HABITAT

The ECLS subsystem baselined for the SPS modules is a regenerable system with closed water and oxygen loops designed to require a minimum of expendibles. The atmosphere revitalization section controls cabin humidity, removes CO_2, generates O_2 from water and removes trace contaminants from the atmosphere. Two water reclamation systems are included to purify wash water and distill clean water from urine. The thermal control section removes waste heat from the cabin and electronics and then rejects it to space.

It should be noted that the system described is for a typical 100 man module using regenerable type systems. No attempt was made to perform detail trades of various concepts to perform a specific function because this effort is more appropriately done in a later design phase and not in a systems study. The concepts shown, therefore, are not necessarily optimum but are typical and form a baseline to determine realistic weight and costs.

ENVIRONMENTAL CONTROL/LIFE SUPPORT – 100 MAN HABITAT



MASS CHARACTERISTICS

ECLS ELEMENTS	MASS	RATIONALE
ATMOS REVITAL	9.8	DETAIL EST
WATER MGT	2.6	DETAIL EST
WASTE MGT	4.3	DETAIL EST
THERMAL CTL	6.1	PART EST & GUESS
TOTAL MASS 22.8 MT		

CONSUMABLES W 10% CONTINGENCY

• 90 DAY RESUPPLY	6.9MT	
– O_2 & H_2 MAKE UP	(3.4)	PREL EST
– H_2O MAKE UP	(0.4)	PREL EST
– REPLACMT. PARTS	(3.1)	PREL EST
• 6 WEEK EMER. SUPPLY	13.8	
– O_2 GAS	(3.4)	METABOLIC REQ
– H_2O	(10.4)	METABOLIC REQ

CREW MODULE AND WORK MODULE MASS ESTIMATES

This table presents a summary of the current Grumman weight estimate for the crew module. It shows weights for crew modules in both low earth orbit and geosynchronous orbit.

The structural weight has been estimated based on an aluminum structure of cylindrical shape 16.5 m in diameter and 17.8 m long, capable of supporting 14.7 psi internal pressure. Numerous decks divide the cylinder. Two large access/egress ports are located on eitner end, and 12 berthing ports are located around the circumference. Partitions and equipment mounting weights have also been estimated.

No shielding is required for LEO. A "storm shelter" approach has been used for GEO. A 7.2 m cylindrical band around the module protects one deck from solar storms. The storm shelter provides 20 grams/cm^2 shield thickness protection.

Environmental control subsystem weights are based on 100% redundant systems capable of sustaining 100 men. In addition, a weight growth/contingency factor of 33% has been maintained. All other subsystem weights remain the same as those listed in Boeings Phase 1 SPS study Final Report, Volume III Reference System Description 17180-25037-3.

The lower part of the facing page summarizes the weight of four similar size work modules. The weight for these modules has been adjusted from Boeing's earlier report D180-24071-1 to reflect Grummans estimates for habitat structure and ECLS.

CREW MODULE & WORK MODULE MASS ESTIMATES

HABITAT SUBSYSTEM MASS (MT)	LEO	GEO	BASIS
STRUCTURE	69.7	69.7	PREL EST
ENVIRON PROTECTION (20 g/cm^2)	0	68.3	PREL EST
ELECTRICAL POWER SUPPLY	5.0	5.0	D180-25037-3
ENVIRON CONTROL/LIFE SUPPORT	22.8	22.8	PREL EST
CREW ACCOMMODATIONS	11.0	11.0	
COMMUNICATIONS/DATA HANDLING	6.0	6.0	D180-25037-3
GUIDANCE & CONTROL	0	0	
PROP/REACTION CONTROL	0	0	
SPECIAL EQUIPMENT	0	0	
SUBTOTAL	114.5	182.8	
GROWTH/CONTINGENCY (33%)	37.8	60.3	
TOTAL DRY	152.3	243.1	

WORK MODULE STRUCTURE & ECLS UPDATED FROM D180-24071-1

- OPERATION CTR 173 MT
- BASE MAINTENANCE 128 MT
- MISC SUPT 112 MT
- SPS MAINTENANCE 117 MT

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BASE ELECTRICAL POWER DEFINITION

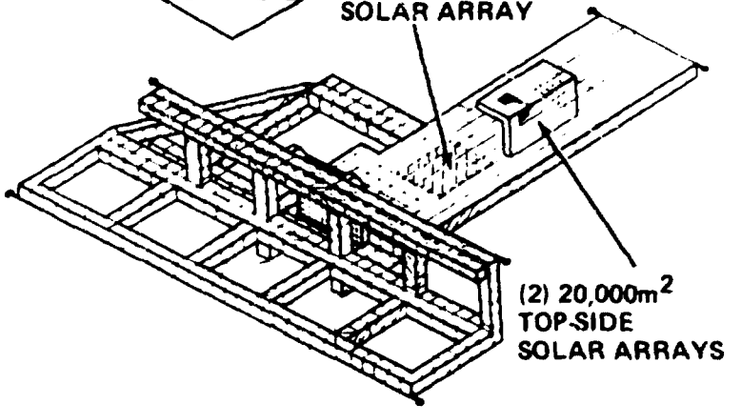
The GEO Base electrical power requirements are mainly derived from the previous Boeing study which defined SPS LEO construction methods (Report D180-24071-1). Power requirements for crew modules have been revised to reflect more operative modules (15 vs 10) and also adjusted commensurate with the updated ECLS weight estimate. The 14400KW requirement for ion propulsion assumes that no more than four thruster panels would be fired simultaneously.

The base electrical power system provides 1500KW for operative crew modules, construction equipment and external lighting. This system also provides 14,400KW to operate the low thrust ion propulsion flight control system. Fixed body mounted solar array blankets, which are similar to those on the satellite, are used for electrical power generation. To accommodate SPS off-sun/on-sun construction attitudes, base solar arrays are located underneath the antenna construction platform and also on the top and outer side of the antenna assembly facility. It also has a nickel hydrogen battery energy storage system, which is used for brief periods during equinoctial occultation.

BASE ELECTRICAL POWER DEFINITION

POWER REQMTS	KW	BASIS
15 CREW MODULES	1030	UPDATE 15 VS 10
ION PROP FLIGHT CTL	14400	4 THRUSTERS
CHEM PROP FLIGHT CTL	5	D180-24071-1
CONSTRUCTION EQUIP	150	
EXTERNAL LIGHTING	320	
TOTAL 15905 TO 1505 KW (W & W/O ION)		

• BASE OPS NEED AT LEAST 2-16 MW_e



SUBSYS ELEMENT	MASS	BASIS
SOLAR ARRAYS	102.2	0.426 Kg/m^2
NiHz BATTERIES	34.6	52 WH/Kg
POWER CONDITIONING	4	SCALED TO SPS
POWER DISTRIBUTION	53.6	
TOTAL 194.4 MT		

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1622-035W

GEO BASE MASS & COST BREAKDOWN

WBS ELEMENT	MASS, MT	COST – 1979 $M		DATA BASE
		DELTA DEV.	PROD	
1.2.1.1 WORK SUPPORT FACILITIES	4762	> 767	3212	
.1 STRUCTURE	2927	107 **	337	ϕ1
.2 CONSTRUCTION EQUIP	460	660	1800	ϕ1 ADJ
.3 CARGO HDLG/DISTRIBUTION	399	ND	430	ϕ1 ADJ
.4 SUBASSEMBLY FACTORIES	38		323	ϕ1
.5 TEST/CHECKOUT FACILITIES	ND *		ND	
.6 TRANSPORT VEH. MAINTENANCE	ND		ND	
.7 SPS MAINT. SUPT FACILITIES	ND		ND	
.8 BASE SUBSYSTEMS	938		322	ϕ2
.9 BASE FACILITEIS & EQUIP. MAINT.	ND		ND	
.10 COMMAND & CONTROL SYS	ND	ND	ND	
1.2.1.2 CREW SUPPORT FACILITIES (CONSTR)	1628	> 2271	2554	
.1 CREW QUARTERS	1215	2271 ***	1923	ϕ2
.2 WORK MODULES	413	ND	631	ϕ1 ADJ
WRAPAROUND COSTS (47%) PROJ MAT. SE & I, SYS TEST INST ASSY & C/O, GSE & SPARES		1428	2710	
1.2.1 GEO CONSTRUCTION BASE FACILITIES	6390	> 4466	8476	

* ND – NOT DETERMINED
** EXCLUDES MINI FACILITY TO BUILD BASE
*** INCLUDES NEW 8 STORY MANUFACTURING PLANT

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GEO BASE RESUPPLY REQUIREMENTS (W/10% CONTINGENCY)

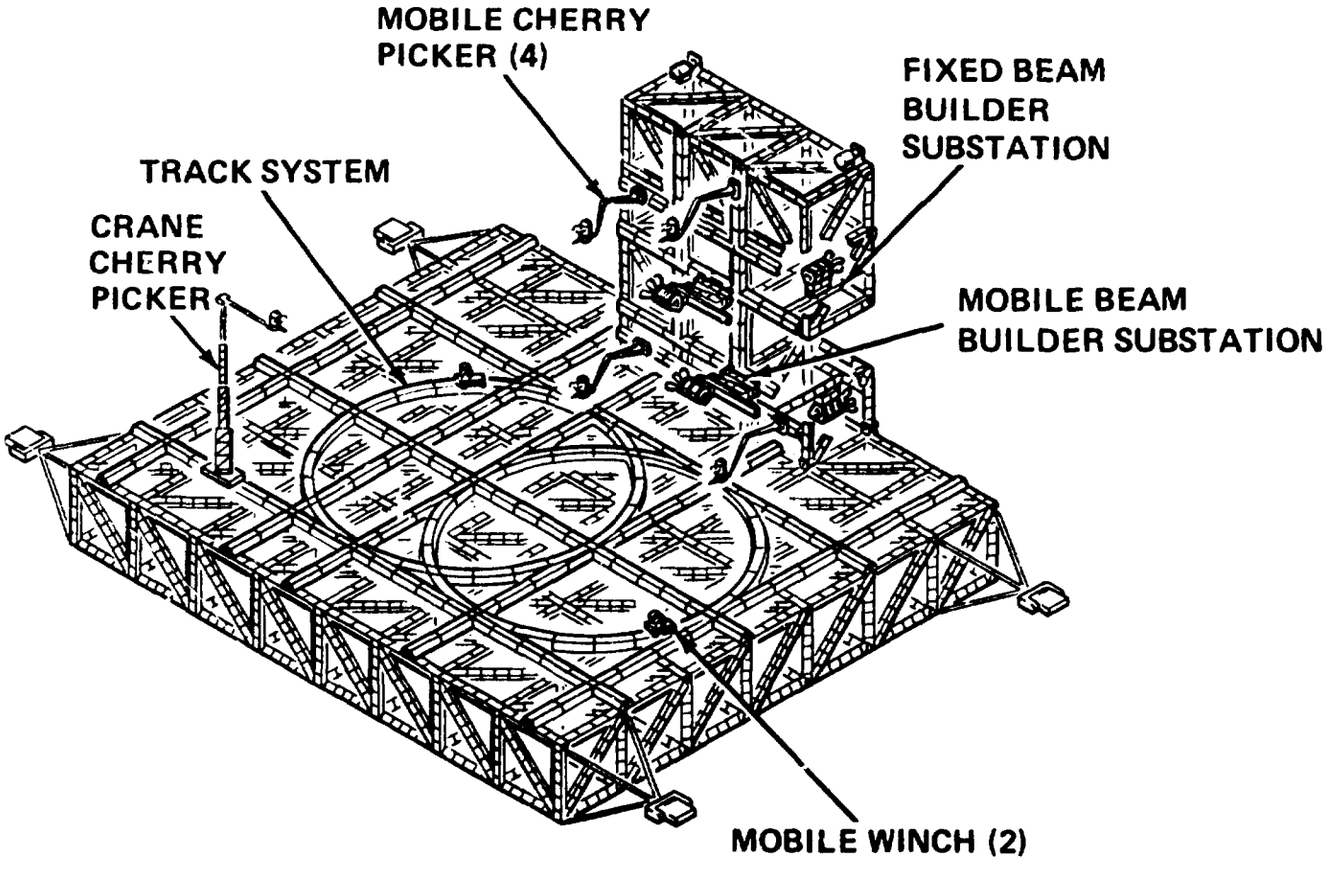
MASS-MT / RESUPPLY ITEM	CONSTR OPS 444 CREW	SPS MAINT OPS 383 TO 1149 CREW	BASIS
CREW SUPPLIES (FOOD, HOUSEKPG, ETC)	418	361 TO 1081	DET EST & PRIOR STUDIES
CREW MODULE SUPPLIES (0_2, N_2, H_20, ECLS PARTS ETC)	190	151 TO 454	EST ECLS & GUESS ETC
WORK MODULE SUPPLIES	126	108 TO 323	SCALED TO HAB. UNITS
WORK FACILITY SUPPLIES	398	(ND) (ND)	
CONSTR EQUIP PARTS	37	– –	GUESS 2%/QTR
CARGO HDLG/DIST PARTS	32	– –	GUESS 2%/QTR
CREW BUS (0_2, N_2)	7	– –	SHUTTLE LEAKAGE
SUB ASSY FACTORY PARTS	3	– –	GUESS 2%/QTR
REMOTE WORK STA (0_2 N_2 & PARTS)	145	ND ND	MRWS EST
BASE SUBSYS PARTS	75	– –	GUESS 2%/QTR
FLT CTL PROPELLANTS	99	– –	ESTIMATE
BASE MAINT & TEST PARTS	ND*	– –	–
TRANSPORT VEH MAINT PARTS	ND	– –	–
SPS MAINT SUPT PARTS	–	ND ND	–
TOTAL	1125MT	620 TO 2478 MT	

* ND – NOT DETERMINED

FACILITY CONCEPT FOR BUILDING THE SPS GEO BASE

The facility (Mini Base) illustrated uses the end builder construction system which is tailored to the 100m cross-section of the GEO base structural members. Four (4) dedicated semi-fixed 7.5m beam machines fabricate the longitudinal members and (2) 7.5m mobile beam machines fabricate the lateral, vertical and diagonal members of the structural assembly. The facility provides a track system for mobile indexers, winches and crane cherry pickers. The mobile winches (2), indexers and turntable tracks allow the facility to index itself about any and all sides of the structure it has fabricated. The 120m crane cherry picker is used to assemble those structural joints which are beyond the reach of the mobile cherry pickers.

FACILITY CONCEPT FOR BUILDING GEO BASE



FACILITY FOR BULDING SPS GEO BASE

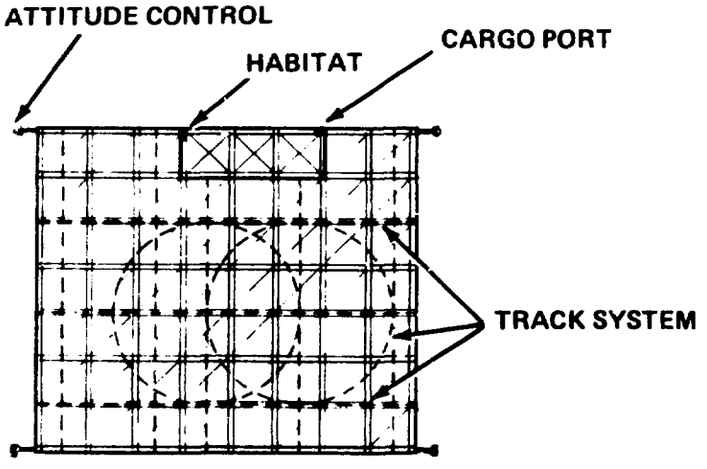
A general arrangement for the facility (mini base) is shown on the opposite page. This arrangement consists of a 150 m wide X 250 m high tower mounted from a 400 m X 350 m platform. 50 m square structural beams are used to construct the facility; these beams are assembled from 7.5m triangular elements.

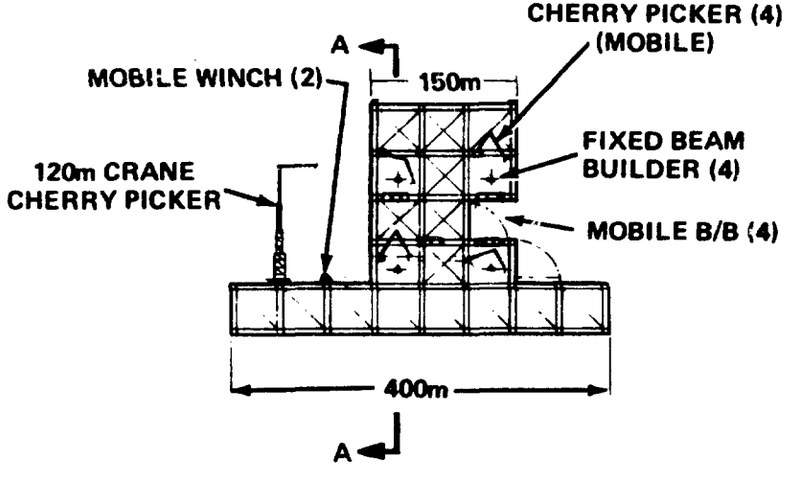
The tower houses (4) fixed beam machines which are arranged to provide the longitudinal members of the 100 meter square structure to be fabricated. Two (2) mobile beam machines and four (4) cherry pickers used for assembly of the structure ride a track system on the tower. Crew habitats and a cargo port are located on the upper level of the tower.

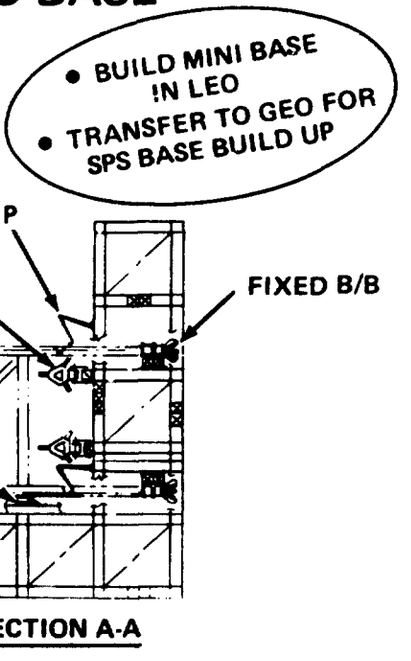
The platform provides support for the attitude control system, a track system for the mobile winches, indexers and crane cherry picker.

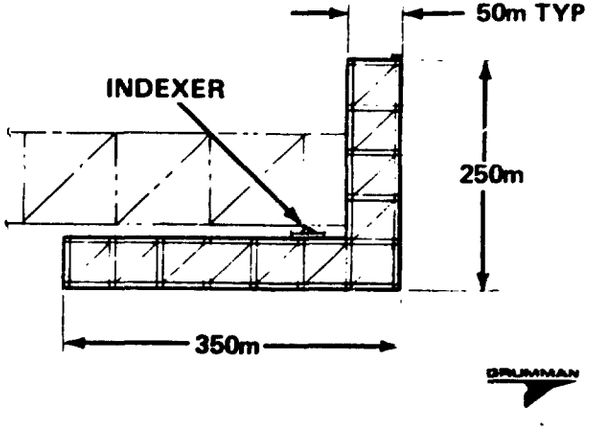
This mini base is assembled in LEO and transferred to GEO for SPS base buildup.

FACILITY FOR BUILDING SPS GEO BASE









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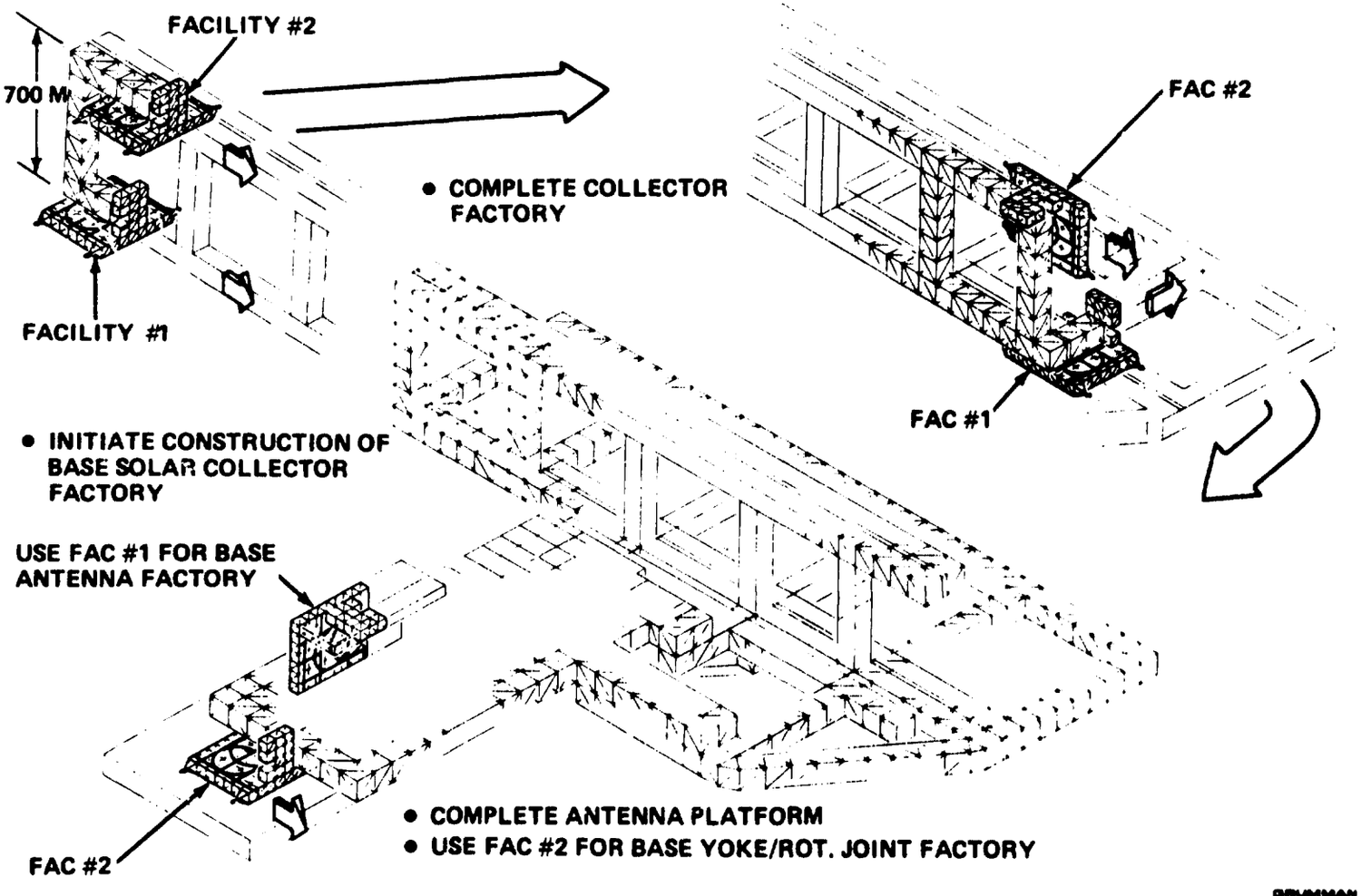
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GEO BASE BUILD UP SEQUENCE

The opposite page illustrates a construction scenario for the structural assembly of the SPS GEO base. As shown, two facilities are used for this assembly. Construction starts with the assembly of the solar collector factory. Facility #1 fabricates and passes off the 700 m long structural member to facility #2. Facility #2 attaches to this member via its indexer truck system and starts the fabrication of the upper horizontal beam while facility #1 re-indexes and initiates the fabrication of the lower horizontal beam. At the appropriate structural intersection, facility #2 re-indexes to fabricate the vertical member of the grid and facility #1 interrupts fabrication of the lower beam to make the attachment of the vertical and lower beams. Once the joint is completed, facility #1 continues its fabrication of the lower member. When fabrication of this lower member is completed, facility #1 starts the construction of the lower horizontal structural grid of the collector factory as facility #2 completes the over hang area of the vertical structure.

After completion of the collector factory the base antenna facility is constructed. When approximately three quarters of the antenna platform is assembled facility #2 is anchored to the platform and as shown is used as the structure for the antenna assembly factory of the base. Facility #1 completes the platform construction and then is indexed over to the vertical wall of the collector factory and in turn is used as the structure for the GEO base yoke/rotary joint factory.

GEO BASE BUILDUP SEQUENCE



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SOLAR POWER SATELLITE (SPS)

PHASE II

FINAL BRIEFING

R. B. Crisman

STUDY OBJECTIVES

The study objectives shown are to be accomplished for the SPS program for that period in the program at which twenty SPS's and their corresponding rectennas have been completed and are in operation. In addition, additional SPS's and rectennas are being completed and going into operation at the rate of two per year.

STUDY OBJECTIVES

- DEVELOP AN INTEGRATED OPERATIONS CONCEPT THAT WILL INSURE THAT THE SPS SYSTEM SATISFIES ALL REQUIREMENTS IN A TIMELY FASHION, AND IS CAPABLE OF REACTING TO PROBLEMS IN REAL TIME WHEN NECESSARY

- THIS CONCEPT TO ENCOMPASS THE ENTIRE SYSTEM FROM INDUSTRIAL COMPLEX TO AND INCLUDING THE RECTENNA/GRID INTERFACE

INTEGRATED OPERATIONS CONCEPTS

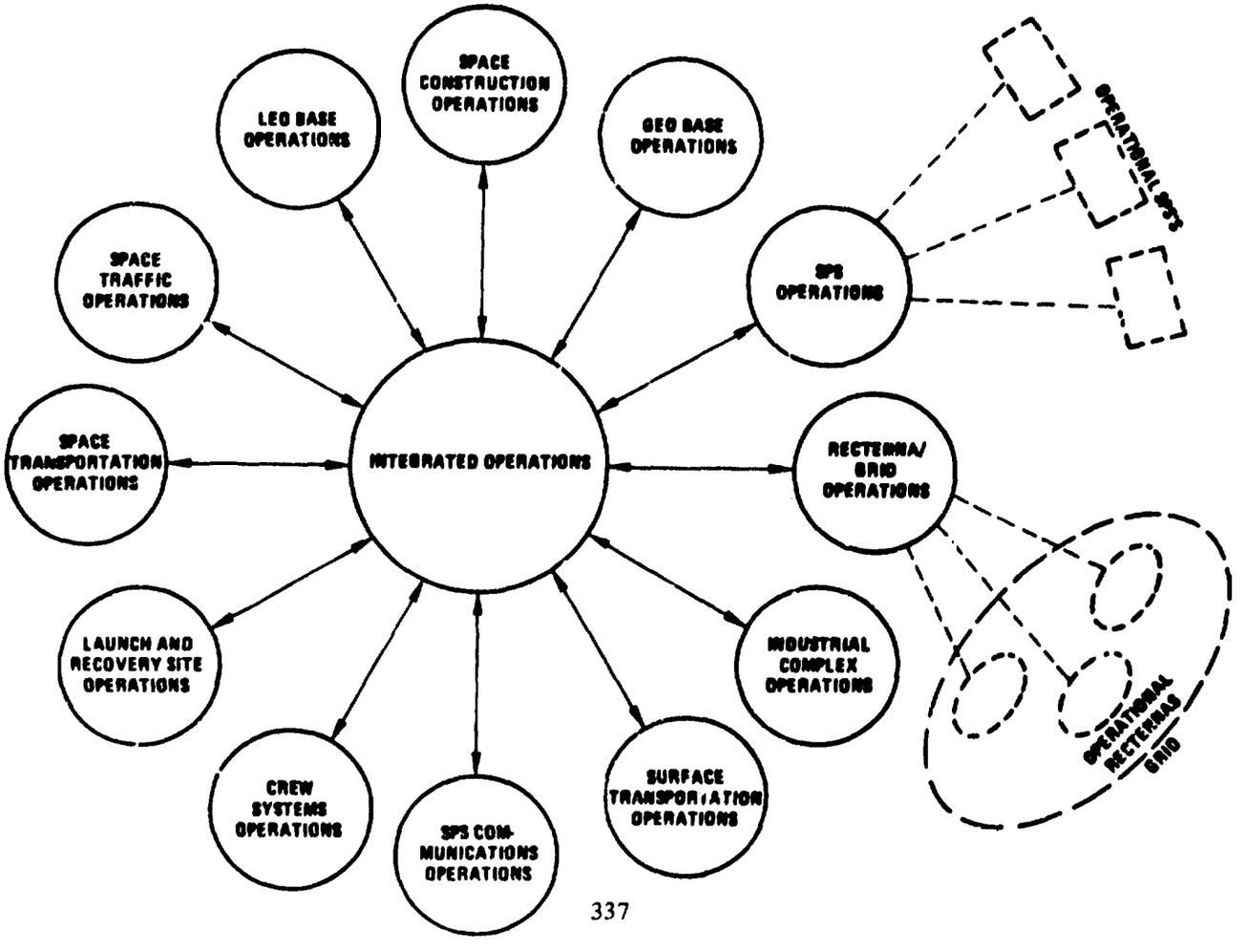
In the Phase I study a mission command and control concept was developed for control of the space elements of the SPS system. In Phase II the concept has been expanded to include the entire system.

The approach selected to develop the concept was to define, at a summary level, the tasks which must be performed to assure proper execution of the program. To accomplish this the program was divided into major segments (using the WBS as a starting point) and the tasks for each segment were defined. Related tasks were then regrouped resulting in the definition of different major segments. After several iterations the concept shown was developed. This concept consists of twelve "local operations" which will be responsible for the performance of an assigned group of tasks to the required standards and on time. As indicated one of these local operations is responsible for command and control of the operational SPS's and another is responsible for command and control of the operational rectennas.

The activities of these twelve local operations are coordinated and integrated by a single central organization "Integrated Operations". The principal functions of this organization are to define program requirements, to prepare and maintain the master program plans and schedules, to coordinate the activities of the 12 local operations and to continuously monitor program performance.

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INTEGRATED OPERATIONS CONCEPT



TYPICAL LOCAL OPERATION DETAILED TASK ANALYSIS

To the extent possible within the time available the command and control tasks associated with each task of the local operations were identified. Based on these detailed analyses the tasks which are of sufficient importance to be monitored by Integrated Operations were determined and summarized. This figure is a typical page from such a local operation task analysis.

In addition to identifying the tasks, the interfaces with other local operations and Integrated Operations were also identified as shown in the last column.

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TYPICAL LOCAL OPERATION DETAILED TASK ANALYSIS

LOCATION/OPERATION: LEO BASE OPERATIONS (CONTINUED)

LOCAL OPERATION TASK	COMMAND AND CONTROL TASK	LOCAL OPERATION ACTIVITY	OTHER OPERATION INTERFACE
CARGO INTRA-BASE TRANSPORTATION OPERATIONS	– MONITOR STATUS OF ALL CARGO TRANSPORTERS (20-30 UNITS). (AVAILABILITY, LOCATION, DESTINATION, ETC)	X	
	– CONTROL MOVEMENT OF ALL CARGO TRANSPORTERS (ACTIVATE, DEACTIVATE, CONTROL MOVEMENT, SWITCHING, ETC)	X	
	– COORDINATE CARGO TRANSPORTER MAINTENANCE REQUIREMENTS WITH BASE EQUIPMENT MAINTENANCE GROUP	X	
CARGO SORTING AND STORAGE OPERATIONS	– RECEIVE CARGO MANIFEST		LAUNCH AND RECOVERY SITE
	– RECEIVE CARGO STORAGE LOCATION ROADMAP		LAUNCH AND RECOVERY SITE
	– RECORD STORAGE LOCATIONS OF EACH COMPONENT	X	
	– RECEIVE CARGO DISTRIBUTION INSTRUCTIONS		SPACE CONSTRUCTION
	– RECORD REMOVAL OF COMPONENTS FROM STORAGE	X	
	– CHECK INVENTORY CONTROL RECORDS	X	
CARGO DISTRIBUTION OPERATIONS	– RECEIVE USER EQUIPMENT COMPONENT DELIVERY REQUIREMENTS		SPACE CONSTRUCTION
	– INTEGRATE CARGO DELIVERY REQUESTS	X	
	– ISSUE CARGO DISTRIBUTION INSTRUCTIONS TO WAREHOUSE	X	
	– MONITOR CARGO DELIVERY OPERATIONS INCLUDING MACHINE LOADING	X	

GENERAL TASKS PERFORMED BY INTEGRATED OPERATIONS

Most of the tasks performed by Integrated Operations with respect to the functions of each local operation are very similar for all local operations. These general tasks are presented in the next three charts. In order to estimate the magnitude of the Integrated Operations, however, it was necessary to define the number of tasks which each local operation performs that is of sufficient importance to be monitored by Integrated Operations. These tasks are summarized on the six charts following the next three.

Integrated Operations is the official program source of requirements and is responsible for the documentation and allocation of the requirements for other elements of the program.

Integrated Operations is also responsible for preparing and maintaining the master program plans and schedules and for monitoring the program for proper compliance. In order to do this a system for obtaining performance feedback from the local operations is necessary.

GENERAL TASKS PERFORMED BY INTEGRATED OPERATIONS

GENERAL TASK	DESCRIPTION
IDENTIFY, DEFINE AND ALLOCATE OVERALL PROGRAM REQUIREMENTS	– BASED ON STUDY AND TEST RESULTS IN COMBINATION WITH NATIONAL NEEDS, IDENTIFY OVERALL PROGRAM REQUIREMENTS – ANALYZE REQUIREMENTS AND ALLOCATE TO LOCAL OPERATIONS – PREPARE PROGRAM LEVEL DOCUMENTATION (SYSTEM SPECIFICATIONS, PROGRAM REQUIREMENTS DOCUMENTS, PROGRAM DIRECTIVES) – ALLOCATE RESPONSIBILITIES FOR PREPARATION OF LOWER TIER DOCUMENTATION AMONG LOCAL OPERATIONS – REVIEW AND APPROVE LOWER TIER DOCUMENTATION AS NECESSARY
PREPARE MASTER PROGRAM PLANS AND SCHEDULES. MONITOR PROGRAM PERFORMANCE AGAINST THESE	– PREPARE, COORDINATE AND IMPLEMENT MASTER PLANS AND SCHEDULES OF PROGRAM ACTIVITIES WHICH WILL ASSURE A PROGRAM THAT MEETS ALL REQUIREMENTS IN A TIMELY FASHION – OBTAIN DETAILED PLANS AND SCHEDULES THAT COMPLY WITH MASTERS FROM EACH LOCAL OPERATION – SET UP SYSTEM FOR FEEDBACK OF PLAN AND SCHEDULE PERFORMANCE FROM EACH LOCAL OPERATION – SET UP SYSTEM FOR MONITORING PLAN AND SCHEDULE PERFORMANCE WHICH WILL FLAG PROBLEMS – RESOLVE PROGRAMMATIC PROBLEMS AND/OR PROBLEMS WHICH INVOLVE INTERFACING LOCAL OPERATIONS – ASSURE COORDINATION AMONG OPERATIONS

GENERAL TASKS PERFORMED BY INTERGRATED OPERATIONS (CONTINUED)

Integrated Operations is responsible for monitoring the technical performance of the program using the methods shown as well as others, such as personal contacts, to insure that all technical requirements imposed on the program are satisfied.

It is also the central logistics agency for the entire program. All 12 local operations have logistics requirements which must be coordinated and integrated in the interest of program efficiency. This function is assigned to Integrated Operations which has the overall coordination/integration functions for the program.

GENERAL TASKS PERFORMED BY INTEGRATED OPERATIONS (CONT)

GENERAL TASK	DESCRIPTION
ASSURE SATISFACTORY TECHNICAL PERFORMANCE	– MONITOR TECHNICAL PERFORMANCE AT PROGRAM LEVEL – REVI[illegible]STUDIES, ANALYSES, TEST RESULTS, ORBITAL PERFORMANCE – CONDUCT PERIODIC TECHNICAL REVIEWS – RESOLVE TECHNICAL CONCERNS – APPLY ADDITIONAL TECHNICAL RESOURCES – REALLOCATE REQUIREMENTS AMONG PROGRAM ELEMENTS – REVIEW AND MODIFY REQUIREMENTS
PROVIDE LOGISTICS FOR PROGRAM	– OBTAIN LOGISTICS REQUIREMENTS FROM LOCAL OPERATIONS WHICH THEY MUST HAVE TO COMPLY WITH PROGRAM REQUIREMENTS – PREPARE, COORDINATE AND IMPLEMENT MASTER LOGISTICS PLAN AND SCHEDULE – OBTAIN COMPLYING DETAILED PLANS AND SCHEDULES FROM EACH LOCAL OPERATION – SET UP LOGISTICS STATUS REPORTING SYSTEM FOR LOCAL OPERATIONS – MONITOR LOGISTICS STATUS VS PLANS AND SCHEDULES – MATERIALS, EQUIPMENT, PROPELLANT FLOW – INVENTORIES – SPARES – USE RATES – RESOLVE PROGRAM LEVEL PROBLEMS AND/OR PROBLEMS WHICH INVOLVE INTERFACING LOCAL OPERATIONS

GENERAL TASKS PERFORMED BY INTERGRATED OPERATIONS (CONTINUED)

As the number of operational SPS's and rectennas increase, the schedules for removing and returning satellites to service (due to satellite maintenance, rectenna maintenance, eclipses, electrical load level variations, etc.) will become increasingly complicated as will coordination with the grids involved. Although the SPS Operations and Maintenance will provide information on the satellites and Rectenna/Grid Operations will coordinate with the grids, Integrated Operations will evaluate the overall system conditions and develop the master power-generation plan and schedule.

GENERAL TASKS PERFORMED BY INTEGRATED OPERATIONS (CONT)

GENERAL TASK	DESCRIPTION
PREPARE AND MAINTAIN MASTER POWER-GENERATION PLAN AND SCHEDULE	– PREPARE MASTER PLAN AND SCHEDULE FOR SATELLITE-RECTENNA/GRID COMBINATIONS AND OPERATIONS. PLAN MUST CONSIDER – RECTENNA/GRID POWER LOADING SCHEDULES – ECLIPSE SEASONS – RECTENNA MAINTENANCE SCHEDULES – SATELLITE MAINTENANCE SCHEDULES – CONTINGENCIES

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS

The next six charts show the functions performed by each local operation which are of sufficient importance to be monitored by Integrated Operations.

The Industrial Complex Operation is responsible for the provision of all materials, equipment and propellants required by the SPS program. This includes all activities from operation of wells or mines, if necessary, through processing and fabrication to packaging for use on orbit.

Surface Transportation Operations is responsible for transportation of the packaged products from the Industrial Complex to the Launch and Recovery Site. It is responsible for operating any SPS-dedicated transportation equipment which may be required due to the location of the Launch and Recovery Site.

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS

LOCAL OPERATION	TASKS MONITORED BY INTEGRATED OPERATIONS
INDUSTRIAL COMPLEX	– PLANNING AND SCHEDULING TO HAVE CORRECT PARTS AND EQUIPMENT FABRICATED IN TIME FOR TRANSPORTATION TO SPACE ON SCHEDULE – ACQUISITION OF FACILITIES, MATERIALS, PROPELLANTS, PERSONNEL, EQUIPMENT – FABRICATION AND/OR PROCESSING – PACKAGING FOR SHIPMENT AND DIRECT USE ON ORBIT
SURFACE TRANSPORTATION	– PLANNING AND SCHEDULING FOR TIMELY MOVEMENT OF CARGO, PROPELLANTS, PERSONNEL FROM INDUSTRIAL COMPLEX TO LAUNCH AND RECOVERY SITE – PLANNING AND SCHEDULING OF INTER-COMPLEX MOVEMENTS – ASSURE AVAILABILITY OF TRANSPORTATION MEANS – TRANSPORTATION OF CARGO, PROPELLANTS, PERSONNEL

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONTINUED)

The Launch and Recovery Site activities will require large and extensive space vehicle and space passenger support facilities due to the numbers of vehicles, the number of flights and the number of space passengers involved. It is responsible for all activities from receipt of cargo, propellants and personnel through launch, recovery and hands-on maintenance/refurbishment of space vehiceles.

The responsibilities of LEO Base Operations are principally transfer of cargo and personnel between space vehicles and construction of EOTV's. The base will utilize a ground support group which will perform routine functions for the base such as planning and scheduling, inventory control, etc., using daily inputs from the base. These functions will be performed on the ground to reduce the number of personnel required in space. This support group is located in Integrated Operations as will be shown later.

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONT)

LOCAL OPERATION	TASKS MONITORED BY INTEGRATED OPERATIONS
LAUNCH AND RECOVERY SITE	– OPERATE AND MAINTAIN SITE – PLANNING AND SCHEDULING OF SITE OPERATIONS – HLLV AND HLLV PAYLOAD FLIGHT PROCESSING – PLV AND PLV PASSENGER FLIGHT PROCESSING – PLV, HLLV LAUNCH – PLV, HLLV LANDING COMMAND AND CONTROL (BOOSTERS AND ORBITERS) – PLV, HLLV TRANSPORTATION AND REFURBISHMENT
LEO BASE	– OPERATE AND MAINTAIN BASE – CONSTRUCT EOTV's – COORDINATE CONSTRUCTION PERSONNEL, MATERIAL, EQUIPMENT REQUIREMENTS – PROVIDE RENDEZVOUS/DOCKING, LAUNCH CAPABILITY, AND SUPPORT FOR SPACE TRANSPORTATION VEHICLES – OPERATE CREW HABITATS AND ASSURE CREW HEALTH AND SAFETY – PROVIDE IN-SPACE MAINTENANCE FOR SPACE TRANSPORTATION VEHICLES – UNLOAD, PROVIDE INTRA-BASE TRANSPORTATION, STORE OR RELOAD CARGO

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONTINUED)

GEO Base Operations includes all the functions associated with construction of the SPS's, servicing of the Space Transportation vehicles involved, as well as operation and maintenance of the base itself. Although many of the functions must be done at the base, many of the bookkkeeping functions associated with such tasks will be performed on the ground utilizing daily inputs from the base for updating, as in the case of the LEO Base.

The number of space transportation vehicles involved, as well as the similarity among many of them, suggests that a single operator, Space Transportation and Maintenance should be responsible for operation of the vehicles and for the crews which operate them. It appears that a certain amount of cross-training and use of the same personnel on different vehicles will be possible if the activities are properly integrated. Since this operation will be in real time communication with all operating vehicles it will be able to collect performance and anomaly data in real time. For this reason the vehicle maintenance function is assigned to the same operation.

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LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONT)

LOCAL OPERATION	TASKS MONITORED BY INTEGRATED OPERATIONS
GEO BASE	– OPERATE AND MAINTAIN BASE – CONSTRUCT SPS's – COORDINATE CONSTRUCTION PERSONNEL, MATERIAL, EQUIPMENT REQUIREMENTS – COORDINATE BASE/SPS SEPARATION SCHEDULE – SUPPORT OPERATIONAL SPS MAINTENANCE – PROVIDE RENDEZVOUS/DOCKING, LAUNCH CAPABILITY FOR SPACE TRANSPORTATION VEHICLES – SERVICE SPACE TRANSPORTATION VEHICLES – OPERATE CREW HABITATS AND ASSURE CREW HEALTH AND SAFETY
SPACE TRANSPORTATION AND MAINTENANCE	– PLAN, SCHEDULE, PROVIDE SPACE TRANSPORTATION FOR SYSTEM – OPERATE ALL SPACE TRANSPORTATION VEHICLES – MONITOR AND CONTROL SPACE TRANSPORTATION VEHICLES IN REAL TIME – DEFINE FLIGHT CREW REQUIREMENTS, ASSIST IN TRAINING AND MAKE ASSIGNMENTS – DEFINE GROUND (MISSION) CONTROL CREW REQUIREMENTS, TRAIN AND MAKE ASSIGNMENTS – DEFINE AND IMPLEMENT SPACE TRANSPORTATION VEHICLE MAINTENANCE PROGRAM

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONTINUED)

Although the actual construction of the SPS's and EOTV's will take place at the orbital bases, it is desirable to keep the number of personnel required at the bases to a minimum by performing as many support functions as possible on the ground, as discussed previously. The magnitude of the construction task dictates that this ground operation should be assigned to a separate local operation Space Construction (Ground Operations), and not made a part of Integrated Operations as in the case of the ground support groups for LEO and GEO base operations.

SPS Operations and Maintenance is the organization that will operate the unmanned satellites from the ground in real time, using telemetered information. Although use of extensive on-board data processing is planned as well as are automated techniques on the ground, the amount of equipment and number of satellites involved indicate that extensive human participation will be required. As in the case of the Space Transportation vehicles, since the detailed configuration status for each satellite, as well as its required operating schedule, will be known continuously by this operation, it has also been made responsible for SPS maintenance.

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONT)

LOCAL OPERATIONS	TASKS MONITORED BY INTEGRATED OPERATIONS
SPACE CONSTRUCTION (GROUND OPERATIONS)	– PREPARE AND DIRECT IMPLEMENTATION OF PLANS AND SCHEDULES FOR CONSTRUCTION OF SPS's AT GEO – DEFINE, PROCURE AND COORDINATE TRANSPORTATION OF SPS CONSTRUCTION MATERIALS AND EQUIPMENT – DEFINE REQUIREMENTS AND COORDINATE ACQUISITION AND TRAINING OF SPS CONSTRUCTION PERSONNEL – PREPARE AND DIRECT IMPLEMENTATION OF PLANS AND SCHEDULES FOR CONSTRUCTION OF EOTV's AT LEO – DEFINE, PROCURE AND COORDINATE TRANSPORTATION OF EOTV CONSTRUCTION MATERIALS AND EQUIPMENT – DEFINE REQUIREMENTS AND COORDINATE ACQUISITION AND TRAINING OF EOTV CONSTRUCTION PERSONNEL
SPS OPERATIONS AND MAINTENANCE	– OPERATE ALL OPERATIONAL SPS's FROM GROUND, UTILIZING TELEMETERED INFORMATION – TAKE APPROPRIATE REAL TIME ACTION IN EVENT OF ANOMALOUS OR DEGRADED PERFORMANCE – DEFINE REQUIREMENTS, PREPARE AND IMPLEMENT PLANS AND SCHEDULES FOR OBTAINING AND TRAINING OPERATIONS PERSONNEL – DEFINE, SCHEDULE AND DIRECT SPS MAINTENANCE – DEFINE, ACQUIRE AND COORDINATE TRANSPORTATION OF MAINTENANCE MATERIALS AND EQUIPMENT – DEFINE REQUIREMENTS AND COORDINATE ACQUISITION AND TRAINING OF MAINTENANCE PERSONNEL

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONTINUED)

The Rectenna/Grid Operation is responsible for the construction, operation and maintenance of the rectennas. It is also responsible for coordinating the interface with the operational SPS's and the utility grids. Interface items to be coordinated include satellite temporarily out of service, rectennas temporarily out of service, grid load levels etc.

The large number of space vehicles involved in the SPS system as well as the amount of activity at geosynchronous orbit over the U.S., a location which is already quite populous, dictates the necessity for a Space Traffic Control Operation dedicated to the SPS system. In addition to the functions shown, this operation will serve as a single interface with any other existing space traffic control systems in inform them of SPS system activities as well as to receive information on non-SPS activities.

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONT)

LOCAL OPERATION	TASKS MONITORED BY INTEGRATED OPERATIONS
RECTENNA/GRID	– CONSTRUCT RECTENNAS INCLUDING GRID INTERFACES – OPERATE RECTENNAS – COORDINATE RECTENNA/GRID – SPS OPERATING SCHEDULES TO INSURE ADEQUATE POWER IS PROVIDED TO GRID DURING SPS MAINTENANCE, ECLIPSE, ETC – PLAN, SCHEDULE, PERFORM RECTENNA MAINTENANCE
SPACE TRAFFIC CONTROL	– MAINTAIN POSITION AND VELOCITY DATA ON ALL SPS SPACE EQUIPMENT – DEFINE LAUNCH TIMES/TRAJECTORIES FOR ALL SPACE TRANSPORTATION VEHICLES – DEFINE AND COORDINATE STATION KEEPING REQUIREMENTS FOR ORBITAL BASES AND SPS's – DETERMINE AND IMPLEMENT ACTIONS REQUIRED TO AVOID COLLISIONS BETWEEN SPS SPACE EQUIPMENT AND OTHER SATELLITES, METEORITES, SPACE DEBRIS

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONTINUED)

The large numbers of personnel who will be required to live and work in space and the amount of similar training required by each, suggests that a central operation, Crew Systems, should define integrate and coordinate requirements, acquisition and training of personnel. This operation would be responsible for accomplishing the common training for all personnel living and working in space and would coordinate with other operations for the training on tasks peculiar to each person's assignment. It is anticipated that a significant amount of cross-training will be possible, such that one person can perform in different assignments either for a complete tour of duty or for emergency periods.

The overall communications system for SPS has not yet been defined, however, the extensive nature of the SPS system and its activities indicate that the communications requirements will also be extensive. It is anticipated that a separate operation will be required to perform the functions involved.

TRW
DEFENSE AND SPACE SYSTEMS GROUP

LOCAL OPERATION TASKS MONITORED BY INTEGRATED OPERATIONS (CONT)

LOCAL OPERATION	TASKS MONITORED BY INTEGRATED OPERATIONS
CREW SYSTEMS	– DEFINE/COORDINATE NUMBERS AND TYPES OF PERSONNEL REQUIRED FOR ALL IN-SPACE ACTIVITIES – PREPARE AND IMPLEMENT PLANS AND SCHEDULES FOR OBTAINING NECESSARY PERSONNEL – DEFINE AND IMPLEMENT PERSONNEL TRAINING PROGRAM INCLUDING CROSS-TRAINING – DEFINE AND IMPLEMENT CREW REQUIREMENTS FOR LIVING AND WORKING IN SPACE – DEFINE AND IMPLEMENT SPACE PERSONNEL FLIGHT PREPARATION AND REHABILITATION PROGRAM
SPS COMMUNICATIONS	– PROVIDE REQUIRED COMMUNICATION AMONG SPS SYSTEM ELEMENTS – OPERATE AND MAINTAIN SPS-DEDICATED COMMUNICATIONS EQUIPMENT – DEFINE REQUIREMENTS, PREPARE, IMPLEMENT PLANS AND SCHRDULE FOR OBTAINING AND TRAINING NECESSARY PERSONNEL

INTEGRATED OPERATIONS ORGANIZATION

As shown previously, the major functions of Integrated Operations are to define program requirements, to prepare and maintain the master program plans and schedules (including logistics), to coordinate the activities of the 12 local operations implementing these, and to continuously monitor performance.

Since the activities of each local operation involve widely different skills and disciplines, it is necessary to have within Integrated Operations a specific group of people to interface with each local operation. These groups will act as representatives of the local operation within Integrated Operations, performing the general Integrated Operations functions with respect to the local operation and insuring that the needs and requirements of the local operation are adequately considered during Integrated Operations decision-making.

As indicated in the figure, in addition to the twelve groups interfacing with local operations there are three additional "staff" groups:

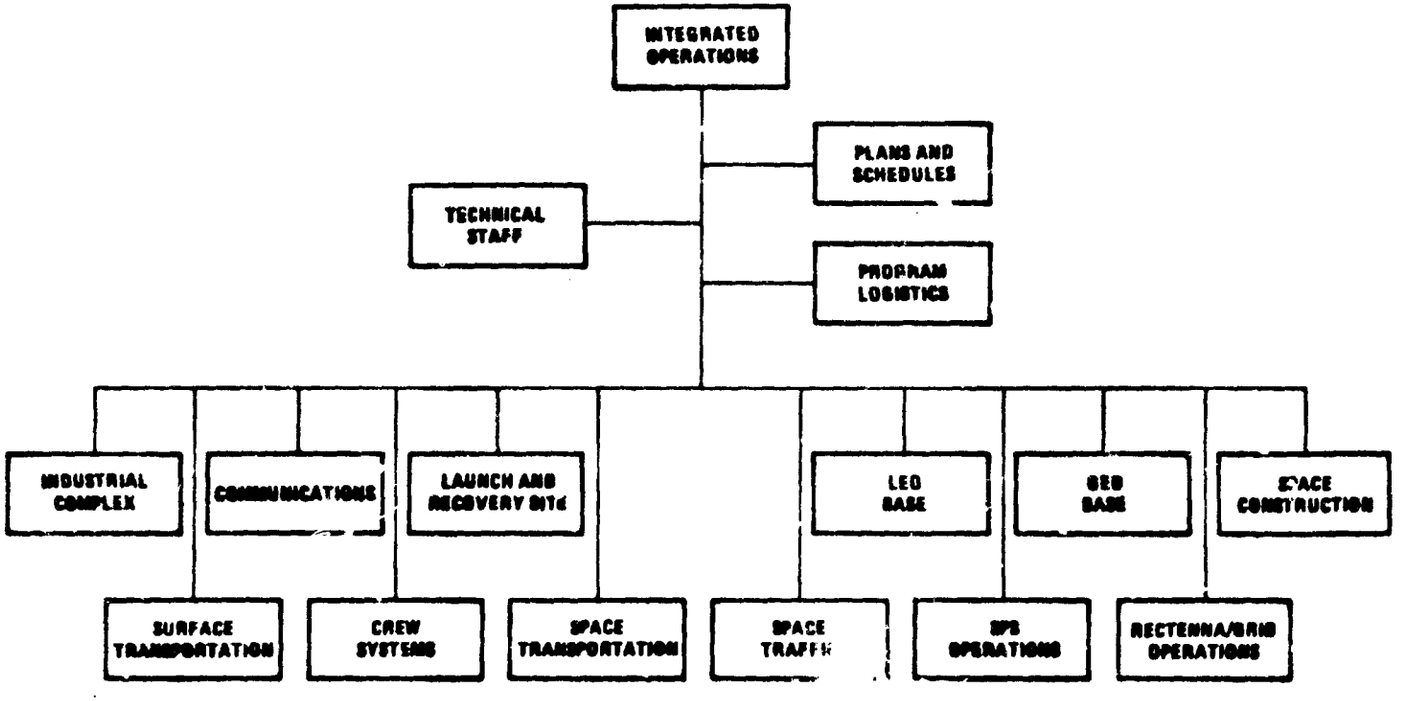
a) A technical staff with the technical skills and disciplines which are not provided by the twelve interfacing groups. Typical of these disciplines are SPS design expertise, rectenna design expertise and space transportation vehicle design expertise. This staff, together with the technical personnel of the interfacing groups, provide the top level technical knowledge necessary to resolve technical problems and make programmatic decisions. This staff will also be the technical pool to which operations personnel can turn in the event of real-time problems with space vehicles during flight.

b) A central planning and scheduling staff which will perform the mechanics of preparing and maintaining master program plans and schedules.

c) A program logistics staff which will coordinate all logistic requirements of the program to assure an efficient, coordinated logistics system.

TRW
DEFENSE AND SPACE SYSTEMS GROUP

INTEGRATED OPERATIONS ORGANIZATION



SPACE TRANSPORTATION

This section will present a brief description of the major transportation system elements including HLLV, PLV, EOTV and POTV. The utilization of these systems in terms of a transportation scenario will be discussed in addition to the cost associated with transportation in performing the SPS program.

TOPICS

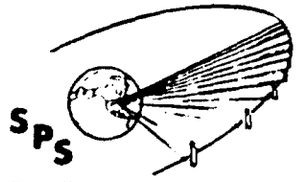
- SYSTEM DESCRIPTIONS
- TRANSPORTATION SCENARIO
- COST

TWO-STAGE WINGED SPS LAUNCH VEHICLE

The reference launch vehicle used to transport the majority of cargo to the LEO base is a two-stage winged fully reusable system referred to as Heavy Lift Launch Vehicle (HLLV). The booster employs (16) LO_2/LCH_4 engines (thrust = 10 million N each) while the orbiter uses (14) SSME engines.

A GLOW of 10,978 MT results for a gross payload of 424 MT. The net payload value is that associated with actual components, propellant, etc. The difference between the two values is 40 MT for payload containers and rack to support the various containers and 24 MT to support the payload rack within the orbiter cargo bay.

It should also be noted that the gross payload value relates to the reference trajectory which has a burnout at approximately 120 km. Should environmental factors require suppression of the trajectory so burnout occurs at 75 km, a gross payload of 360 MT would result. Such action has not been required as yet.

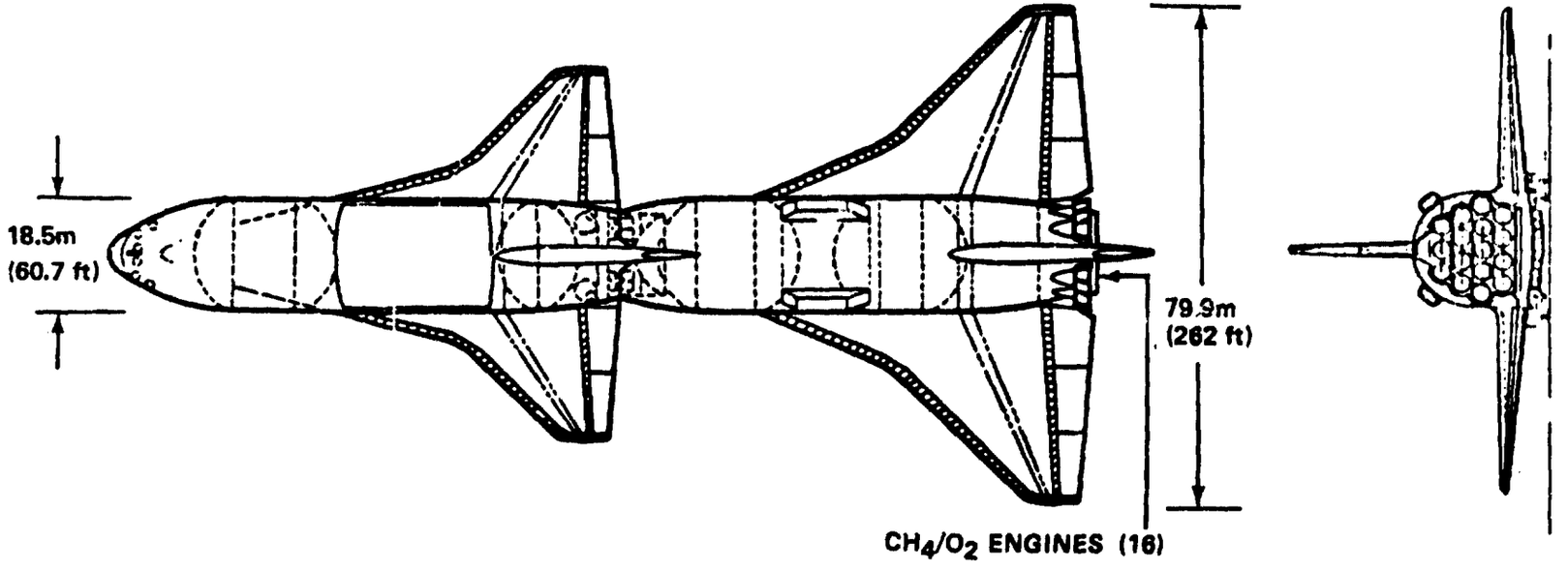


Two-Stage Winged SPS Launch Vehicle

(Fully Reusable Cargo Carrier)

BOEING

SPS-1953



	MT
GLOW	10978
PAYLOAD	
Gross	424
Net	360

SHUTTLE DERIVED PERSONNEL LAUNCH VEHICLE

Orbital crews are delivered to the LEO base using a Shuttle derived Personnel Launch Vehicle (PLV). The vehicle consists of a winged liquid propellant fly-back booster that employs four O_2/CH_4 engines similar to the HLLV booster, a resized, smaller version of the space shuttle external tank and the space shuttle orbiter. The payload capability to the LEO base in a 477 km/31 degree orbit is approximately 89 MT.

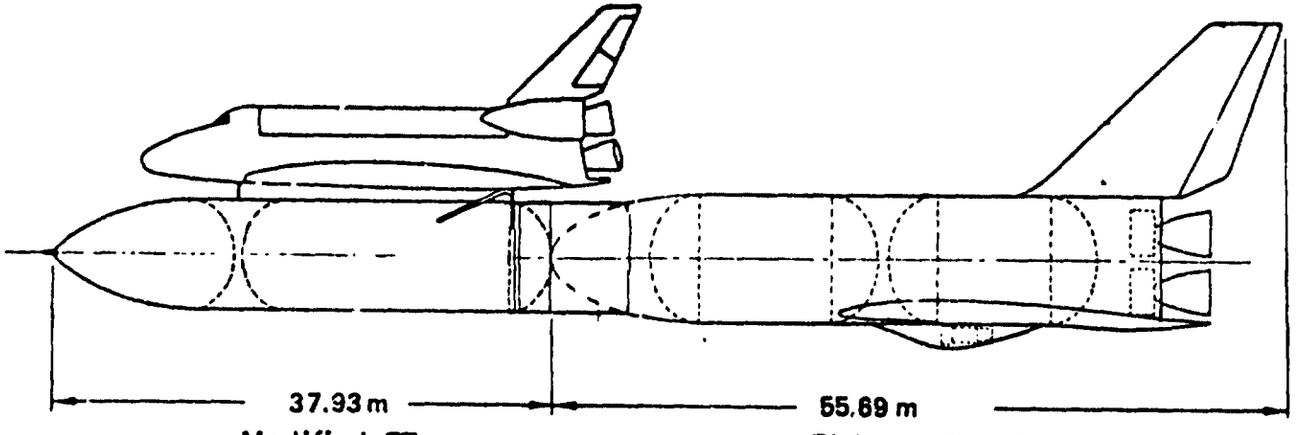
SHUTTLE DERIVED PLV

SPS-2088

VEHICLE CHARACTERISTICS:

GLOW	2,714,750 kg
BLOW	1,959,140 kg
W_{P_1}	1,699,820 kg
OLOW (ET)	666,880 kg
W_{P_2}	551,720 kg
PAYLOAD	88,730 kg

ENGINE CHARACTERISTICS					
STAGE	E	NO.	TYPE	I_{SP} (SL/VAC)	THRUST (VAC)
1	60	4	HIGH P_C LO_2/LCH_4	318.5/352	2.15×10^6 LBF 9.564×10^6 N
2	77.5	3	SSME	363.2/455.2	$.470 \times 10^6$ LBF 2.091×10^6 N



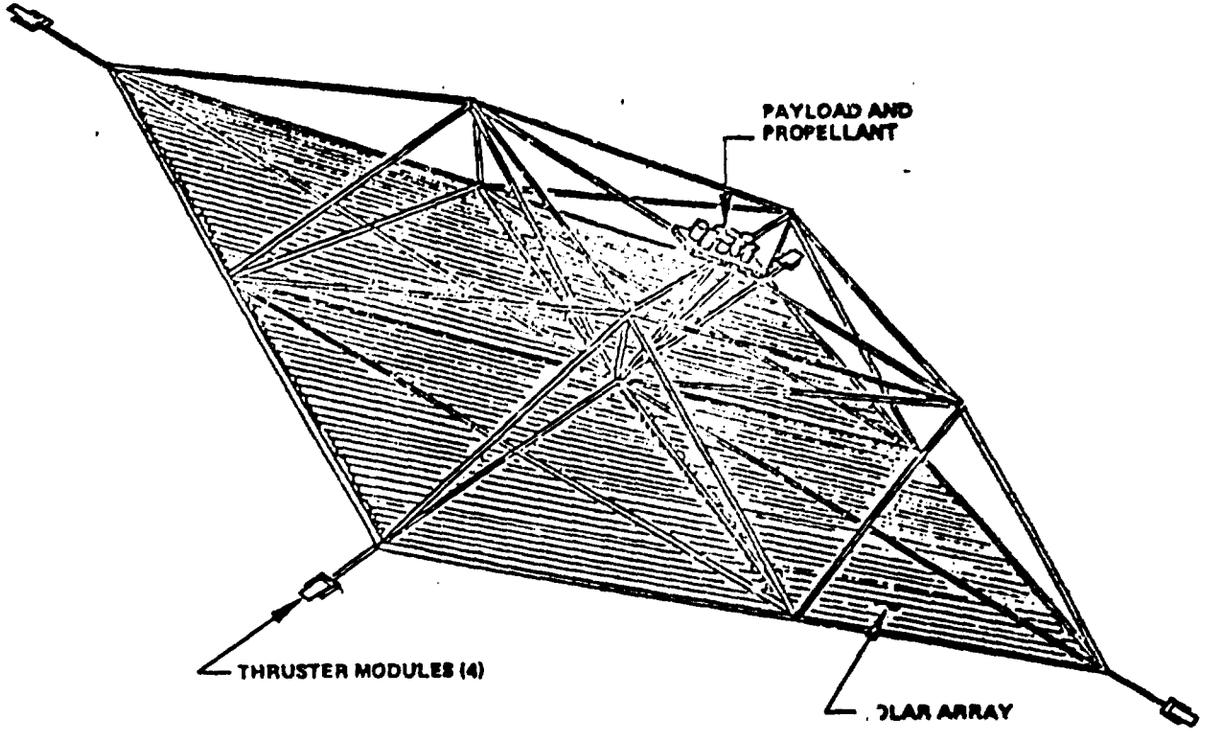
CARGO ORBIT TRANSFER VEHICLE
(ELECTRIC ORBIT TRANSFER VEHICLE)

The reference orbit transfer vehicle used to transport the majority of cargo between LEO and GEO employs electric propulsion and is referred to as an electric orbit transfer vehicle--EOTV. This vehicle has a large planar solar array (blanket design similar to the SPS satellite) generating 300 MW and 1000 x 1500 m in size. Power is processed using solid state systems prior to utilization by the electric thrusters. The thrusters have a beam current of 80 amps, operate at an Isp of 8000 sec and use argon propellant. Isp as well as up trip time of 180 days was determine to be the cost optimum for these two parameters. The down trip time is 39 days. Payload capability is 4000 MT up and 200 MT down.

CARGO ORBIT TRANSFER VEHICLE
(ELECTRIC ORBIT TRANSFER VEHICLE - EOTV)

SPS-3105

BOEING



SYSTEM CHARACTERISTICS

- Initial Power = 300 MW
- Array = 1000 m x 1500 m
- Elec. Thrust = 3345 N
- Empty Mass = 1462 MT
- Argon Prop = 469 MT
- LO_2/LH_2 = 46 MT

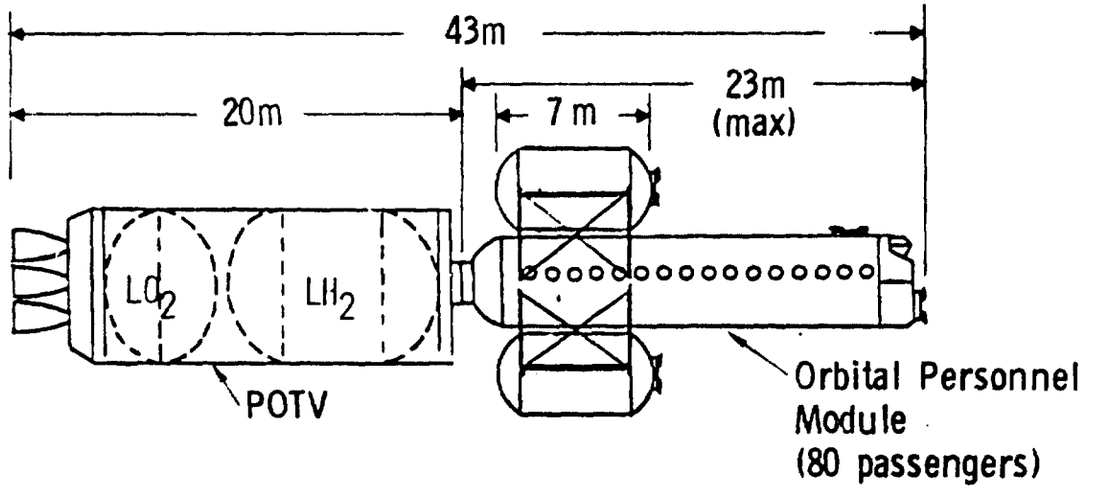
PERFORMANCE

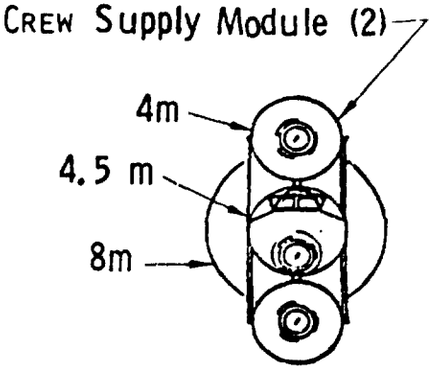
- Payload
  - Up = 4000 MT
  - Down = 200 MT
- Trip Time
  - Up = 130 Days
  - Down = 39 Days
- I_S = 8000 sec

PERSONNEL ORBIT TRANSFER SYSTEM

A LO_2/LH_2 OTV has several applications in the SPS program. One of these is that of crew rotation/resupply as shown on the facing page. In this capacity, a crew of 80 passengers and supplies of food and crew accommodations are transferred between the LEO and GEO bases. The OTV concept now consists of a single stage system that requires refueling at GEO in order to make the return trip to LEO. The concept employed previously has a two-stage round trip vehicle. Delivery of the POTV down propellant to the GEO base by the high performance EOTV results in approximately a 175 MT propellant saving for each POTV flight as compared with the previous two-stage system.

PERSONNEL ORBIT TRANSFER SYSTEM
CREW ROTATION/RESUPPLY





STAGE CHARACTERISTICS

- Dry = 14 MT
- Up Prop = 200 MT
- Down Prop = 185 MT
- Up Payload = 90 MT
- Down Payload = 80 MT
- Refuel at = GEO Base

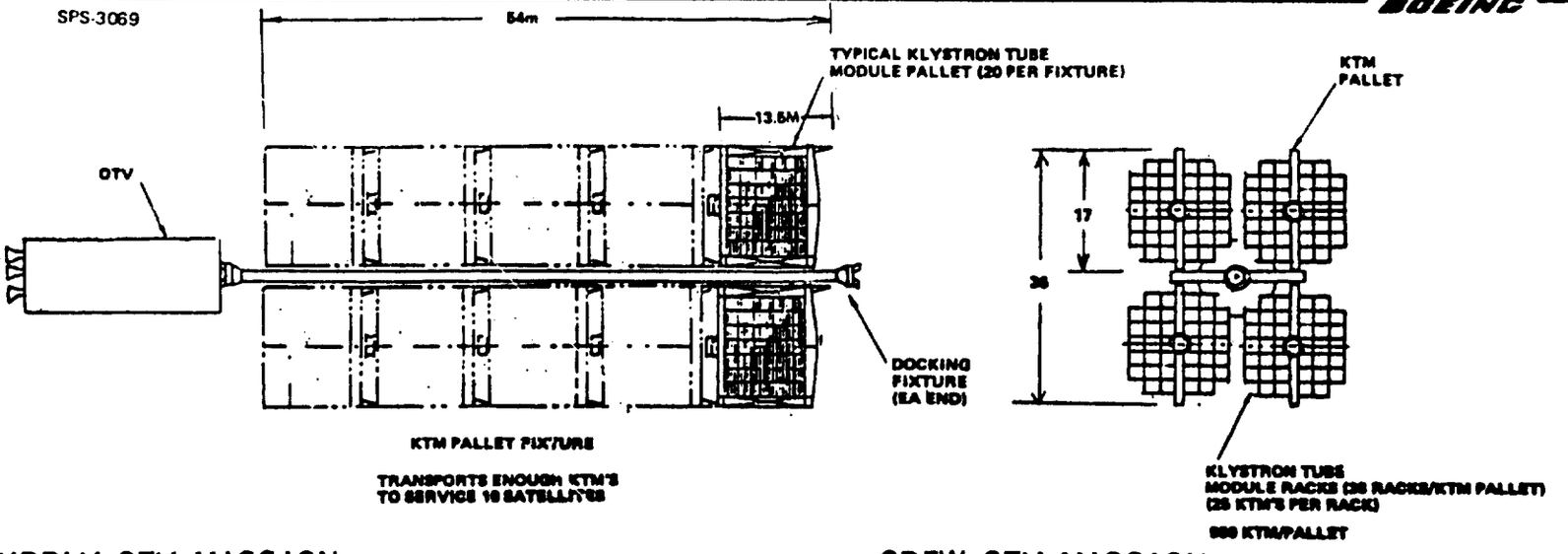
PAYLOAD CHARACTERISTICS

- Passengers = 80
- Flight Crew = 6
- OPM = 59.6 MT
- Supplies 13.7 MT (6600 Man Days)
- Supply Modules 12.3 MT
- Priority Cargo 3.5 MT
- Struct Frame 1.5 MT

SATELLITE MAINTENANCE SORTIE TRANSPORTATION

The other application for the LO_2/LH_2 OTV is that associated with satellite maintenance. In this application, the OTV is based at the GEO base and is used to transport both satellite supplies (propellant and new parts) and mobile crew modules that house the repair crews while at the satellite(s). The reference mission characteristics for the supply mission are shown with the resulting propellant requirement being 77 MT and considerably less than the stage capacity. Mission characteristics associated with transfer of the mobile crew module are given and result in a propellant requirement of only 32 MT. The significant difference in propellant requirements for the three applications suggests that future work in the LO_2/LH_2 OTV could focus on how to obtain a better matchup in requirements or maybe the use of several sizes of OTV's.

SATELLITE MAINTENANCE SORTIE TRANSPORTATION



SUPPLY OTV MISSION

- SUPPLIES TO 10 SATELLITES/SORTIE

Maneuver	Longitude Change (Deg)	Time (Days	Payload (MT)
Base to 1st	5	5	2050
Between ea.	2	1	1850 (avg)
Return to Base	25	5	1720

- OTV PROP. REQMT = 77 MT
  (CAPACITY = 200 MT)

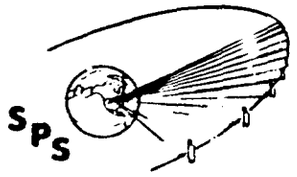
CREW OTV MISSION

- TRANSPORT MOBILE CREW MODULE to 20 SATELLITES IN 90 DAYS
- MODULE MASS = 287 MT
- OTV PROP REQMT - 32 MT

SPACE TRANSPORTATION SCENARIO

OVERVIEW

The space transportation scenario provides the data that defines how each transportation element is used in performing the SPS program. The overall goal, specific objectives and key guidelines are indicated.



SPACE TRANSPORTATION SCENARIO OVERVIEW

- OVERALL GOAL
  - PROVIDE TRACEABILITY
- SPECIFIC OBJECTIVES
  - IDENTIFY PAYLOADS FOR EACH SYSTEM
  - IDENTIFY TRANSPORTATION SCHEDULE
  - IDENTIFY FLIGHT RATE AND TOTAL QUANTITY
  - PROVIDE VISIBILITY BETWEEN TRANSPORTATION FOR SATELLITE CONSTRUCTION AND MAINTENANCE
- KEY GUIDELINES
  - CONSTRUCT TWO 5 GW SATELLITES PER YEAR
  - CONSTRUCT A TOTAL OF 60 SATELLITES

CUM @	YEAR 5	-	2
	YEAR 13	-	20
	YEAR 23	-	40
	YEAR 33	-	60

  - MAINTAIN EACH SATELLITE TWO TIMES PER YEAR

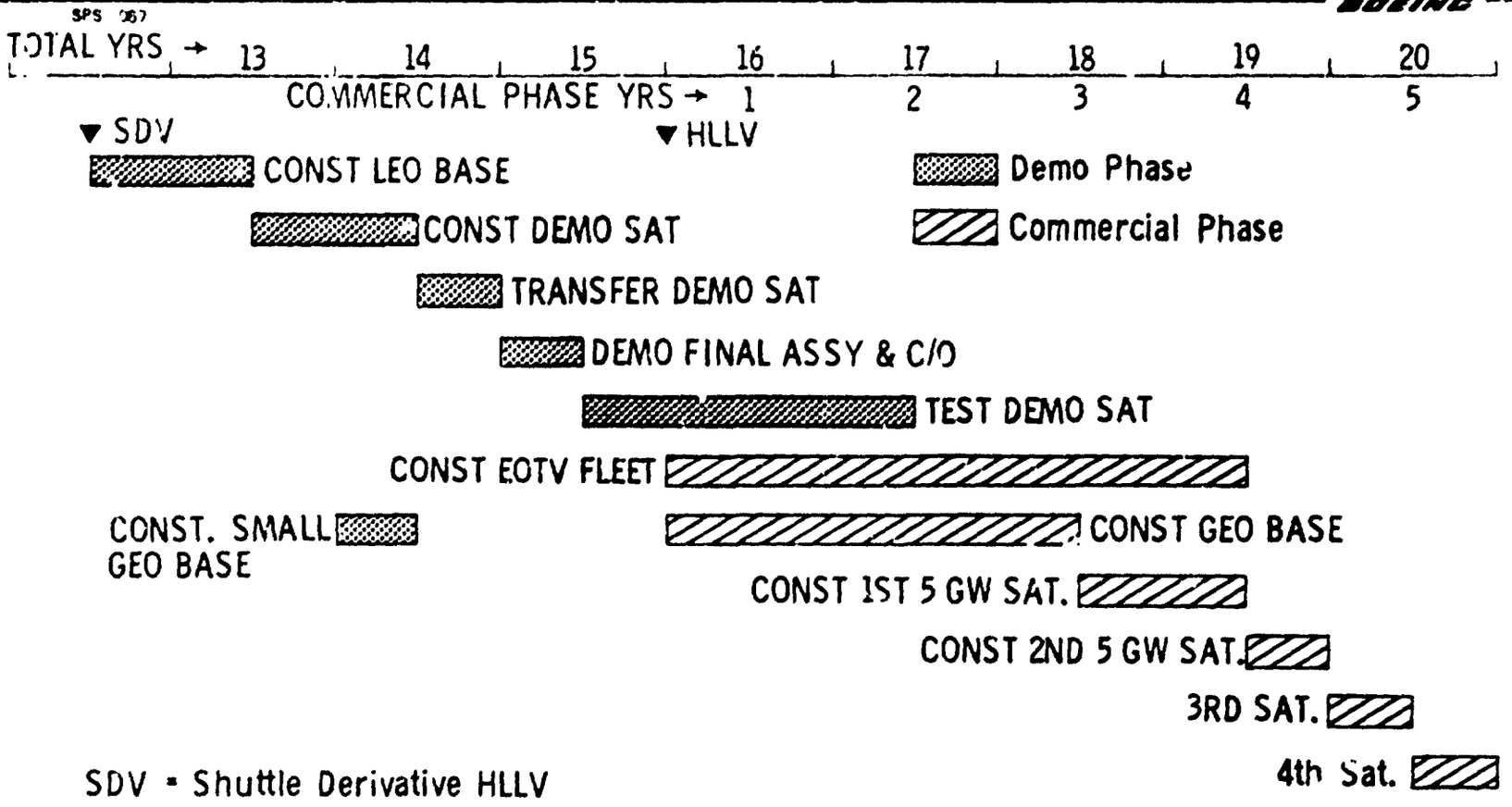
SPS DEMONSTRATION AND COMMERCIALIZATION SCHEDULE

The data included in the transportation scenario only involves the activity associated with the commercialization phase. The schedule shown also indicates the key activities of the demonstration phase so that one knows what system elements are available for the commercial phase.

The commercialization schedule begins with the construction of the EOTV fleet and GEO construction base. One year is allowed to construct the first 5 GWe satellite which comes on line 3½ years into the commercial phase. Each subsequent satellite is constructed in 6 months. As indicated earlier, a total of 60 satellites are constructed over a 33 year time period.

SPS DEMONSTRATION AND COMMERCIALIZATION SCHEDULE

BOEING



SDV = Shuttle Derivative HLLV

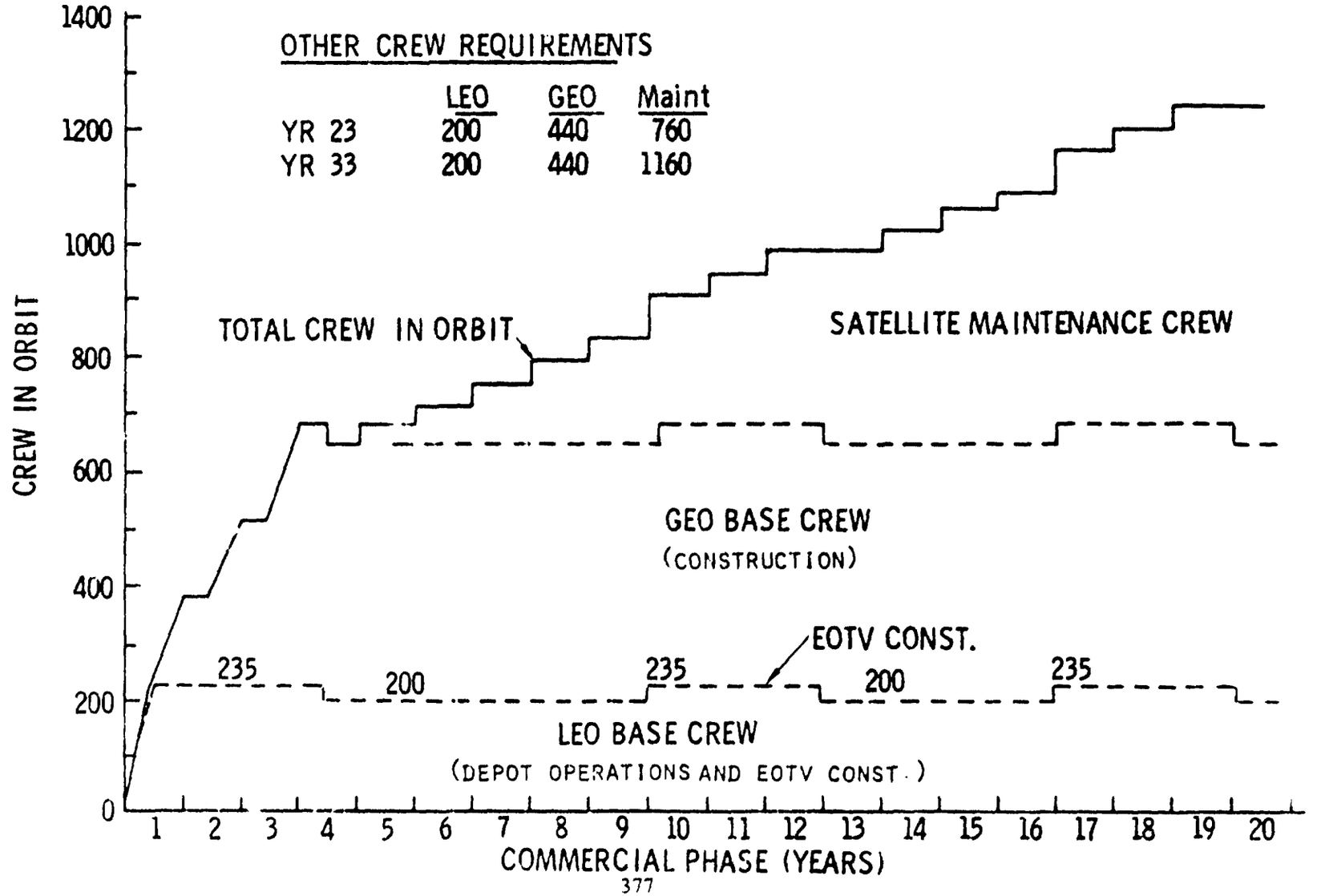
CREW IN ORBIT

Payloads to be transported include crews and cargo. The crew requirements in orbit as a function of time is shown. The LEO base crew normally is 200, the GEO base construction 440 for the construction of two satellites per year while the satellite maintenance crew varies with the number of satellites in orbit. The indicated maintenance increases at a rate of 40 people per year which is a time averaged value based on a detail maintenance analysis associated with 20 satellites in orbit and requiring 380 people. The total crew in orbit when 20 satellites are installed is 1000, 40 satellites (Yr 23) involve 1400 and 60 satellites (Yr 33) 1800.

CREW IN ORBIT

BOEING

SPS-3068



PAYLOAD CHARACTERISTICS

The cargo payloads to be transported are shown. It should be noted that the payload mass constitute one time expenditures or annual requirements. Total annual requirements are discussed later. The majority of the items are self-explanatory but several require some explanation for more clarity.

Crew facility supplies relate to the spares, atmospheric gases and water expendables associated with all the large crew modules (crew quarters, operations module and maintenance module). Work facility supplies cover the same items as listed for the crew modules but in this case they are associated with small manned systems such as the cherrypickers (MRWS), crew buses, etc. in addition to base type spares and expendables such as flight control propellant.

In the case of the GEO base work facility supplies, the value includes an allocation of 500 MT for flight control propellant based on using LO_2/LH_2 propellant and a base/satellite gravity gradient attitude. This propulsion and attitude approach is different from that which is described in the GEO base discussion where electric propulsion and a POP attitude are indicated as the reference. The LO_2/LH_2 and gravity gradient approach has been used for transportation analysis since it is worst case in terms of mass but also because when safety and operational factors are considered this approach may be the most practical.

In the area of SPS maintenance, the supplies include spares (new parts) as well as flight control propellant. Crew and work facilities is the mass required for each 20 satellites which covers three crew modules and one maintenance module at the GEO base and one mobile crew module that goes out to the satellite.

Cargo tug propellant relates to that required to move payloads between the LEO base and EOTV. Crew supplies include food and crew accommodation items constituting 0.9 MT/manyear including packaging. The supply module contribution is 0.8 MT/manyear.

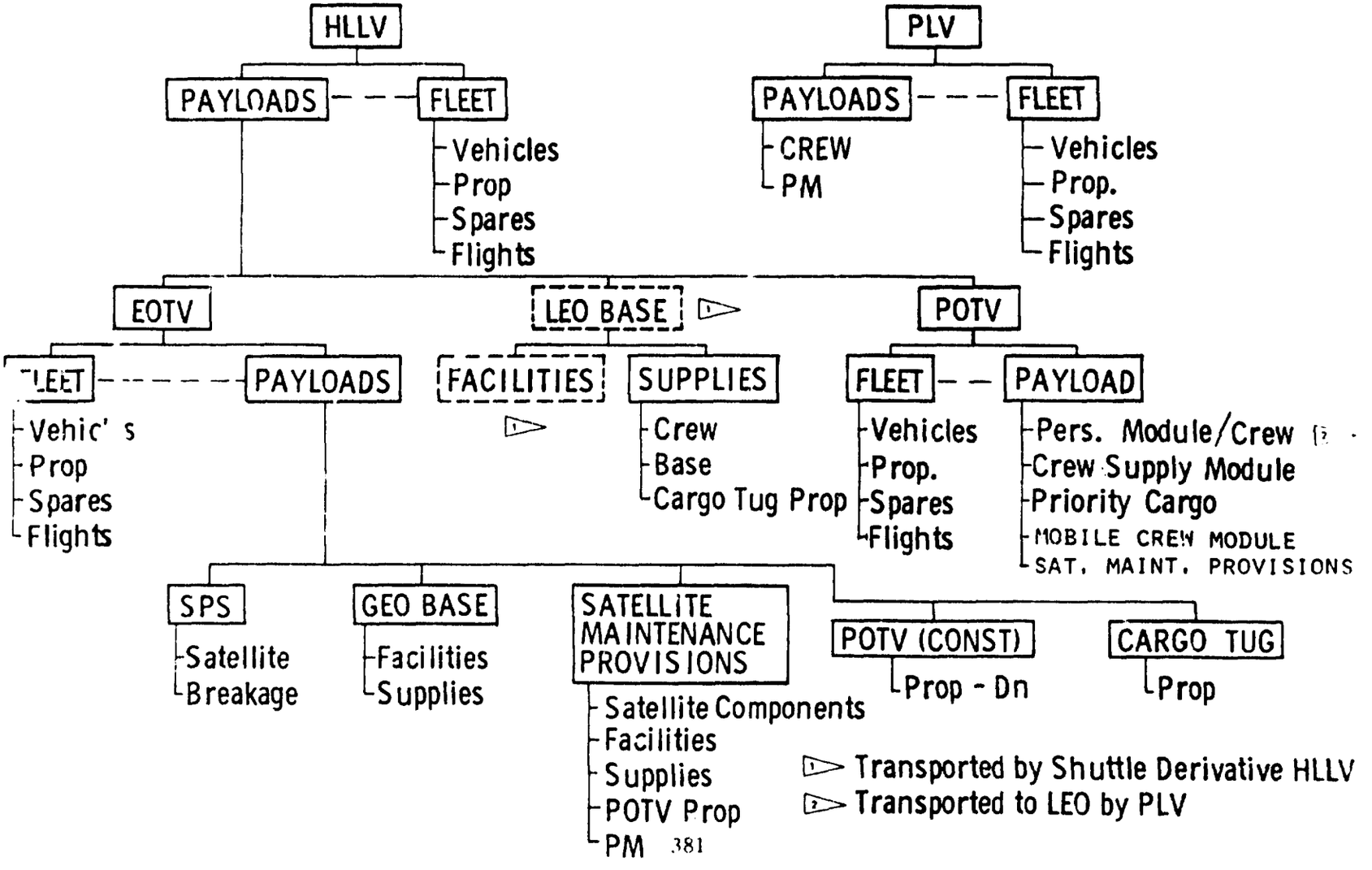
PAYLOAD CHARACTERISTICS
(All Weights in Metric Tons)

SPS	
Satellite (1)	50,984
Allowance for Breakage (2%)	1,020
Total per Satellite	52,004
LEO BASE	
Base	1,603
Crew Facilities Supplies/Yr	313
Work Facilities Supplies/Yr	72
GEO BASE	
Base	4800
Crew Facilities Supplies/Yr	568
Work Facilities Supplies/Yr	683
EOTv	
Vehicle	1,462
Propellant/Flight	515
Refurbishment/Flight	40
POTV - CREW ROTATION/SUPPLY	
Stage	14
Propellant/Flight (Up/Dn)	200/185
Refurbishment/Flight	0.1
Personnel Module	53
SPS MAINTENANCE	
SPS Supplies/Satellite/Yr (to GEO Base)	236
Crew & Work Facilities/20 Satellites	1154
Crew & Work Supplies/Yr/20 Satellites	206
POTV Maintenance Sortie Prop/Satellite/Yr	25
Maintenance Sortie Satellite Supplies/Yr	410
CARGO TUG	
Vehicles	24
Propellant/Refurb/EOTV Flight	37
CREW SUPPLIES/MAN YEAR (Incl. supply module contribution)	1.7

SPACE TRANSPORTATION TRACEABILITY

As indicated earlier, a key goal in the scenario analysis is to show traceability of the transportation elements, the payloads and whether they relate to construction or maintenance. The traceability approach to be used is illustrated. Each transportation element consists of payloads and fleet characteristics. The payload portion identifies all payloads to be transported by that element. When used in conjunction with the payload mass characteristics identified earlier, the total mass can be determined thus allowing fleet characteristics such as number of flights and vehicle quantities to be determined. It will also be noted that the POTV, EOTV and HLLV are interrelated while the PLV is completely independent. An example of employing this traceability technique will be presented in the following charts using the EOTV.

SPACE TRANSPORTATION TRACEABILITY

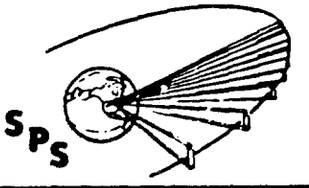


EOTV PAYLOADS TO GEO CONSTRUCTION

As can be seen on the traceability charts, the payloads to be transported to GEO by the EOTV are those associated with satellite maintenance and those categories relating to satellite construction. The facing chart deals with the construction payloads although a similar chart has been prepared for the maintenance payloads.

In this format, the quantity of satellites completed and the payload mass are identified by year for the first 13 years of the commercial program and for the 23rd and 33rd years. Up through the first 13 years is sufficient to see the impact of construction the second fleet of EOTV's and the maintenance of 20 satellites in orbit. The 23rd and 33rd year values have also been identified since they correspond to 40 and 60 satellites respectively being in orbit so the impact of the additional maintenance activity can be assessed.

The total payload per year to be transported by the EOTV and eventually transported by the HLLV is indicated. The HLLV value is lower by the amount equal to the POTV down propellant. This POTV down propellant is not included since it is being "book kept" or charged against the POTV contribution to HLLV payloads (see Traceability Chart).



EOTV PAYLOADS TO GEO FOR CONSTRUCTION

BOEING

SPS-3108 YEAR	SAT QTY	SPS	GEO BASE	GEO BASE SUPPLIES	TUG PROP	POTV PROP [1]	TOTAL PAYLOAD EOTV	TOTAL PAYLOAD HLLV
1		-	2400	127	48	740	3315	2575
2		-	2400	455	63	1480	4398	2918
3		26002		796	296	2590	29684	27094
4	2	78006		1251	851	4070	84178	80108
5	4	104008		1251	1147	4070	110476	106406
6	6	104008		1251	1151	4070	110480	106410
7	8	104008		1251	1161	4070	110490	106420
8	10	104008		1251	1170	4070	110499	106429
9	12	104008		1251	1180	4070	110509	106439
10	14	104008		1251	1195	4070	110524	106454
11	16	104008		1251	1199	4070	110528	106458
12	18	104008		1251	1210	4070	110539	106468
13	20	104008		1251	1224	4070	110553	106481
23	40	104008		1251	1300	4070	110629	106559
33	60	104008		1251	1406	4070	110735	106665

[1] Not incl. in EOTV contribution to HLLV P/L since all POTV prop. is charged to POTV fleet.

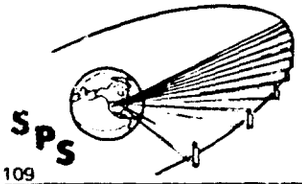
ALL MASS IN METRIC TONS

EOTV FLEET

Once the total payloads to be transported are established, the EOTV fleet characteristics can be determined as shown. Using a net delivery capability of 3600 MT per EOTV flight the number of flights is established. (Fractions of flights are indicated although in reality the fraction would be eliminated by using more propellant per flight for a fixed trip time.) The vehicles required are based on a 235 day turnaround (flight + refurb) for two successive flights of a given EOTV. This results in 1.5 flights per year per EOTV and with the total flights, the number of vehicles can be determined.

The number of vehicles constructed is also indicated with construction of a new fleet of vehicles based on a 7 year (10 flight) design life. From the quantity of vehicles, the vehicle mass can be determined based on a dry mass of 1462 MT/vehicle. Propellant and spares are 515 MT and 40 MT per flight (note: totals are based on fractions of flights). Fleet mass is the sum of the vehicle mass and propellant and spares mass.

It will also be noted that for most parameters, visibility is provided regarding contributions to construction or maintenance of satellites.



SPS-3109

EOTV FLEET

BOEING

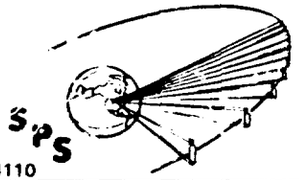
YR	FLIGHTS CONST	FLIGHTS MAINT	VEH REQD	VEH AVAIL.	NEW VEH CONST	NEW VEH MAINT	VEH. MASS CONST	VEH. MASS MAINT	PROP & SPARES CONST	PROP & SPARES MAINT	FLEET MASS CONST	FLEET MASS MAINT
1	0.9	-	4	6	6	-	8772	-	508	-	9280	-
2	1.2	-	4	12	6	-	8772	-	678	-	9450	-
3	8.2	-	8.3	18	6	-	8772	-	4633	-	13405	-
4	23.4	0.4	18.3	21	3	-	4386	-	13221	226	17607	226
5	30.7	0.5	23.1	24	2	1	2924	1462	17345	282	21731	1744
6	30.7	0.7	28.3	24	-	-	-	-	17345	396	17345	396
7	30.7	1.1	23.5	24	-	-	-	-	17345	622	17345	622
8	30.7	1.2	23.6	24	-	-	-	-	17345	678	17345	678
9	30.7	1.5	23.8	24	-	-	-	-	17345	847	17345	847
10	30.7	1.8	24.0	24	8	-	11696	-	17345	1017	29041	1017
11	30.7	2.0	24.1	24	8	-	11696	-	17345	1130	29041	1130
12	30.7	2.2	24.2	25	7	.2	10234	2924	17345	1243	27579	4167
13	30.7	2.6	24.5	25	-	-	-	-	17345	1469	17345	1469
23	30.7	4.9	26	26	(1)		-	-	17345	2769	17345	2769
33	30.7	7.6	27.7	28	(1)		-	-	17345	4294	17345	4294

(1) These years miss the time period when new EOTV's are constructed.

ALL MASS IN METRIC TONS

HLLV PAYLOADS TO LEO

All payloads to be transported to LEO by the HLLV are indicated. Again, in the full description of the scenario in the System Description document, analysis sheets are provided for each payload and/or fleet.



SPS-3110

HLLV PAYLOADS TO LEO

BOEING

YEAR	SAT. QTY.	LEO BASE SUPPLIES	EOTV FLEET CONST	EOTV FLEET MAINT	EOTV PAYLOADS CONST	EOTV PAYLOADS MAINT	POTV FLEET CONST	POTV FLEET MAINT	POTV PAYLOAD CONST	POTV PAYLOAD MAINT
1	-	555	9280	-	2575	-	1554	-	123	-
2	-	785	9450	-	2918	-	3080	-	238	-
3	-	785	13405	-	27094	-	5390	-	476	-
4	2	725	17607	226	80108	916	8470	770	748	69
5	4	725	18807	1744	106406	838	8484	834	794	115
6	6	725	17345	396	106410	1310	8470	1640	748	136
7	8	725	17345	622	106420	2107	8484	2460	794	204
8	10	725	17345	678	106429	2292	8470	3280	748	272
9	12	725	17345	847	106439	2764	8484	4114	794	386
10	14	785	29041	1017	106454	3561	8470	4920	748	408
11	16	785	29041	1130	106458	3746	8484	5754	794	476
12	18	785	27579	4167	106468	4218	8470	6569	748	544
13	20	725	17345	1469	106481	5245	8484	7374	794	658
23	40	725	17345	2769	106559	10133	8470	14824	748	1224
33	60	725	17345	4294	106665	15357	4570	23780	748	1972

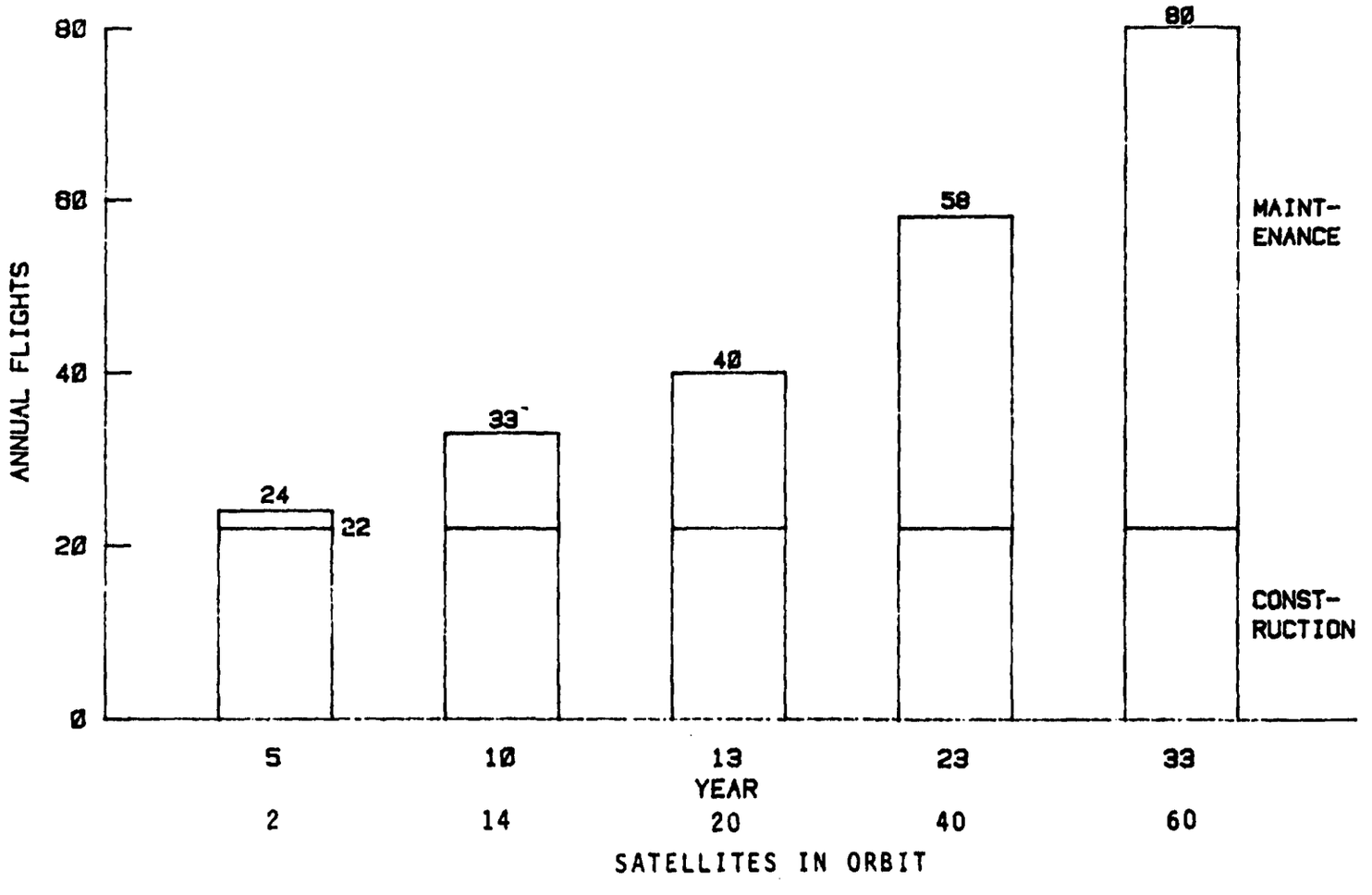
ALL MASS IN METRIC TONS

POTV FLIGHTS

The results of the space transportation scenario analysis in terms of number of flights for the transportation elements are presented in the next four charts. Annual flights for the POTV are shown as a function of several key years and the associated number of satellites in orbit requiring maintenance. Again, distinction between maintenance and construction flights is indicated. Each flight includes transportation of 80 people.

POTV FLIGHTS

SPS-3111

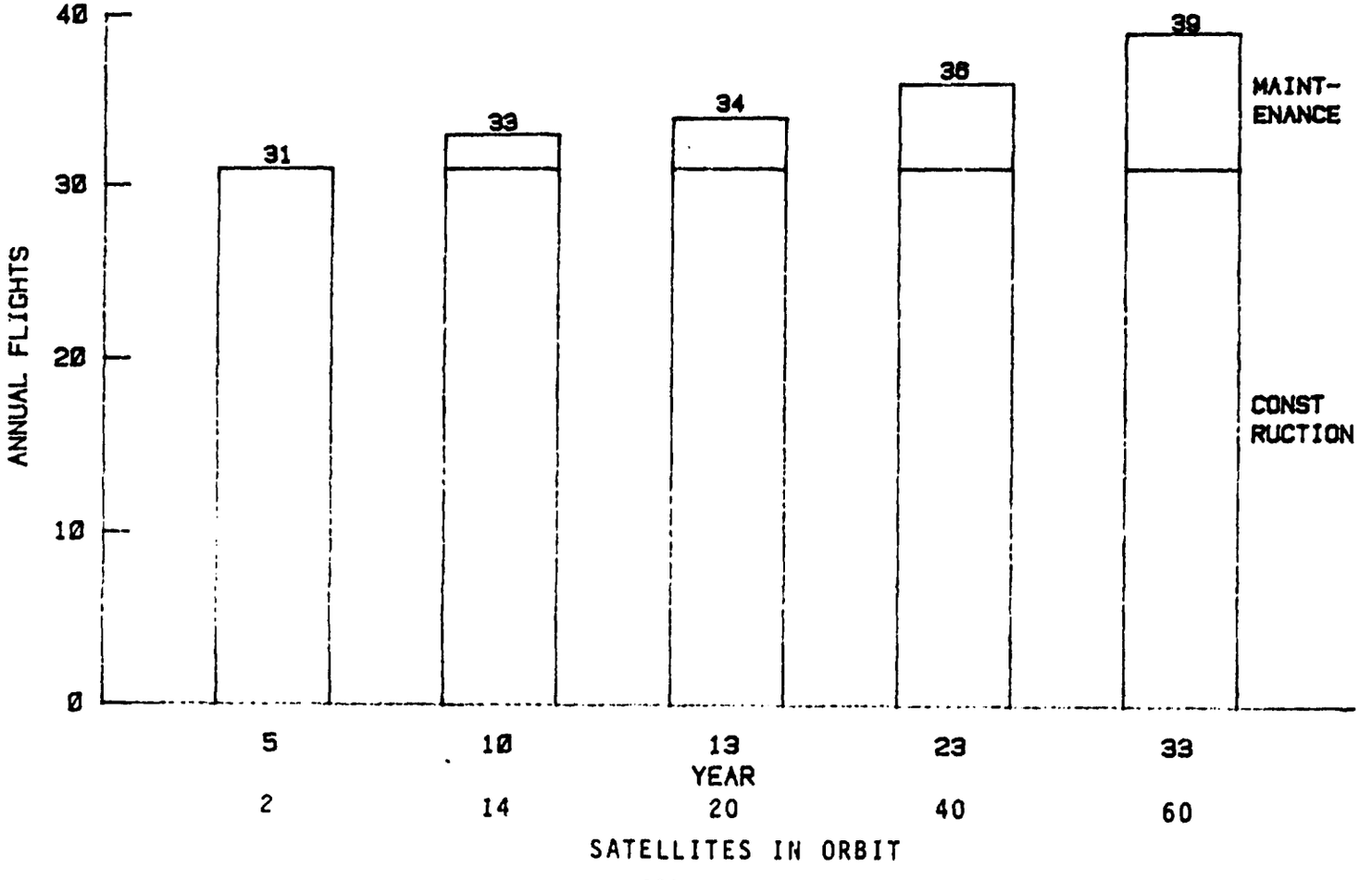


EOTV FLIGHTS

The annual number of EOTV flights are indicated for key years of the program. It may be noted that the number of EOTV flights does not increase as rapidly with larger numbers of satellites as the POTV since the cargo payloads do not increase as rapidly as crew requirements, and in addition, the cargo capability of the EOTV is so large, a significant impact in EOTV flights does not occur.

EOTV FLIGHTS

SPS-3112

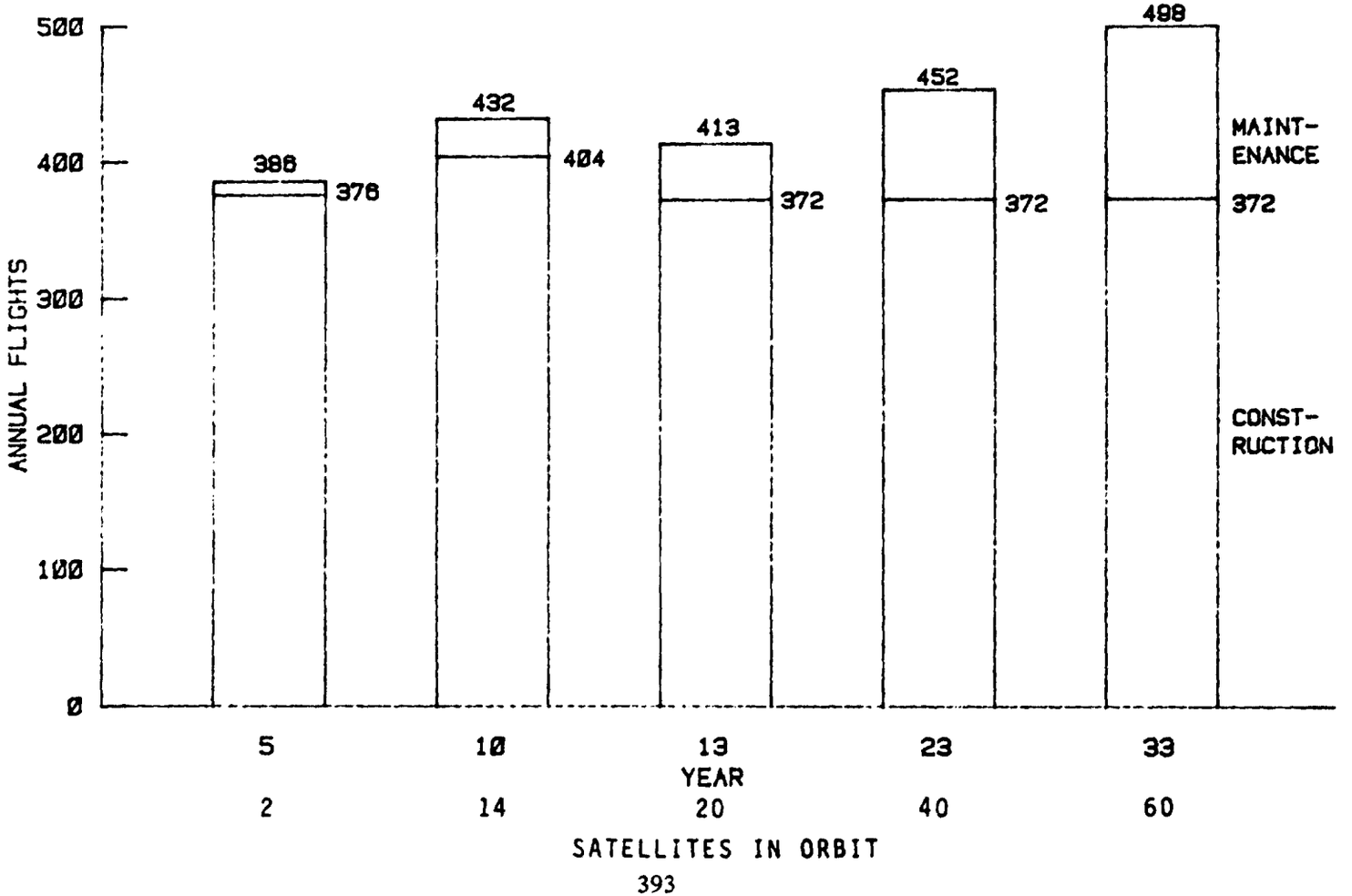


HLLV FLIGHTS

The annual number of HLLV flights are indicated for key years of the program. It may be noted, that even for the time period of 60 satellites in orbit, an average of only 1.5 launches per day is required.

HLLV FLIGHTS

SPS-3113

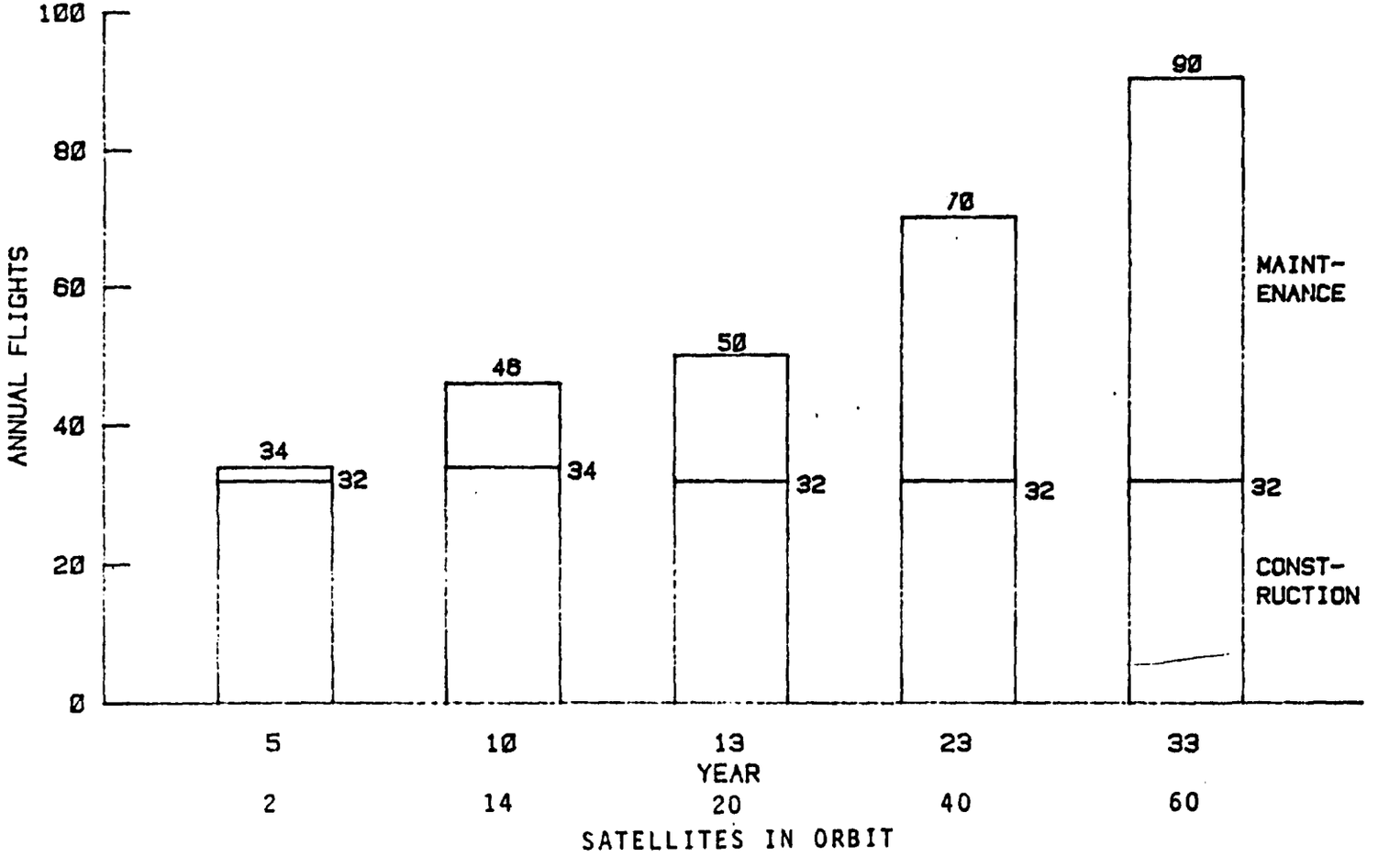


PLV FLIGHTS

The annual number of PLV flights are indicated for key years of the program. As in the case of the POTV, the number of flights for the PLV is also quite sensitive to the increase in maintenance activity. A passenger load of 80 is assumed with the indicated number of flights rounded off.

PLV FLIGHTS

SPS-3114



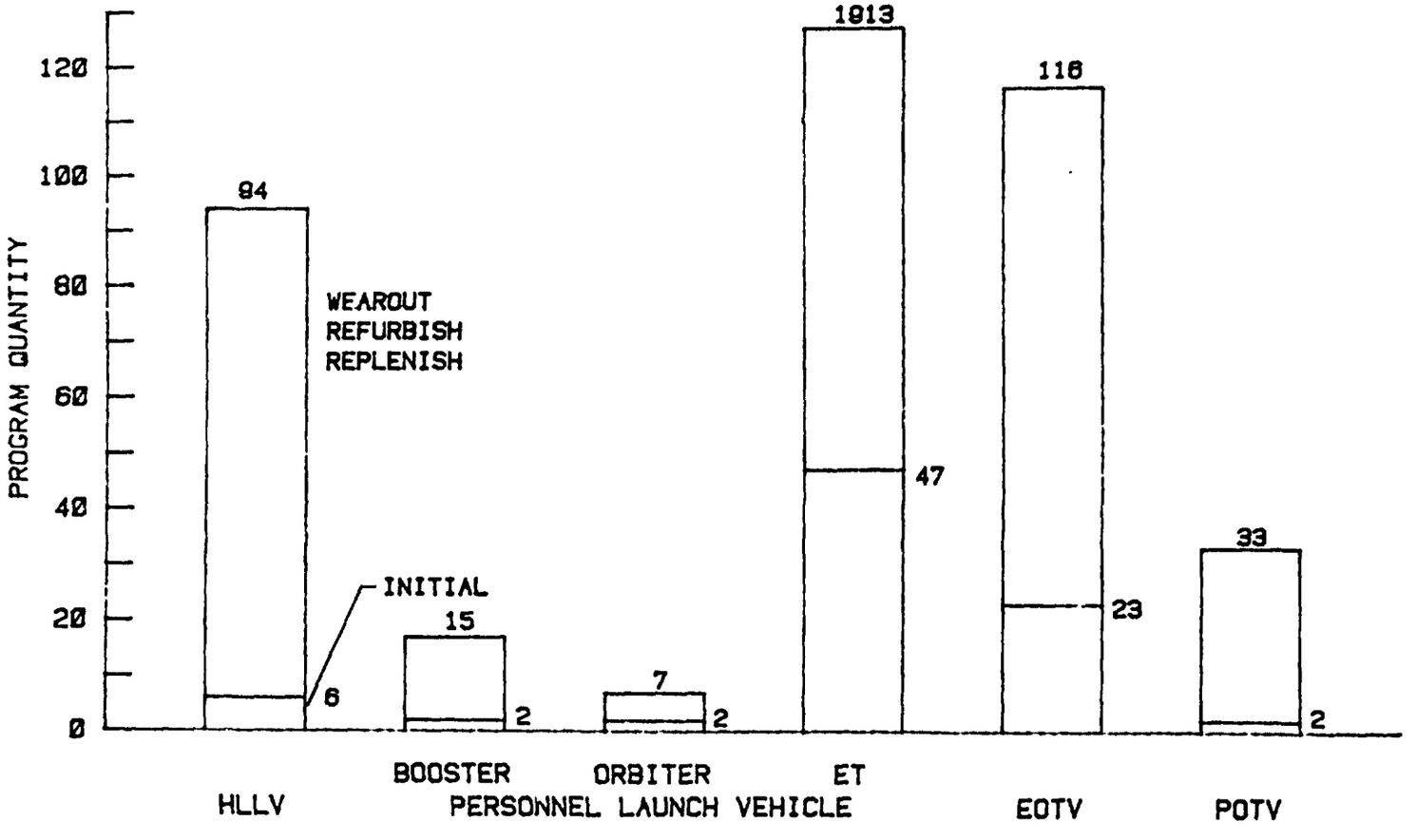
TRANSPORTATION VEHICLE QUANTITIES

The results of the space transportation scenario in terms of the total number of vehicles required for the program are indicated. Quantities are actually equivalent units and include initial requirements to satisfy basic turnaround as well as that required for wearout, refurb, and replenishment. The HLLV value relates to total vehicle meaning 94 boosters and 94 orbiters. The initial quantity of HLLV's is to satisfy an average of 400 flights per year with 4 day turnaround. The HLLV, PLV booster and orbiter values are based on 300 flight design life for air frames and unlimited engine life. The ET is expendable each flight with the initial quantity relating to the time period to complete construction of the initial EOTV fleet and GEO base.

The initial quantity of EOTV's relates to satisfying requirements associated with constructing two 5 GW satellites per year plus a spare, while the total quantity is based on 10 flight design life. The POTV quantity is based on 50 flight design life.

TRANSPORTATION VEHICLE QUANTITIES

SPS-3115



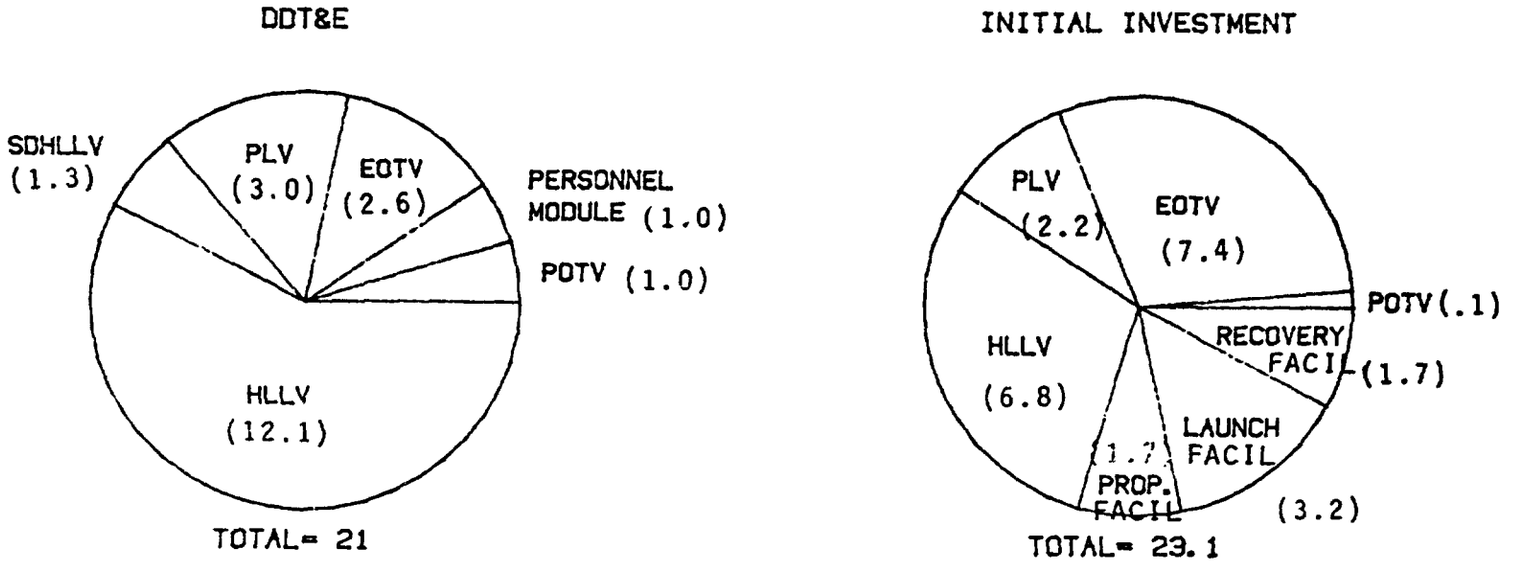
TRANSPORTATION NONRECURRING COST

DDT&E and initial investment cost are presented. The $21 billion DDT&E cost was determined by using detail mass statements of each element and the Boeing Parametric Cost Model (PCM). The PLV cost relates to obtaining the flyback booster and ET modifications. The SDHLLV contribution to DDT&E relates to that cost associated with obtaining a payload cannister and engine capsule to replace the orbiter of the PLV.

The $23 billion initial investment includes flight hardware cost based on the initial number of vehicles required as previously discussed, and their average cost and also the cost of facilities for launch, recovery and propellant production. In this case, the large fleet and expensive average cost of the EOTV make it the largest contributor.

TRANSPORTATION NONRECURRING COST

SPS-3116



TOTALLS ARE BILLIONS OF 1979 DOLLARS

COST PER FLIGHT

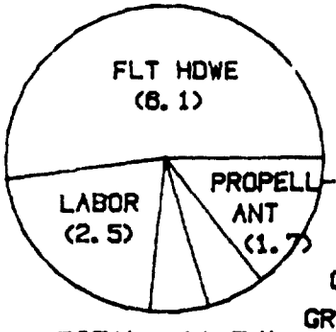
The cost per flight for each transportation element and the major contributors are presented. Costs are also expressed per unit of mass which makes for interesting comparisons. The flight hardware for all elements is the largest contributor, and for launch vehicles and POTV, is based on the total number of units required and learning of 85% on airframes and 90% on engines. EOTV power conditioning components have quantities that merit 70% learning, thrusters and solar cells use mature industry costing (2 times material cost) and the remainder of components use 85% learning. Unlike previous values for the EOTV and POTV the current values do not include the launch costs associated with refueling the vehicles. (Note: total transportation cost is covered for this by the number of HLLV launches which include propellant launches.) One observation from this data is that the high cost per kg of the PLV is due to the expendable ET and brings about the consideration of not using this vehicle in the commercial phase of the program and use the HLLV for this task.

COST PER FLIGHT

SPS-3117

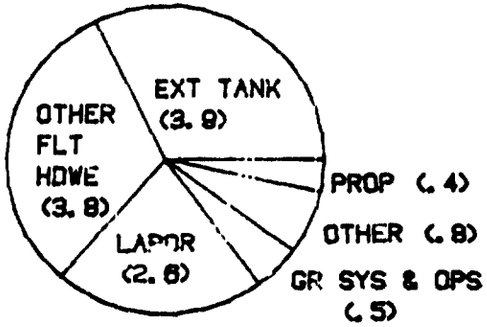
COSTS ARE IN MILLIONS OF 1979 DOLLARS

HLLV
($29/KG)



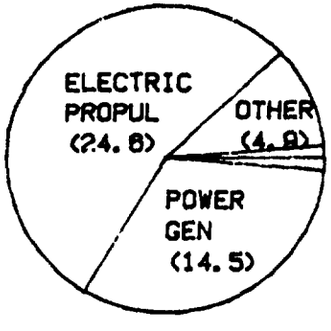
TOTAL= 11.7 M

PLV
($137/KG)



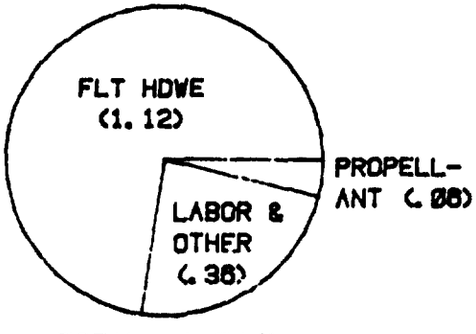
TOTAL= 12.1 M

EOTV
($11.3/KG)



TOTAL= 45.2 M

POTV
($17/KG)



TOTAL= 1.54 M

TRANSPORTATION RECURRING COST

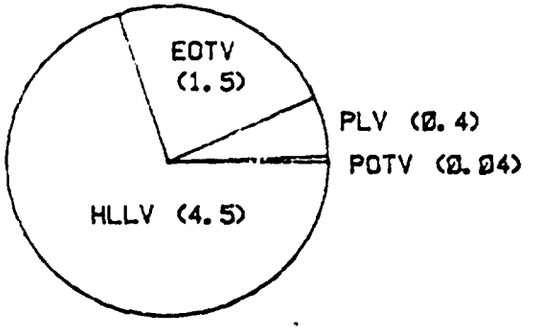
The total transportation recurring cost is presented for several key years of the program. These costs are obtained by multiplying the cost per flight values by the number of flights for a given year. The range of annual costs are $6.4 billion near the beginning of the program and $8.8 billion when 60 satellites are present with the HLLV cost being the most dominating in all cases.

TRANSPORTATION RECURRING COST

SPS-3118

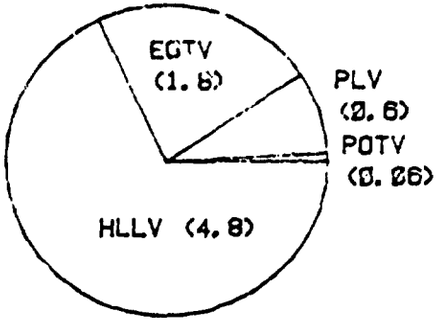
(COST IN BILLIONS (1979$)

YEAR 5
2 SATELLITES



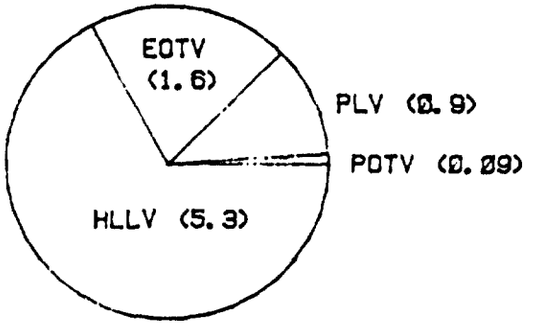
TOTAL= 6.44

YEAR 13
20 SATELLITES



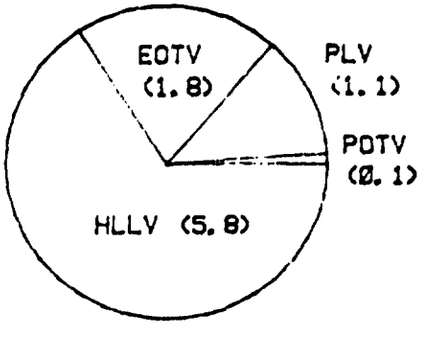
TOTAL= 7.06

YEAR 23
4Ø SATELLITES



TOTAL= 7.89

YEAR 33
6Ø SATELLITES



TOTAL= 8.8

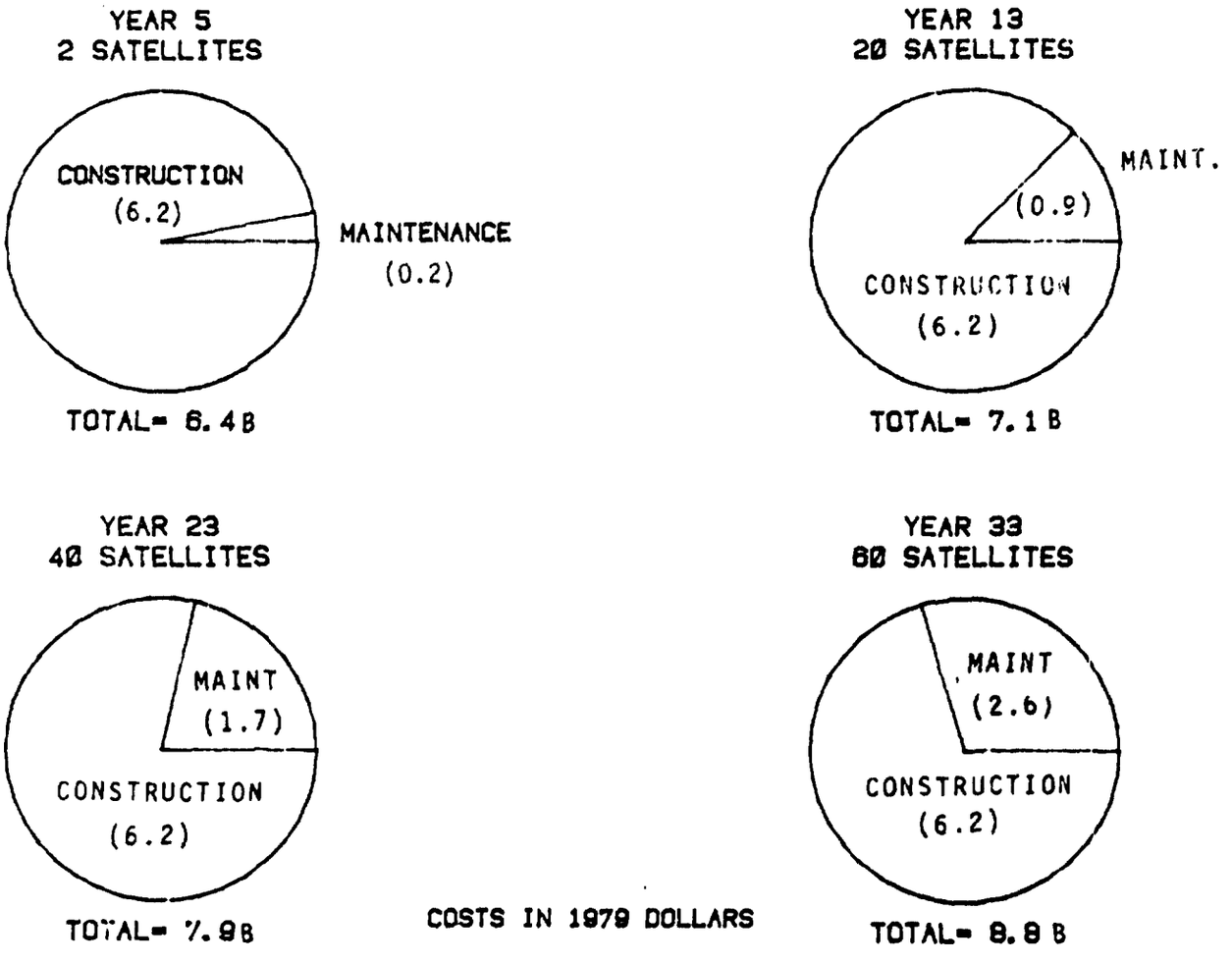
TRANSPORTATION RECURRING COST

CONSTRUCTION AND MAINTENANCE

Recurring transportation cost is presented in terms of its division between construction and maintenance activities. In the beginning, very little maintenance expense is incurred, however, by the time 40 satellites are in orbit approximately 25% of the transportation cost is related to maintenance. In summary, approximately $0.8 billion additional cost is incurred for each 20 satellites in orbit.

TRANSPORTATION RECURRING COST

SPS-3119



COSTS IN 1979 DOLLARS

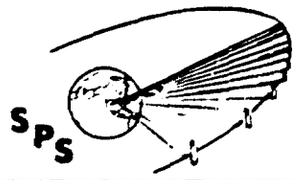
FUTURE TRANSPORTATION SYSTEM WORK

Should money become available for future work, the indicated areas are suggested for consideration. In all cases, the work would involve system level analysis rather than detail design analysis. In the area of HLLV, a smaller payload capability such as 100-200 MT should be considered with the potential advantage being lower DDT&E cost and a vehicle not so physically imposing or oversized for other space applications should SPS not proceed. Other assessment factors would include impact on cost per flight, launch complex operations due to significantly more flights per year and the impact on satellite design due to smaller physical envelope of the payload bay.

The investigation related to the PLV would be that of eliminating this from the transportation fleet during the commercial phase of the program due to its extremely high delivery cost per kg. Instead, the orbital crews would be launched in the HLLV--either in personnel modules like in the PLV or have the crew compartment of several HLLV orbiters enlarged to accommodate the crew.

Introduction of the EOTV relatively late in the SPS studies has resulted in one analysis pass completely through the system but no iteration. It is suggested that additional work be performed in the area of solar cell performance as influenced by thermal effects and ratiation and the resulting impact on vehicle design life and ultimately fleet size. In addition, another examination should be made on the overall configuration for its impact on constructability and flight control.

Converting the POTV to a single stage system refueled at GEO late in the current study also has prevented iteration of the mission and design analysis. The task suggested is to try and adjust the requirements of the various missions of the stage to determine if a more optimum stage or multiple size stages are best.



FUTURE TRANSPORTATION SYSTEM WORK

- HLLV
  - ASSESS IMPACT OF SMALLER PAYLOAD CAPABILITY
- PLV
  - CONSIDER ELIMINATION DURING COMMERCIAL PHASE--LAUNCH CREW IN HLLV
- EOTV
  - ASSESS PERFORMANCE AND LIFE CHARACTERISTICS
- POTV
  - ASSESS SIZING FOR MATCH-UP BETWEEN CREW ROTATION/RESUPPLY AND SATELLITE MAINTENANCE SORTIES

SOLID STATE

SPS

WHY SOLID STATE?

The principal motivator for the solid state system is the much greater projected reliability than is expected for vacuum tube devices. The device mean-time-between-failure may be as much as two orders of magnitude better than vacuum tube devices. Further, lower mass per unit area is expected, and research and development activities may be conducted with small hardware items that can be quickly modified, tested, improved and retested.

However, there are certain problems associated with the solid state system. They are low-temperature, low-voltage, and low-power devices. The efficiency is somewhat uncertain, the cost of high performance devices is today high, and the complexity of the solid state transmitter appears to be greater.

Presently on-going system study efforts are attempting to trade off these advantages versus disadvantages to arrive at practical approaches for employing solid state transmitters, and more importantly, to arrive at the most relevant research objectives and approaches.

Why Solid-State?

- RELIABILITY
- LOWER MASS/AREA
- DEVELOPMENT ON SMALL HARDWARE ITEMS

BUT

- TEMPERATURE LIMITS
- LOW VOLTAGE, LOW POWER
- EFFICIENCY?
- COST??
- COMPLEXITY??

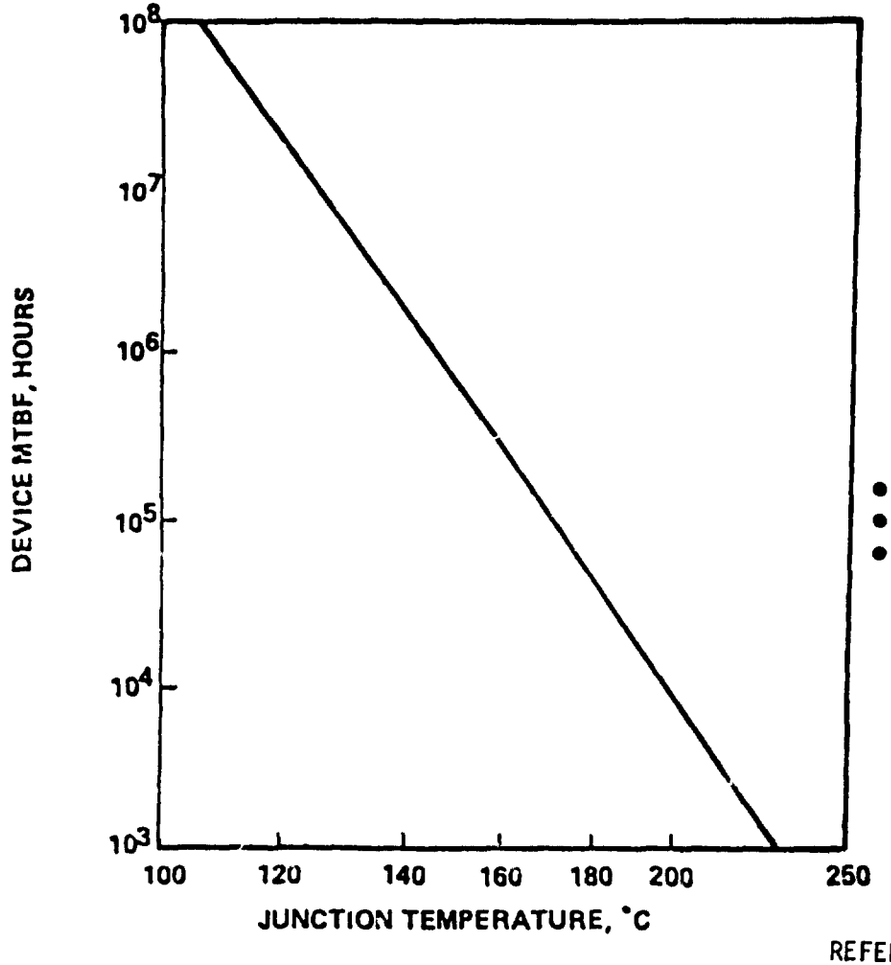
SOLID STATE DEVICE LIFETIME

Solid state devices are attractive for SPS because they may have extremely long operating lifetimes if their operating temperatures are kept low.

This curve shown is the best existing dynamic MTF vs junction temperature curve for GaAs FETS. The devices tested were small signal GaAs FETS, which, while structurally similar to power GaAS FETS, are not operated at similar electric field intensities.

Currently DOD's Rome Air Development Center has sponsored several power GaAs FET reliability studies. These will be complete in about a year and should provide the required data.

Solid State Device Lifetime



- SMALL SIGNAL GaAs FET
- RF POWER ON DURING TEST
- LOG NORMAL FAILURE DISTRIBUTION

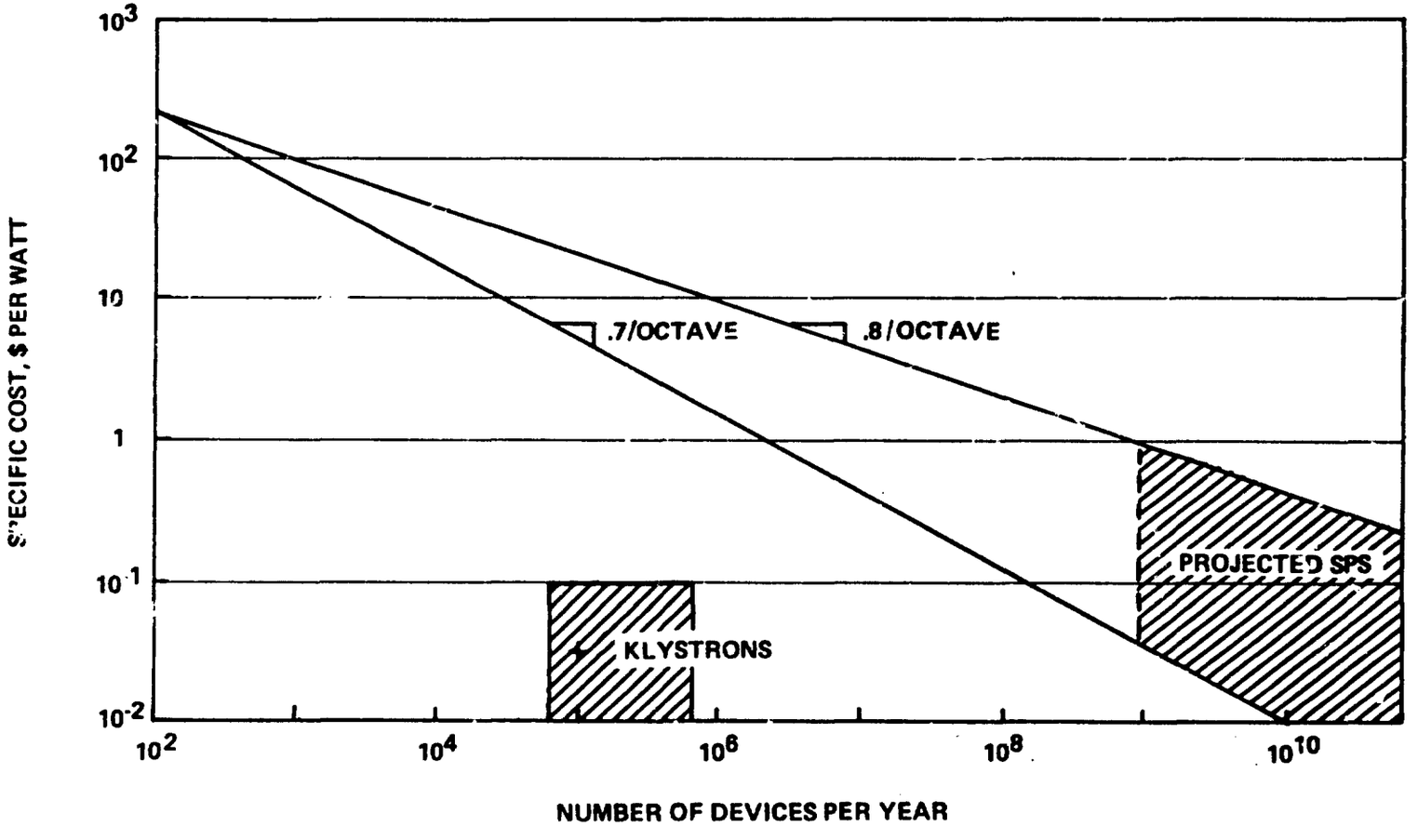
$\sigma = 1$

REFERENCE: LUNDGREN AND LADD, PROCEEDINGS OF IEEE 1978 RELIABILITY PHYSICS SYMPOSIUM

SOLID STATE DEVICE MATURE INDUSTRY COSTING

With a 70% production rate improvement curve (i.e., units produced at the rate of 2n per year cost 70% as much as units produced at the rate of n per year), cost per unit power for GaAs FETS is about the same as the projected cost per unit power for klystrons.

Solid State Device Mature Industry Costing



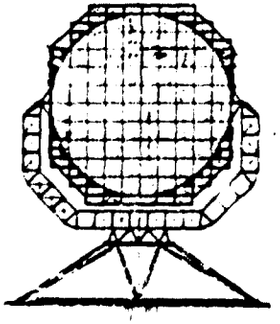
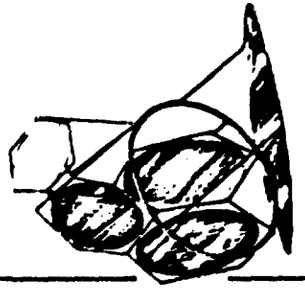
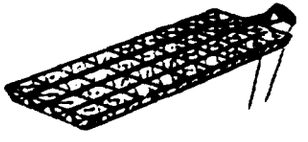
SPS RF DESIGN OPTIONS

Integration of the transmitting aperture with the solar array represents one of the fundamental decisions to be made in an SPS design. The basic choices are: 1) to construct a separate transmitting antenna and buss power to it from the solar array, or 2) to have local DC-RF converters on the solar array. Note that in (2) the basic two-vector geometry of a solar power satellite requires at least one RF or solar mirror.

In the interests of conservatism and to allow the ability to make fair comparisons of solid state and the NASA/DOE reference SPS designs, an antenna mounted approach was chosen for the solid state reference satellite.

BOEING SPS

SPS RF Design Options

RF CONVERTER → ANTENNA MOUNTED			SOLAR CELL MOUNTED (CONCENTRATION RATIO = 3)	
SPS DESIGN ↓			OPTICAL REFLECTOR 	RF REFLECTOR 
	KLYSTRON OR CFA	SOLID STATE	SOLID STATE	SOLID STATE
POWER OUTPUT TO GRID	5 GW	2 GW	0.7 GW	0.2 GW per km^2 SOLAR CELLS
SPACE ANTENNA DIAMETER	1 km	1.5 km	2.7 km	HIGH POWER WAVEGUIDE
RECTENNA DIAMETER @ 23 mw/cm^2	10 km	6.7 km	3.8 km	NOT DETERMINED
ANTENNA	10 db TAPER	10 db TAPER	UNIFORM	ADVANCED HORN FED PARABOLOID

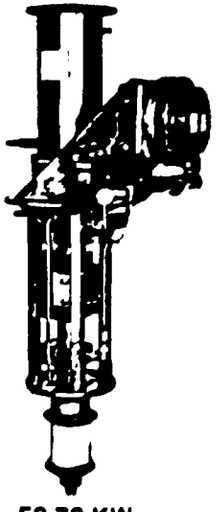
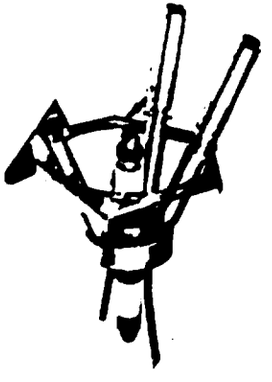
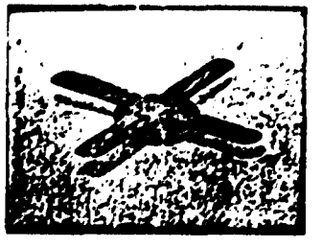
DC-RF CONVERTER FEATURES

The three principal DC to RF converter systems that have been considered for SPS application are the klystron, the crossed-field amplifier and the solid state transistor. Klystrons have received most of the emphasis in past systems definition studies. Current emphasis is being directed to solid state systems because of their potential long operating lifetimes.

BOEING SPS

DC-RF Converter Features

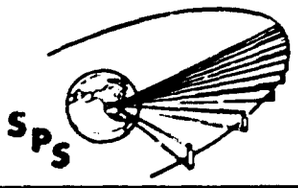
79-200

DEVICE ⇨ / PROPERTY ⇩	KLYSTRON	CROSSED FIELD AMPLIFIER		SOLID STATE TRANSISTOR
		AMPLITRON	INJECTION LOCKED MAGNETRON	FET
				
POWER (CW)	50-70 KW	5 KW		1-5 WATTS
VOLTAGE	40 Kv	<20 Kv		10-20 V
EFFICIENCY	>80%	>85%		75%
MTBF (1985)	>10 YEARS	>10 YEARS		>>100 YEARS
NO. OF OUTPUT DEVICES PER ANTENNA	10^5	10^6		$>10^9$
TEMPERATURE	300-500°C	300-500°C		100-130°C
CATHODE	THERMIONIC	COLD OR THERMIONIC		NONE
SATURATION GAIN	40db	<10 db		10 db

SOLID STATE TRANSMITTING ANTENNA QUANTIZATION

The ten-step baseline SPS Gaussian taper was adapted to the solid state transmitting antenna. Each step uses power modules with different device RF power outputs. As shown, there are five different types of RF power modules. In the 5.5 kw/m^2 center of the transmitting array the cavity radiator design is used whereas 2/5 of the way to the periphery the lower power/area allows the use of considerably less massive simple dipole radiator modules.

Note the prodigious number of FETs required--2.4 billion per 10 GW SPS-derived grid capacity.



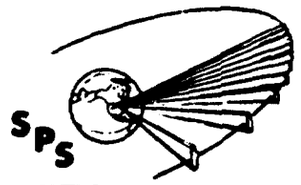
SOLID STATE TRANSMITTING ANTENNA QUANTIZATION

BOEING

SPS-3075 STEP	OUTSIDE RADIUS (m)	STEP AREA (m^2)	NUMBER OF SUBARRAYS	MODULE TYPE	MODULE POWER (W)	$(P/A)_{RF}$ (Kwm^{-2})	$(M/P)_{RF}$ ($kg\ km^{-1}$)	STEP MODULE MASS (T)	NO. FETS (M)
1	124.8	48,970	456	High Power 4-FET, Cavity Radiator (4.06 kgm^{-2})	28.7	5.50	.742	200	37.82
2	249.6	146,830	1,360	"	24.0	4.45	.917	600	112.80
3	322.4	130,820	1,208	Reduced Power 4-FET Cavity Radiator (3.58 kgm^{-2})	19.2	3.56	1.006	468	100.20
4	384.8	138,640	1,280	"	16.0	2.97	1.207	496	108.17
5	457.6	192,680	1,784	2-FET Cavity Radiator (3.06 kgm^{-2})	12.8	2.37	1.289	590	73.99
6	520.0	191,680	1,776	2 FET Dipole (1.47 kgm^{-2})	12.8	1.78	.826	582	55.24
7	561.6	141,390	1,312	"	9.6	1.33	1.101	208	40.81
8	582.4	74,795	696	"	8.5	1.18	1.244	110	21.65
9	644.8	238,950	2,208	1 FET Dipole (1.47 kg m^{-2})	6.4	.89	1.652	351	34.34
10	707.2	264,880	2,448	"	4.3	.59	2.476	389	38.07
	TOTALS		14,528					3,694	621.09

COMBINER MODULE CONCEPT FEATURES

Using our present SPS maximum ionospheric power/area of 23 mw/cm^2, the choice of the type of power module to be used at the center of an SPS transmitting array determines the maximum link power. The features that led to the choice of the solid state cavity combiner-radiator module used in the central region of the transmitting array are outlined.



COMBINER MODULE CONCEPT FEATURES

- **ADAPTABLE TO ANTENNA-MOUNTED SYSTEM**
- **THERMALLY EFFICIENT**
  - GOOD HEAT PATHS
  - RADIATE FROM BOTH SIDES
- **EFFICIENT COMBINING OF LOW-POWER (~5-WATT) DEVICES**
  - ATTAINS ADEQUATE POWER DENSITY
- **HIGH GAIN, PHASE-STABILIZED**

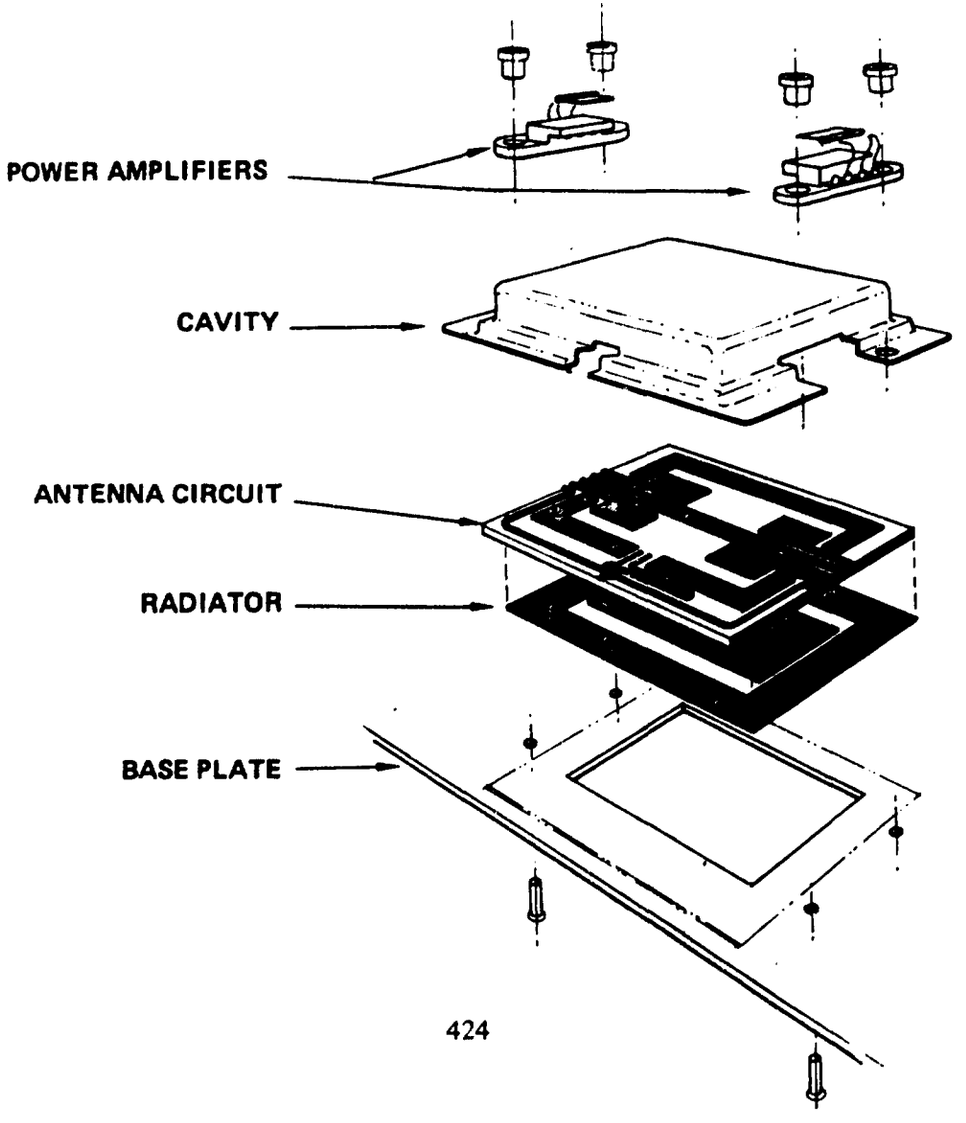
SOLID STATE COMBINER RADIATOR MODULE

The main features of the combiner radiator module are illustrated on this chart. The antenna circuit itself is capacitively coupled to the radiator patch through a ceramic dielectric. The radiator patch functions as a double slot, emitting linearly polarized RF radiation. The antenna circuit is driven by a pair of push-pull power amplifiers employing 5 watt gallium arsenide FET transistors in each of the four final output stages. DC supply connections are routed through the center of the antenna along the zero potential line. Output from the radiator is compared to the input RF drive signal by a phase comparator circuit and the phase of the RF drive to the amplifiers is adjusted accordingly to maintain phase control of each individual radiator. This compensates for through phase variations in the power amplifiers and antenna circuitry. The antenna is covered by a resonant cavity which provides filtering at the amplifier outputs. The entire assembly is mounted to an aluminum baseplate and ground plane.

BOEING SPS

Solid State Combiner-Radiator Module

SPS-2836



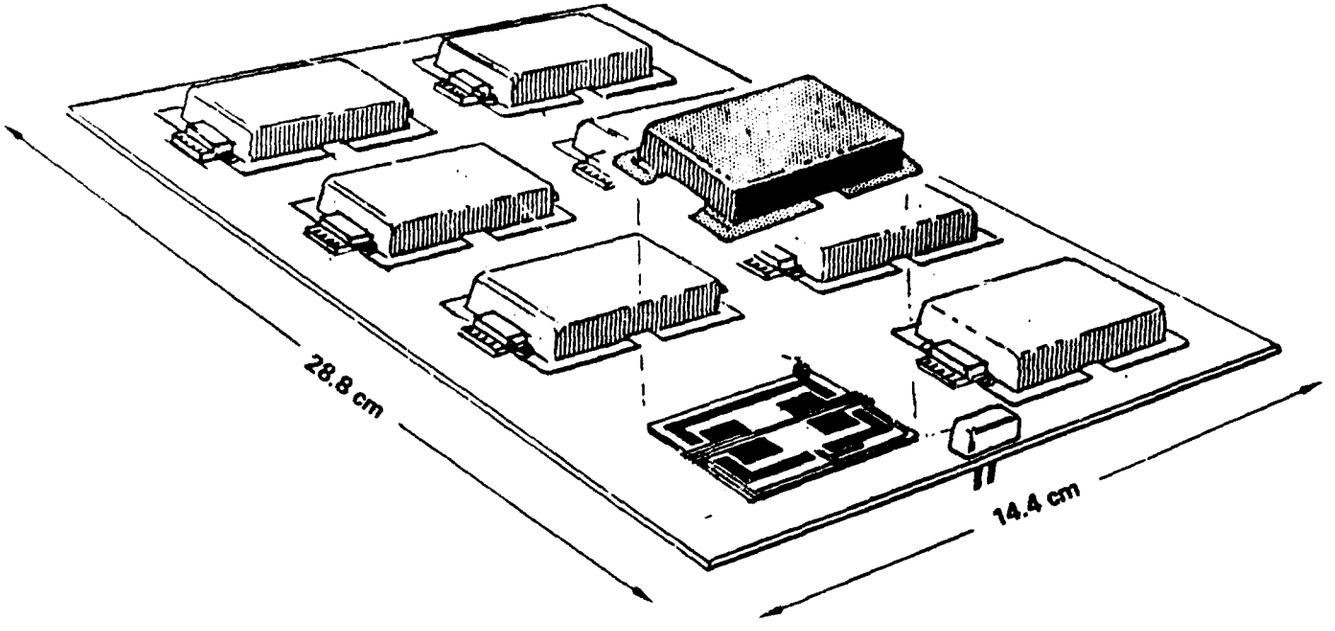
INTEGRATION OF MODULES INTO ANTENNA PANEL

The modules would be integrated into an antenna panel as illustrated here. The dimensions give an idea of the size of these modules. Each module radiates about 30 watts of linearly polarized RF power. Experiments have indicated that this module design provides a very low loss means of combining the output of 4 solid state power amplifiers. The module also includes phase correction feedback to phase stabilize the amplifiers and a fault detection system to substitute a load resistor for any amplifier that open circuits.

BOEING SPS

Integration of Modules into Antenna Panel

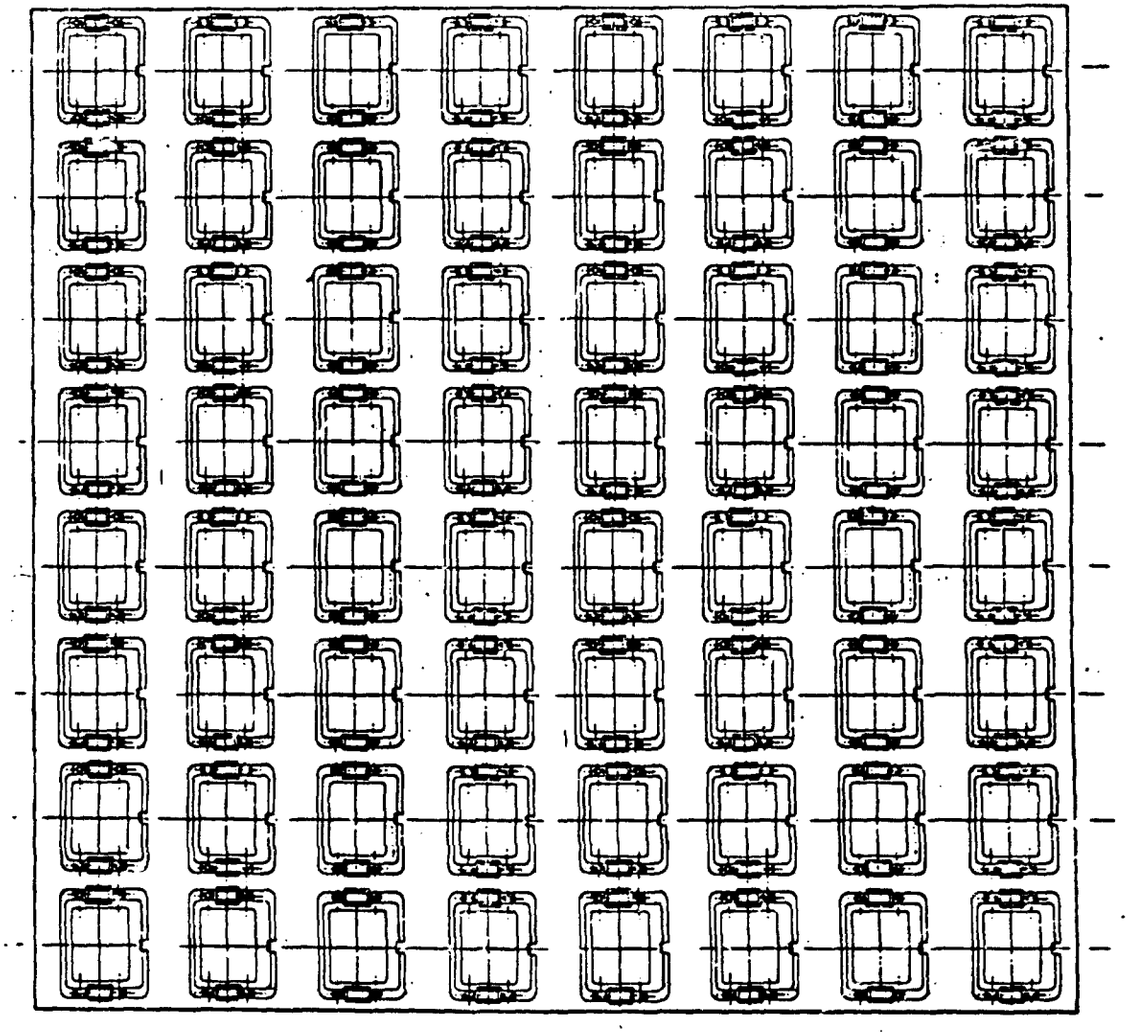
SPS-2837



64 MODULE PANEL LAYOUT

Illustrated on the facing page is the layout of a basic panel including 64 solid-state combiner modules. A fiber optic phase-feed goes into the center of this panel where a pre-amplifier converts the fiber-optic phase signal to a microwave signal which is then distributed by the phase distribution network shown. This network at this level is presently conceived as open-loop. Further analysis and experiment will be necessary to ascertain to what degree open loop phase-feed can be employed with solid-state systems.

64-Module Panel Layout

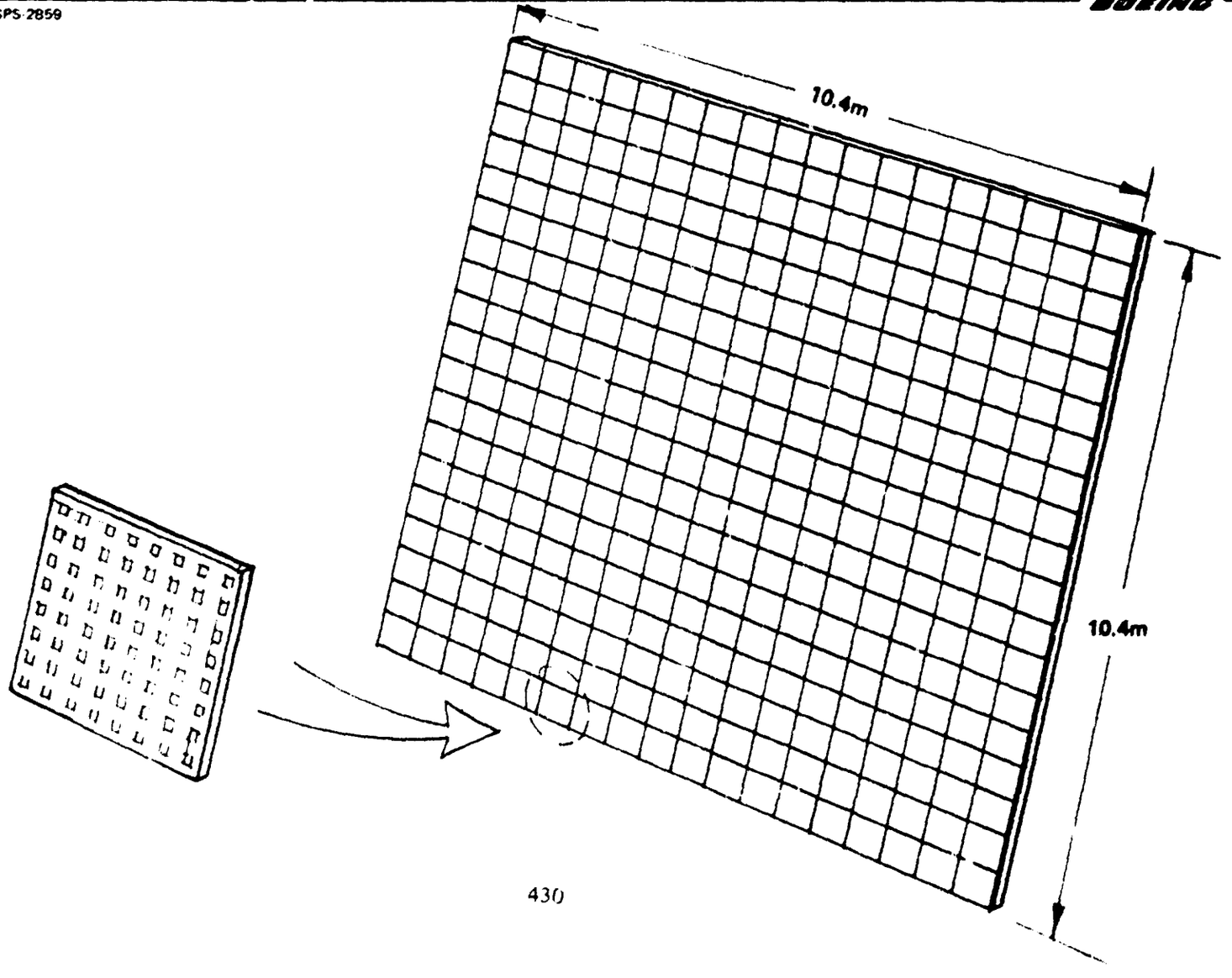


SECONDARY
TREE PHASE
FEED

SUBARRAY ASSEMBLY

A mechanical subarray includes 324 of the panels illustrated on the previous charts. The subarray will include four phase control receivers, one for each 5-by-5 meter subsection of the subarray. These phase control receivers will generate the local phase signal. This signal is distributed to the panel level by fiber-optic distribution links and within the panels by a microstrip phase-feed as illustrated on an earlier chart.

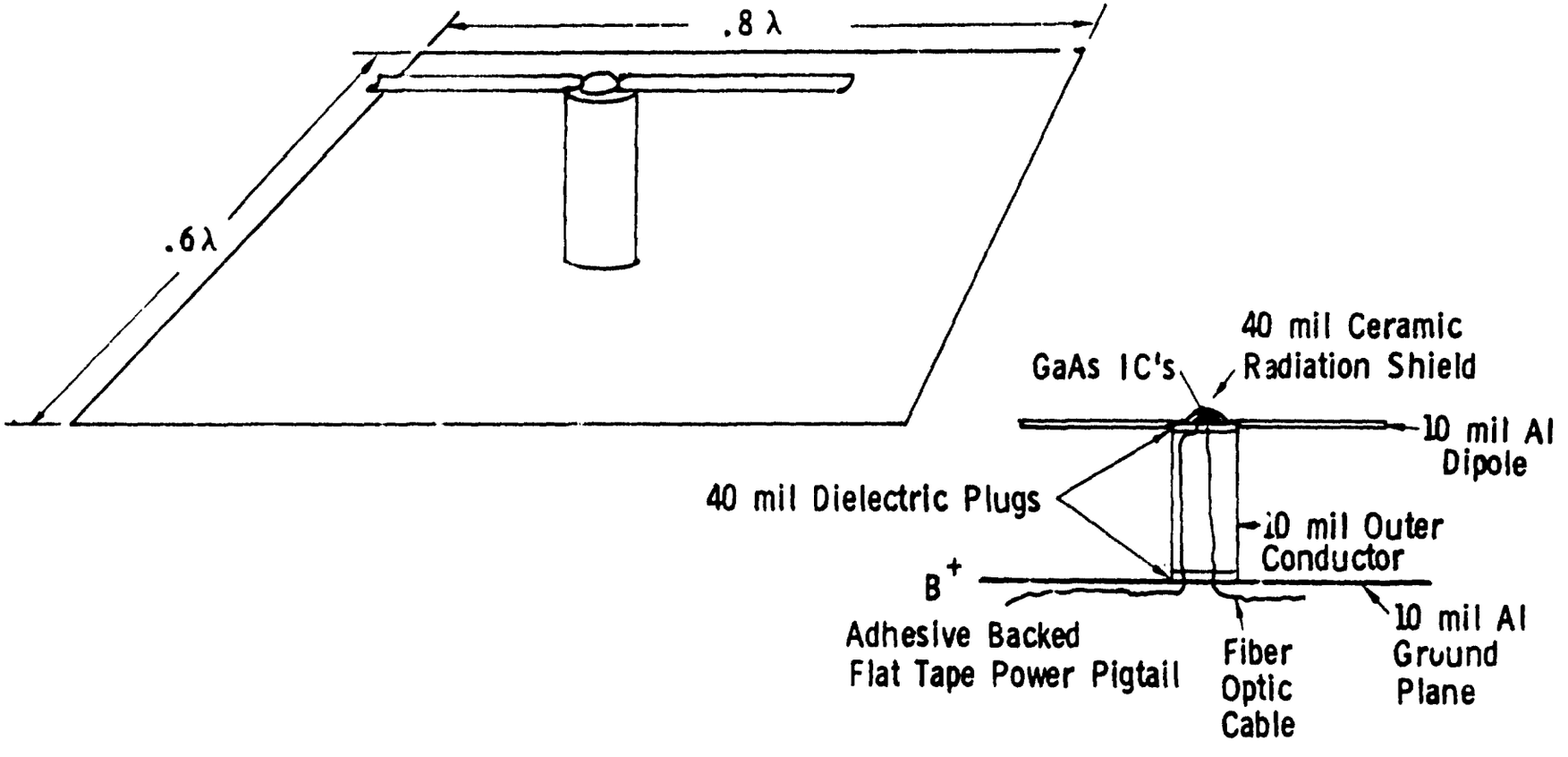
Subarray Assembly (324 Panels; 20, 736 Modules)



SOLID STATE DIPOLE RADIATOR MODULE

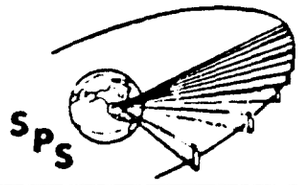
For the lower power/area periphery of the transmitting array, this dipole radiator module design allows a 62% reduction in mass/area. Note that these modules are also somewhat larger ($.6\lambda$ x $.8\lambda$ instead of $.6\lambda$ x $.6\lambda$).

SOLID STATE DIPOLE RADIATOR MODULE



DIPOLE RADIATOR MODULE MASS STATEMENT

A mass estimate for the dipole radiator module design is shown. Note that 78 percent of the module mass is 10 mil stamped aluminum.



SPS-3090

DIPOLE RADIATOR MODULE MASS STATEMENT

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ITEM	MASS PER MODULE* (g)	MASS/AREA (kg m^{-2})
10 MIL AL GROUND PLANE	4.93	.686
CERAMIC SHIELD	.7	.097
DIPOLE AND SUPPORT; 10 mil Al	3.75	.522
DIELECTRIC PLUG	.7	.097
CHIPS, METALLIZATIONS, BENDING, ETC.	.5	.070
TOTAL	11.08	1.472

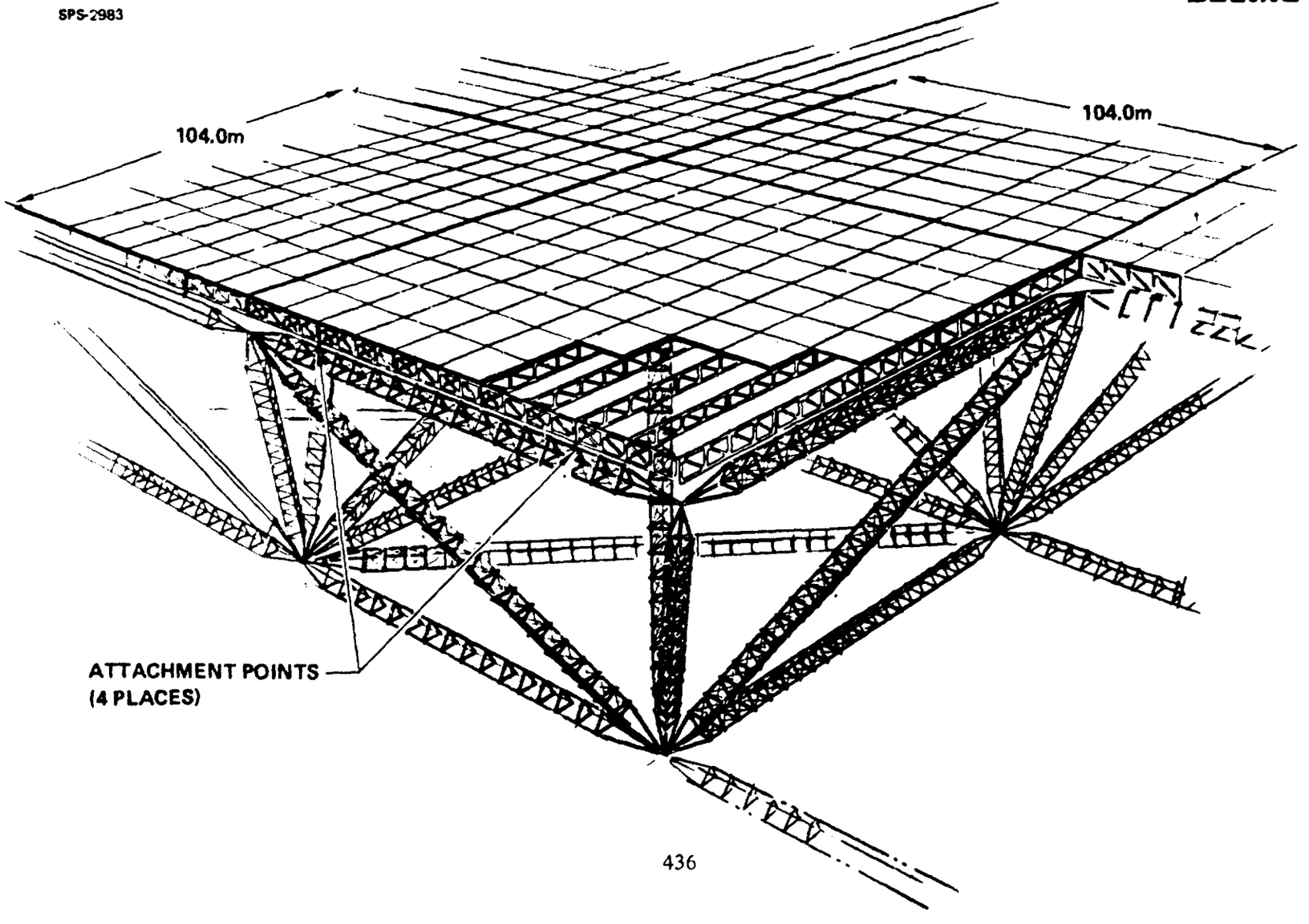
* .6 λ x .8λ

THE ANTENNA SUBARRAY AND SUPPORT STRUCTURE INTERFACE

The support structure for the subarrays is comprised of simple linear truss members supported to the primary structure at four support points for each bay. This linear truss structure can be fabricated by beam machines or prefabricated and nested for shipment. This structural design approach provides a much simpler secondary structure than the earlier reference as well as improved access for maintenance equipment.

Antenna Subarray and Support Structure Interface

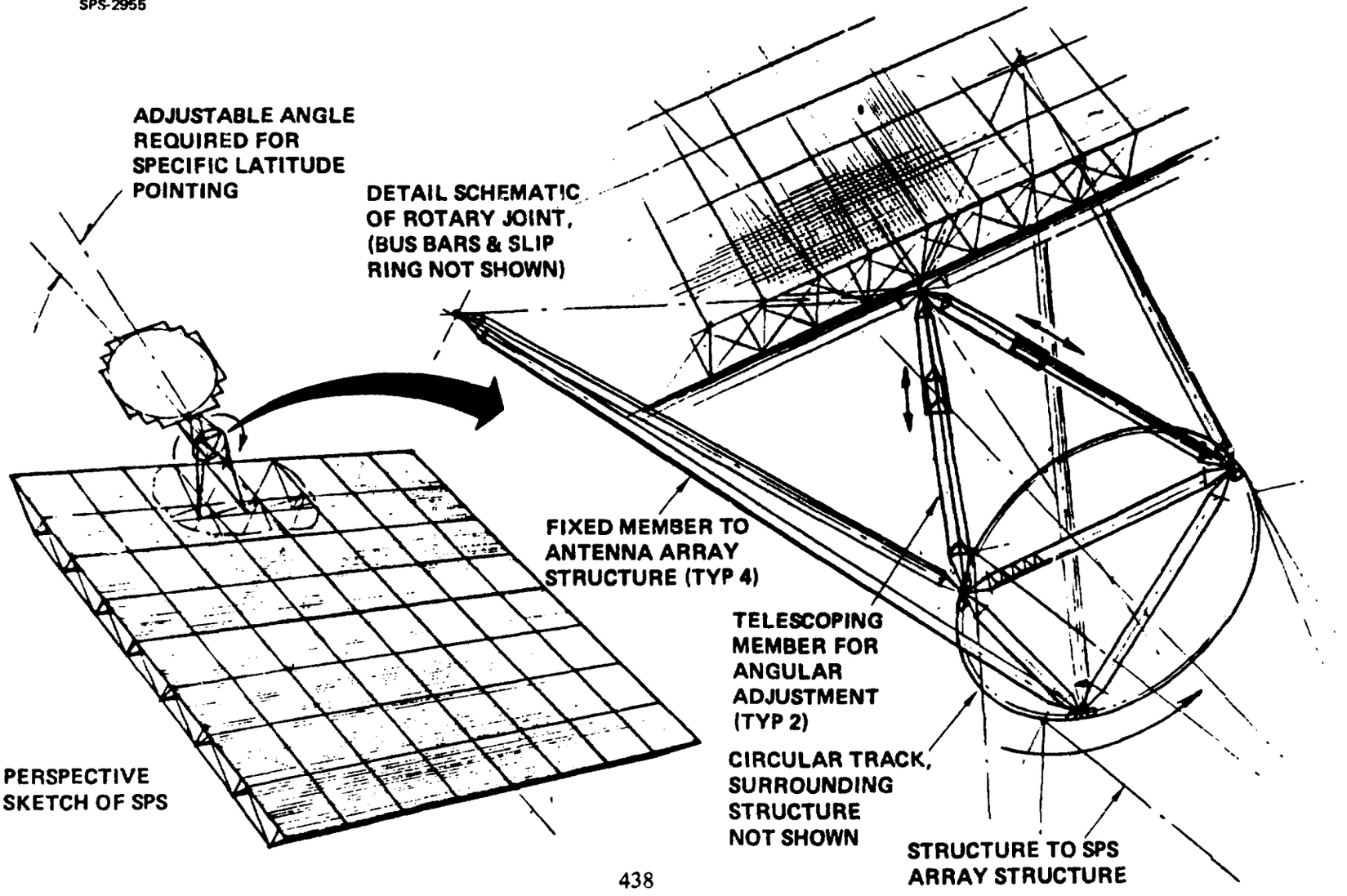
SPS-2983



ANTENNA ARRAY ANGULAR ADJUSTMENT CONCEPT

Since large aperture antennas are needed for the solid state option, an investigation of alternative rotary joint assemblies was conducted. The concept shown here employs linear motor drives of the telescoping members, with electronic feedback, to establish the tilt angle for the transmitter necessary to accommodate the range of latitudes for the power beam. The electrical rotary joint would be similar to that shown on an earlier chart in the reference system description.

Antenna Array Angular Adjustment Concept
2.5 GW Solid-State SPS



SOLID STATE POWER SUPPLY OPTIONS

This chart illustrates the power supply options considered for the 2.5 GW solid state satellite design.

Solid state devices suitable for microwave power amplification operate at voltages on the order of 15 volts. Distribution voltages suitable for SPS application range from 2,000 to 40,000 volts. If it were necessary to process all this power down to a voltage of 15 volts, the cost and efficiency of power processing combined with the I^2R losses and conductor mass for such operations might be prohibitive. Therefore, an approach to elimination of power processing is highly desirable and constitutes the first option identified, Direct High Voltage DC (DHV DC). An aspect of this approach is series-parallel connection of the microwave power amplifiers (as regards DC power supply) similar to that used for solar cells in generation of the DC power. Aggregate sets of microwave power generators can then be supplied at comparatively high distribution voltages. This option raises concerns regarding stability, matching, and balance of the power supply and control network. However, while nontrivial to analyze, these problems all appear to be tractable.

The minimum risk option is use of DC/DC converters but this will result in significantly greater SPS mass and cost.

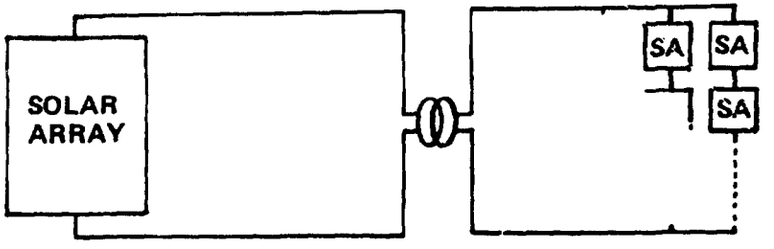
AC power distribution may provide a means of minimizing distribution losses and reducing solar array voltage. Mass and cost penalties will be similar to those for full DC/DC processing.

Solid State Power Supply Options

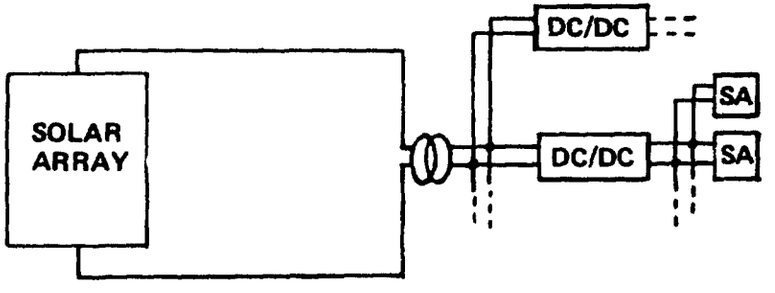
BOEING

SPS-2542

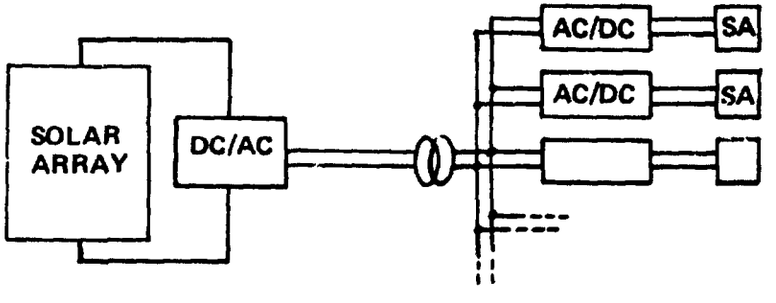
- DIRECT HIGH VOLTAGE DC
  - REQUIRES SUBARRAYS IN SERIES
    - CONNECTION TOPOLOGY A PROBLEM
  - HIGH E-FIELDS NEAR ADJACENT SUBARRAYS
    - MAY CAUSE ARCS, WILL SUSTAIN THEM



- DC-DC CONVERSION ON MPTS
  - PERFORMANCE PENALTIES
    - DC-DC CONVERTERS ≈ 1kg/kw
    - POWER LOSSES IN CONVERTERS
  - SERIES/PARALLEL CONNECTIONS WITHIN SUBARRAYS STILL REQUIRED



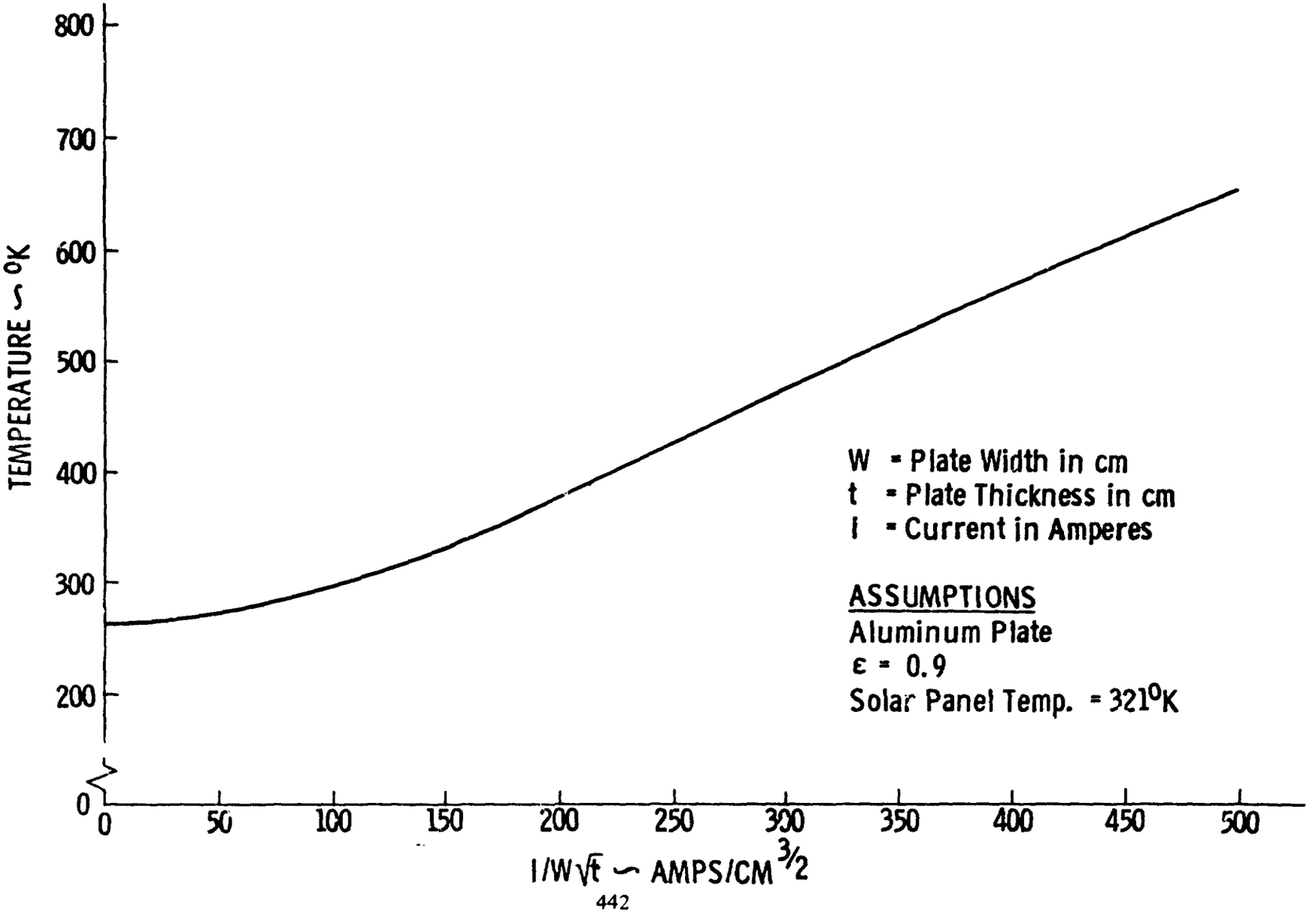
- AC POWER DISTRIBUTION
  - CONVERT
    - DC/AC ON SOLAR ARRAY
    - AC/DC AT SUBARRAY
  - REQUIRES S/P TO SOME EXTENT ON SUBARRAY



POWER BUSS SIZING

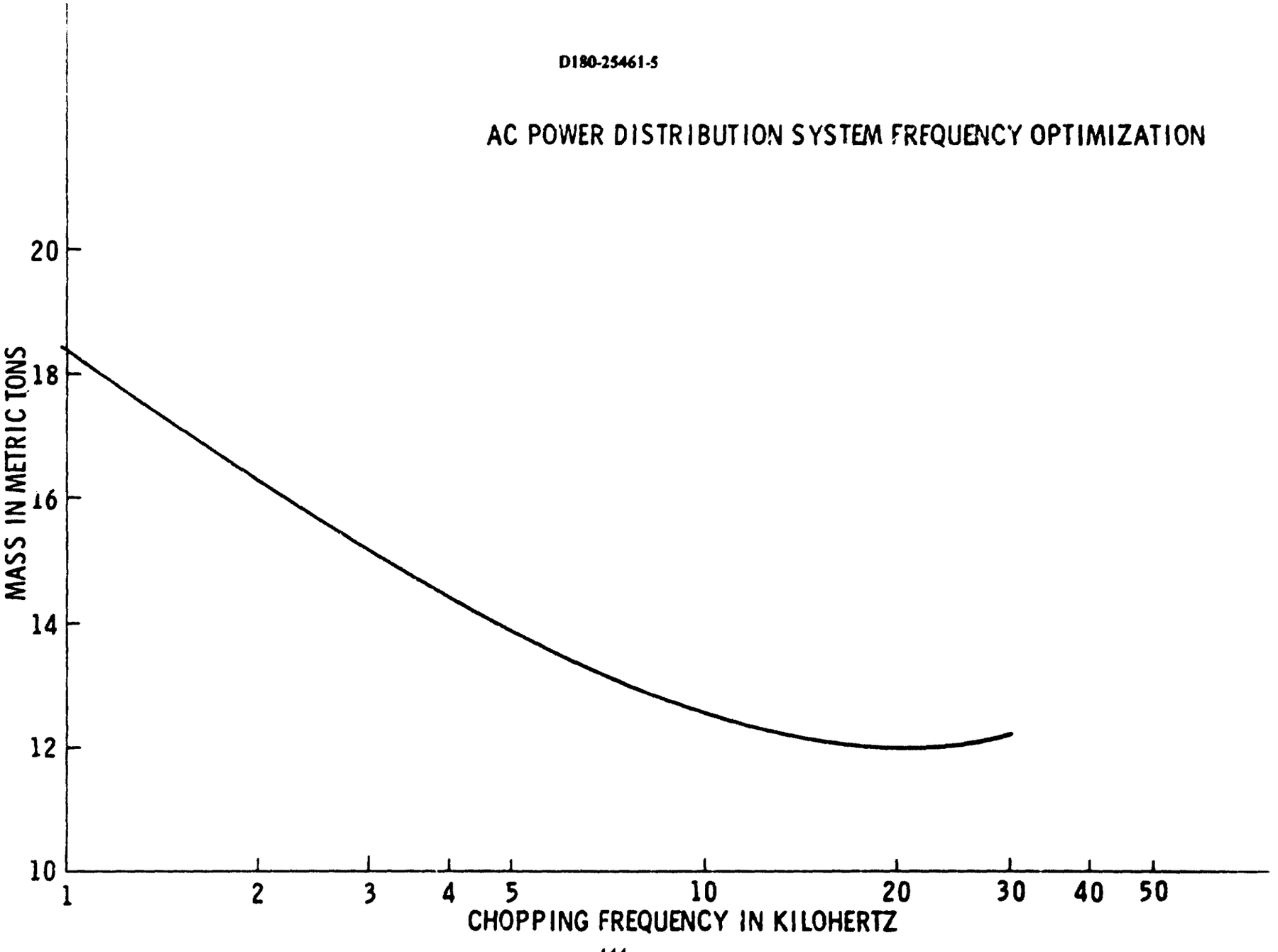
Parametric analyses of passively-cooled flat plate power busses in space underneath the SPS solar array yields the result that the bus temperature is a function of the parameter $IW^{-1}T^{-\frac{1}{2}}$, where I is the bus current and W and T are the plate width and thickness, respectively.

POWER BUS SIZING



AC POWER DISTRIBUTION SYSTEM FREQUENCY OPTIMIZATION

The mass of a 5.6 megawatt power distribution system as a function of frequency is shown. The least mass system occurs at 20 kiloHertz.


AC POWER DISTRIBUTION SYSTEM FREQUENCY OPTIMIZATION
MASS IN METRIC TONS
20
18
16
14
12
10
1
2
3
4
5
10
20
30
40
50
CHOPPING FREQUENCY IN KILOHERTZ

AC POWER DISTRIBUTION SUMMARY

System element masses and losses are shown for an AC power distribution system for the 2.5 gigawatt solid state SPS. The switching frequency of 10 kHz, although not mass optimal, is nearly so and allows the use of 1-mm thick aluminum power busses with minimal skin effects.

AC POWER DISTRIBUTION SUMMARY

2.5 GW SATELLITE, FREQUENCY = 10 KHz, T_c = 100°C
Operating Voltages Array 11 KV, Main Bus 100 KV

SYSTEM ELEMENT	MASS (MT)	I^2R LOSS (MW)
Non P-Max Power Loss Penalty	-	-
Acquisition Buses	19.7	46.0
DC/AC Converters	4,146.5	135.2
Main Buses	257.2	115.0
Switchgear	203.3	-
AC/DC Converters	5,175.9	164.4
TOTAL	9,802.6	406.6

Array Power = 4,760.6 MW
System Efficiency = 90.3%
System Losses = 9.7%
Array Area = 28.53 km^2
Array Mass = 12,119.0

Mass (Array + Pwr Dist) = 21,921.6 MT

DC POWER DISTRIBUTION - 44 KV

Mass and loss estimates for the DC/DC power supply option for the 2.5 GW solid state SPS are given here.

DC POWER DISTRIBUTION - 44 KV
2.5 GW SATELLITE, 100% POWER PROCESSING
T_C = 100°C, DELIVERED POWER = 4,300 MW to DC/RF CONVERTERS

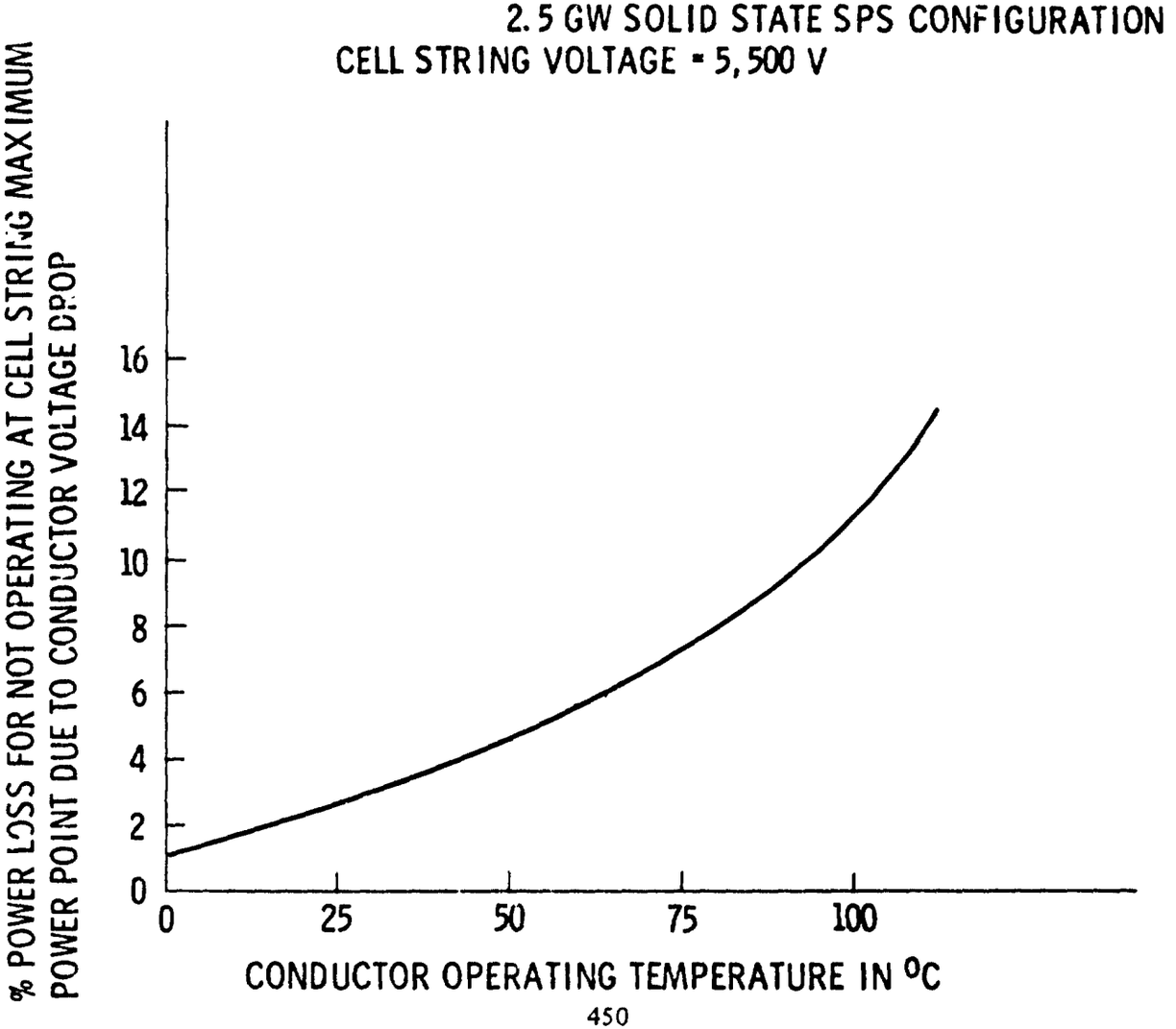
SYSTEM ELEMENT	MASS IN METRIC TONS	LOSSES IN MEGAWATTS
Non-P-Max Power Loss Penalty	-	24.2
Acquisition Buses	19.8	11.3
Main Buses	401.0	264.1
Switchgear	85.7	-
DC/DC Converters	7,239.6	253.2
TOTAL	7,746.1	552.8

Array Power (MW)	=	4,852.8
Array Area (KM^2)	=	29.09
Array Mass (MT)	=	12,356.0
System Efficiency	=	88.6%
Mass (Array + Pwr. Dist) (MT)	=	20,102.1

ARRAY MISMATCH LOSSES

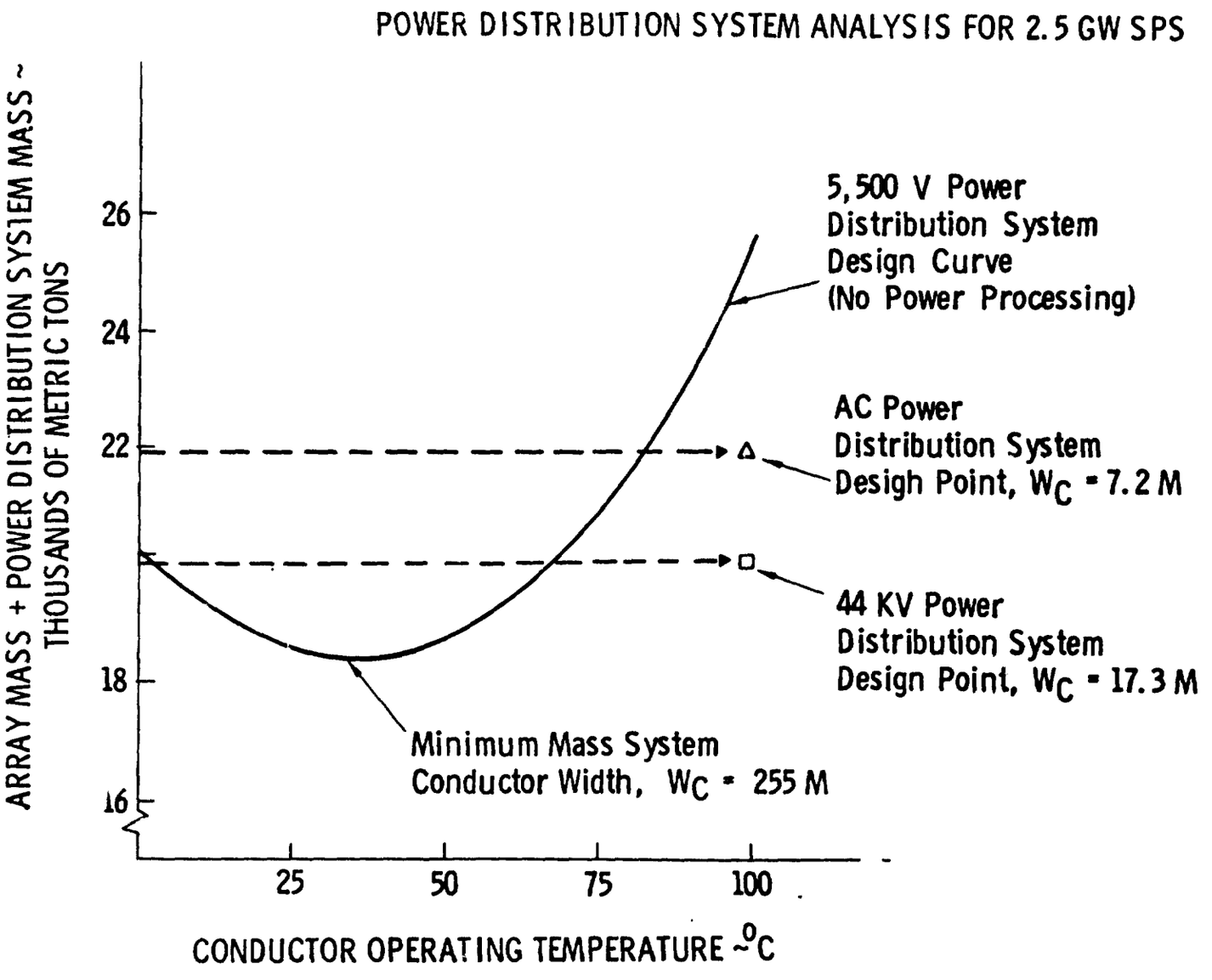
When solar array strings are connected in parallel along a constant-width bus with significant voltage drop along the bus, a power loss occurs due to operation of cells away from their maximum power point. This may be compensated by using variable length strings to match to local bus voltage. For the present solid state SPS definition this was not done. The assessed loss as a function of bus conductor operating temperature is shown. This loss is negligible for the Klystron reference SPS design.

ARRAY MISMATCH LOSSES



POWER DISTRIBUTION SYSTEM ANALYSIS FOR 2.5 GW SPS

Masses of the power distribution options as a function of conductor temperature are compared here. The direct 5500 volt DC option has the least mass and is also the simplest system. It was selected for the solid state reference SPS.

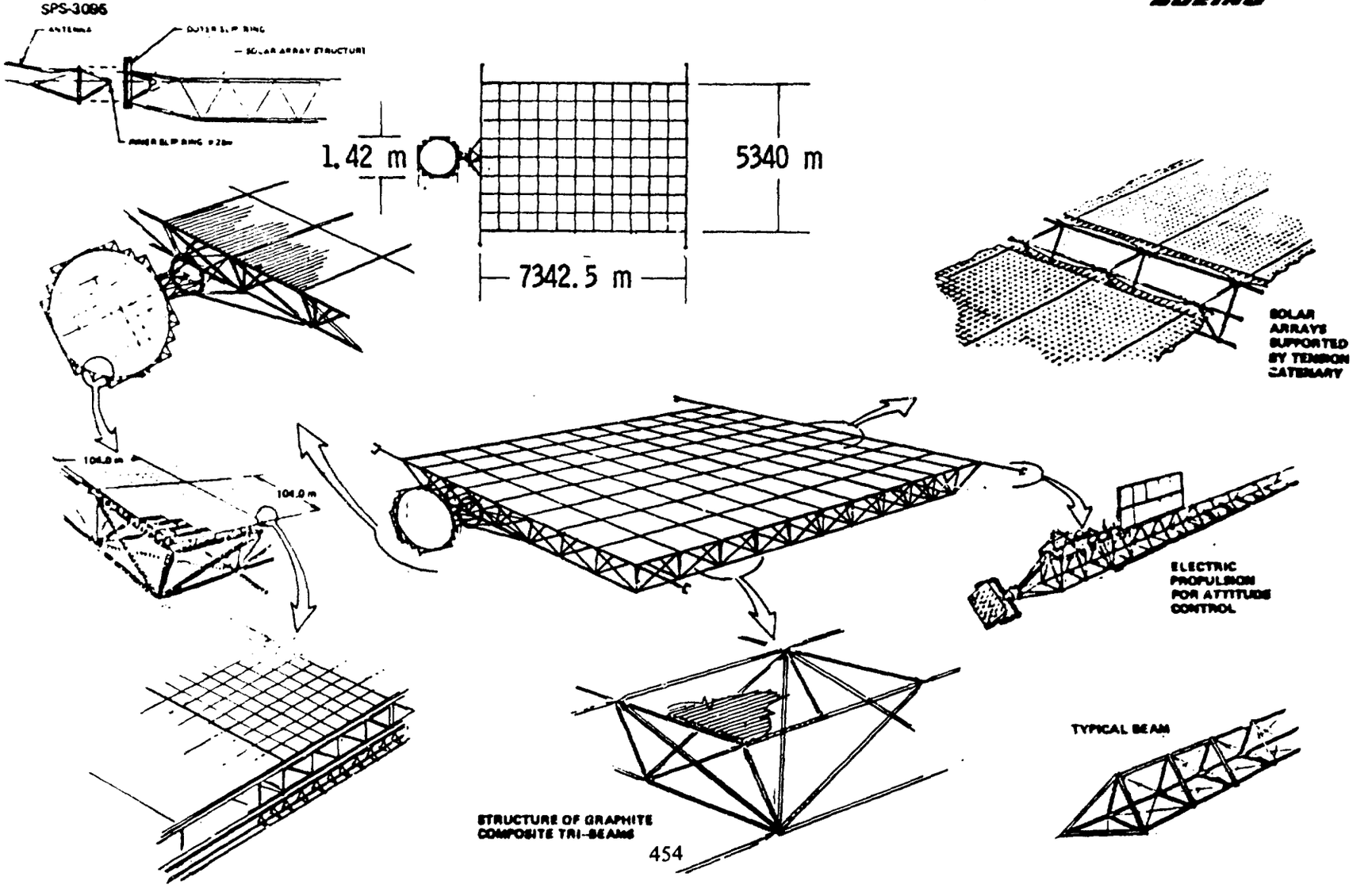

POWER DISTRIBUTION SYSTEM ANALYSIS FOR 2.5 GW SPS
ARRAY MASS + POWER DISTRIBUTION SYSTEM MASS ~ THOUSANDS OF METRIC TONS
26
24
22
18
16
5,500 V Power Distribution System Design Curve (No Power Processing)
AC Power Distribution System Desigh Point, W_C = 7.2 M
44 KV Power Distribution System Design Point, W_C = 17.3 M
Minimum Mass System Conductor Width, W_C = 255 M
25
50
75
100
CONDUCTOR OPERATING TEMPERATURE ~^{o}C

2.5 GW SOLID STATE SPS CONFIGURATION

The selected configuration for the solid state SPS is illustrated here. It is similar in layout to the 5-GW Klystron reference system described by the DOE/NASA reference system report. There are, however, significant differences. First, the transmitting antenna consists of 10.4 x 10.4 meter subarrays made up of solid state RF amplifier modules. Secondly, pentahedral truss structure is used throughout the satellite. Finally, the yoke-type mechanical interface has been replaced by a direct actuator interface using linear electric motors.

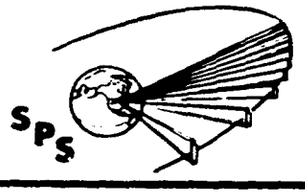
2.5 GW SOLID STATE SPS CONFIGURATION

BOEING



SOLID STATE SPS EFFICIENCY AND SIZING

The power losses and sizing of the 2.5 GW solid state SPS design are summarized here. Note that the two major loss terms are the main bus I^2R losses and the DC-RF conversion losses. These both contribute to the lower end-to-end efficiency of this system.



SOLID STATE SPS EFFICIENCY & SIZING

SPS-3087

ITEM	EFFICIENCY	MEGAWATTS	
Array Mismatch			
Array Mismatch	.965	6050	Ideal Array Output
Main Bus I^2R	.729	5838	
Antenna Distr	.97	4256	Total Antenna Input
DC-RF Conversion	.8	4128	
Waveguide I^2R	N/A	3303	Total RF Radiated Power
Ideal Beam	.965	3303	
Inter-Subarray Losses	.976	3187	
Intra-Subarray Losses	N/A	3110	
Atmosphere Loss	.98	3110	
Intercept	.95	3048	
Rectenna RF-DC	.89	2896	Incident on Rectenna
Grid Interface	.9	2577	
	.413	2500	Net to Grid

TOTAL ARRAY OUTPUT 6050 MW
TOTAL SOLAR ARRAY ARE ~ 33.8 km^2

ARRAY SIZING

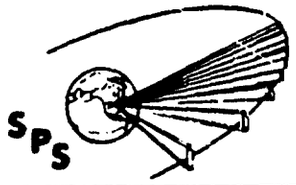
The array sizing procedure for the solid-state SPS is the same as that used for the Klystron reference system.

ARRAY SIZING

Solar Input:	1,353 W/m^2
Solar Cell Conversion Efficiency (0.173)	234.1
Blanket Factors (0.9453)	221.3
Thermal Degradation (0.954)	211.1
Orientation Loss (0.919)	194.0
Aphelion Intensity (0.9675)	187.7
Nonannealable Radiation Degradation (0.97)	182.1
Regulation, Auxiliary Power and Annealing (0.983)	179
EOL BLANKET OUTPUT:	179 W/m^2

SOLID STATE TRANSMITTING ANTENNA COSTS

The costing methodology for the solid state transmitting antenna is shown. An 80% learning curve was used where applicable. Largely due to the lower bulk of the solid state panels and their high component production rates, the solid state transmitting array appears to have a lower "RF system" cost per unit power than the Klystron reference system.



SOLID STATE TRANSMITTING ANTENNA COSTS

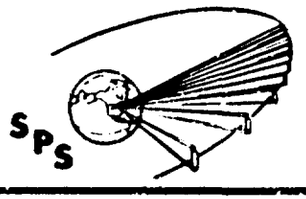
BOEING

SPS-3076

ITEM	COST ESTIMATING RELATION	COST ($M)
MODULE MASS	$70 kg^{-1}	258.6
MODULE POWER	$ .1 w^{-1}	330.3
HOOKUP	$ .15 FET^{-1}	93.2
TOTAL MODULE ASSOCIATED COSTS		682.1
SUBARRAY, STRUCTURE	$65 kg^{-1}	47.2
MASTER REFERENCE RECEIVER (3)	500K ea.	1.5
SLAVE REPEATERS (800)	25K ea.	20.0
LEVEL 1 CABLES (112)	9.2K ea.	1.1
LEVEL 2 CABLES (760)	5.0K ea.	3.8
LEVEL 3 CABLES (58,112)	$800 ea.	46.5
PCR's (58,112)	$560 ea.	32.5
QUADRANT - PANEL CABLES (81 x 58,112)	$45 ea.	21.2
PCV's (58,112)	$350 ea.	20.3
PANEL PHASE SLAVE REPEATER (81 x 58,112)	$15 ea.	7.6
PANEL CKT BREAKER (81 x 58,112)	$10 ea.	4.7
TOTAL NON-MODULE COSTS		206.4
TOTAL SOLID STATE TRANSMITTING ANTENNA "RF SYSTEM" COSTS		888.5

SOLID STATE SPS MASS AND COST SUMMARY

Masses, costs, and estimating bases for the solid state SPS design are summarized here. Total mass and cost per unit power are 40% higher than for the Klystron reference system. This is primarily due to the lower DC bussing and DC-RF efficiencies.



SOLID STATE SPS MASS & COST SUMMARY

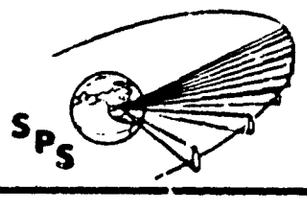
SPS-3070

BOEING

		MASS (MT)	ESTIMATING BASIS	(COST ($M)
1.1	SPS	35,204		4,541
1.1.1	ENERGY CONVERSION	22,087		2,350
1.1.1.1	STRUCTURE	2,851	Detailed Estimate	275
1.1.1.2	CONCENTRATORS	(0)	Not Required	(0)
1.1.1.3	SOLAR BLANKETS	14,409	Scaled from Reference	1,355
1.1.1.4	POWER DISTRIB.	4,400	Detailed Estimate	530
1.1.1.5	THERMAL CONTROL	(0)	Allocated to Subsystems	(0)
1.1.1.6	MAINTENANCE	427	Scaled from Reference	190
1.1.2	POWER TRANSMISSION	6,365		1,134.5
1.1.2.1	STRUCTURE	460	Scaled from Reference	38
1.1.2.2	TRANSMITTER SUBARRAYS	4,480	Detailed Estimate	888.5
1.1.2.3	POWER DISTR. & COND.	1,262	Scaled from 1.1.1.4	124
1.1.2.4	PHASE DISTR.	25	Scaled from Reference	51
1.1.2.5	MAINTENANCE	20	Docking Ports Only	20
1.1.2.6	ANTENNA MECH. POINTING	118	Scaled by Mass x Area	13
1.1.3	INFO MGMT & CONTROL	145	Scaled from Ref.	73
1.1.4	ATT. CONT. & STA. KP.	146	Scaled From Ref	110
1.1.5	COMMUNICATIONS	0.2	Same as Ref.	8
1.1.6	INTERFACE	113	Est. Based on Simplification	46.3
1.1.7	GROWTH & CONTINGY.	6,348	Same % as Reference	819

2.5 GW SATELLITE SYSTEM RECURRING COST

Recurring costs for the solid state SPS are snown. The efficiency factors which drive the solid state SPS mass are the prime contributors to the relatively higher unit cost of this satellite system.



2.5 GW SOLID STATE SATELLITE SYSTEM RECURRING COSTS

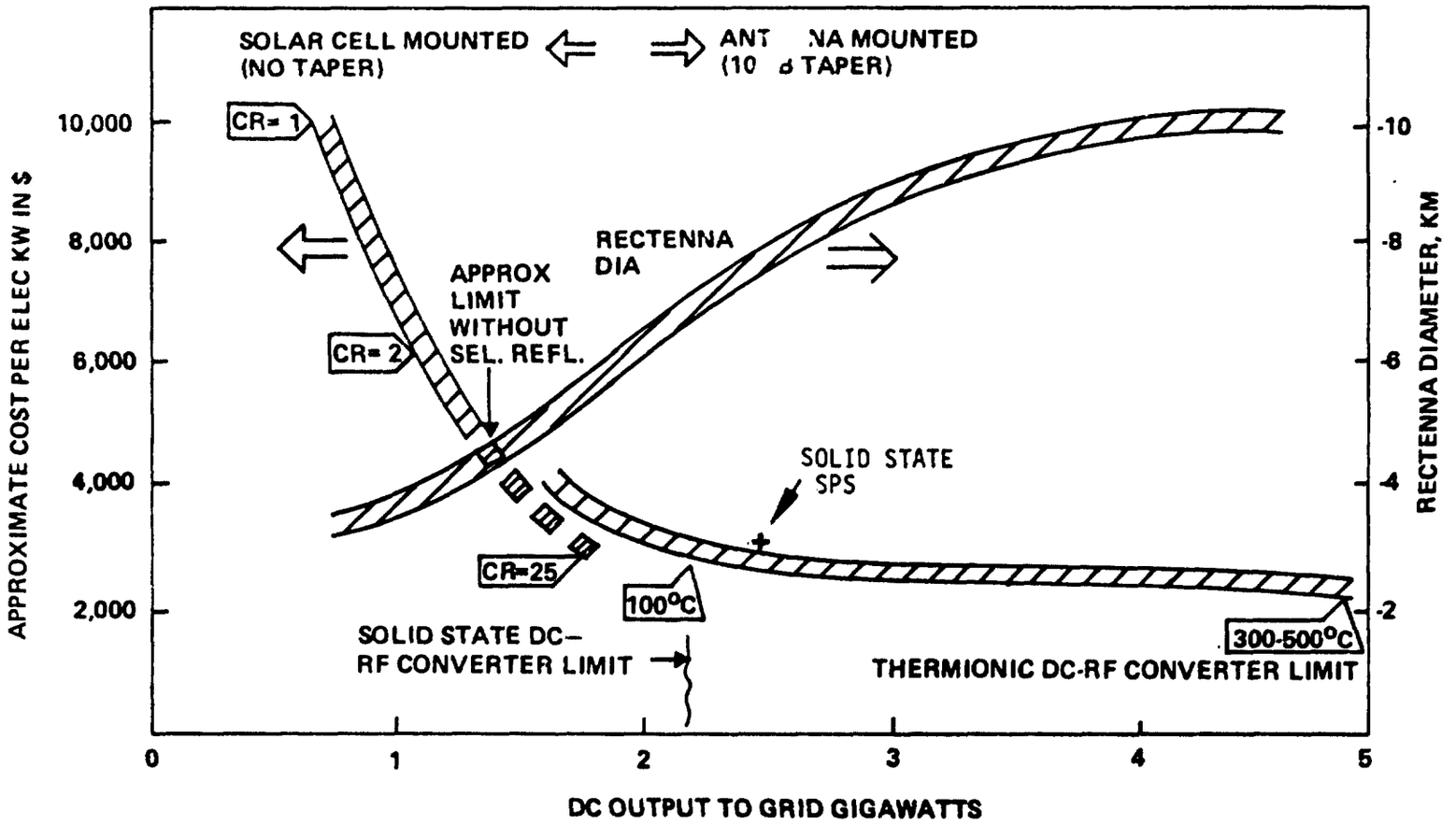
BOEING

ITEM	COST ($M)
SATELLITE	3,722
LESS IMPLICIT AMORTIZATION	327
	3,395
CONSTRUCTION AND SUPPORT	664
SPACE TRANSPORTATION	2,154
GROUND TRANSPORTATION	20
RECTENNA	1,290
MISSION CONTROL	10
MGMT AND INTEGRATION	385
MASS GROWTH (17% Net Hardware)	577
TOTAL DIRECT OUTLAY	8,505

SPS COST TRENDS

We have empirically observed that cost projections for various SPS designs tend to fall on broad trend lines that are primarily power dependent. The solid state SPS design is very close to this trend line and projected improvements should bring it down to or slightly below the line. These projected improvements are mainly aimed at increasing power distribution efficiency.

SPS Cost Trends



SOLID STATE RECOMMENDATIONS

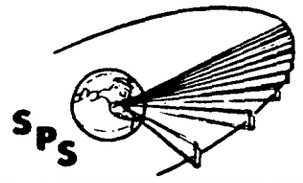
Several items of further work are recommended here; these would improve understanding of the solid state SPS concept and improve its cost and mass characteristics.

The first item is to examine more sophisticated beam shaping to utilize the receiving aperture more efficiently and to remove the solid state maximum power constraint. These techniques would investigate combined phase and amplitude tapers to "square up" and spread the power beam.

Secondly, two engineering improvements are recommended: (1) - to determine if higher DC distribution voltages can be used, and (2) - to develop an intermediate-mass RF amplifier module for unit power levels intermediate between the 4-way combiner level and the low-mass dipole level.

A noise and harmonics investigation of high-efficiency RF amplifiers coupled to representative radiators is important. This should include laboratory as well as analytical work.

Lastly, increasing the level of design detail for the solid state SPS and development of a system description/cost document is seen as important as a basis for future research and analysis.



SOLID-STATE RECOMMENDATIONS

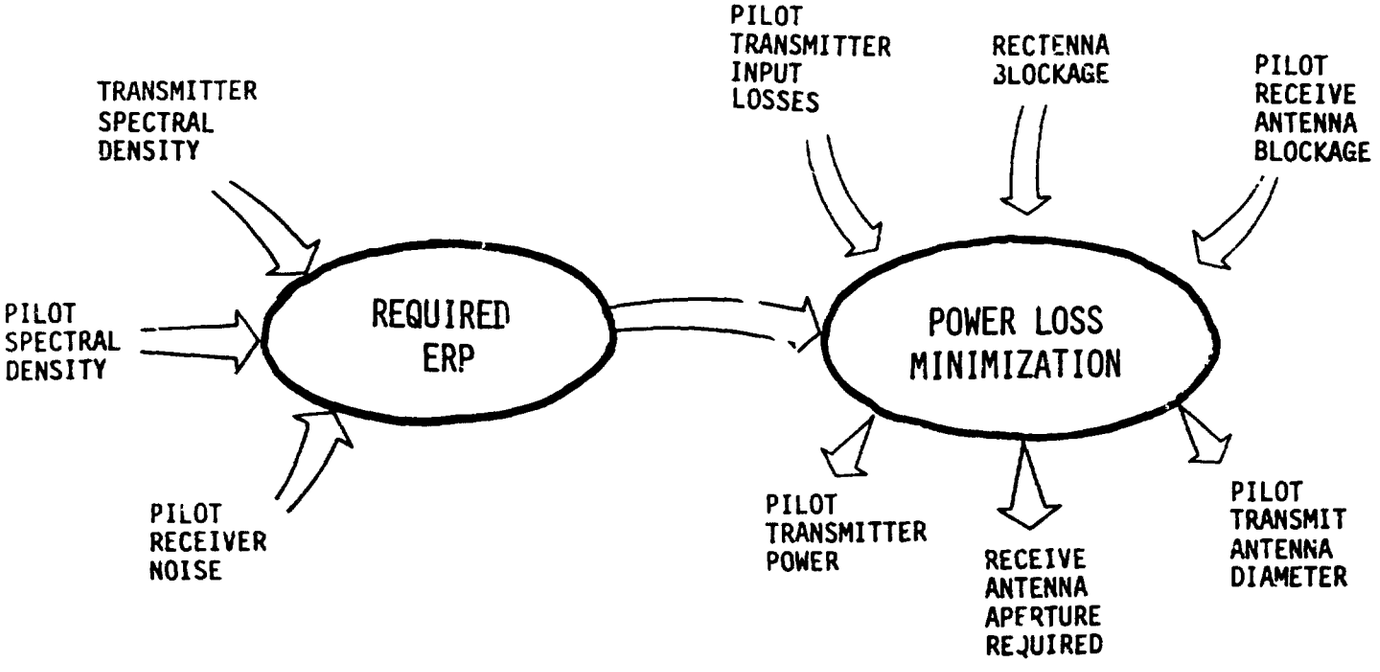
- EXAMINE BEAM TAILORING
  - Square Up Beam
  - Open Power Constraint
- TRY FOR HIGHER DISTRIBUTION VOLTAGE
- INVESTIGATE "INTERMEDIATE" POWER MODULE OF LOWER MASS/POWER
- CONDUCT NOISE & HARMONICS ANALYSIS
- INCREASE DESIGN DETAIL
- PROVIDE SYSTEM DESCRIPTION/COST DOCUMENT

PILOT LINK ANALYSIS

The primary objective of this pilot beam link study was the specification of the pilot beam receiving antenna. Although many factors were taken into account, the ultimate consideration was to maximize overall system efficiency.

The system efficiency is degraded to the extent of: required pilot transmitter power, receiving antenna blockage of the spacetenna, and pilot transmitting antenna blockage of the rectenna. These factors were related (through the effective radiated power) to the pilot receiver noise, the pilot spectral density, and the transmitter spectral density.

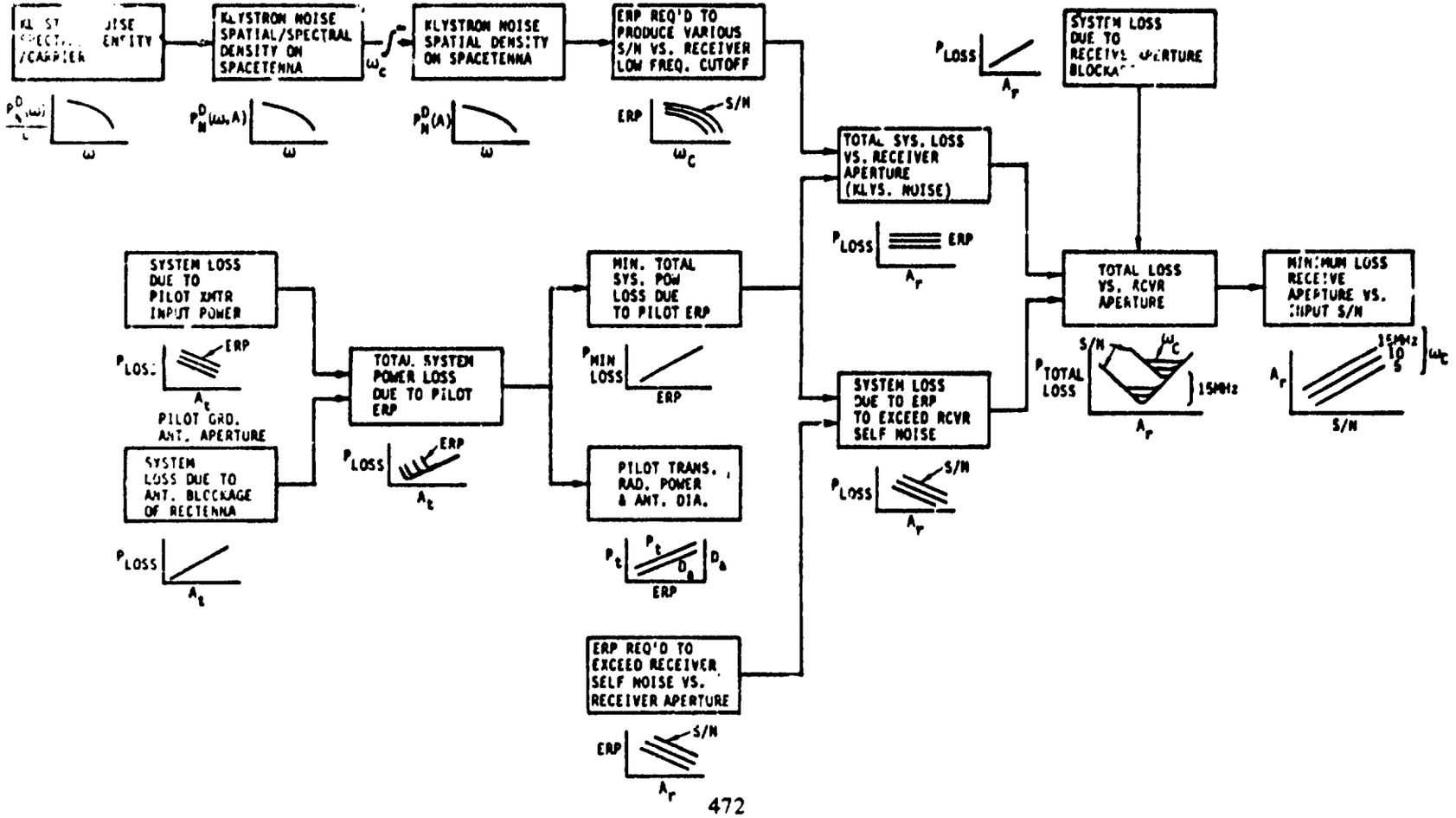
PILOT LINK ANALYSIS



PILOT LINK ANALYSIS FLOW CHART

The relationships between the various parameters of the pilot link study are shown in this diagram.

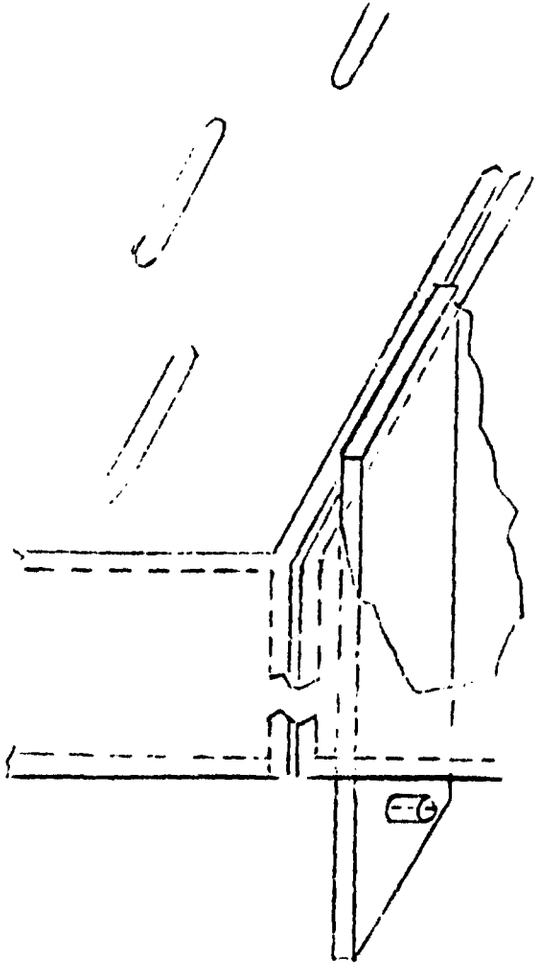
PILOT LINK ANALYSIS FLOW CHART



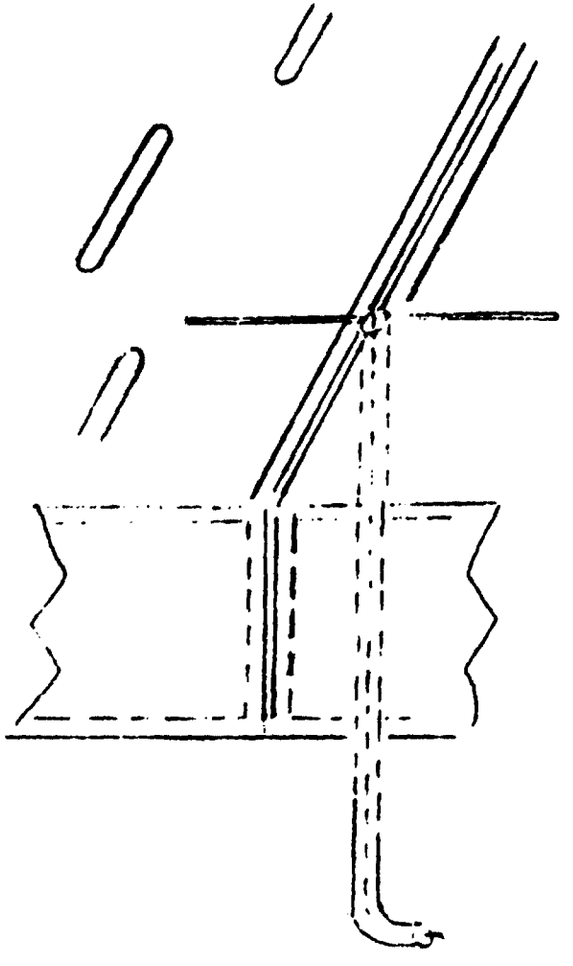
CANDIDATE PILOT BEAM RECEIVING ANTENNAS

Two candidate pilot beam receiving antennas are the microstrip slot antenna and the cross polarized dipole. The microstrip slot antenna acts as a dielectrically loaded waveguide which slips through a slot cut from the waveguide walls. Its polarization is the same as that of the radiating slots. The cross polarized dipole is fed by rigid coax which slips through a hole cut from the waveguide walls. It sits $\lambda/4$ above the slot array. The fact that it is cross polarized to the radiating slots should result in reduced pickup of transmitter noise.

CANDIDATE PILOT BEAM RECEIVING ANTENNAS



MICROSTRIP SLOT ANTENNA



CROSS-POLARIZED DIPOLE

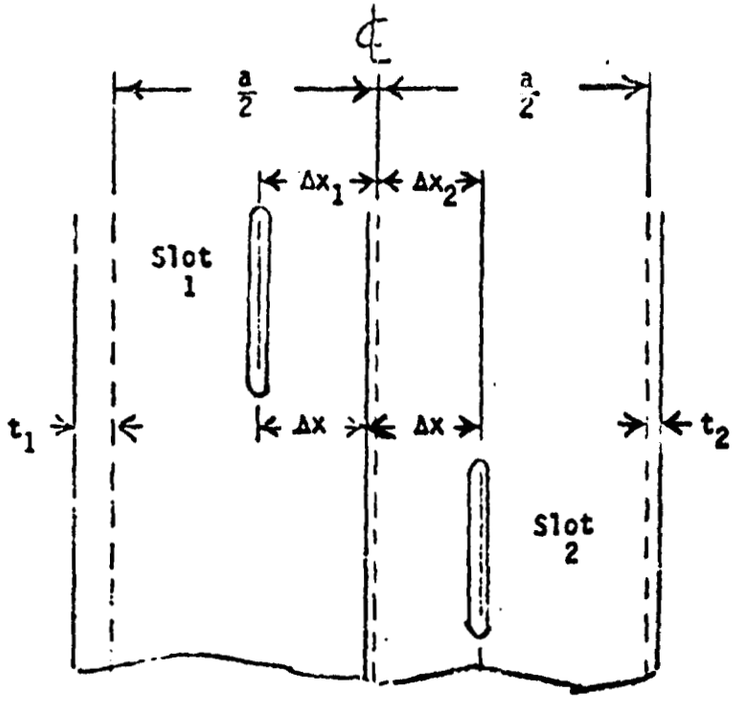
SCATTERED POWER ERROR DUE TO WAVEGUIDE TOLERANCE

Because of waveguide mechanical tolerances, the inside waveguide centerline will generally not coincide with the outside centerline. Consequently, placement of waveguide slots according to waveguide outside dimensions is liable to be incorrect.

Incorrect slot placement will result in a slot conductance which differs from the desired value. For a given placement error, the error in slot conductance is greater for narrower (lower WR number) waveguide.

A particular fractional error in slot conductance will result in a proportionate fractional scattered (loss) power.

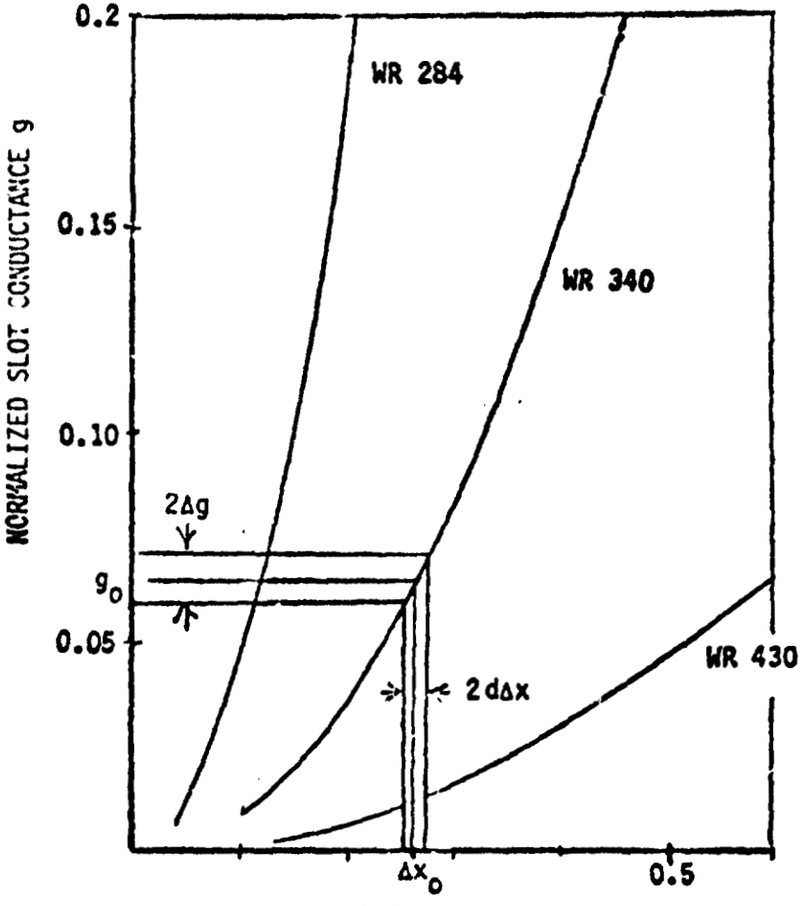
SCATTERED POWER ERROR DUE TO WAVEGUIDE TOLERANCE



Outside Dimensions

Inside Dimensions

$$\frac{P_s}{P} \approx \frac{\Delta_2}{g}$$

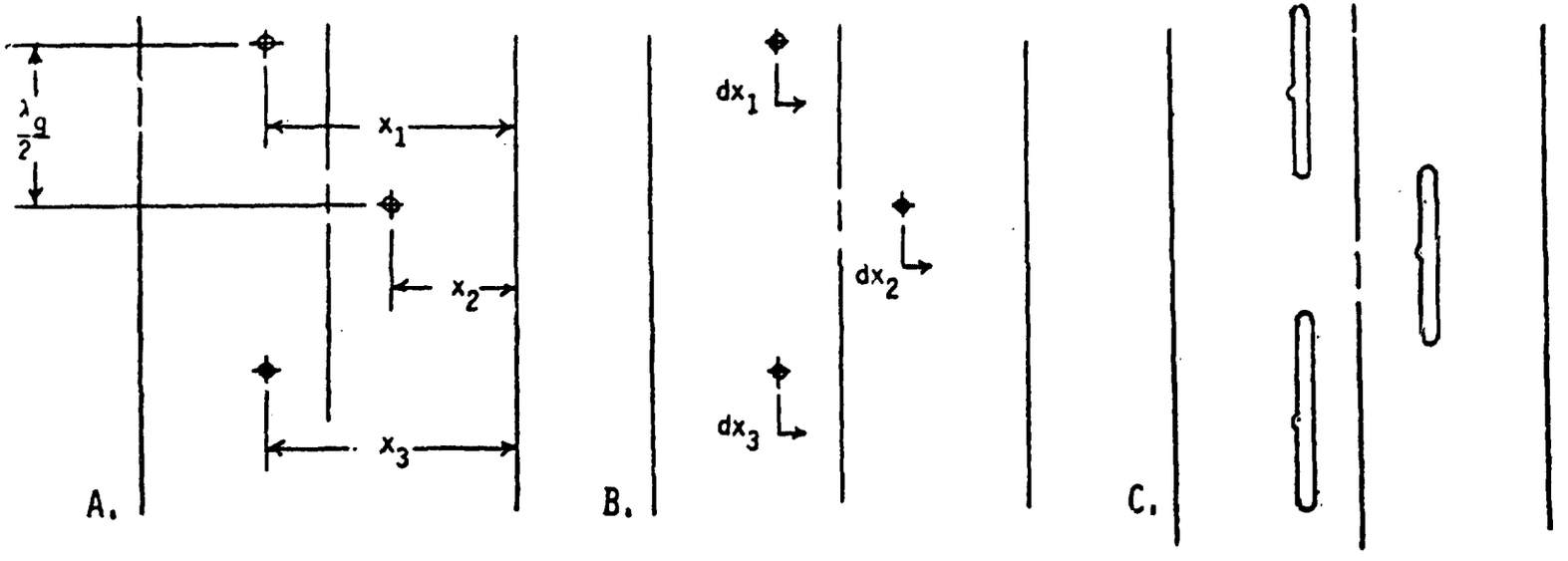


Maximum Error Δx = 0.007"

SEQUENCE FOR PILOT-HOLE SLOT POSITIONING

By the pilot-hole slot positioning technique, slots are placed according to internal microwave fields which are probed through 1/8" pilot holes.

SEQUENCE FOR PILOT-HOLE SLOT POSITIONING



A. PILOT HOLES ARE POSITIONED ACCORDING TO WAVEGUIDE OUTSIDE DIMENSIONS.

B. AFTER FIELD PROBING, CORRECTIONS TO PILOT-HOLE POSITION ARE MARKED ON THE WAVEGUIDE.

C. RADIATING SLOTS ARE MILLED AT THE CORRECTED POSITIONS.

COMPARISON OF SCATTERED POWER DUE TO PILOT HOLE AND MECHANICAL SLOT PLACEMENT TECHNIQUES

Pilot hole slot placement offers accuracy superior to that characteristic of mechanical placement. The advantage of this technique diminishes, however, as waveguide size increases. Note that precision machining has a minimal payoff.

COMPARISON OF SCATTERED POWER DUE TO PILOT HOLE AND

MECHANICAL SLOT PLACEMENT TECHNIQUES

	Pilot Hole Placement		Mechanical Placement (1)	
Waveguide	Standard	Precision	Standard	Precision
WR 284	0.1	0.1	0.78	0.78
WR 340	0.1	0.1	0.33	0.33
WR 430	0.1	0.1	0.176	0.173

(1) Assuming worse case placement error $d\Delta x = 0.007$.
All values are in dB.

MODULE I^2R LOSSES VS STICK WIDTH

I^2R losses were evaluated for various module aspects ratios (stick length/feedguide length). For each aspect ratio, the waveguide width was varied.

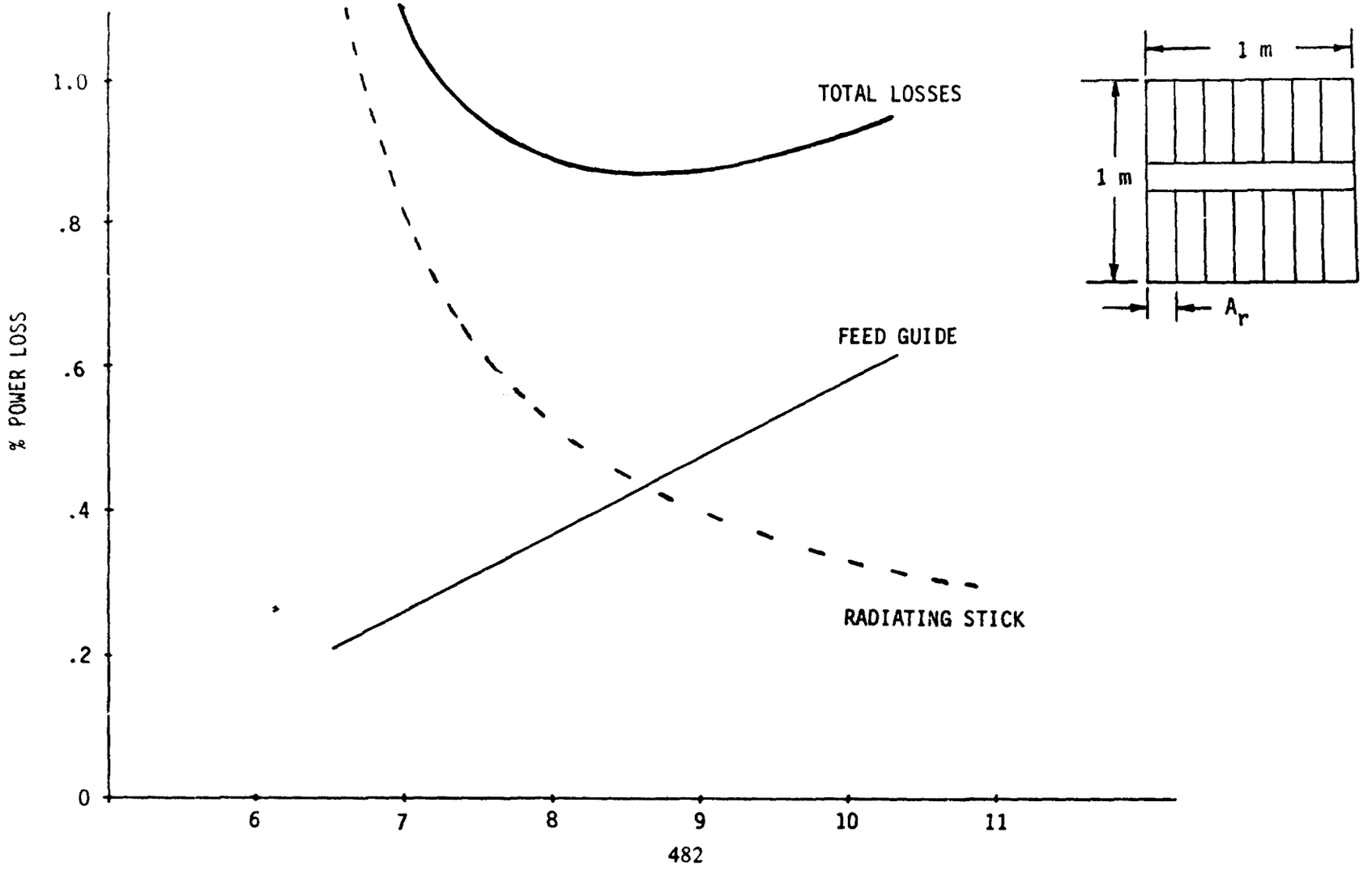
From this study the following have been concluded:

- I^2R losses are not sensitive to module aspect ratio.
- I^2R losses are not very sensitive to waveguide size.
- Stick standing wave considerations dictate end feeding preferable.

ENGINEERING TECHNOLOGY

MODULE I^2R LOSSES VS. STICK WIDTH

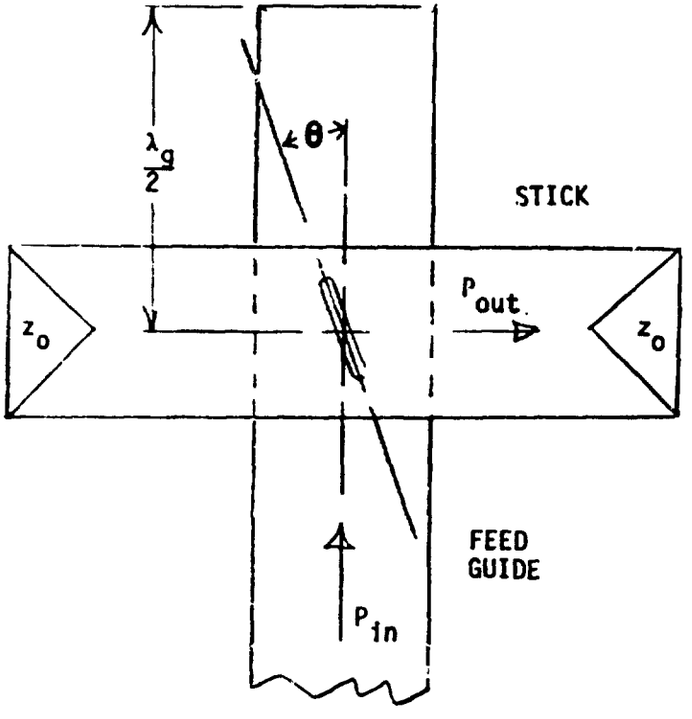
BOEING AEROSPACE COMPANY

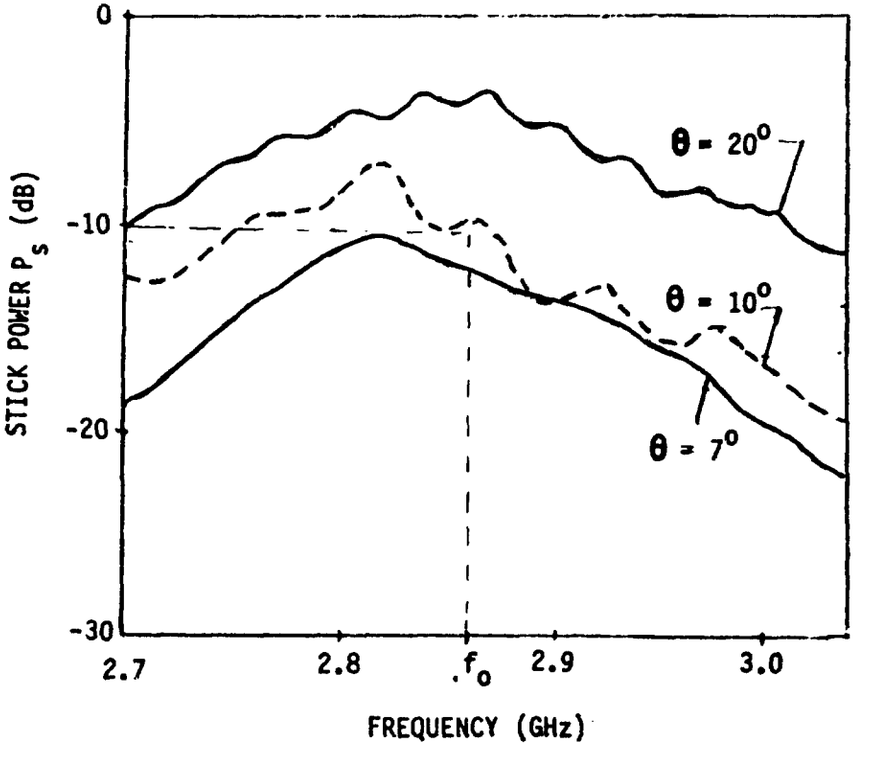


DETERMINATION OF COUPLING SLOT ORIENTATION

The coupling of a feedguide to a simulated radiating stick has been measured for several coupling slot angles. For a 10 stick array, the coupling to a single stick should be about -10 dB. This magnitude is provided by a coupling slot angle of about 8°.

DETERMINATION OF COUPLING SLOT ORIENTATION





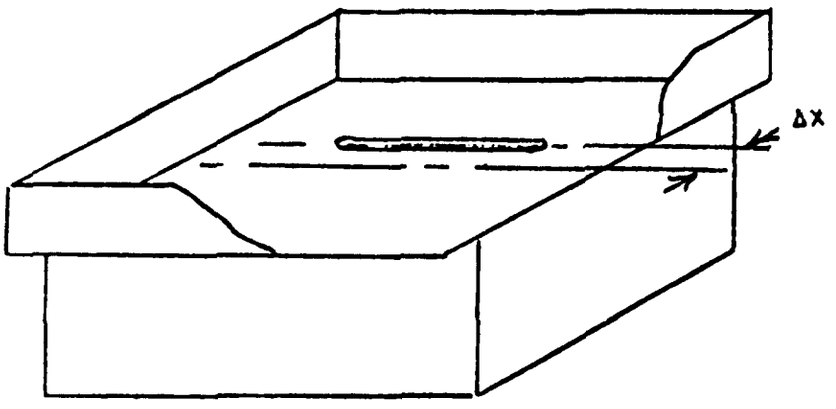
- COUPLING SLOT LENGTH ADJUSTED FOR RESONANCE AT 2.86GHz
- FOR A 10 STICK ARRAY, DESIRE A SINGLE STICK POWER OF -10DB
- FROM ABOVE DATA, OPTIMAL SLOT OFFSET IS ABOUT 8°.

IMAGE PLANE SIMULATION OF RADIATING SLOT COUPLING

Mutual coupling between slots will alter considerably the slot impedance, and hence the requisite slot placement. The exact quantitative relationship between slot conductance and mutual coupling is not presently known. Nevertheless, experimental data indicate the effect to be significant.

Neighboring slots are approximated by images of the real slot in the reflecting plane. Slot conductance is derived from the loaded cavity Q. For an uncoupled slot, the measured conductance is in good agreement with the theory. The considerable change in conductance with the image planes in place is indicative of the potential magnitude of mutual coupling effects in the SPS array.

IMAGE PLANE SIMULATION OF RADIATING SLOT MUTUAL COUPLING



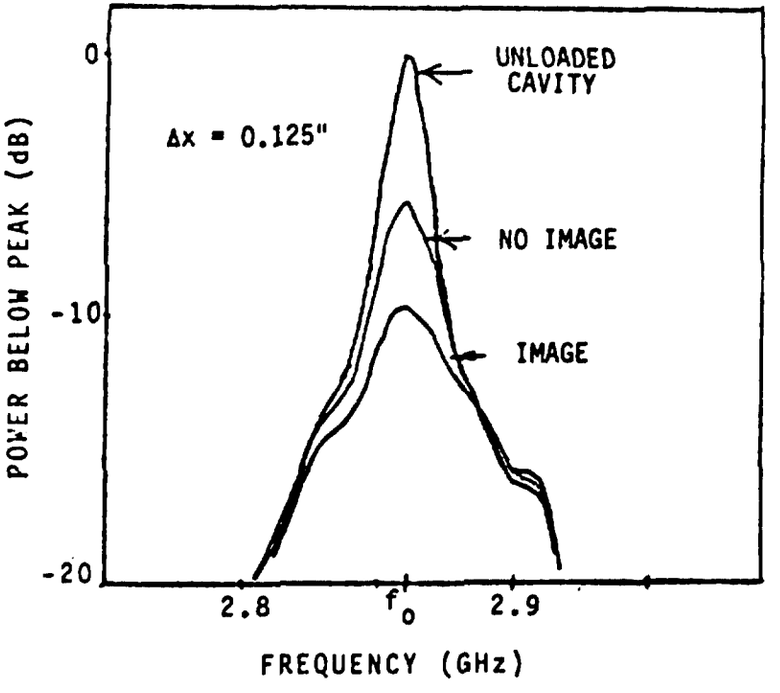


IMAGE PLANES ARE SPACED SO THAT THE VIRTUAL SLOT IMAGES OF THE RADIATING SLOT APPEAR AT THE POSITIONS OF THE CORRESPONDING SLOTS IN THE REAL ARRAY.

$$\frac{1}{Q_{slot}} = \frac{1}{Q_c} - \frac{1}{Q_o}$$

$Q_o = 220$

$$g_{slot} = \frac{2\pi}{Q_{slot}}$$

CONDITION	Q_c	g_{slot}
NO IMAGE	119	0.024
IMAGE	92	0.039

ESTIMATE OF MUTUAL COUPLING IN SPS SLOTTED WAVEGUIDE ARRAY

Slot admittance has been calculated, as a function of the number of neighboring slots, for a single slot in a slot array. The calculation is an adaptation, using Babinets principle of an existing analysis of a dipole over a ground plane, in an infinite array of similar dipoles. The results vary for different array configurations, but, in each case, coupling to slots beyond the fifth neighbor appears to be minimally important.

ESTIMATE OF MUTUAL COUPLING IN SPS SLOTTED WAVEGUIDE ARRAY

ANALYTICAL EXPRESSION[1]

$$\frac{Y}{y_0} = \frac{4\,a\,S_\epsilon\,S_H\left[1-jw\right]}{b\,\lambda^2\left[1+w^2\right]\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}}\cos^2\left(\frac{\pi}{2}\sqrt{1-\frac{\lambda^2}{2a}}\right)\sin^2\left(\frac{\pi x}{a}\right)$$

where

$$w = \sum_{\substack{m=1 \\ m\neq 0}}^{m=+i}\sum_{\substack{n=-k \\ n\neq 0,}}^{n=k}\left[\frac{\sin\left[\frac{\pi g}{2}\left(\frac{m}{S_\epsilon}\right)\right]}{\frac{\pi g}{2}\left(\frac{m}{S_\epsilon}\right)}\right]^2\left[\frac{\cos\left[\frac{\pi n\lambda}{2S_H}\right]}{1-\left[\frac{n\lambda}{S_H}\right]^2}\right]^2\frac{\left[\left[\frac{n\lambda}{S_H}\right]^2-1\right]}{\sqrt{\left(\frac{n\lambda}{S_H}\right)^2+\left(\frac{m\lambda}{S_\epsilon}\right)^2}}$$

i = ½ the number of neighboring slots considered in the 'ε' plane

k = ½ the number of neighboring slots considered in the 'H' plane

a = guide I.D. width = 7.21 cm x = slot offset = .457 cm

b = guide I.D. height = 2.55 cm g = slot width = .3175 cm

S_ϵ = slot 'ε' plane spacing = 7.62cm Y = slot shunt admittance

S_H = slot 'H' plane spacing = 7.62cm Y_0 = guide characteristic "

DESIGN APPROACH FOR RF MATCH

1. Check asymptotic value for single stick = (.058 - j .032)

   i.e., $\frac{Y}{y_0} = 19(.058-j.032) = 1.1 - j.6$

   this verifies single slot $\frac{Y}{y_0}$

2. Compare asymptotic expression in square array

   N = M 5 with single slot (N = M = 0)

   N = M = 0; $y/y_0 = .075 + j\,0$

   N = M = 5; $y/y_0 = .063 + j\,.028$

   Select modified slot offset

   $$\Delta x = \Delta x_0\sqrt{49/9} = .457\left(\sqrt{.075/.063}\right) = .50\text{ cm}$$

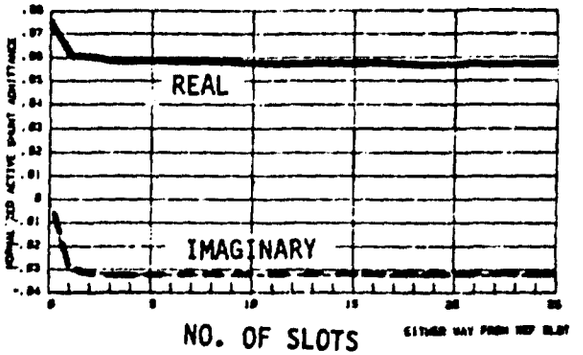
   Select increased slot length to result in susceptance of j(.028) from JASIK (pg. 9-5)

   $$\frac{\Delta L}{L} = \frac{1}{14}\,\frac{\Delta B}{E_0} = \frac{1}{14}\left\{\frac{.028}{.075}\right\} = .026 \text{ is 2.6\% longer slot}$$

---

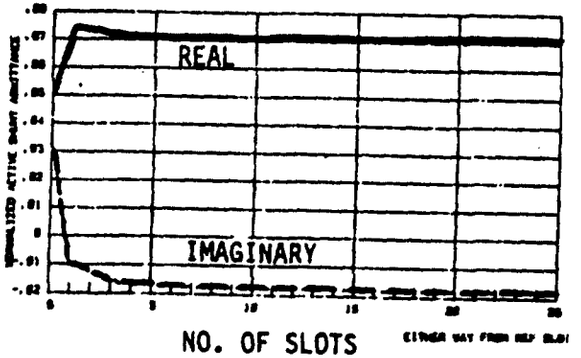
1. MODIFICATION OF STARK'S DIPOLE EXPRESSION TO SLOTS

SINGLE STICK



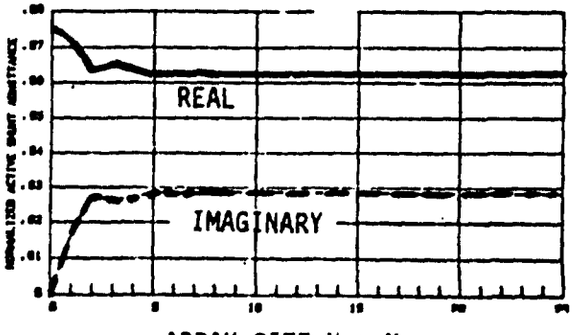
$\frac{Y}{y_0}$

TWO STICKS



$\frac{Y}{y_0}$

SQUARE ARRAY
N x M



$\frac{Y}{y_0}$

ITERATIVE DESIGN PROCEDURE FOR RADIATING STICK PARAMETERS

This chart provides experimental data on three waveguide sticks (1-3) manufactured with slightly different slot offsets and slot lengths. The goal of this effort is to empirically arrive at a configuration resonant at 2850 MHz and matched with 16-18 slots including the effect of mutual coupling due to adjacent sticks.

The next planned iteration, stick number 4, is expected to have the desired resonant frequency of 2860 MHz.

ITERATIVE DESIGN PROCEDURE FOR RADIATING STICK PARAMETERS

STICK NUMBER	NO. OF SLOTS[1] FOR BEST MATCH		SLOT[3] OFFSET	SLOT LENGTH	COMMENT
	SINGLE STICK	WITH[2] NEIGBOR			
1	22	20	.18"	2.04"	RESONANCE @ 2800 MHz SLOT TOO LONG
2	16	14	.20"	1.94"	RESONANCE @ 2880 MHz SLOT TOO SHORT TOO MUCH CONDUCTANCE PER SLOT
3	18	16	.187"	1.98"	RESONANCE AT 2875MHz
4	18	18	.180"	2.00"	EXPECT 2860 MHz[4]

1. SLIDING SHORT MEASUREMENT: VSWR AT RESONANCE < 1.1
2. NON-DUPLICATE STICKS ARE USED TO APPROXIMATE MUTUAL COUPLING EFFECT
3. AFFECTS PRIMARILY SLOT CONDUCTANCE
4. DESIRED FREQUENCY FOR FEED GUIDE TO BE IDENTICAL TO RADIATING STICK GUIDE (WR240)

DIAGONALLY FED SLOTTED ARRAY

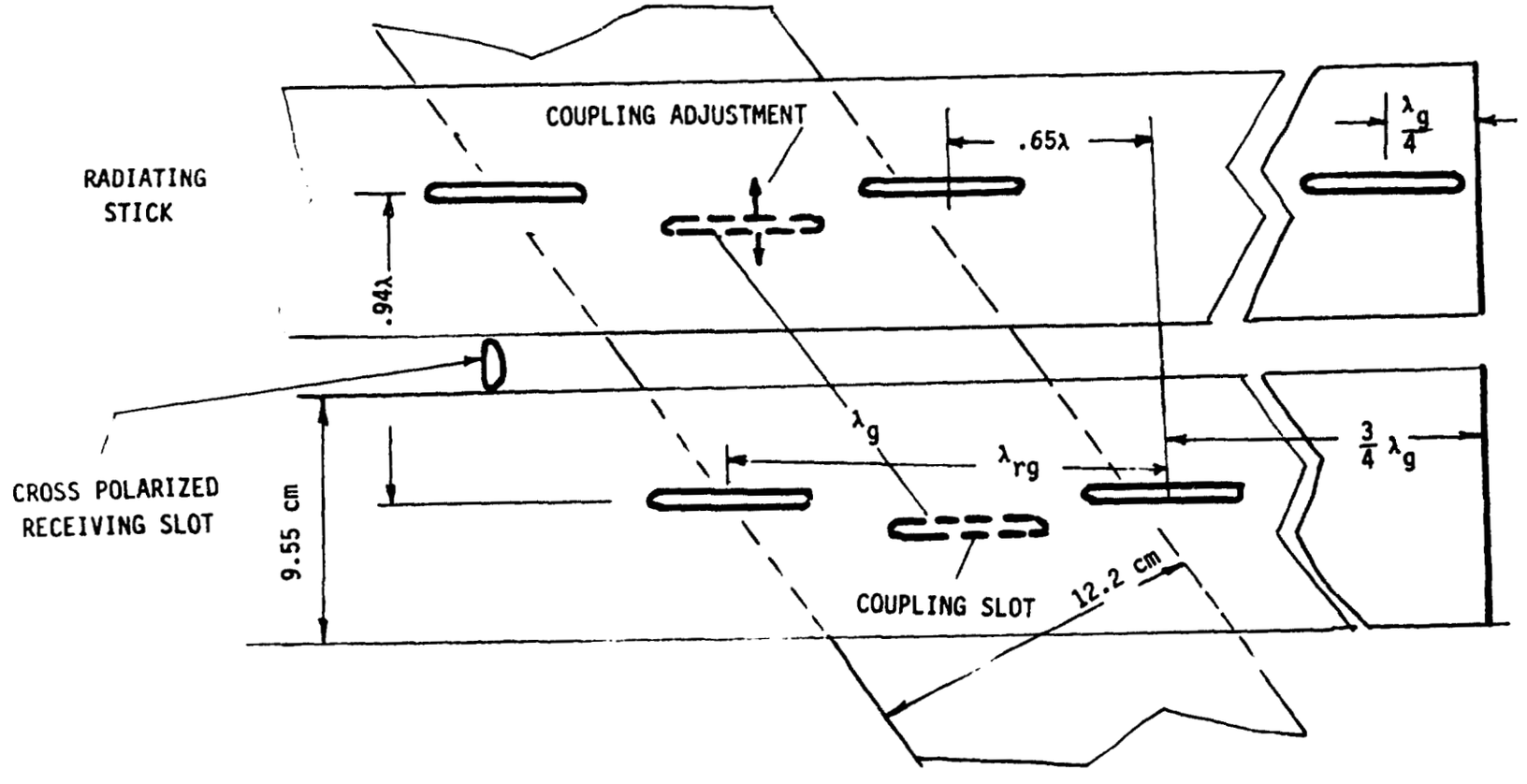
In this design, a potential reference system refinement, both the coupling slots and the radiating slots are spaced by λ_g, rather than by $\lambda_g/2$ as in the baseline design.

The relative advantages of this design are several:

- Gaps will exist between the sticks giving more flexibility in the design and placement of receiving antennas.
- Larger, hence lower loss, waveguide can be used.
- Sensitivity of conductance to systematic slot placement errors is reduced because slots all lie on the same sipe of the stick center.
- Although not apparent in the figure, a corporate feedguide is obviated.
- Total coupling of feedguide to sticks can be readily adjusted merely by transverse displacement of the coupling guide relative to the sticks.

ENGINEERING TECHNOLOGY

DIAGONALLY FED SLOTTED ARRAY



SPS FIBER OPTIC LINK ASSESSMENT CONTRACT NAS 9-15636A

TASKS:

- Analyze existing optical fibers for applicability for use in the test with emphasis on phase change effects, attenuation and bandwidth.
- Analyze suitable optical emitters and detectors to determine feasibility of operation and usage at 980 MHz.
- Select and purchase candidate optical fibers and an emitter and detector for testing.
- Test candidate fibers at 60 MHz for phase sensitivity to temperature.
- Design and construct impedance matching system for matching the optical emitter and detector to Boeing laboratory equipment.
- Assemble and test a two way opto-electronic link at 980 MHz consisting of two selected emitters and detector units and a jacket material 2-fiber cable of minimum length of 200 meters.

SPS TEST LINK COMPONENT STATUS

The design approach chosen utilizes a GaAlAs single mode injection laser diode, a fused silica graded fiber and a silicon avalanche photodiode. The features of each element and the alternatives considered are outlined in the opposite figure.

ENGINEERING TECHNOLOGY

SPS TEST LINK COMPONENT STATUS

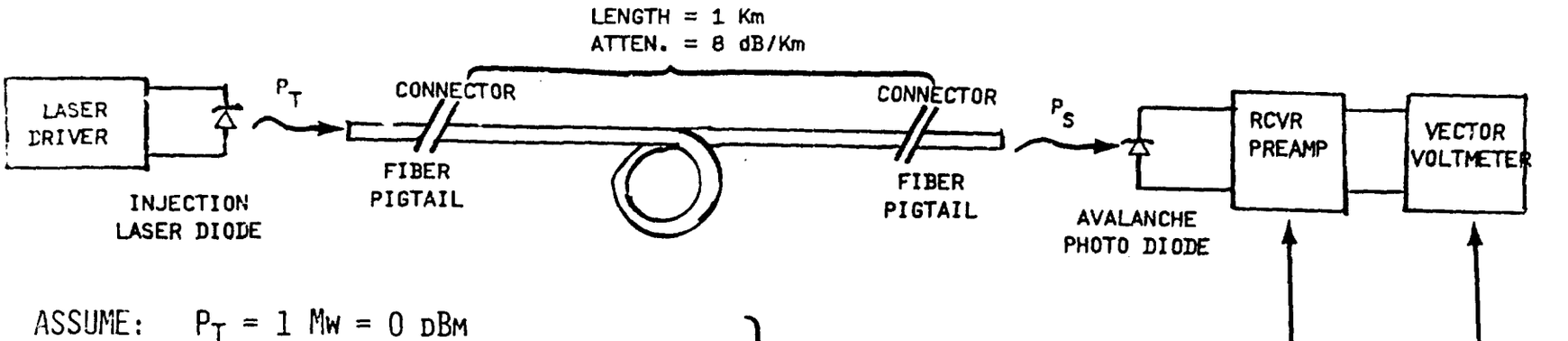
DEVICE UNDER CONSIDERATION	TYPE	FEATURES
EMITTER	GaALAs MULTI-MODE INJECTION LASER DIODE	1) LOW COST 2) HIGH POWER
	GaALAs SINGLE-MODE INJECTION LASER DIODE	1) HIGH POWER 2) HIGH COUPLING EFF. 3) LOW THRESHOLD 4) LOW DISTORTION 5) NARROW SPECTRAL WIDTH 6) HIGH RELIABILITY
DETECTOR	SILICON AVALANCHE PHOTO DIODE	1) GAIN-BW PRODUCT = 80 GHz 2) HIGH RCVR S/N 3) LOW COST
DEVICE COUPLING NETWORKS	RESONANT CAVITY	1) STABLE 2) HIGH Q
	STRIPLINE NETWORK	1) LOW COST 2) EASY TO MANUFACTURE

SPS FIBER OPTIC TEST LINK ANALYSIS

Link margins for the proposed components, with a 1 km long fiber, are estimated in the opposite chart. For a depth of modulation of .3, an optical signal power of 1.3×10^{-6} watts is expected at the detector.

ENGINEERING TECHNOLOGY

SPS FIBER OPTIC TEST LINK ANALYSIS



ASSUME: P_T = 1 MW = 0 DBM

EMITTER COUPLING LOSS = 10 DB

CONNECTOR LOSSES = 2 x 1 DB = 2 DB

FIBER LOSS = 8 DB/KM x 1 KM = 8 DB

DETECTOR COUPLING = 2 DB

} TOTAL LOSS = 22 DB

P_S = 0 DBM - 22 DB = - 22 DBM = 6.3 μWATT

ASSUME: MODULATION DEPTH OF ILD = 0.3

RESPONSIVITY OF PHOTODIODE = 10 AMPS/WATT

RCVR NEP = 0.5 NWATT

THEN: OPTICAL RMS SIGNAL POWER AT DETECTOR = 0.3 x 0.707 x 6.3 μWATT = 1.34 μWATT

$$\text{OPTICAL POWER MARGIN} = \frac{1.34\ \mu\text{WATT}}{0.5\ \text{NWATT}} = 2.68 \times 10^3\ (\approx 35\ \text{DB})$$

FIBER ASSESSMENT RESULTS

A number of graded index fibers were investigated for applicability to the test link at 980 MHz. The properties of seven fibers investigated for this application are given, and the four types recommended for further testing are identified.

ENGINEERING TECHNOLOGY

FIBER ASSESSMENT RESULTS

BOEING AEROSPACE COMPANY

FIBER MANUFACTURER	CORNING	CORNING	TIMES WIRE & CABLE	ITT E/O PROD.	NIPPON SHEET GLASS	VALTEC	GALILEO
PRODUCT #	5101	5100	GA10-90	T-223	GI-60A	MG05	6000A-1
MINIMUM BANDWIDTH	1 GHz-Km	1 GHz-Km	300 MHz-km	400 MHz-Km	200 MHz-Km	600 MHz-km	400 MHz-Km
MAXIMUM ATTENUATION @ 820 nm	5 db/Km	5 db/Km	10 db/Km	5 db/km	10 db/Km	5 db/Km	6 db/Km
MANUFACT. TECHNIQUE	CVD-IVPO	CVD-OVPO	CVD-OVPO	CVD-IVPO	DOUBLE CRUCIBLE	CVD-IVPO	CVD-IVPO
DOPANTS	Ge,B,P	Ge,B	B	Ge,B,P	B,Ge ??	Ge,B,P	Ge,B,P
NUMERICAL APERTURE	.21	.21	.21	.21	.16(1)	.21	.21
DIAMETERS(2) (MICRONS)	63,125,138	63,125,138	90,125,200	55,125,500	60,150,900	63,125,225	63,125,230
BUFFER COATING	LACQUER OR ACRYL.	LACQUER OR ACRYL.	FLUORO-CARBON	RTV, HYTREL	RTV, NYLON	SILICONE, UV RESIN	UV RESIN
AVAILABLE ?	YES	YES	YES	YES	YES	YES	YES
CHOSEN FOR TESTS	*	*	*		*		

NOTES: (1) @ 1 km. All others measured on short lengths.

(2) Core, cladding, coating

CONTRACT EXTENSION - COMPONENT STATUS

The components required for the contract extension have all been ordered and should arrive on time for contract execution.

CONTRACT EXTENSION - COMPONENT STATUS

- JACKETED 2-FIBER CABLE SIECOR 222 SHIPMENT DATE OCT 29
  250 METER, $4.40/METER

- NEC INJECTION LASER DIODE TYPE 3205P SHIPMENT NOV26
  THERMOELECTRIC COOLER NEEDED FOR THRESHOLD STABILIZATION

- IMPROVED PHOTODIODE DETECTOR WITH LIGHTPIPE ORDERED RCA-C 30908E
  (SELECTED FOR OUR APPLICATION)

STATUS OF 980 MHz MEASUREMENTS

The one way link measurements are in progress, while the assembly of the two way link test unit is under way.

ENGINEERING TECHNOLOGY

STATUS OF 980 MHz MEASUREMENTS

- ONE WAY LINK
  - LABORATORY CIRCUIT ASSEMBLED
  - SAMPLE MEASUREMENT TO CONFIRM MODULATION FEASIBILTY IN PROGRESS
- TWO WAY LINK
  - COMPONENTS ON ORDER
  - PACKAGING FOR FINAL UNIT 50% COMPLETE

INITIAL 980 MHz LINK TESTS

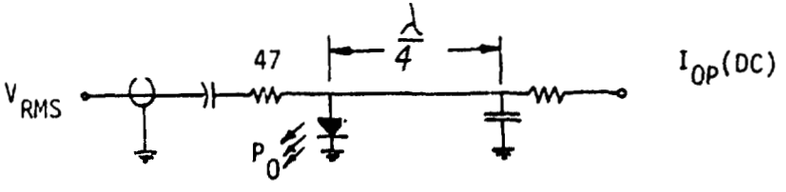
The initial results, with direct modulation of the injection laser, are shown in the attached figure. For a high output of 0.26 mwatt, the detector output through a 300 meter fiber was 19 μ watts.

ENGINEERING TECHNOLOGY

INITIAL 980 MHz LINK TESTS

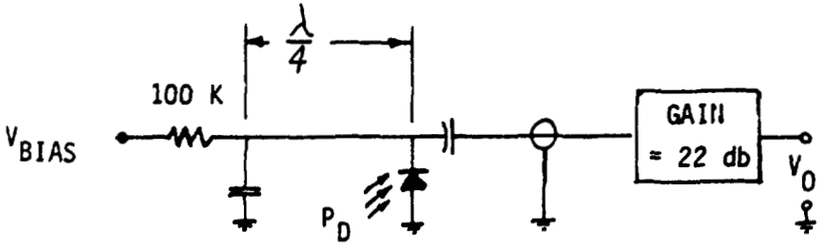
EMITTER MODULE:

- I_{THRESH} = 60 ma
- I_{OP} = 67 ma DC
- V_{MOD} = 0.7 V RMS
- P_O = 262 Watts



DETECTOR MODULE:

V_{BIAS}	185 Volts	315 Volts
V_O	71 MV RMS	283 MV RMS
P_D	19.1 Watt	19.1 Watt



FIBER: CORNING IVPO

- Length = 303 Meters
- Atten = 3.9 db/km @ 900 nm
- BW = 870 MHz-km
- N.A = 0.218

SPS SOLID STATE ANTENNA POWER COMBINER CONTRACT NAS 9-15636B

TASKS:

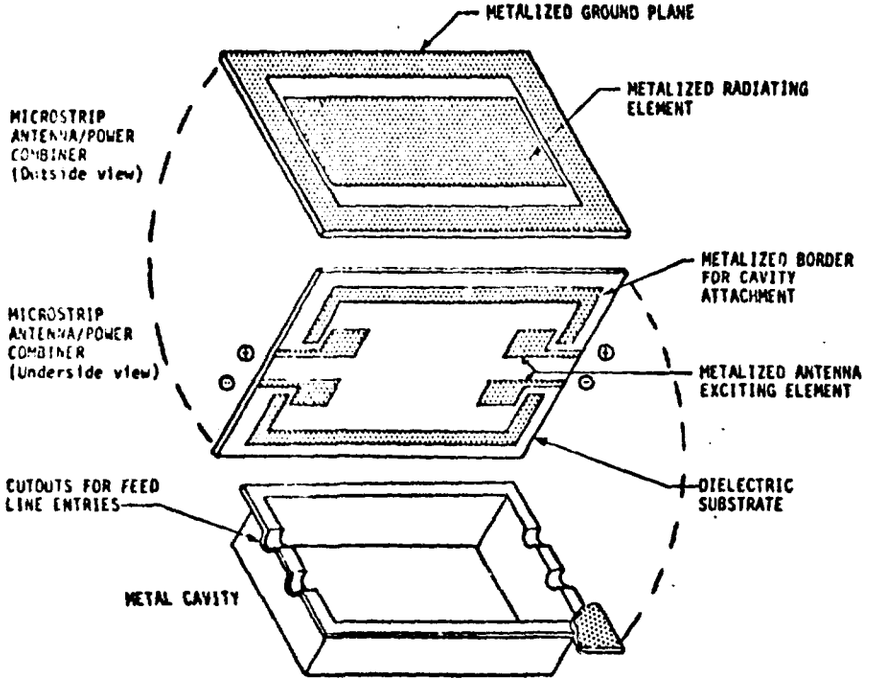
- Specify, purchase and bench test four solid state power amplifiers for adequate phase and amplitude response to verify suitability for power combiner module test.
- Incorporate four power amplifiers into a four-feed combiner module. Refine the four combining antenna design in terms of substrate size, cavity size, slot width, slot spacing and slot feed mechanism to properly match the amplifiers to the module. The designed minimum combined power output will be one-half watt.
- Demonstrate via antenna range measurement the efficiency of the power combining antenna utilizing a 0° - 180° feed system. Demonstrate via antenna range measurement the efficiency of the power combining antenna driven by the four solid-state amplifiers. Range of accuracies of approximately $\pm$ .5 dB will be applied.

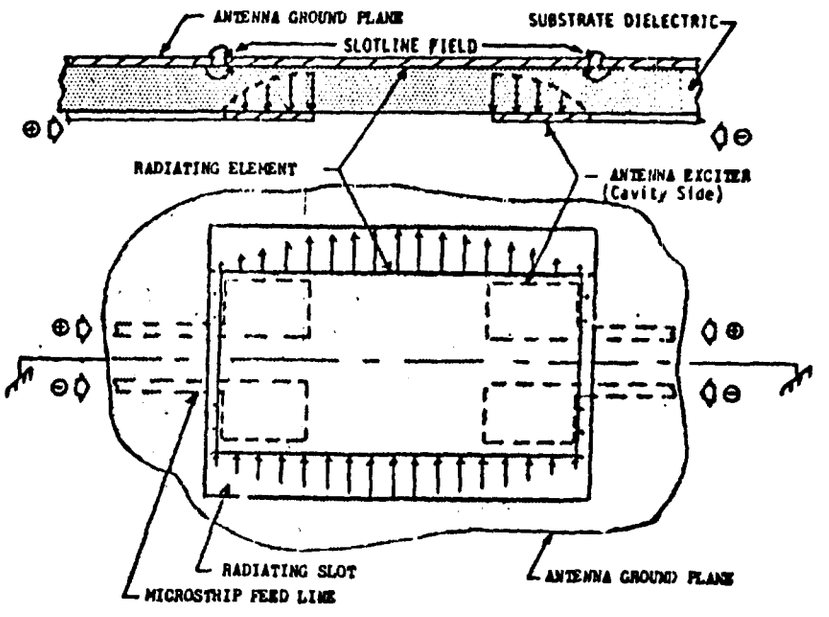
POWER COMBINING MICROSTRIP ANTENNA

The main elements of the combiner radiator module are outlined showing the radiating element, the dielectric subtrate and the baseline cavity.

POWER COMBINING MICROSTRIP ANTENNA

BOEING PROPRIETARY





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BOEING PROPRIETARY

POWER COMBINING ANTENNA TEST HARDWARE BLOCK DIAGRAM

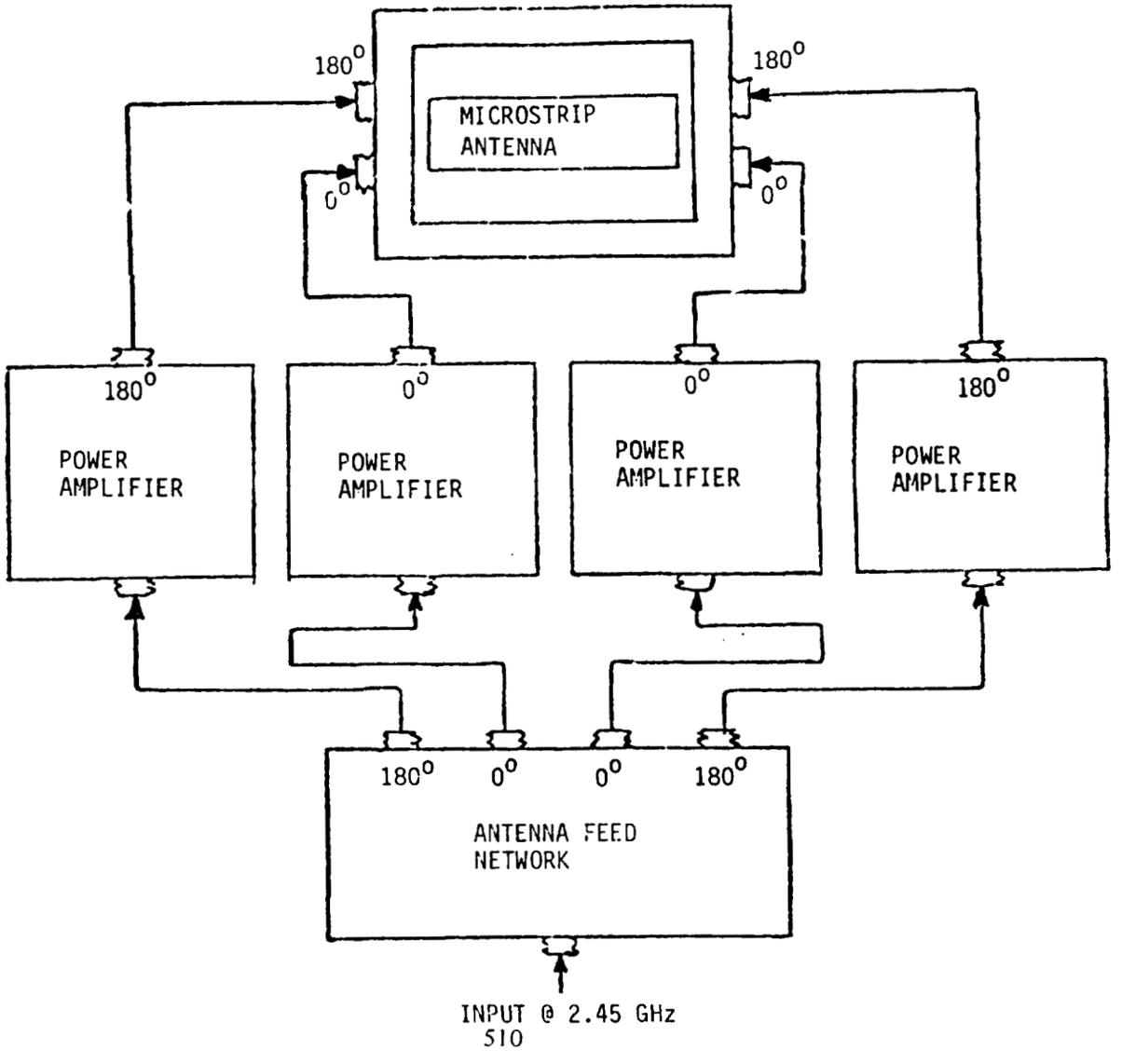
The three main elements of the antenna power combiner test setup are outlined:

(1) The precision antenna feed network

(2) The four power amplifiers (125-mw silicon bipolars)

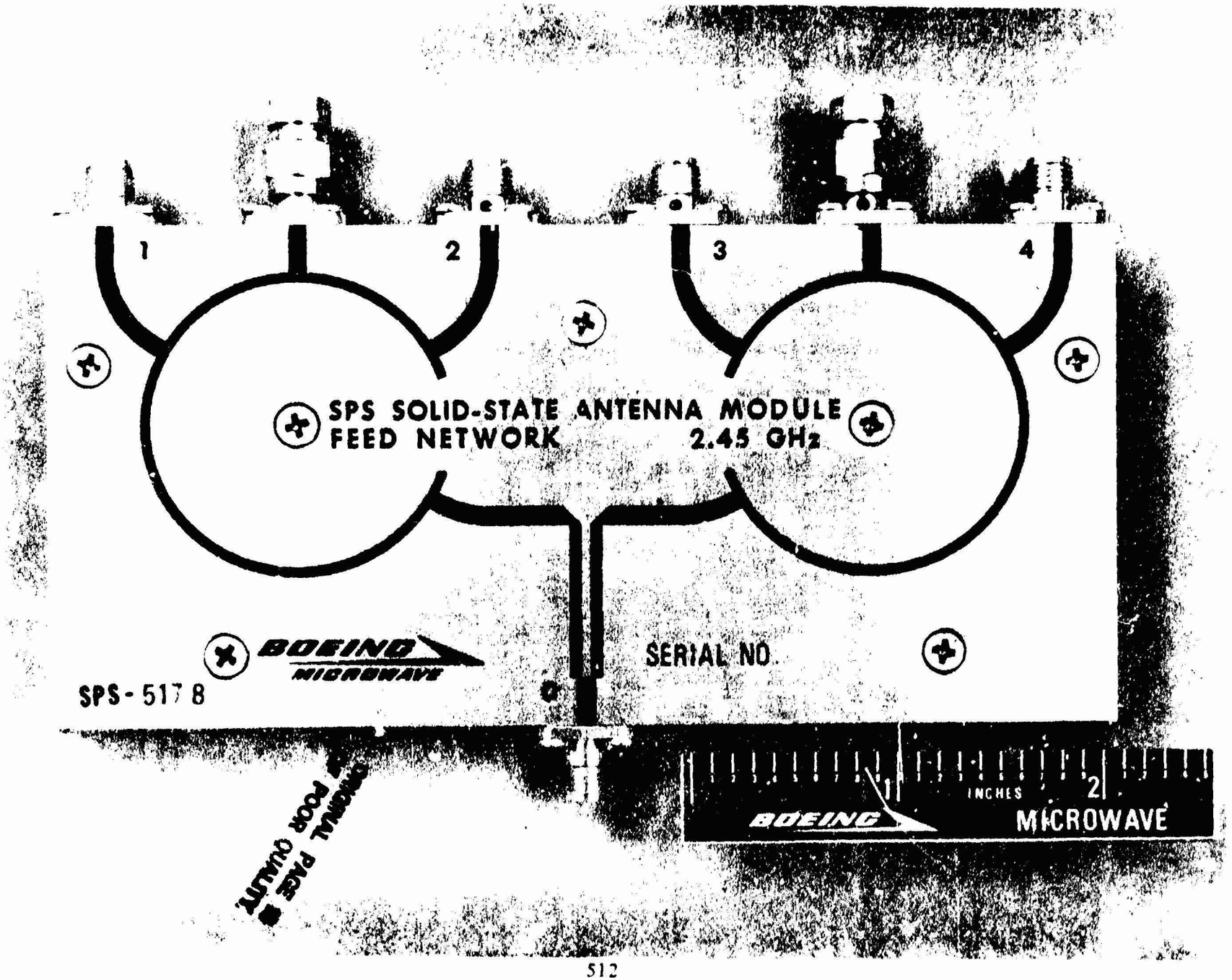
(3) The microstrip combiner-radiator antenna unit.

POWER COMBINING ANTENNA TEST HARDWARE BLOCK DIAGRAM



SOLID STATE ANTENNA MODULE FEED NETWORK

Three precision 4-way power splitters were designed and constructed on stripline to feed the four solid state power amplifiers driving the microstrip antenna/combiner module.


1
2
3
4
SPS SOLID-STATE ANTENNA MODULE
FEED NETWORK
2.45 GHz
BOEING
MICROWAVE
SERIAL NO.
SPS-517 8
INCHES
BOEING
MICROWAVE
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STRIPLINE ANTENNA FEED NETWORK SPECIFICATIONS

Measured values of phase balance, loss balance, insertion loss, and isolation for the three stripline antenna feed networks all exceed design goals.

STRIPLINE ANTENNA FEED NETWORK SPECIFICATIONS

- o ALL THREE UNITS COMPLETED AND TESTED - - - EXCELLENT PERFORMANCE
- o TWO REQUIRED FOR TESTS, ONE SPARE
- o MEASURED RESULTS:

SERIAL #	PHASE BALANCE	LOSS BALANCE	INSERTION LOSS	ISOLATION & RETURN LOSS
001	$\pm .73^0$	$\pm .03$ db	.154 db	>25 db
002	$\pm .39^0$	$\pm .03$ db	.189 db	>25 db
003	$\pm .81^0$	$\pm .015$ db	.172 db	>25 db
GOAL	$< \pm 1^0$	$< \pm .05$ db	<.2 db	>20 db

POWER AMPLIFIER STATUS

Specifications for the four custom-built and matched power amplifiers to be used in the solid state combiner/antenna tests are shown. All specifications were adequately met.

POWER AMPLIFIER STATUS

- ALL FOUR AMPLIFIERS HAVE BEEN SHIPPED (10-12-79).

- FULL POWER PHASE & GAIN MEASUREMENTS TO BE PERFORMED BY BOEING.

PARAMETER		SPECIFICATION	ACHIEVED (FROM NOTES TAKEN BY TELEPHONE)
FREQUENCY		2.45GHz	2.45GHz
GAIN		6 dB MIN.	7.8 dB
VSWR	IN:	2.5:1	2.5:1
	OUT:	1.5:1	1.6:1
GAIN MATCH		± .5 dB	NIL
PHASE MATCH		$\pm 5^{o}$	NIL
PHASE CONTROL ADJUSTMENT		$\pm 10^{o}$	$\pm 2^{o}$
INFINITE VSWR		DEMONSTRATE AT FULL POWER	O K
POWER OUTPUT		1/8 WATT MIN.	> 1/8 WATT

PART 4-PHASE 2
FINAL REVIEW

SOLAR POWER SATELLITE

GENERAL ELECTRIC
SPACE DIVISION

SUMMARY OF SPS SYSTEM DEFINITION STUDY
PART 4 ACCOMPLISHMENTS

In Part 4-Phase 1 General Electric performed a study of the microwave phase control system layout consisting of four layers called: SECTOR, GROUP, UNIT & SUBARRAY. Next a microwave power transmission failure mode analysis and microwave power transmission maintenance requirements analysis was performed. It was found that the SPS system is more reliable than present power generation systems. A rectenna construction and power distribution analysis was used to develop the cost of the ground system at about $2 Billion.

Part 4 - Phase 2 of the study, which we are presenting today, General Electric has developed a Satellite-Rectenna-Utility Grid Integration and Operations Analysis as well as Technology Advancements of the Phase Control System and the Rectenna.

GENERAL ELECTRIC

SUMMARY OF SPS SYSTEM DEFINITION STUDY PART 4 ACCOMPLISHMENTS

space division

- PHASE CONTROL SYSTEM LAYOUT
- MICROWAVE POWER TRANSMISSION FAILURE MODE ANALYSIS
- MICROWAVE POWER TRANSMISSION MAINTENANCE REQUIREMENTS
- RECTENNA POWER CONDITIONING
- RECTENNA CONSTRUCTION ANALYSIS
- SATELLITE-RECTENNA-UTILITY GRID INTEGRATION AND OPERATION ANALYSIS
- TECHNOLOGY ADVANCEMENT REQUIREMENTS OF PHASE CONTROL AND RECTENNA

SPACE ANTENNA DC POWER DISTRIBUTION AND RF REFERENCE PHASE DISTRIBUTION SYSTEM SUMMARY

The following is a summary of the study performed on the Space Antenna Phase control system and distribution.

This work is more fully described in Part 4 - Phase 1 presentation held in March 1979 at JSC.

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SPACE ANTENNA DC POWER DISTRIBUTION AND RF REFERENCE PHASE DISTRIBUTION SYSTEM

space division

SUMMARY

- DC DISTRIBUTION IS USING 228 MAIN SECTOR LINES AND AN AVERAGE OF 446 KLYSTRON LINES ATTACHED TO EACH SECTOR LINE.
- DC TO DC CONVERTERS MUST BE REDUNDANT FOR ACCEPTABLE DC POWER AVAILABILITY.
- FOUR LAYER REFERENCE PHASE DISTRIBUTION NETWORK IS USED WITH 20, 19 AND 19 BRANCHES AT THE CONSECUTIVE NODES (SECTOR, GROUP, SUBARRAY, KLYSTRON). THE POWER DIVISION AT THE LAST (KLYSTRON) LEVEL IS DETERMINED BY THE NUMBER OF KLYSTRONS PER SUBARRAY.
- THE PHASE DISTRIBUTION AND CONJUGATION PROCESS IS COMPLETELY SEPARATED.
- TRIPLE REDUNDANCY IS USED IN THE FIRST AND DOUBLE REDUNDANCY IN THE SECOND LAYER OF THE PHASE DISTRIBUTION TREE.
- THE ELECTRONIC CIRCUIT CONCEPT IS AS PER RECOMMENDATIONS OF THE LINCON REPORT.

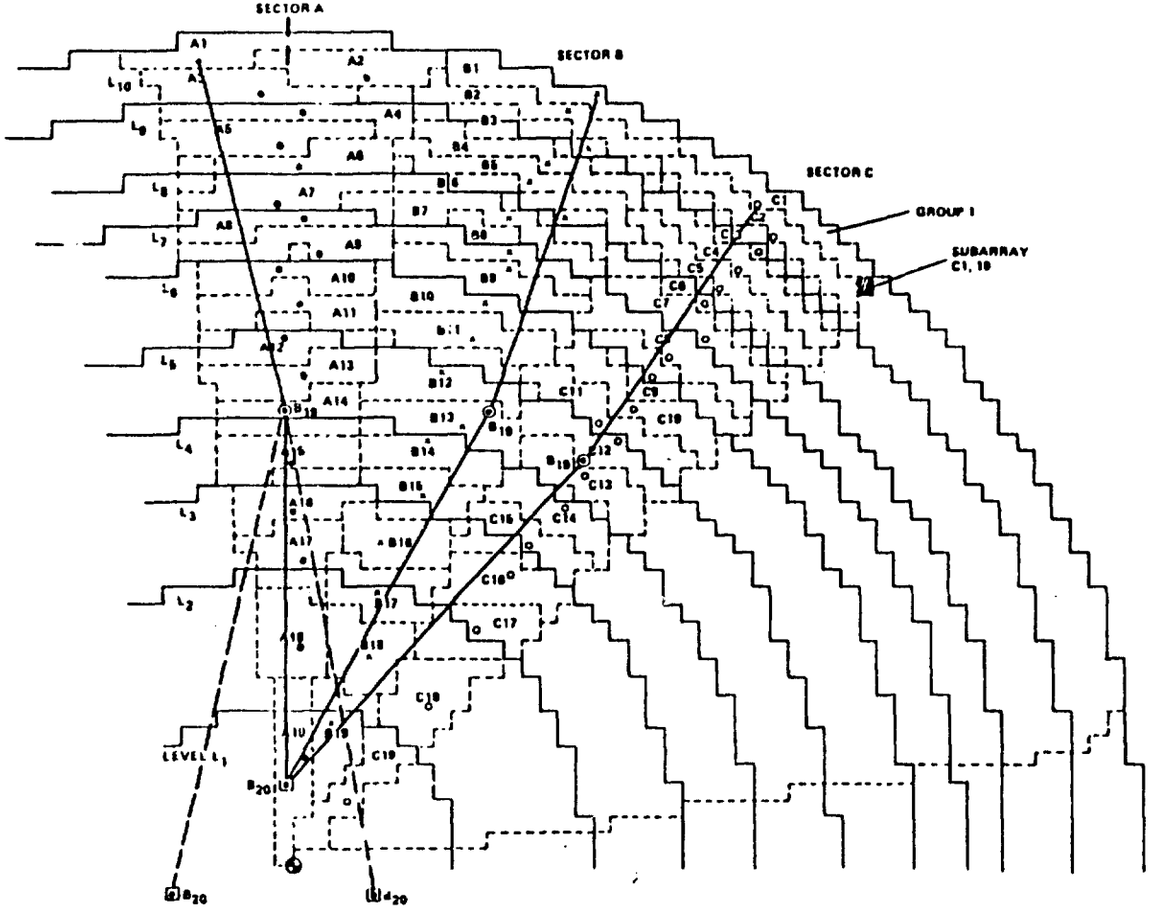
LOCATION OF REFERENCED PHASE REPEATER STATIONS OF SECTORS AND GROUPS

The figure shows the layout of the reference phase distribution network and the location of the phase repeater stations. The phase distribution network is a four layer tree. The first, second and third layers have 20, 19 and 19 way power dividers respectively at the nodes of the network. The first layer is called sector, the second group, the third unit, the fourth subarray. The power dividers at the fourth layer correspond to the number of klystrons carried by the subarray.

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LOCATION OF REFERENCED PHASE REPEATER STATIONS OF SECTORS AND GROUPS

space division



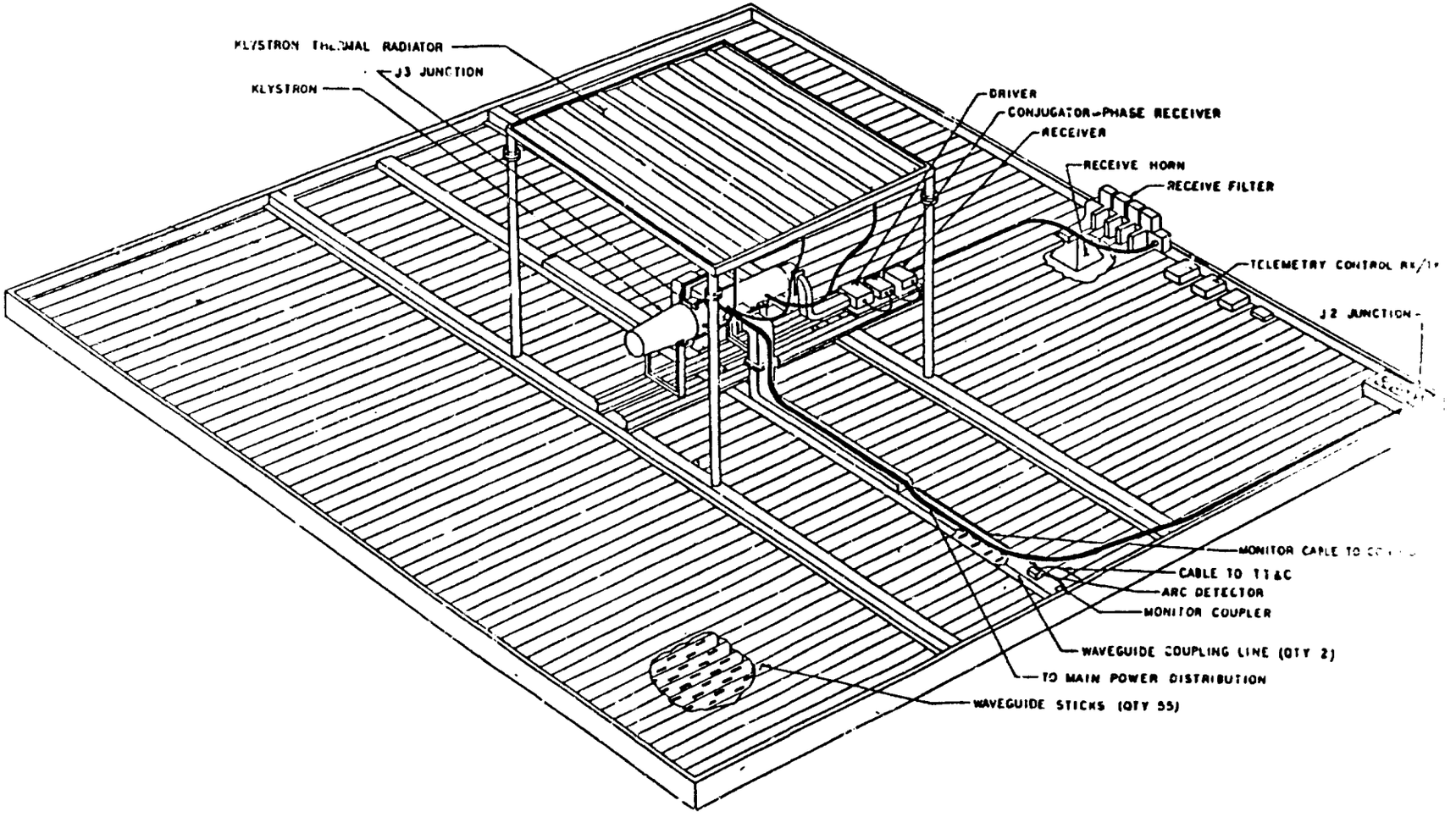
MECHANICAL LAYOUT OF A TYPICAL KLYSTRON MODULE IN THE OUTER RING OF THE SPACE ANTENNA

The figure shows the conceptual layout of all the components which are related to a "klystron" module of the space antenna. The example shown is for a subarray, at the edge of the antenna, which carry a total of four klystrons.

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MECHANICAL LAYOUT OF A TYPICAL KLYSTRON MODULE IN THE OUTER RING OF THE SPACE ANTENNA

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FAILURE MODES AND EFFECTS ANALYSIS

The failure modes and their effects was analyzed for the power transmission system between the elevation flexible joint on the spacecraft to the utility interface on the ground. The summary presents some of the most important results.

GENERAL ELECTRIC

FAILURE MODES AND EFFECTS ANALYSIS SUMMARY

space division

- WITH CONVERTER REDUNDANCY THE SPACE ANTENNA DC SYSTEM HAS A MEAN AVAILABILITY OF APPROXIMATELY 99.5%.
- THE PHASE CONTROL SYSTEM MEAN AVAILABILITY IS 99%. THIS CAN BE IMPROVED IF THE FOURTH LAYER IS DUPLICATED, BUT THE COST PENALTY IS VERY LARGE. ANOTHER POTENTIAL IMPROVEMENT IN AVAILABILITY (AND COST) MAY BE POSSIBLE BY OMITTING THE FOURTH LAYER ALTOGETHER.
- THE MEAN AVAILABILITY OF THE KLYSTRON AND ITS DRIVER IS 97.45% WITH 20 YEAR LIFETIME TUBE AND HALF YEARLY MAINTENANCE. POWER LOSS CAN BE CUT BY NEARLY A FACTOR OF TWO IF QUARTER YEARLY MAINTENANCE IS IMPLEMENTED.
- COMBINED EFFECTS OF RANDOM ERRORS IN THE APERTURE DISTRIBUTION AND LOSSES IN THE PROPAGATION MEDIA ARE COMPARABLE TO THAT OF THE KLYSTRONS.
- MEAN AVAILABILITY ASSOCIATED WITH DIODE FAILURES IS APPROXIMATELY 99.45%, ASSUMING NO DIODE OR PANEL RELATED MAINTENANCE.
- THE RESULTANT DC POWER COLLECTION SYSTEM CAN HAVE A MEAN AVAILABILITY OF 98.4%.
- THE RESULTANT AC POWER COLLECTION SYSTEM MEAN AVAILABILITY IS 99.7%.
- RESULTANT SYSTEM EQUIPMENT AVAILABILITY BETWEEN ELEVATION FLEXIBLE JOINTS AND UTILITY GRID IS APPROXIMATELY 90%, POWER AVAILABILITY IS HIGHER THAN 86%.
- NUMBER OF POTENTIAL AREAS WERE DETECTED WHERE AVAILABILITY IMPROVEMENT CAN BE IMPLEMENTED IN COST EFFECTIVE MANNER.

SUMMARY OF EQUIPMENT AND POWER AVAILABILITY CALCULATIONS

The table summarizes the equipment availability and AC power to utility grid availability on the account of the analyzed part of the SPS system. Input interface is at the output of a flexible DC cable on space antenna, output interface is at input to utility grid. All effects which cause statistical variation of availability (failures, errors, propagation) are included. Some of the major assumptions:

- Space antenna DC to DC converter is redundant.
- Phase control uses four layer tree, down to klystron level, only first and second layers are redundant.
- Nonredundant, 20 year lifetime klystrons are used. (This is a factor of ten better than state-of-the-art).
- Random phase and amplitude errors of space antenna are the same as calculated in Part III Study.
- Elevation angle toward satellite is 55°.
- Diode failure rate is .02 per million hrs. Diode is not refurbished for 30 years. (Failure rate is a factor of two better than state-of-the-art).
- Critical components in AC power collection system are redundant, rest are covered by on-site spares.
- Space antenna is refurbished within 84 hrs biyearly periods.
- No power Recovery is assumed when a failure occurs in space antenna aperture segment related to items (1), (2) or (3) in table.

Note that with power recovery methods the power availability (85.85% mean value) can be improved to the equipment availability (90.12% mean value).

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SUMMARY OF EQUIPMENT AND POWER AVAILABILITY CALCULATIONS

space division

$P^{\%}$	10	66	80	90	99	99.9	99.99
Hrs/Year	7889	2980	1753.2	876.6	87.66	8.766	.8766
A. Space Antenna	97.75	93.20	91.56	89.59	84.12	78.62	71.28
1 DC Distribution	100.00	99.50	99.22	98.95	98.00	97.00	95.95
2 Phase Control	99.84	98.92	98.44	97.83	96.10	94.40	91.30
3 Klystron	98.90	97.50	97.02	96.55	95.48	94.58	93.60
4 Random Phase	99.40	98.50	98.20	97.82	96.80	95.75	94.80
5 Random Amp.	99.60	98.60	98.40	98.00	96.65	94.90	91.70
B. Propagation	99.05	98.54	98.28	97.84	96.24	94.17	91.77
6 Attenuation	99.05	98.62	98.40	98.10	96.90	95.20	93.15
7 Faraday Rotation	100.00	99.92	99.98	99.74	99.32	98.92	98.52
C. Rectenna	98.38	98.13	97.61	97.03	95.06	92.96	87.65
8 DC power Collection	99.38	98.45	98.15	97.81	97.00	96.38	95.80
9 AC Power Collection	100.00	99.68	99.45	99.20	98.00	96.45	91.50
Total Power Transmission System Equipment Availability	96.22	90.12	87.78	84.99	76.96	68.88	57.33
Power Availability at Power Grid Interface Relative to Equipment Without Failure	95.00	85.85	83.19	79.43	69.20	59.65	47.01

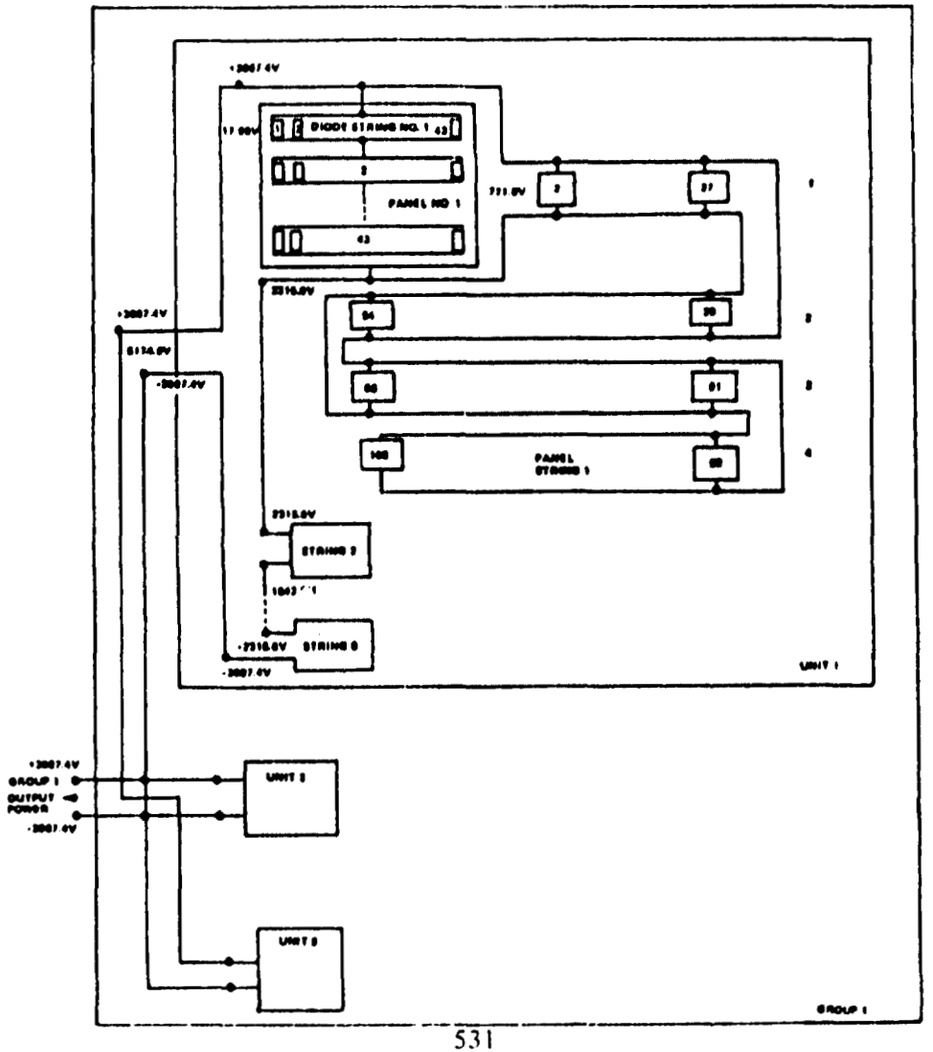
BLOCK DIAGRAM OF A TYPICAL LOW VOLTAGE RECTENNA GROUP (GROUP 1, RING 1)

The figure shows the block diagram from diodes to "groups" of the rectenna for Group 1 of Ring 1. (Example shows a group close to the center of the rectenna.)

GENERAL ELECTRIC

BLOCK DIAGRAM OF A TYPICAL LOW VOLTAGE RECTANNA GROUP (GROUP 1, RING 1)

space division



RECTENNA POWER CONDITIONING

The rectenna power conditioning network from input aperture plane to utility grid interface was developed conceptually including detailed geometry and conductor sizes. The summary displays some of the most important results.

GENERAL ELECTRIC

RECTENNA POWER CONDITIONING SUMMARY

space division

- MECHANICAL AND ELECTRICAL LAYOUT OF A TYPICAL RECTENNA WAS DEVELOPED FOR A TEXAS SITE.
- THE FOLLOWING COMPONENTS ARE DISTINGUISHED: DIPOLE, ARRAY, PANEL, UNIT, GROUP.
- A LOW VOLTAGE AND A LOW CURRENT DESIGN WAS CONCEIVED, THE LOW VOLTAGE, USING MAX. 3 KV (NOMINAL) WAS SELECTED AS THE BASELINE.
- FOUR DIFFERENT TYPES OF PANELS AND SEVEN DIFFERENTLY WIRES UNITS ARE NECESSARY TO FORM THE OVERALL NETWORK.
- ALL PANEL DIMENSIONS ARE IDENTICAL (3 M X 3.33 M) AND THE NS DIMENSIONS OF ALL UNITS ARE EQUAL (117.18 M).
- MOST OF THE LOSS IS IN THE PANEL WIRING, MOST OF THE WEIGHT IN THE UNIT LINES. USING ALUMINUM CONDUCTORS TOTAL NETWORK LOSS IS 1.39% AND TOTAL NETWORK WEIGHT IS 225,490 METRIC TONS.
- HIGH VOLTAGE DESIGN CAN CONSIDERABLY REDUCE THE NECESSARY WEIGHT OF CONDUCTORS, BUT IT INCREASES THE WEIGHT OF INSULATORS.
- LOSS IN THE AC SYSTEM IS APPROXIMATELY 1.5%.

MAINTENANCE REQUIREMENTS SUMMARY

This is a summary of the microwave system space and ground segment maintenance requirements.

This work is more fully described in Part 4 - Phase 1 presentation held in March 1979 at JSC.

GENERAL ELECTRIC

MAINTENANCE REQUIREMENTS SUMMARY

space division

- SPACE ANTENNA MAINTENANCE HOURS FOR 2 MAN CREWS, PER BIYEARLY CYCLES

DC DISTRIBUTION	281.2
RF REFERENCE PHASE DISTRIBUTION	680.5
KLYSTRONS	2544
TOTAL CREW HOURS PER REPAIR CYCLE	3506.3
TOTAL MAN HOURS PER REPAIR CYCLE	7012.7
TOTAL MAN HOURS PER YEAR	14025.4

- RECTENNA DC PER YEAR 5762.5

- RECTENNA AC PER YEAR 69457

- THE MANPOWER REQUIREMENT IS EQUIVALENT TO APPROXIMATELY SEVEN MAN YEARS PER YEAR IN SPACE (ON THE AVERAGE) AND 64 MAN YEARS PER YEAR ON THE GROUND FOR 5 GW SPS SYSTEM.

CHARACTERISTICS OF AVAILABLE POWER VARIATION IN THE SPS SYSTEM

THE TABLE SHOWS 12 RECOGNIZED SOURCES FOR DYNAMIC POWER VARIATION IN THE SPS SYSTEM. AMONG THE LISTED SOURCES NO. 1 AND NO. 2 CAUSES SCHEDULED DOWN TIMES OF 1.36% AND 1% RESPECTIVELY. THE REMAINING EFFECTS ARE SMALL AND ESSENTIALLY RANDOM. TOTAL ENERGY LOSS IS LESS THAN 2.7% PER YEAR IF SHUT DOWN AND START UP TIMES ASSOCIATED WITH ECLIPSES ARE ALSO CONSIDERED. ONLY SOURCE NO. 1 AND NO. 2 CAN CAUSE TOTAL LOSS OF POWER.

GENERAL ELECTRIC

CHARACTERISTICS OF AVAILABLE POWER VARIATION IN SPS SYSTEM

space division

NO.	SOURCE OF POWER VARIATION	RANGE %	FREQUENCY OF OCCURENCE PER YEAR	AV. DURATION OF OUTAGE PER OCCURRENCE MIN/YEAR	TOTAL OUTAGE HR./YEAR	MAX. POWER REDUCTION GW	AV. YEARLY ENERGY LOSS GW HR.	TIME TO MAX POWER LOSS	SCHEDULED YES	SCHEDULED NO
1.	SPACECRAFT MAINTENANCE	0-100	2	2 x 3600	120	5	600	6 MIN	X	
2.	ECLIPSE	0-100	62	[illegible]6 TOTAL 7 [illegible]AX PER/ OCCURRENCE	56.26	5	281.3	1 MIN	X	
	ECLIPSE WITH SHUTDOWN AND STARTUP			5270	87.8		439	1 MIN	X	
3.	WIND STORM	75-100	0.01	5260	87.6	1.25	109.5	5 MIN		X
4.	EARTHQUAKE	90-100	0.01	1800	30	0.5	15	10 SEC		X
5.	FIRE IN RECTENNA SYSTEM	80-100	0.01	840	14	1	14	30 MIN		X
6.	METEORITE HIT OF SPACECRAFT EQUIPMENT	90-100	0.01	1200	20	0.5	10	100 MS		X
7.	RECTENNA EQUIPMENT FAILURE	91.5-100	1	50	0.833	0.425	0.35	100 MS		X
8.	PRECIPITATION	93.3-100	50	1	0.833	0.335	0.28	1 M		X
9.	POINTING ERROR	94.8-100	5000	0.6	0.833	0.29	0.24	1 S		
10.	IONOSPHERE	98.5-100	20	10	3.32	0.15	0.24	1 S	X	
11.	GROUND CONTROL EQUIPMENT FAILURE	95-100	5	3	0.25	0.25	0.06	0.3 S		X
12.	AIRCRAFT SHADOW	99.99-100	20	20 M 1 M MAX/ OCCURENCE	0.3	0.0005	0.0015	1 S		X

TOTAL			
	WITHOUT SHUTDOWN/STARTUP:	331 HR (3.77%)	1039.8 (2.35%)
	WITH SHUTDOWN; /STARTUP:	362 HR (4.12%)	1188.5 (2.71%)

VARIOUS METHODS TO REDUCE POWER INTO RECTENNA

THE TABLE SHOWS 7 METHODS TO CONTROL THE POWER INPUT INTO THE RECETENNA. REDUCTION OF POWER TO ZERO WILL REQUIRE MAXIMUM .45 SEC. THE VARIOUS METHODS HAVE DIFFERENT NOISE ENVIRONMENTAL EFFECTS.

GENERAL ELECTRIC

VARIOUS METHODS TO REDUCE POWER INPUT TO RECTENNA

space division

METHOD	EFFECT ON LIFETIME	RANGE OF POWER	TIME DELAY	ON	OFF	WHERE THE POWER GOES	ENERGY REQUIREMENT
1. REDUCE KLYSTRON BEAM VOLTAGE	SMALL	100-80	300 MS	X		THERMAL RADIATION ON SPACECRAFT	NONE
2. INTRODUCE QUADRATIC PHASE ERROR TO ANTENNA APERTURE	NONE	100-50	300 MS	X		INCREASES POWER AROUND RECTENNA. (~ 14 KM)	NONE
3. RANDOMIZE ANTENNA PHASES	NONE	100-0	450 MS	X		INTO 1000 KM DIA. FOOT-PRINT	NONE
4. TILT OF ANTENNA PHASE	NONE	100-0	1 SEC.	X		OFF EARTH	NONE
5. TILT OF ANTENNA	MODERATE	100-0	216 S	X		OFF EARTH	MODERATE
6. DISCONNECT KLYSTRON RINGS		100-0	3 S		X	AROUND RECTENNA	NONE
7. TILT SOLAR ARRAY AND 6	LIFE OF SLIP RING	100-0	131 MIN.		X	TO UNIVERSE	LARGE

AVAILABLE SPS POWER TO UTILITY GRID

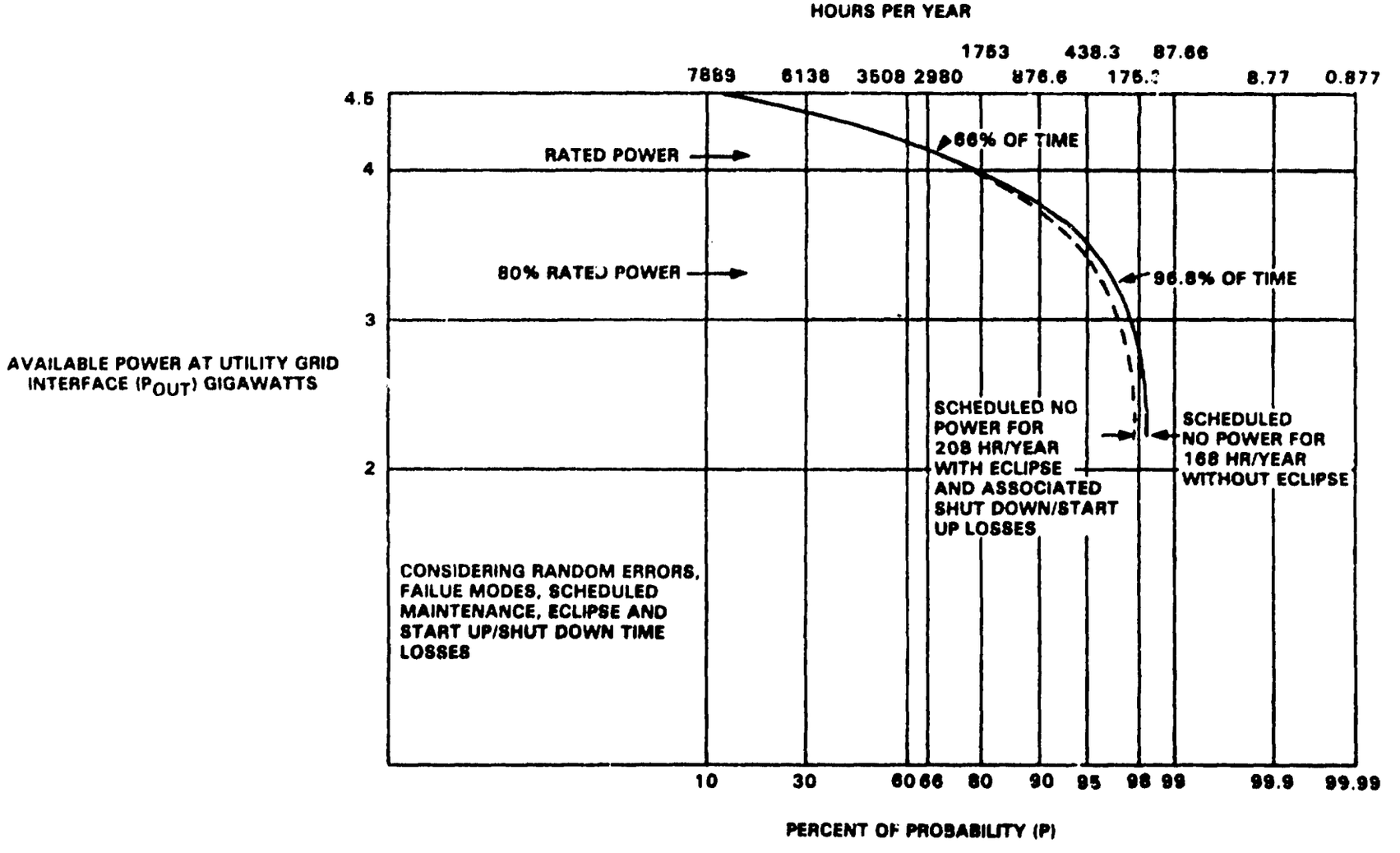
CHART SHOWS AVAILABLE SPS POWER TO UTILITY GRID CONSIDERING RANDOM ERRORS, FAILURE MODES, SCHEDULED MAINTENANCE AND ECLIPSE, INCLUDING SHUT DOWN AND START UP TIMES. TOTAL SYSTEM DOWN TIME IS 207.8 HOUR PER YEAR (2.37%).

GENERAL ELECTRIC

AVAILABLE SPS POWER TO UTILITY GRID

CONSIDERING RANDOM ERRORS AND FAILURE MODES, SCHEDULED MAINTENANCE, ECLIPSE AND START UP/SHUT DOWN TIME LOSSES

space division



TECHNOLOGY DEVELOPMENT TASKS FOR SPACE ANTENNA AND ASSOCIATED MICROWAVE TRANSMISSION SYSTEM

THE SUMMARY TABLE LISTS THE MOST IMPORTANT AREAS OF CONCERN IN THE SPACE SEGMENT OF THE MICROWAVE TRANSMISSION SYSTEM, EXCLUDING THE RECEIVER-CONJUGATOR-TRANSMITTER SYSTEM, WHICH IS COVERED ELSEWHERE. THE KEY QUESTIONS FOR THESE COMPONENTS OR SUBSYSTEMS ARE RELATED TO DEVELOPMENT RISK, ACCURACY, LOSS, WEIGHT, AVAILABILITY AND LIFETIME.

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TECHNOLOGY DEVELOPMENT TASKS FOR SPACE ANTENNA AND ASSOCIATED MICROWAVE TRANSMISSION SYSTEM

space division

NO.	DESCRIPTION	DURATION (WORK DAYS)	NON-RESOURCE COST (EXCLUDING FLIGHT EXP) (K$)
1	LINE SOURCES (W.G. STICK) AND ASSOCIATED W.G. POWER DIVIDER CIRCUIT ELEMENTS	1250	600
2	RF DIXPLEXER	1000	250
3	IF DIPLEXER	750	250
4	. HASE DISTRIBUTION CABLE	650	170
5	MONITOR/CONTROL NETWORK	500	500
6	PHASE COMPUTING PHASE CONTROL SYSTEM	700	400
7	PILOT TRANSMIT STATION	400	200

TECHNOLOGY DEVELOPMENT TASKS FOR RECTENNA

THE SUMMARY TABLE LISTS THE MOST IMPORTANT AREAS OF CONCERN IN THE GROUND SEGMENT OF THE MICROWAVE TRANSMISSION SYSTEM. THE KEY QUESTIONS FOR THESE COMPONENTS OR SUBSYSTEMS ARE RELATED TO RF/DC CONVERSION EFFICIENCY, FABRICABILITY, COST, WEATHER EFFECTS, ENVIRONMENTAL IMPACT, DYNAMIC LOAD HANDLING.

GENERAL ELECTRIC

TECHNOLOGY DEVELOPMENT TASKS FOR RECTENNA

space division

NO.	DESCRIPTION	DURATION (WORK DAYS)	NON-RESOURCE COST (K$)
1	RECTENNA ELEMENTS FOR 4 DIFFERENT EFFECTIVE RECEIVE AREA VALUES	700	650
2	CONTROL OF EDGE OF PANEL DIFFRACTION METHODS	350	280
3	LOAD HANDLING TECHNOLOGY, TRANSIENTS, THERMAL/VOLTAGE HANDLING	100	80
4	SHORT TERM POWER STORAGE TECHNOLOGY	100	60
5	MODELING AND CONTROLLING RERADIATION IN THE FREQUENCY SPECTRUM	400	320
6	CONTROL AND MONITOR TECHNOLOGY	150	80
7	WEATHER PROTECTION TECHNOLOGY	250	140
8	PANEL FABRICATION AND INSTALLATION TECHNOLOGY	200	100 (WITHOUT PILOT FAB.)

SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Subarray	How many line source types are needed? How many power divider/combiner types are necessary? What electrical, mechanical, thermal characteristics are achievable? What are the material, fabrication, packaging, assembly problems? What tolerances are necessary and achievable? Is there a long term aging problem? What frequency band, power handling limitation exists? What industrial facilities are needed for production What rates are achievable?	Achievable transmission efficiency, reliability, weight, production rate, cost. May need material development. Interface with structure, power amplifiers. Could influence practical bandwidth, frequency plan, ultimate No. of SPS's, lifetime. Could influence PA design.	All SPS's using planar array transmit antennas.	1. Continue system level studies 011103019	500	100K		2.1
					2. Design, fab and test all necessary types. 010304019	750	500K	011103029 010305019 SS100	1.1.2 4.1.1 1.3:0.5 4.2.2 3.2.0.5 2.1:0.5 2.1:0.5 10.5:0.5 3.4:1 3.5:2 1.4:2 3.1:1
					3. Test modules in space environment. 010304019	750	10M		

NOTES

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FS - finish-to-start

(4) Resources are defined in resources library.
Values are headcount for each type.

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AA designates program phase:
01 = ground-based research;
02 = research flight tests.
BB designates technical area, e.g., solar arrays
CC designates subject; e.g., silicon solar cells
DD designates task #
E designates priority, 0-9 with 9 highest.

SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	RF diplexer	How many types are needed? What isolation is practical? Separate or common receive aperture? What bandwidth is desirable? How it impacts weight, loss, isolation, stability, aging, temperature range? How many cavities? What types? Where should the diplexer be located? What material? Fabrication, alignment methods? Installation, verification methods?	Achievable transmission efficiency, reliability, production rate, weight, cost. May need material development. Impacts receiver design, ground pilot power. Interface with subarray.	All SPS's.	1. Continue system level studies. 011103019	500	50K		2.1
					1. Design fab and test a number of basic types. 010304019	500	200K	011103029	1.6

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SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	IF diplexer	How many IF? What is optimum frequency plan? What is separation between tones? What frequency band? What is optimum loss, isolation, match? What is the effect of temperature? Where should be located?? What is diplexer contribution to phase distributing system errors? What is optimum implementation configuration?	Frequency plan, modulation technique, power levels, errors in phase distribution system.	All SPS's that use microwave power transmission	1. Continue system level studies. 01110301$	250	50K		
					2. Design, build and test diplexers. 01030401$	500	200K		

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SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Phase distribution cable.	What type? What is optimum loss-weight tradeoff point? Temperature effect? Aging? Differential expansion between center and outer conductor? Is redundancy needed? What failure modes exist? How to install? How to check? Is acceptable type available or needs new development?	Effects phase distribution tree layout, redundancy, reliability, levels in network, phase errors.	All SPS's that have microwave power transmission.	1. Continue system level studies.	250	20K		
					2. Implement simulation for applicable environmental conditions.	400	150K		

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SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmissior	Monitor control network.	Which are the key characteristics to monitor? How frequently? What accuracy? How much on-board processing? How much ground processing? What control strategy should be adapted? What is data volume? What telemetry system should be used? (Frequency, bandwidth, modulation, power.)	Determines required telemetry capacity. Influences availability, power transmission efficiency, maintenance requirements, maintenance procedures.	All SPS's.	System design.	500	500K		

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SPS RESEARCH PLANNING . TAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	SK AND TWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Phase computing phase control system	Is it feasible? How it compares to baseline? Is its speed adequate? Where is accuracy-speed-cost tradeofff optimum? What is band-width requirement? What is reliability? Impact on maintenance, cost, power, consumption, weight? What is optimum architecture? What new technologies are needed?	Cost, accuracy, development requirement, maintenance, weight.	All SPS's.	1. Analyze and optimize phase computing system.	500	300K		
					2. Simulate operation by computer model.	200	100K		

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SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Pilot transmit station.	How many antenna locations? What is optimum antenna size-transmit power trade-off? How many transmitters? What phase and amplitude control? What modulation? Bandwidth? Control-monitor requirements? What is optimum location? Redundancy?	Selection may effect phase control system design. Affects achievable accuracy, risk, development cost.	All retro-directive SPS's.	1. Develop system design. 2. Develop specifications.	400	200K		

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SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Rectenna elements	How many type of rectenna elements and how many type of rectifier elements should be used? If one type of rectifier is optimum is 4 different rectenna element adequate? What is optimum receive area size for each element? What is optimum physical configuration electrically, mechanically cost and fabricability point of view? What is achievable RF to DC conversion efficiency for optimum designs as a function of power level, incoming angle, temperature range, weather effects and aging? What is reliability of optimum element?	Rectenna size, complexity, cost, production schedule. is determined by element. Rectenna efficiency/cost ratio is affected in a major way and SPS produced energy per cost significantly by element design. Fabrication methods are influenced by element design in a major way. Sensitivity to weather will be affected. Rectenna generated r-f noise may be influenced by circuit attached to elements.	All SPS's employing microwave power transmission.	1. Conduct theoretical study which is addressing all the key questions.	200	150K	010310029 SS100 011103019	1.1:0.5 1.2:0.5 1.3:0.5 1.4:1 1.7:0.5
					2. Breadboard at least 4 different receive area rectenna element as they are needed for overall rectenna layout. Verify theoretical predictions on elements. 3. Construct typical rectenna panels of each of the 4 basic types. Utilize these modules to verify fabrication concepts. Conduct RF tests on each panel types to verify efficiency, reradiation, etc. characteristics.	500	500K	011103029	1.1:1 1.3:1 1.4:2 1.7:0.5 3.1:1 3.2:1 3.4:1 3.5:1 4.1:1 4.2:1 4.7:0.5

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SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Rectenna panel edge diffraction	How much diffraction around the edge of rectenna panels influences the operation of the rectenna? Has the panel size significant influence? What is the effect on efficiency, lifetime of diodes? Can edge effects controlled so that overall efficiency is improved?	Diffraction affects rectenna efficiency. Its control may effect panel design and fabrication methods.	All SPS's employing microwave power transmission	1. Develope theoretical radiation model and trade-off curves showing relationship between panel geometries and net efficiency.	100	60K	010310029 011103019	
					2. Utilize rectenna panels to verify edge diffraction affects on current distribution in rectifiers and achievable efficiency.	250	200K	011103029	

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SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Load handling of rectenna	What is dynamic behavior of rectenna during variations of input power or output load? What limits of power changes and rate of changes are expected, for what reasons? What is tolerable? What control actions are necessary? What protection circuits? What typical scenarios are expected to control input or output loads? What monitor and control elements must be implemented? Who is responsible for control? What will be the environmental impact of input and output power variation?	Operation of the SPS system and its utility interface is affected, operational strategies are determined. Cost of energy unit is affected through amount of lost power and cost of necessary control and safety devices. Radiation of SPS during periods of power control outside rectenna may have effect on environment, communication. Dynamic power variation may generate new forms of energy usage relative to forms we know today.	All SPS's employing microwave power transmission.	1. Develop theoretical models for various load variation scenarios. 2. Implement computer simulation of dynamic behavior of the system covering radiation characteristics, current and voltage transient characteristics in rectenna and output power transient behavior. 1. Implement experimental model on which load variations, circuit protection methods can be studied.	100	60R	010310029 011103019	1.1:0.5 1.3:0.5 1.4:1

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SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Short term energy storage	Is short term energy storage desirable to reduce effects of input or output power load fluctuation? What is the desirable storage capacity? What is best design approach and cost? How storage capacity should be integrated with rectenna, how can it be controlled?	Can reduce necessary control speeds of SPS, reduce environmental impact, increase safety, improve quality of service. May complicate rectenna design. Can improve lifetime of components.	All SPS's employing microwave power transmission.	1. Analyse requirements, design and use of short term energy storage system and determine its usefulness.	100	60K	010310079	

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SPS RESEARCH PLANNING DETAILED WORKSHEET

SUB PROGRAM	SUBJECT	KEY QUESTIONS	IMPLICATIONS	APPLIC ABILITY	TASK AND NETWORK NO.	DURATION (WORK DAYS)	NON-RESOURCE COST	TASKS FED AND LAGS	RESOURCES
Power transmission	Rectenna reradiation	What is the level of rectenna power reradiation as a function of angle, frequency, failure and polarization? Is this level environmentally harmful? Can it be controlled by rectenna design, site selection, R-F fence around rectenna? If control is necessary and feasible what is the impact on rectenna efficiency, cost? What is reradiation behavior during transient and failure conditions? What is reradiation with rain, snow or ice load conditions?	Could effect environmental acceptability of SPS. Could effect site selection, control meth ds, may have significant cost impact.	All SPS's employing microwave power transmission.	1. Determine answers to key questions on the basis of theoretical models.	200	120K	010310029	
					2. Study rain and snow and ice conditions for efficiency and reradiation behavior of rectenna panel.	200	200K	011103029	

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Power transmission	Control monitor of rectenna.	What rectenna characteristics shall be monitored and controlled, how many points, how frequently? How the control-monitor system looks like, what is optimum implementation? What frequency band and bandwidth is necessary for data collection? How much data processing capacity is needed? How data will be used.	Affects rectenna design, operation, efficiency, reliability.	All SPS's employing microwave power transmission.	1 Develop control monitor system concept, basic characteristics and cost estimate.	150	80K	0103100029	

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Power transmission	Weather protection of rectenna	How weather is affecting rectenna design, lifetime, operation and cost? Will site selection have major impact? Is deicing necessary or practical for certain sites? Can SPS power be used for deicing? What is cost tradeoff for external power deicing methods? How efficiency varies as a function of weather? Is this a major contribution to average efficiency? Is "radome" type of protection of element necessary, desirable, practical, economical?	Weather protection of rectenna will influence receive element and panel design and cost. Cost of weather protection must be traded off against longer transmission lines. Weather effects may influence site selection.	All SPS's employing microwave power transmission.	1. Analyse weather effects and develop necessary protection schemes.	250	140K	D10310029	

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Power transmission	Rectenna panel fabrication and installation	What is optimum configuration for the various type of receive elements? What is optimum material selection, how can production, test and installation be automated? Is any new material necessary? What new fabrication, installation test equipment has to be developed?	Fabrication technology has major impact on cost, schedule, material resources.	All SPS's employing microwave power transmission	1. Develop alternative fabrication concepts.	200	100K	0101100029	1.8 1.9
					2. Implement pilot fabrication on a reasonably scale to verify producibility and cost assumptions.	750	10M		1.8 1.9 3.1 3.4 3.5 4.1 4.2 4.3 4.4

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EUSED TASKS IN PHASE II

- Satellite/Rectenna/Utility System Operating Characteristics
  - Start-up and Shutdown
  - Daily Operation
  - Emergency Conditions
  - Necessary Design Modifications
- SPS/Utility System Reliability/Availability
  - SPS Forced Outage Model
  - SPS Planned Outage Model
  - Impacts of SPS Availability on Utility System Reliability

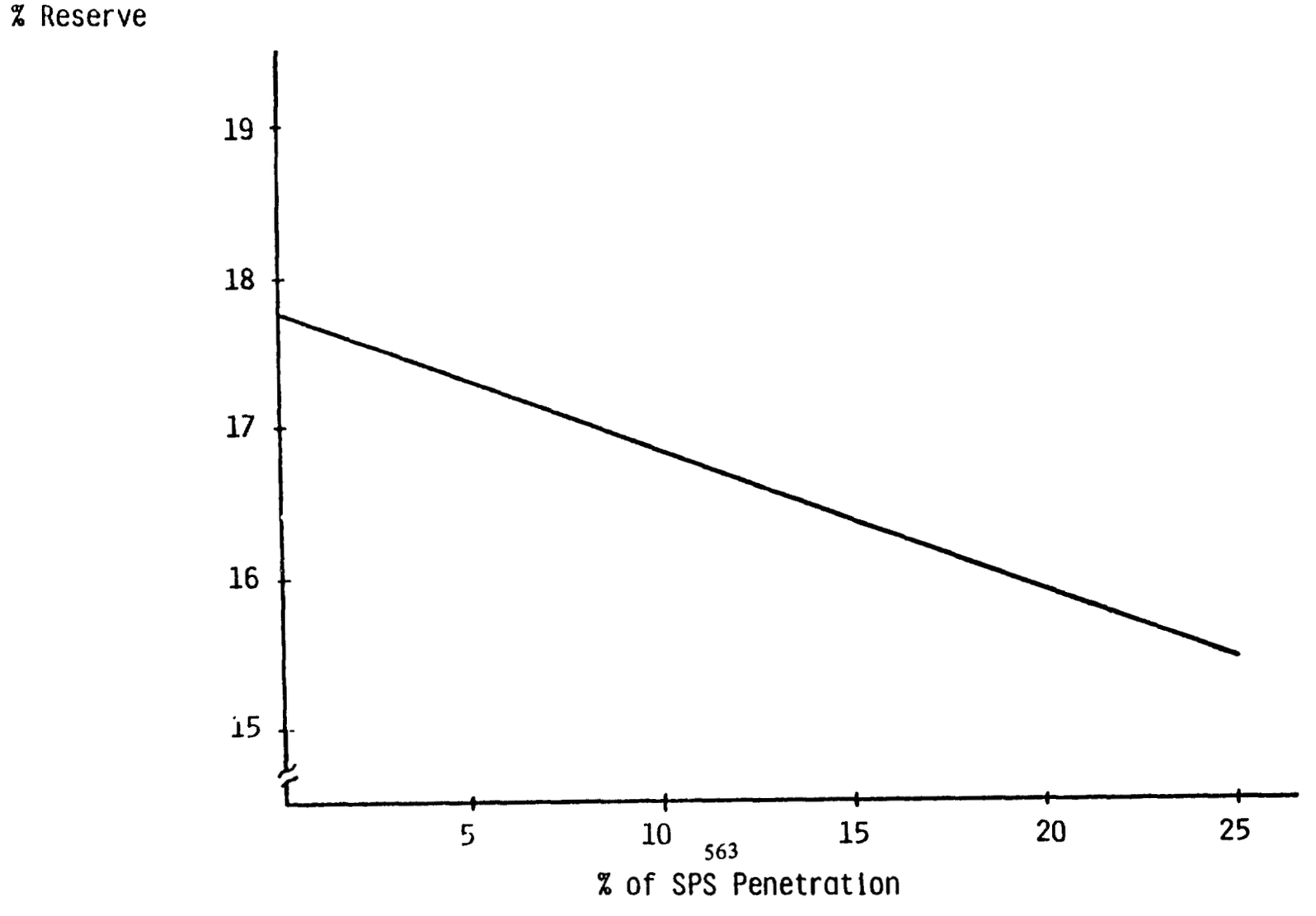
SUMMARY OF MID-TERM REVIEW MEETING

SPS OPERATING CHARACTERISTICS

- 50% Excursion in Output Over .3 Seconds
- 100% Excursion in Output Over 1.0 Seconds

Compares Very Favorably With Conventional Generating Units. These Characteristics Are Indicative of Technical Capability. No Environmental Impacts Are Considered.

SPS Forced Outage Rate Impacts on Utility System Reserve Margin



SUMMARY OF MID-TERM REVIEW MEETING

SPS Scheduled Maintenance

- SPS Maintenance During Eclipse Period in September Could Increase Utility Reserve Levels

- For Moderate SPS Penetration Levels, i.e., 15-20% of Total Generation Capability, No Impact Was Found on Reserve Levels

INTEGRATION OF SPS WITH UTILITY SYSTEMS

New Work Performed After Mid-Term:

- SPS/Rectenna Inverter Control Methods
- Startup, Shutdown, Emergency Operations
- Utility System/SPS Control Considerations
- Parametric Investigation of Reliability Impacts
- Maintenance Scheduling
- Areas of Concern and Need For Further Work

CONDITIONS AND ASSUMPTIONS

It is expected that the Rectenna system will function at optimum efficiency with a fixed load impedance which does not vary with load level. This impedance will be a function of rectenna design.

It is assumed that the SPS system will operate at maximum available power level unless the utility system is not able to accept the power. In that case the power will be controlled at the space station under remote control.

The synchronous condensers provide stable sine wave voltage, short circuit capability and AC voltage regulation as required by the DC/AC converters. They will also supply reactive current required by converter or the AC system.

Filters on the AC bus will absorb harmonic currents generated by the DC/AC conversion process.

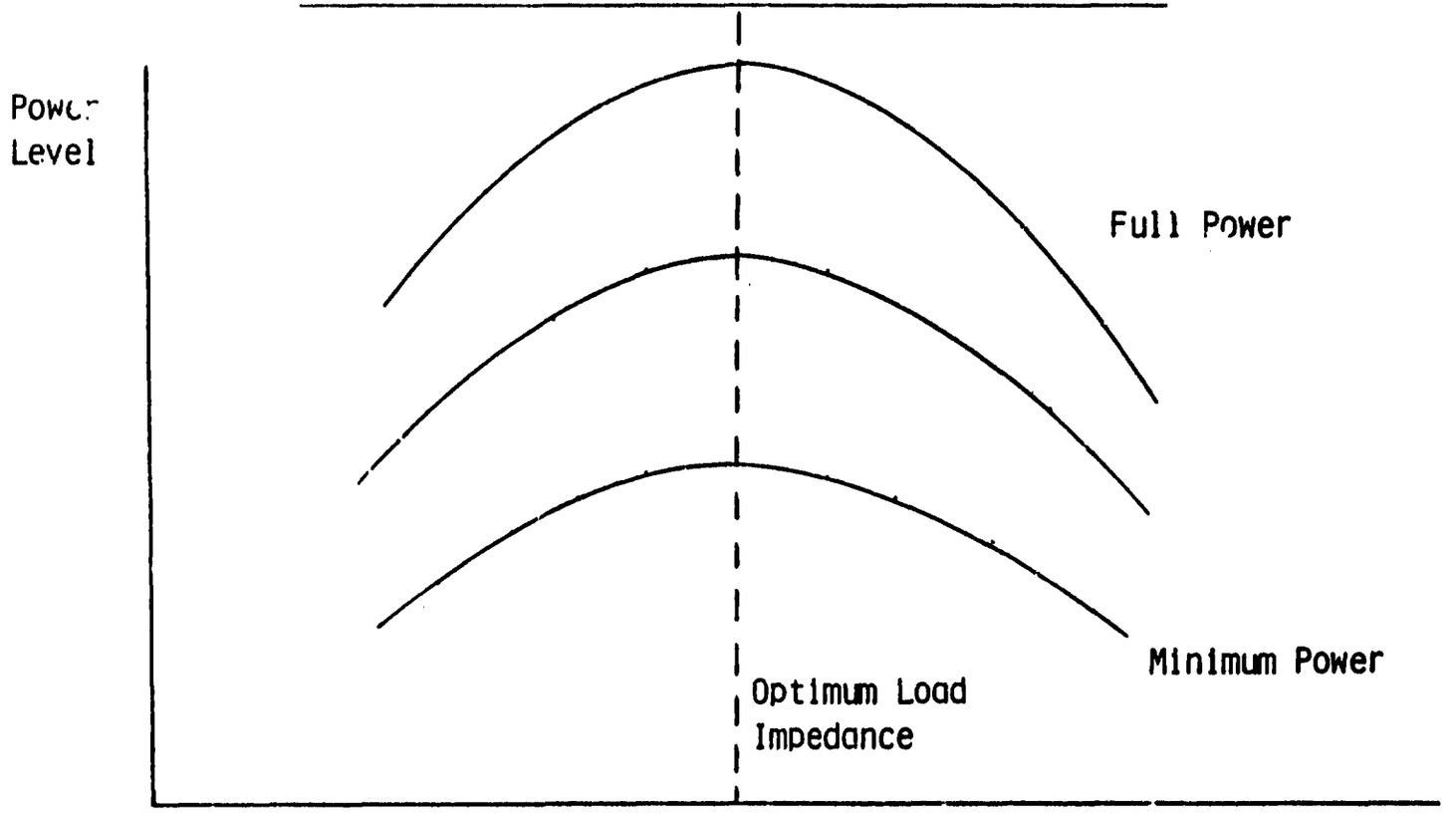
CONDITIONS AND ASSUMPTIONS

- Rectennas Require Constant Load Impedance
- Primary Power Control at Space Station
- Synchronous Condensers Control AC System Voltage
- Filters Absorb Converter Harmonic Currents

ASSUMED CHARACTERISTIC CURVES OF RECTENNA SYSTEM POWER OUT VS. LOAD IMPEDANCE FOR SEVERAL CONSTANT LEVELS OF RADIATION

The anticipated conceptual characteristic curves for rectenna system power output vs. the rectenna load impedance is shown in this figure. These characteristics are assumed, but there is no difficulty in programming the inverters to follow the actual rectenna characteristics to allow maximum efficiency.

ASSUMED CHARACTERISTIC CURVES OF RECTENNA SYSTEM
POWER OUT VS. LOAD IMPEDANCE FOR
SEVERAL CONSTANT LEVELS OF RADIATION



STEADY STATE OPERATION

Rectenna voltage and current are sensed, voltage is divided by currents to give impedance and this value of impedance is compared to a reference. The error becomes the control signal to the regulator which determines the firing angle of the line-commutated, current-fed thyristor converter. This will result in extraction of maximum available power from the rectenna system.

Power level of the system is determined by the klystrons in the space station, in response to signals from the central control station, which receives its directions from the Utility Central Dispatch Facility.

The excitation systems of the synchronous condensers are set up to regulate the voltage of the utility AC bus. This is accomplished by generation or absorption of reactive power as required.

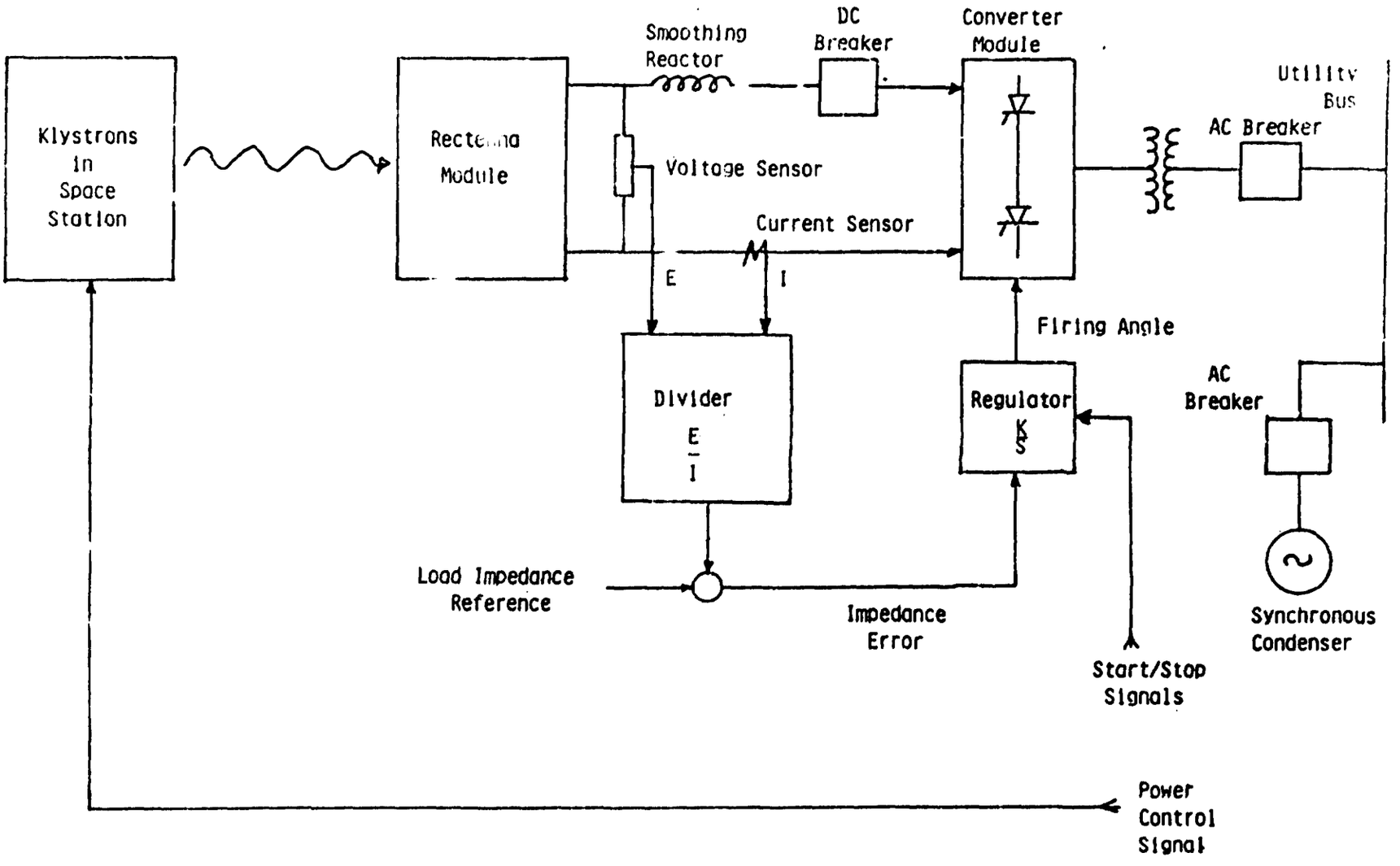
STEADY STATE OPERATION

- Load Impedance Control Loop
- Remote Control of Power Level Through Klystrons
- AC System Voltage Control by Synchronous Condensers

SATELLITE/RECTENNA/UTILITY CONTROL SCHEME

This schematic indicates the necessary control functions for the reccenna inverters, and indicates the SPS and utility system control interface.

SATELLITE/RECTENNA/UTILITY CONTROL SCHEME



START-UP

The following is the sequence for a normal startup of the system.

1. Start synchronous condensers and synchronize them to the AC buses.
2. Close converter AC breakers.
3. Close converter DC breakers.
4. Set klystrons to a start level such as 10% power. Rectenna modules are in crowbar state and all power is reflected.
5. Upon signal from the central control station and under control of an automatic sequence the converter modules are started in sequence. Momentarily the converter voltage is a reverse polarity if this is needed to remove the rectenna from the crowbar state. The automatic converter control brings effective load impedance to its optimum value.
6. Rate of energization of modules will be determined by ability of the utility systems to absorb power increase. When all modules have been energized to the 10% power level, signal is given to the klystrons to go to predetermined level at predetermined rate. Converter modules will follow automatically.

START-UP

- Start Synchronous Condensers
- Close Breakers
- Set Klystrons to Start Level
- Sequential Energization of Converter Modules
- Power Increased to Predetermined Level by Klystron Control

NORMAL SHUTDOWN

Normal shutdown will be essentially the inverse of the startup sequence.

1. Reduce output of klystrons under direction of central control station. Rate of decrease will be determined by requirements of the utility and will depend upon ability of other generation in the system to take up the load.

2. When minimum power level is reached the converter modules will be de-energized according to a predetermined automatic sequence. It is expected that de-energization will be accomplished by opening of the DC circuit breaker accompanied by automatic crowbar of the associated rectennas.

3. Shut off excitation signals to converter and open AC breakers.

4 When all converter modules are de-energized, reduce klystron output to zero by remote control from central control station.

NORMAL SHUTDOWN

- Reduce Klystron Power to Start Level
- Sequentially De-energize Converter Modules
- Shut Off Converter Control - Open Breakers
- De-energize Klystrons

RECTENNA/UTILITY INTERFACE DURING SYSTEM DISTURBANCES

The various disturbances and faults conceived to be affecting the operation of the rectenna is shown in this chart and will be discussed further in the following.

RECTENNA/UTILITY INTERFACE DURING SYSTEM DISTURBANCES

Disturbances May be Divided Into Different Categories as Follows:

1. AC Transmission System Fault
2. Rectenna/Converter/AC Cable Fault
3. Klystron System Fault
4. Semi-Annual Series of Eclipse

AC TRANSMISSION SYSTEM FAULTS

These faults consist of voltage reductions on one or more phases of the AC system which may be up to 100% reduction. They are temporary in nature, being cleared by AC breakers. Usual fault duration is 5 cycles or less, unless primary circuit breaker fails and fault is cleared by back-up protection. In this case fault may persist for 20 cycles.

The AC system fault will often cause a converter to become a short circuit as a result of a commutation failure. In this case the associated DC breaker must be opened automatically and the rectennas feeding it will automatically crowbar.

An automatic restart sequence will reclose the DC breaker and re-energize the converter control which will take the rectennas out of crowbar state and return the module to its operating point. It is important that this reclosure occur promptly when the AC system fault is finished in order to limit the disturbance to the AC systems.

Such automatic restart is presently utilized in HVDC power transmission systems.

AC TRANSMISSION SYSTEM FAULTS

- 5 to 25 Cycles Duration - Reclosable
- Converters Automatically Trip Off
- Automatic Reclosure and Restart

RECTENNA-CONVERTER-AC CABLE FAULT

These faults comprise a group which directly affect a converter module and which are permanent in nature.

It is recommended that a system be provided to initiate converter module shutdown when its associated rectenna systems has lost voltage below some minimum expected value. It may be a result of a fault and should be treated as such. Of course nothing can be done about such a situation without shutdown of the complete RF system.

The converter will be protected by a differential relay system which will detect current flow in any but the normal path. This will cause the DC breaker to open followed by the AC side breaker. There will be no automatic restart for such faults.

The AC power from converter modules will be fed to substation by underground cable where voltage will be stepped up for further transmission by overhead line. The cables, if faulted, will be permanent faults with no reclosure.

All of these faults will reduce total SPS net output but will cause no widespread disturbances other than re-radiation of power from rectennas whose crowbar has activated.

RECTENNA-CONVERTER-AC CABLE FAULT

- Permanent Faults
- Likely No Repair Until Satellite Power Shutdown
- These Faults Will Cause Degradation of SPS Output

SPACE ANTENNA SYSTEM FAULT

Any fault or malfunction of the space antenna systems will not be detected by the rectenna-converter system. The only result will be the tracking of the automatic impedance matching system as available power decreases. If the power should decrease below some level such as 5 or 10%, an automatically initiated normal shutdown might be desirable.

Restart from such a condition would be a normal start-up as previously described.

SEMI-ANNUAL ECLIPSE

If the power system can cope with the rate of power change resulting from the eclipse, the automatic systems can be left to themselves. If not, the power should be reduced gradually in advance of the eclipse by signal from the Central Control Station to the space station. Likewise, when the eclipse is past, power level is returned to normal using the normal start-up sequence and ramp rates. The performance of the SPS system under eclipse conditions will be very much a function of the particular AC system configuration.

SPACE ANTENNA SYSTEM FAULTS AND ECLIPSE

- The Rectenna-Converter System Will Follow the Power Levels Coming In

- Restart Will Follow Normal Startup Sequence

GRAPHICAL REPRESENTATION OF ALTERNATING CURRENT QUANTITIES

In the analysis of a-c electrical systems, the angular relationships or phase angles among the voltages and currents are required. The use of phasors for graphical representation assists in understanding and analysis.

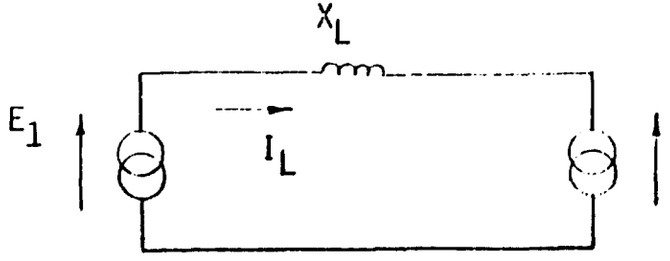
Consider the simple a-c circuit in (A), with the relationship between the two voltages and the current expressed in the phasor equation below. If $\tilde{E}_1 = \tilde{E}_2$ (magnitude equal and coincident in phase) no current will flow ($\tilde{I}_L = 0$) and the equation is satisfied.

If $|\tilde{E}_1| > |\tilde{E}_2|$ (magnitudes different but still coincident in phase, as shown in (B)), a current I_L will flow through the reactance X_L. The phase angle of $\tilde{I}_L$ will lag the voltage drop across the reactance X_L ($\tilde{E}_1 - \tilde{E}_2$) by 90°. Note that with current and voltage in quadrature, no real power flows, only reactive power or VARS.

To transfer real power (Watts) across the reactance requires an angular difference between the voltages $\tilde{E}_1$ and $\tilde{E}_2$ as shown in (C). Now the current I_L has a component in phase with the voltage and there is real power flow.

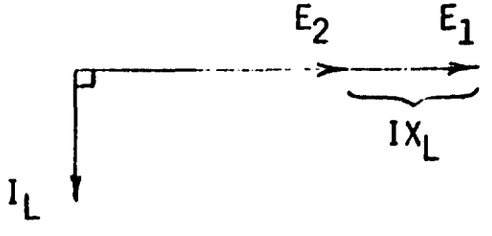
GRAPHICAL REPRESENTATION OF ALTERNATING CURRENT QUANTITIES

(A)



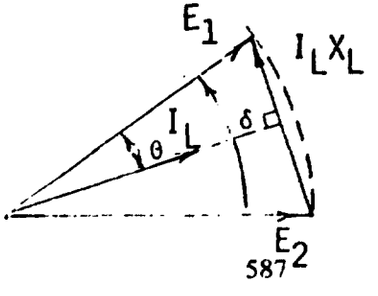
$$\tilde{E}_1 = \tilde{I}_L jX_L + \tilde{E}_2$$

(B)



$$P_{12} = \frac{E_1 E_2}{X_L} \sin\delta$$

(C)



$$P_1 = E_1 I_L \cos\theta$$

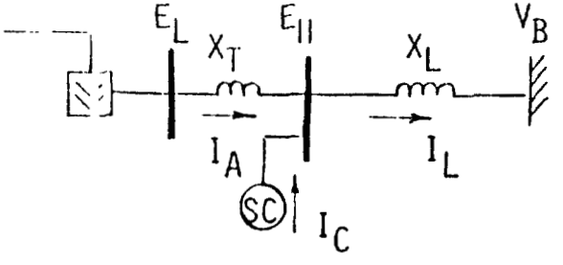
587

SPS/UTILITY SYSTEM INTERFACE SIMPLIFIED ANALYSIS

The proposed interface between the SPS ground system and an electric utility may be represented by the simple one-line diagram of (A). Power is transmitted across a transmission line to the system which is represented by an infinite bus. The synchronous condenser is operated with a field regulator to control the voltage on its bus and therefore the flow of reactive power, Q, (Vars) in the system.

For a particular real power flow, determined by the inverter firing angle control, the relationships among the voltages and currents is illustrated by the phasor diagram of (B). This is a graphical presentation of the phasor equations above.

SPS/UTILITY SYSTEM INTERFACE SIMPLIFIED ANALYSIS



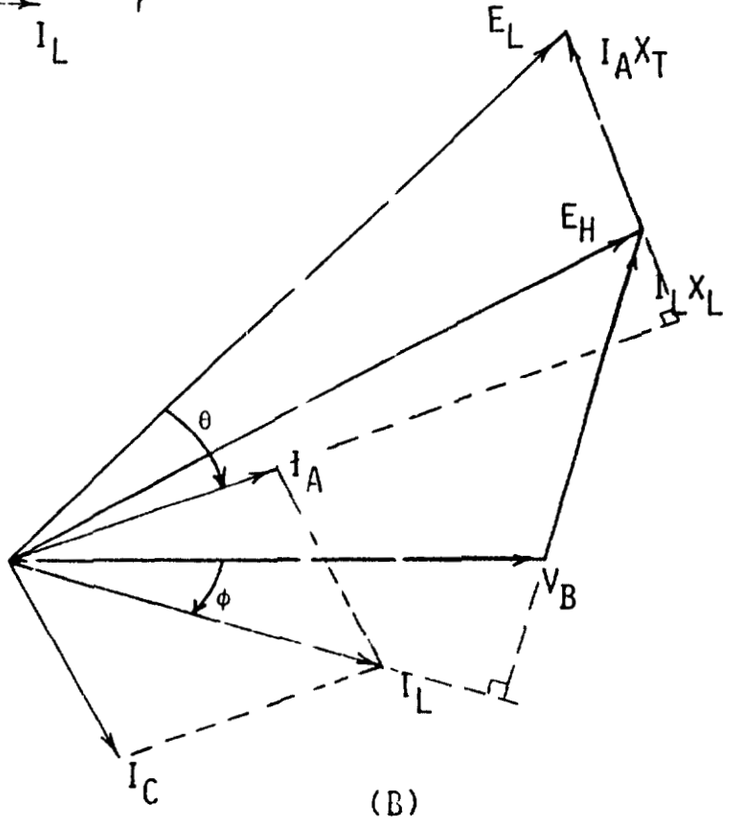
(A)

$$\tilde{E}_L = \tilde{V}_B + \tilde{I}_L jX_L + \tilde{I}_A jX_T$$

$$\tilde{I}_L = \tilde{I}_A + \tilde{I}_C$$

θ is p.f. angle at inverter

ϕ is p.f. angle at infinite bus



(B)

EFFECT OF SPS POWER OUTPUT VARIATIONS

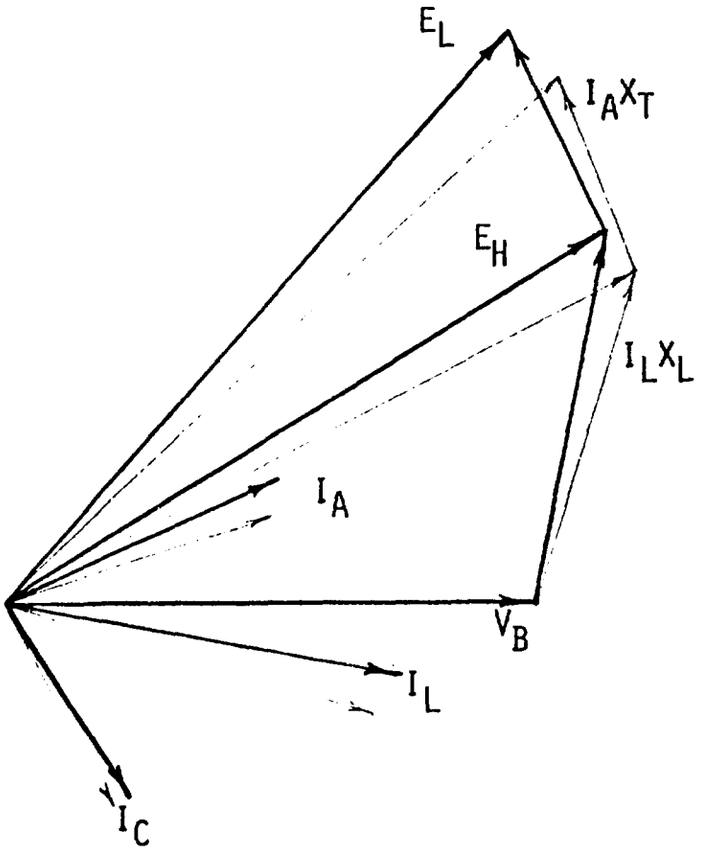
If the energy capture by the rectenna increases, the inverter will be controlled to transfer greater power to the utility system over the transmission tie.

An increase in the a-c current from the inverter, I_A, causes changes in the magnitudes and angular relationships of currents and voltages (except where constrained). This is shown in the new phasor diagram, here superimposed on the prior diagram.

(Magnitude and phase of an infinite bus are fixed; synchronous condenser bus voltage is unchanged in magnitude.)

Note that there is no change in mechanical power levels involved here. No finite rotating masses to accelerate or decelerate. The change is solely an electromagnetic transient measured in milliseconds.

EFFECT OF SPS POWER OUTPUT VARIATIONS



AUTOMATIC GENERATION CONTROL (AGC)

Automatic Generation Control (AGC) with the Economic Dispatch function is used to augment the system operator's capabilities to assure satisfactory operation of the power system.

AGC acts to regulate the power output of the electric generators within the control area in response to system frequency and tie-line power flows so as to maintain the scheduled system frequency, and the established net power interchanges within prescribed limits.

The economic dispatch function acts through the AGC function to adjust the output levels of individual generating units to achieve maximum economy of system operation, taking into account the cost of unit operation, transmission system losses, and current operating constraints.

AUTOMATIC GENERATION CONTROL (AGC)

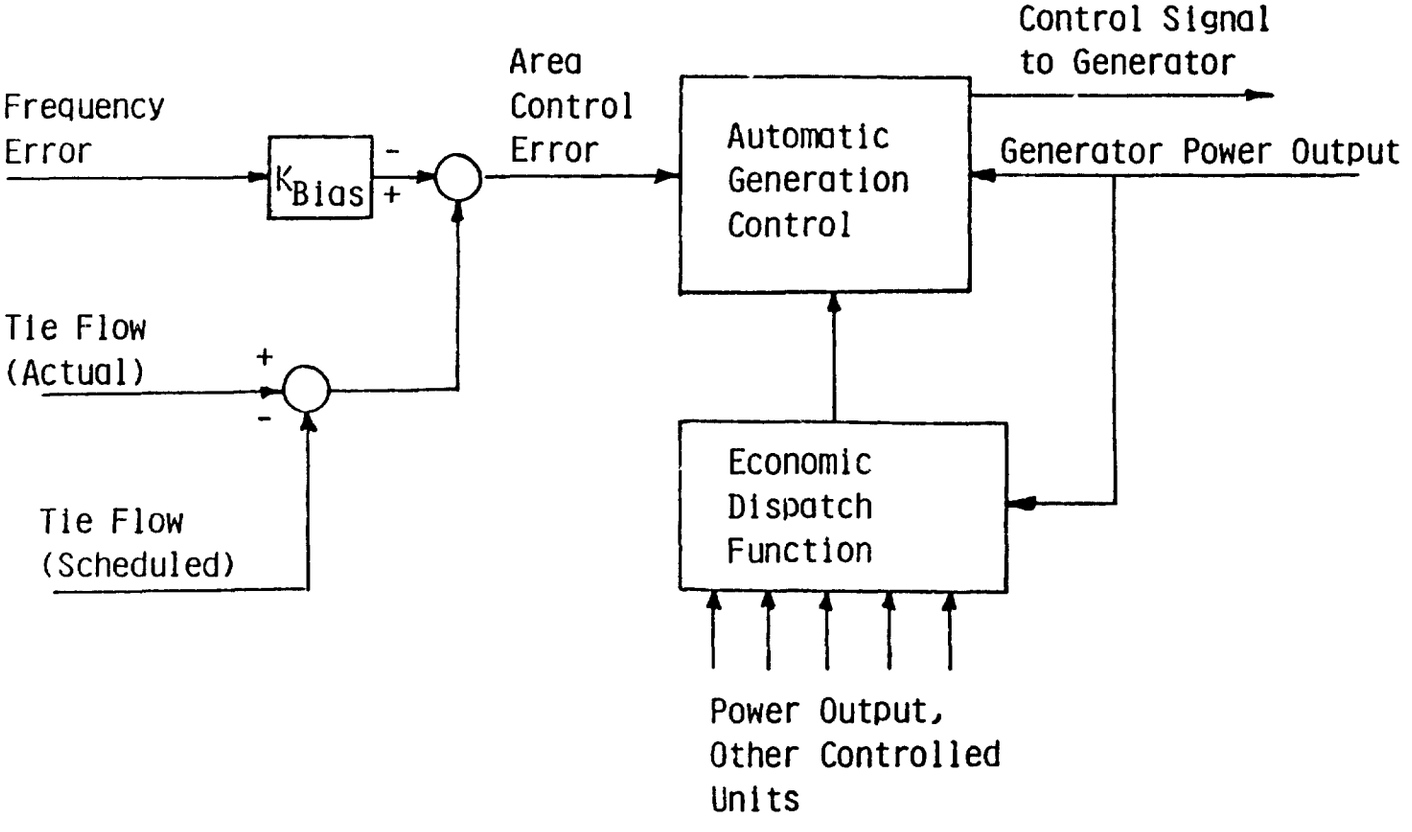


ILLUSTRATION OF AGC ACTION

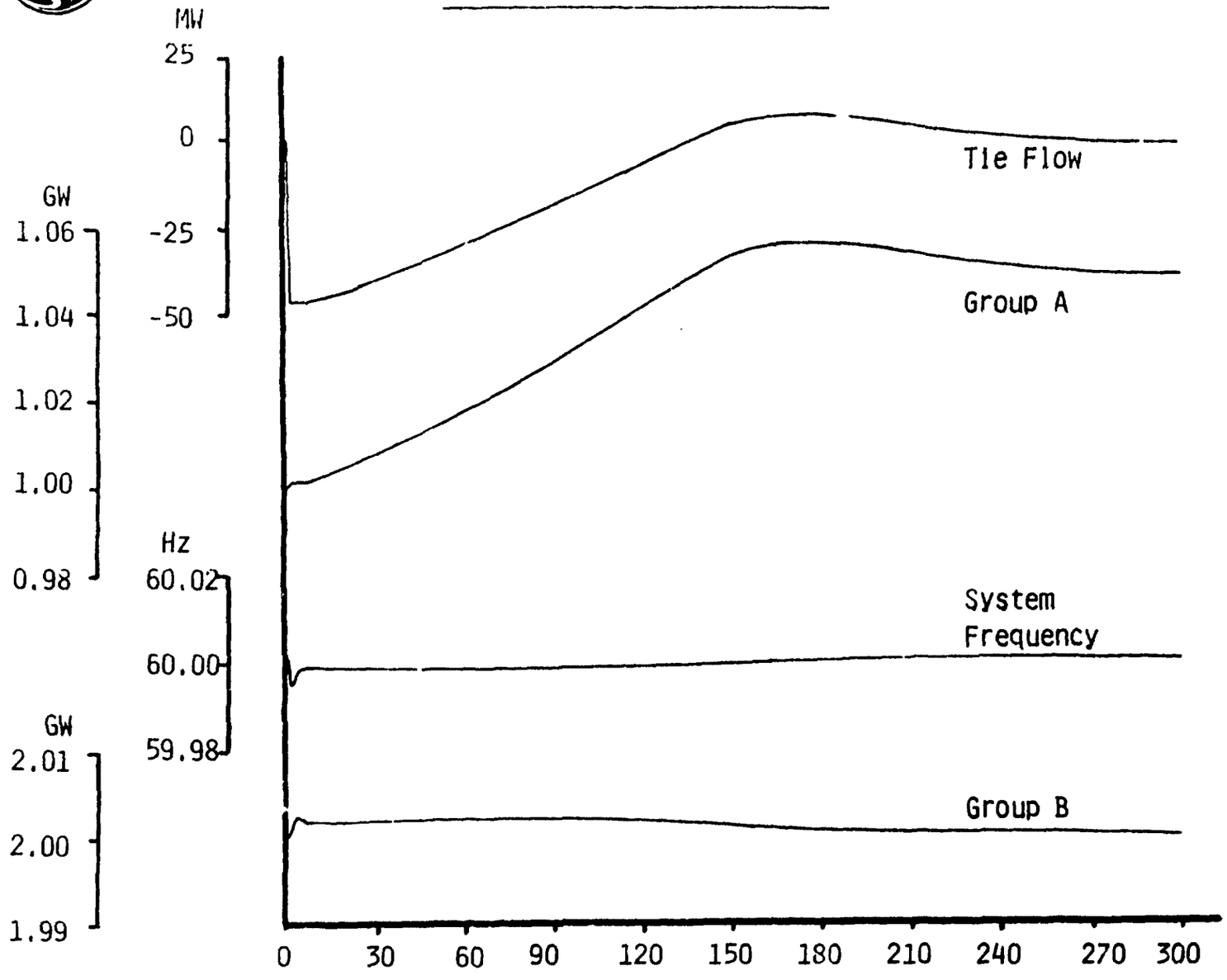
The action of AGC is illustrated by simulation in a hypothetical utility control area of 4 GW generation capacity. 1.25 GW in group A which is controlled by the AGC; 2.75 GW in group B with no AGC.

At time equals zero, load is increased by 50 MW (or 50 MW of generation is lost). The line flow from adjacent area 2 into area 1 increases to almost 50 MW. System frequency dips due to a generation deficiency and governor action on both groups of generators resulting in an increase in power output, which together with the tie flow, supplies the load demand.

AGC action (on unit group A only) raises its output over a 5 minute period to restore the tie flow to zero, and the system frequency to 60 Hz. Note that unit group B, not under AGC, returns to its original output level with the restoration of system frequency.

If group B was a solar power satellite, its output would be totally unaffected by this sequence of events. This would result in an initial tie-line flow of 50 MW, hence increased regulating duty on the units in group A.

ILLUSTRATION OF AGC ACTION



UTILITY SYSTEM CONTROL STRUCTURE

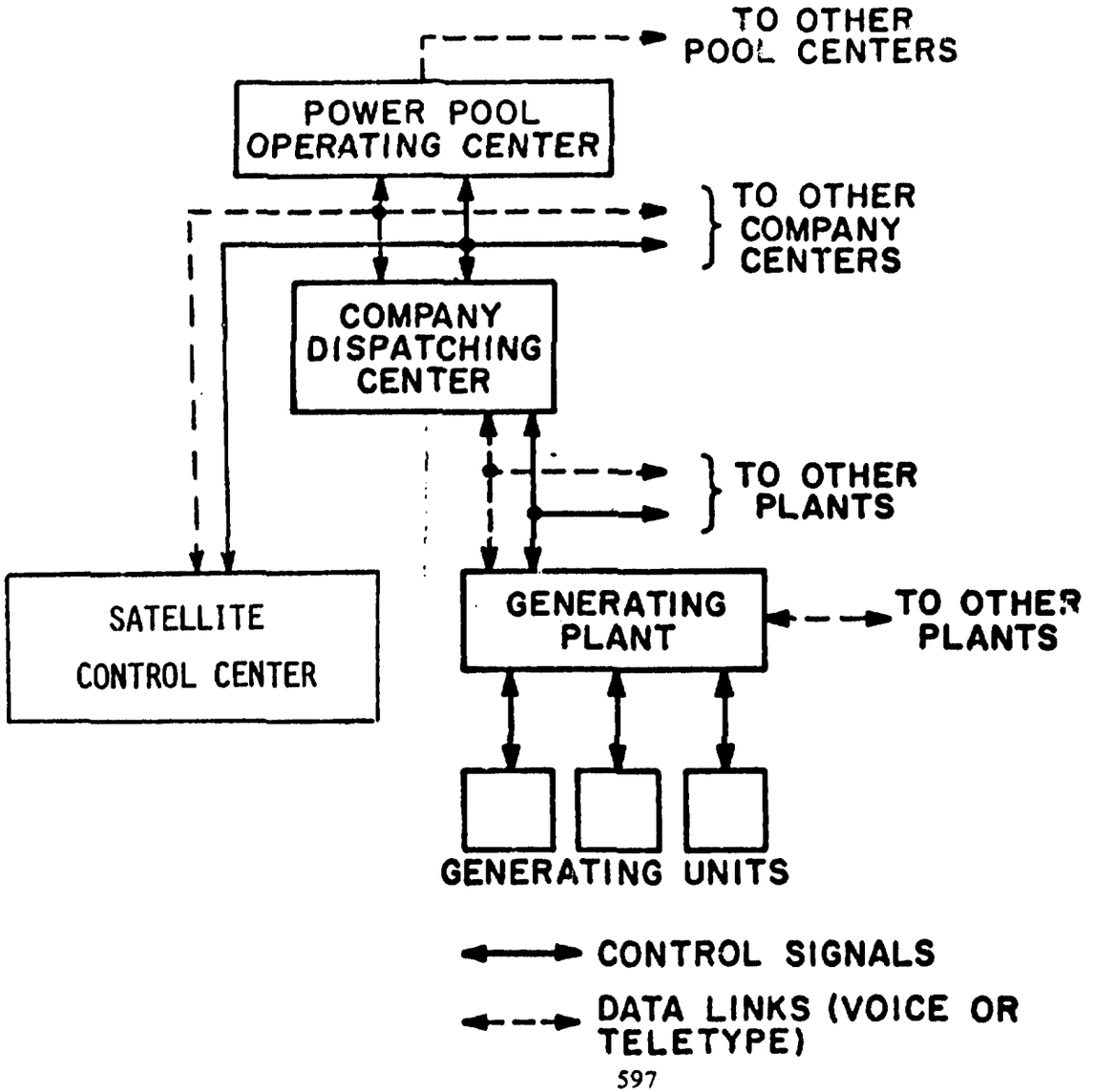
In actuality, generating plants do not operate into isolated loads or infinite buses. As part of a utility system, they become an integral part of that system, and are affected by conditions on the system and the constraints imposed by the system.

Generating plants in a utility network are operated under the direction of a company dispatcher who in most instances is provided direction from a power pool center.

Telemetering of power flows and voltages provides system dispatchers and pool operators a current picture of conditions on the network. As loads and power flows change, generating levels are changed to maintain system frequency, load generating units within ratings and according to most favorable economic considerations, and limit line flows to meet rating or stability considerations.

The Solar Power Satellite, representing a significant block of generation in any operating utility or power pool, would be under the direction of such operations, as indicated on the diagram.

UTILITY SYSTEM CONTROL STRUCTURE



DISTINCTIVE CHARACTERISTICS OF THE SOLAR POWER SATELLITE SYSTEM AS A GENERATION SOURCE

- Contribution to System Frequency Regulation is Probably Not Feasible
- Load Following Capability Exists But Will Only Be Used in Extreme Low Load Situations
- Output Is a Function of Incident Energy at the Rectenna (Self-dispatching)
- Semi-Annual Eclipse Periods Require Loading of Other Generation And May Cause a Higher Than Average Exposure to SPS Forced Outages

SPS RELIABILITY MODEL

The table shows the parametric study performed after the mid-term review. The assumptions for creating a 5 state probability model from the overall SPS Availability profile was made more conservative as the probability of losing all 5000 MW was increased, as well as the selected data points were moved to conservative values.





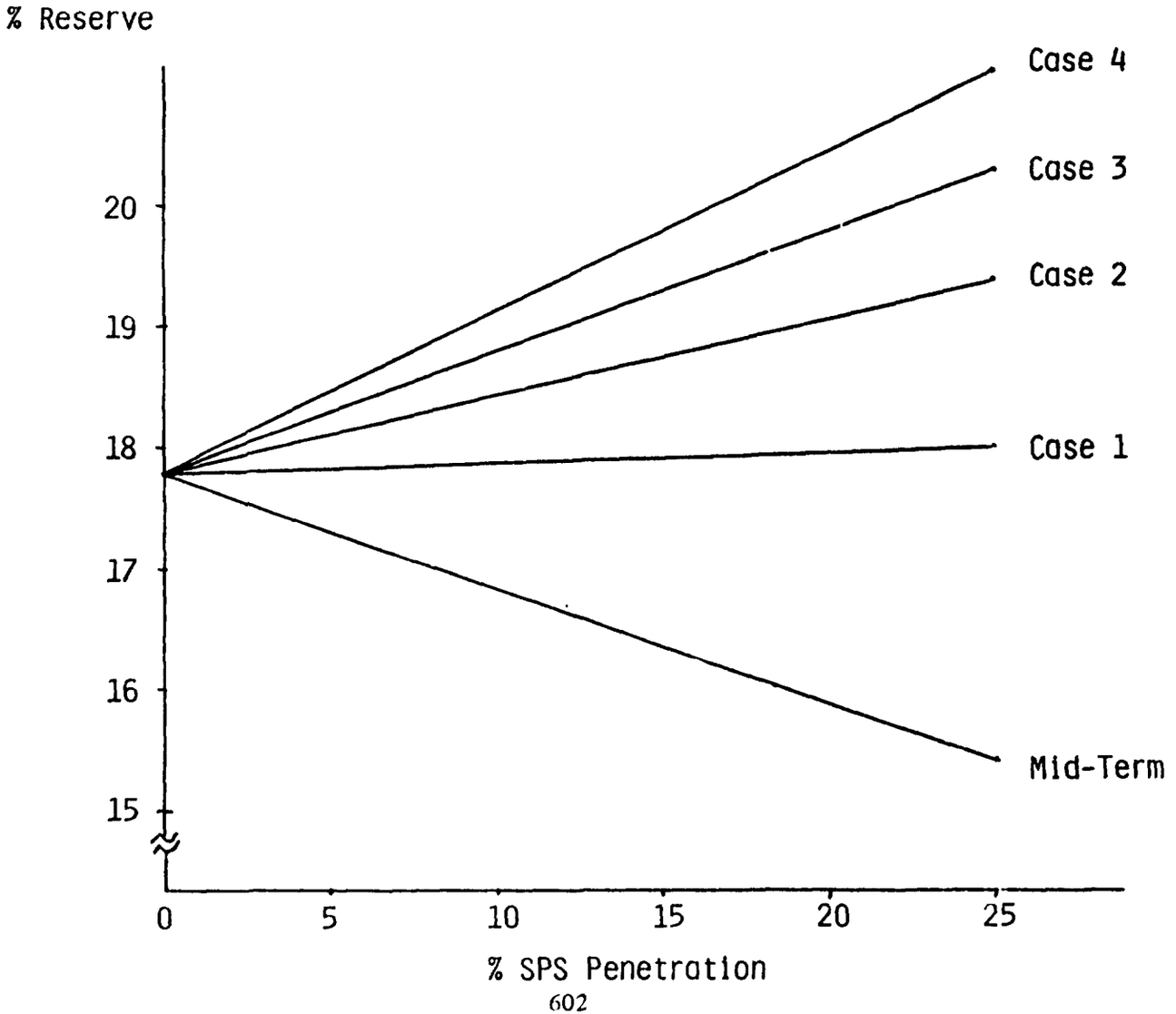
SPS RELIABILITY MODEL

Case #	MW Out P(MW Out)	5000	1500	700	200	0
Mid-Term		0	.01	.33	.56	.1
Case 1		0	.30	.40	.20	.1
Case 2		.01	.29	.40	.20	.1
Case 3		.02	.28	.40	.20	.1
Case 4		.03	.27	.40	.20	.1

UTILITY SYSTEM RESERVE LEVELS VS. SPS PENETRATION

By using the 5-state probability models shown in the previous table, the graphs shown in this slide were developed. It may seem too liberal to use the mechanical availability data developed earlier to form the only basis for the reliability investigation. The earlier curve is marked Mid-Term, and it can be seen that as a higher and higher probability of full (5000 MW) outage is assumed, the SPS will go from improving to deteriorating utility system reliability. A final assessment of proper model selection for an SPS/utility system reliability investigation cannot be done within the current study framework.

UTILITY SYSTEM RESERVE LEVELS VS. SPS PENETRATION



NATIONAL ELECTRIC RELIABILITY COUNCIL

The forecast from NERC shown in the mid-term review was unfortunately in error. The table on this slide shows the updated forecast as well as the best "Guesstimate" by the study team as to year 2020. For a feel for the distribution of SPS power on a MW weighted basis we used 20% SPS penetration and show the results in the right hand column. Due to geographical considerations, this distribution might well be distorted, but does give an indication of the importance of distributed SPS maintenance schedules.

NATIONAL ELECTRIC RELIABILITY COUNCIL

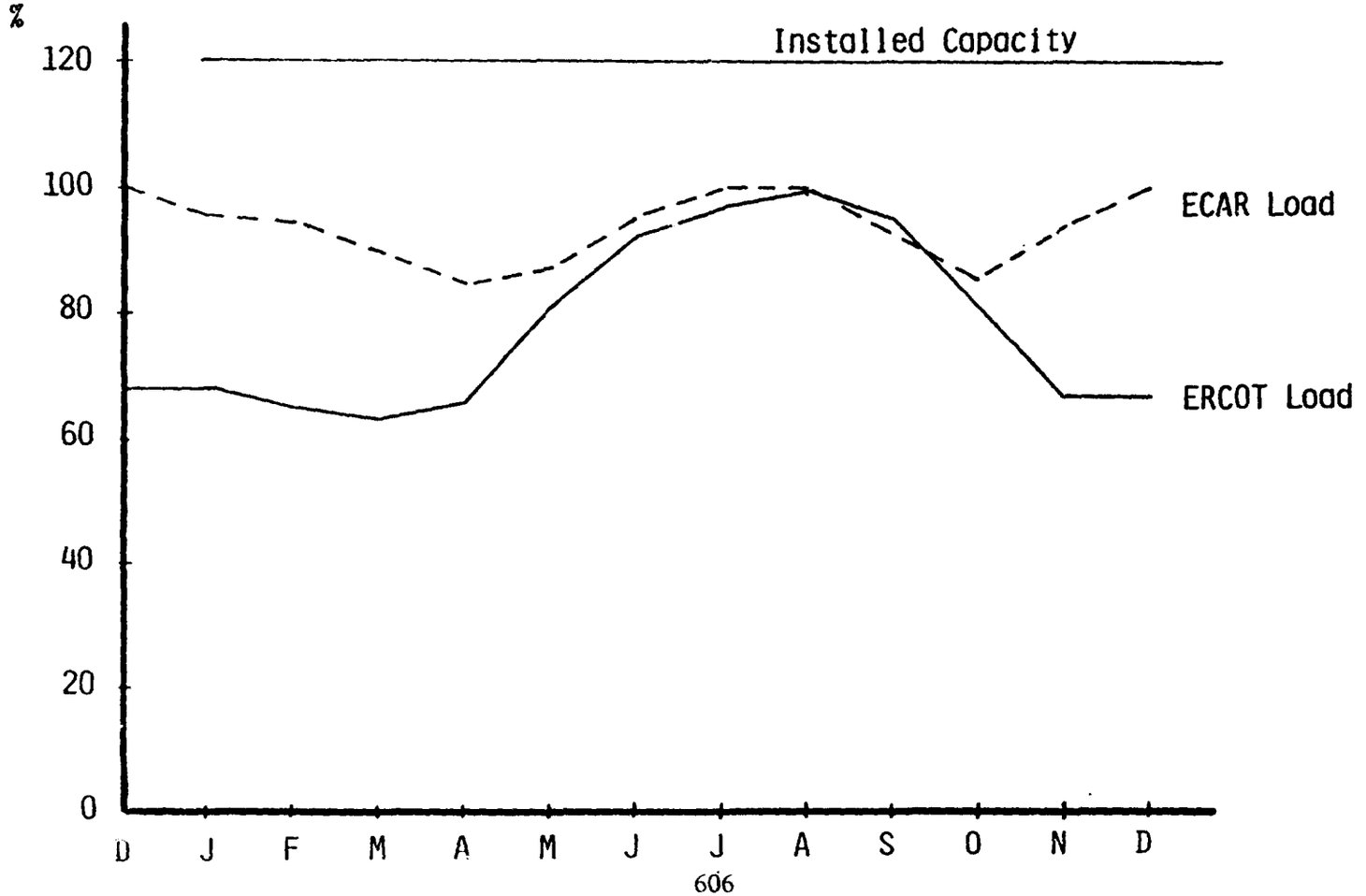
Forecast of Bulk Power System Capabilities

	1998 Forecast GW	2020 "Guesstimate" GW	# of Satellites @ 20% Penetration
Northeast (NPCC) (W)	83	130	5
Southeast (SERC) (W)	258	550	22
Southwest (SPP)	138	380	16
East Central (ECAR) (W)	194	365	14
Mid Atlantic (MAAC)	69	100	4
Mid America (MAIN)	94	210	8
Mid Continent (MARCA)	55	125	5
Texas (ERCOT)	87	200	8
Western (WSCC)	222	440	18
TOTAL	1200	2500	100

MONTHLY LOAD VARIATIONS

To further shed some light on the issues of maintenance scheduling from a utility point of view, two different NERC Regions are shown on this graph. The data plotted is the ratio of monthly peak load to yearly peak load. It is obvious that ECAR with maybe 14 SPS would have a tougher time scheduling maintenance (and may be in need of maintenance reserve generation) as compared to ERCOT with significantly greater monthly load variations.

MONTHLY LOAD VARIATIONS IN EAST CENTRAL REGION (ECAR)
AND ENERGY RELIABILITY COUNCIL OF TEXAS (ERCOT)



AREAS OF CONCERN AND NEED FOR FURTHER WORK

- Power Output Control Methods and Their Impact on Utility Operations
- Protection of Rectenna Receiving Element(s) (Crowbar)
- Siting Feasibility Including Bulk Transmission System Consideration

FEASIBILITY STUDY OF AN OFFSHORE SPACE CENTER

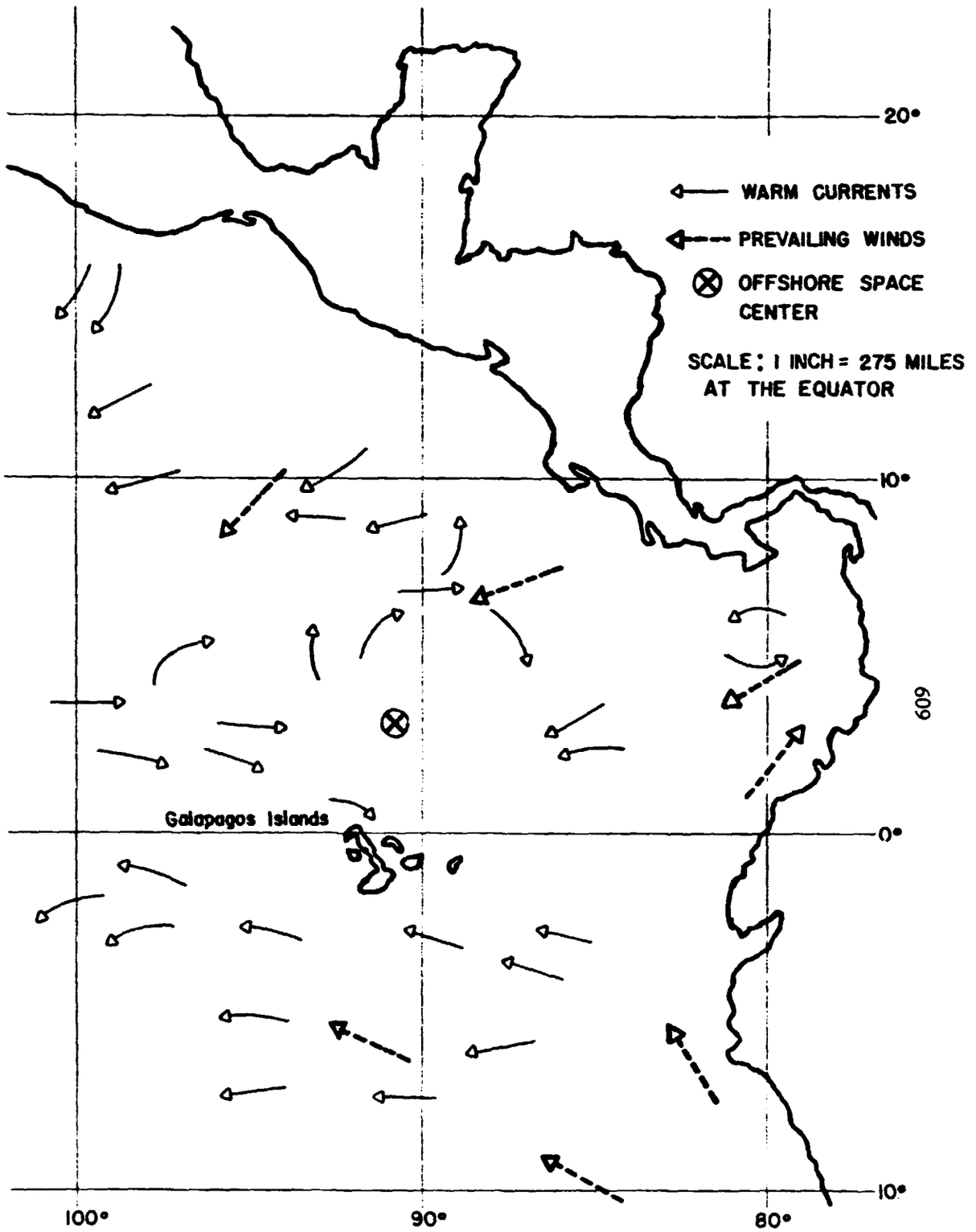
SUBCONTRACT TO BOEING

PRESENTATION TO

NASA JSC

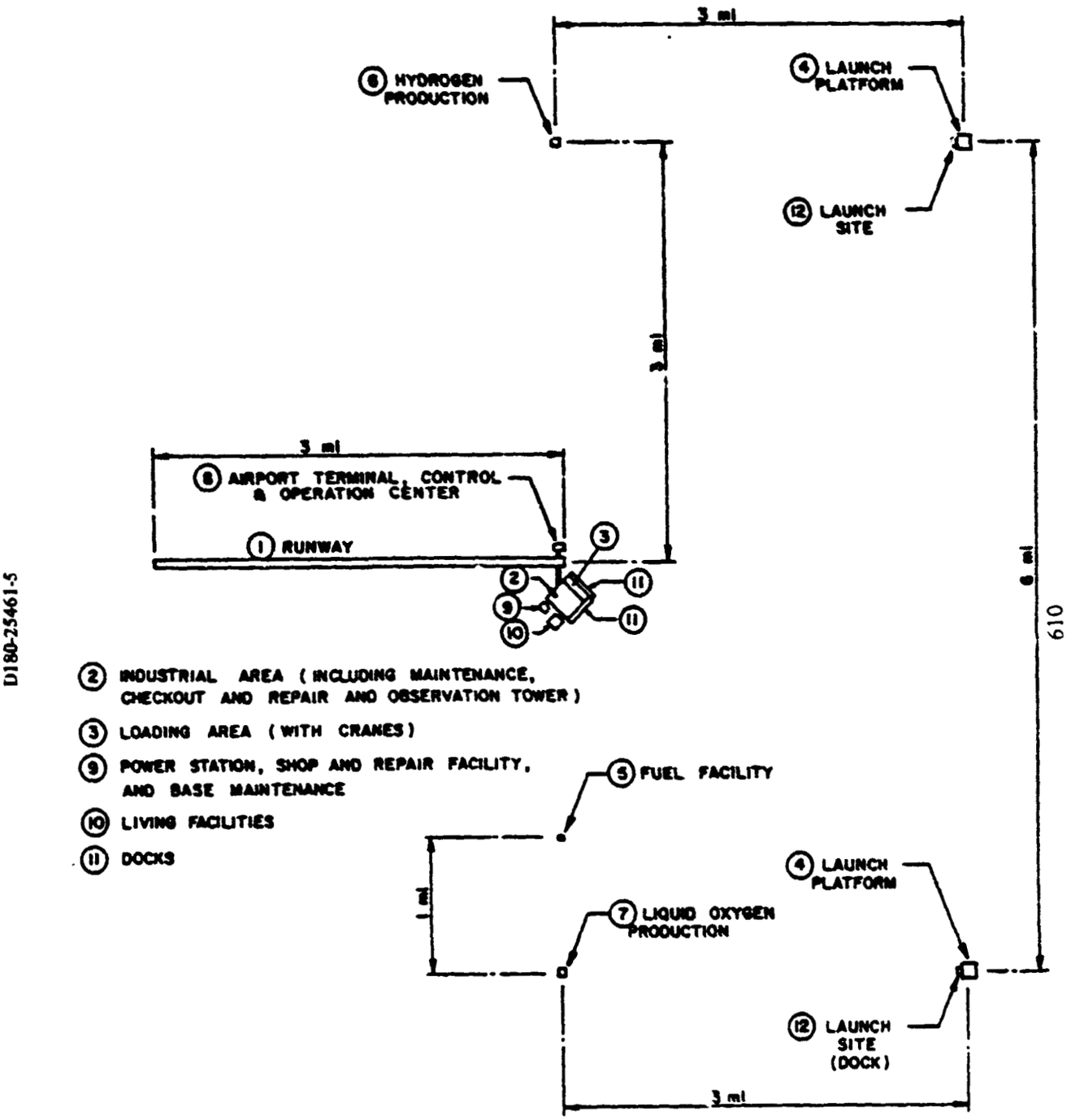
HOUSTON, TEXAS

OCTOBER 18, 1979

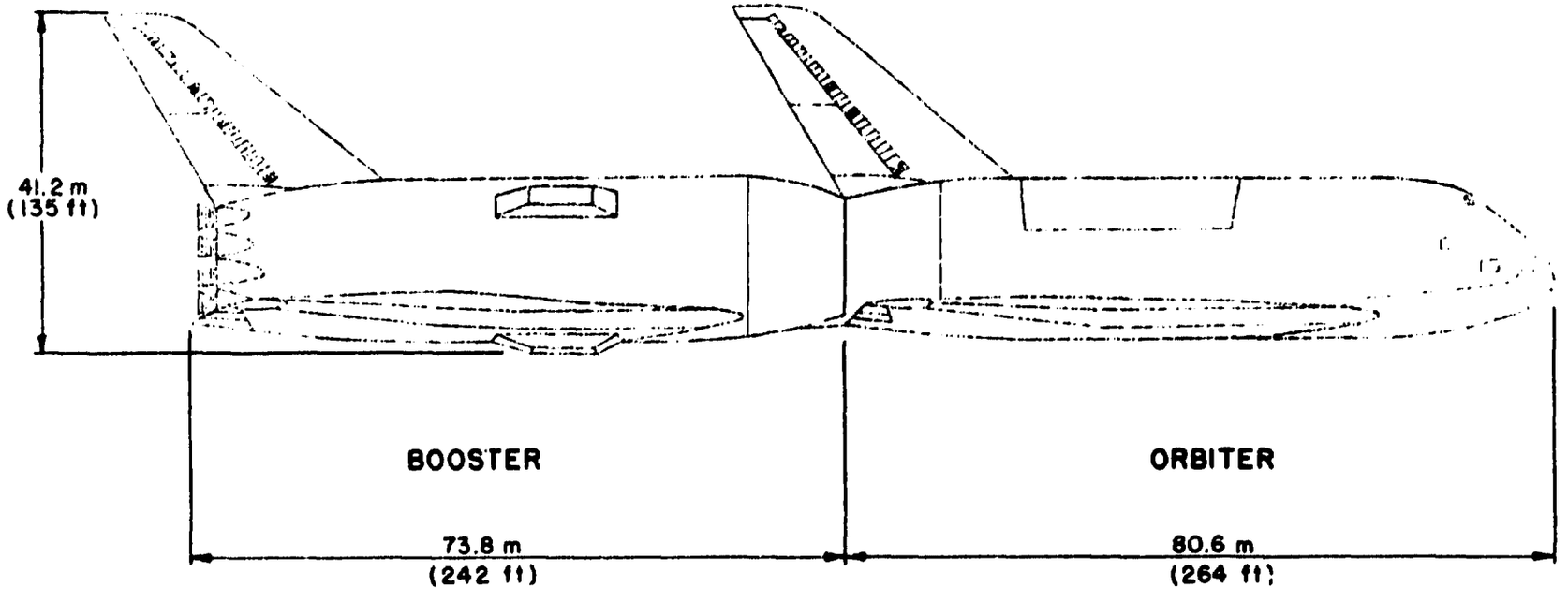


LAUNCH SITE

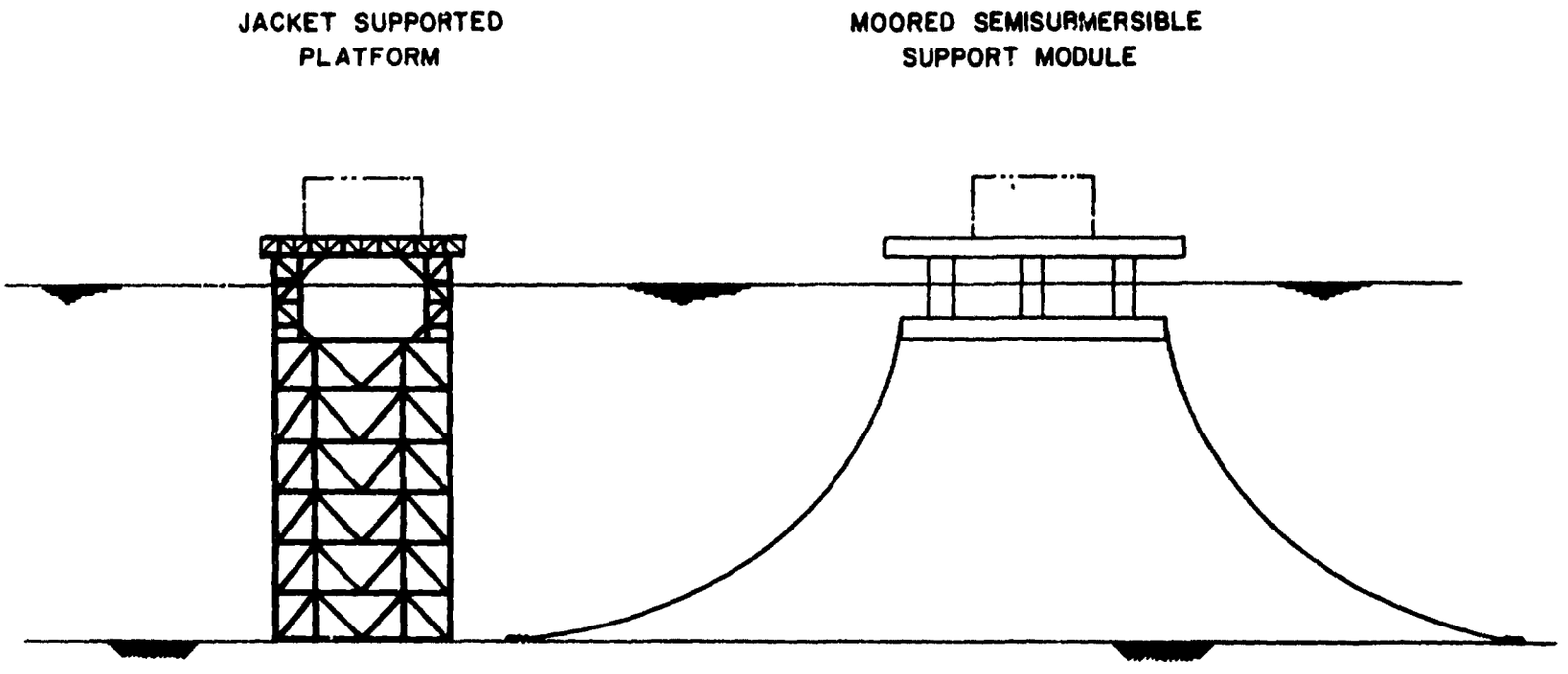
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FACILITIES SCHEMATIC



SPACE FREIGHTER - COMPLETELY REUSABLE



SUPPORT CONCEPTS

SIGNIFICANT RESULTS OF THE OSC STUDY

- TECHNICALLY FEASIBLE
- SIX YEARS FROM CONCEPTUAL DESIGN TO COMPLETION
- TOTAL INSTALLED COST ESTIMATES
    1. MOORED, SEMI-SUBMERSIBLE -$3,005,000,000
    2. STATIONARY, PILE-SUPPORTED -$3,917,000,000
- RUNWAY IS SIGNIFICANT COST DRIVER
- CONCEPT HAS REAL BENEFITS

THE EQUATORIAL-BASED OSC CONCEPT HAS REAL BENIFITS

- 20% MORE PAYLOAD TO ECLIPTIC PLANE
- 1% MORE INITIAL ROTATIONAL SPEED OF EARTH
- CENTRAL LOCATION FOR TRANSPORTATION
- ISOLATED FROM PEOPLE, ENVIRONMENTAL EFFECTS
- INDEPENDENCE OF FOREIGN CONTROL
- ACCEPTABLE SITE(S) DO EXIST
- MILD CLIMATE WITH EXCELLENT WEATHER AND ORBITAL WINDOWS

OSC FEATURES

NO.	FEATURE	QUANTITY	APPROXIMATE SURFACE AREA
1.	RUNWAY	1	300′ x 15,000′
2.	INDUSTRIAL AREA (INCLUDING MAINTENANCE, CHECKOUT AND REPAIR AND OBSERVATION TOWER)	1	1100′ x 900′ (x 150′ HIGH)
3.	LOADING AREA (WITH CRANES)	1	300′ x 1100′
4.	LAUNCH PLATFORM	2 + SPARE	500′ x 500′
5.	FUEL FACILITY	1 + SPARE	100′ x 100′
6.	HYDROGEN PRODUCTION	1 + SPARE	200′ x 200′
7.	LIQUID OXYGEN PRODUCTION	1 + SPARE	200′ x 200′

OSC FEATURES (CONTINUED)

NO.	FEATURE	QUANTITY	APPROXIMATE SURFACE AREA
8.	AIRPORT TERMINAL, CONTROL AND OPERATION CENTER	1	200' x 300' (x 7 STORIES)
9.	POWER STATION, SHOP AND REPAIR FACILITY, AND BASE MAINTENANCE	1	200' x 300' (x 3 STORIES)
10.	LIVING FACILITIES	1	400' x 400' (x 12 STORIES)
11.	DOCKS	2	200' x 1200'
12.	LAUNCH SITE	2	DOCK (200' x 300')
13.	TUG TANKER/BARGE (FOR CRYOGENIC WORK)	4	---

MOORED SEMI - SUBMERSIBLE OSC COST ESTIMATE

NO.	FEATURE	COST ESTIMATE	WEIGHT FACTOR	QUANTITY	FACILITY COST (M$)	
					FINAL COST (EA)	TOTAL
1.	RUNWAY	1432.4	-	1	$ 1432.4	$ 1432.4
2.	INDUSTRIAL AREA (INCLUDING MAINTENANCE, CHECKOUT, AND REPAIR)	315.1	-	1	315.1	315.1
3.	LOADING AREA (WITH CRANES)	105.0	-	1	105.0	105.0
4.	LAUNCH PLATFORM	143.2	1.8	3	143.2	429.6
5.	FUEL FACILITY	3.2	-	2	3.2	6.4
6.	HYDROGEN PRODUCTION	12.7	1.8	2	22.9	45.8
7.	LIQUID OXYGEN PRODUCTION	12.7	1.8	2	22.9	45.8

MOORED SEMI - SUBMERSIBLE OSC COST ESTIMATE (CONTINUED)

NO.	FEATURE	COST ESTIMATE	WEIGHT FACTOR	QUANTITY	FACILITY COST (M$)	
					FINAL COST (EA)	TOTAL
8.	AIRPORT TERMINAL, CONTROL AND OPERATION CENTER	50.9	-	1	$ 50.9	$ 50.9
9.	POWER STATION, SHOP AND REPAIR FACILITY, AND BASE MAINTENANCE	28.6	1.8	1	51.5	51.5
10.	LIVING FACILITIES	203.7	-	1	203.7	203.7
11.	DOCKS	76.4	-	2	76.4	152.8
12.	LAUNCH SITE	19.1	-	2	19.1	38.2
13.	TUG TANKER/BARGE	32.0	-	4	32.0	128.0
	TOTAL SEMI - SUBMERSIBLE SUPPORTED OSC (INCLUDING MOORING)					$3,005.

COST DEVELOPMENT METHODOLOGY

OSC - SEMI - SUBMERSIBLE PLATFORMS

RUNWAY

- WEIGHT ESTIMATE
  - TRUSSES
  - PRESSURE VESSELS
  - FLAT PLATE STRUCTURES
- PERFORMANCE CHECK
  - LOAD CAPACITY
  - STATIC STABILITY
- COST ESTIMATE
  - DECKS @ $2000/L.T.
  - COLUMNS @ $4000/L.T.
  - PONTOONS @ $4000/L.T.
  - MOORING EQUIPMENT @ $300,000/STATION

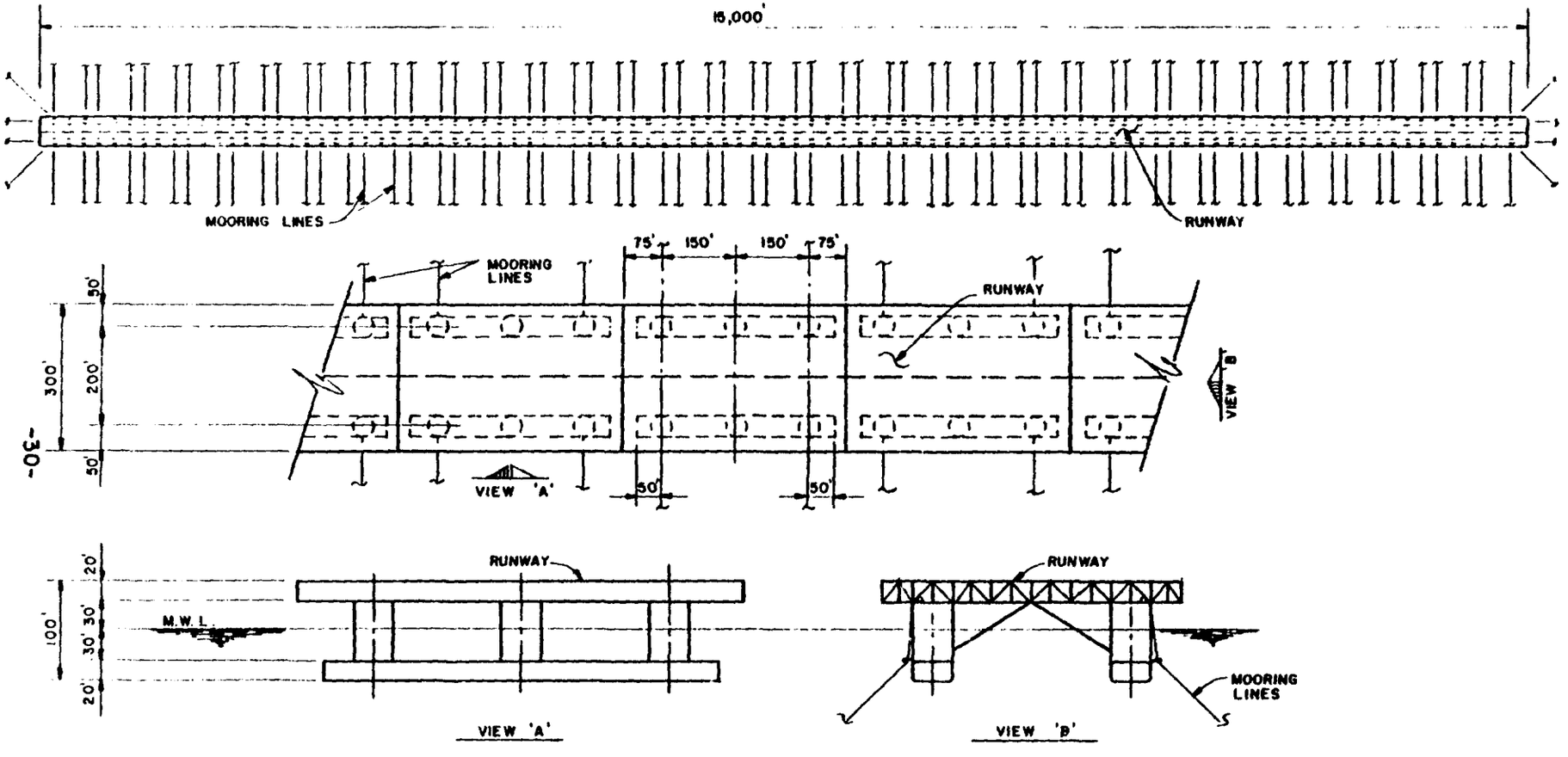


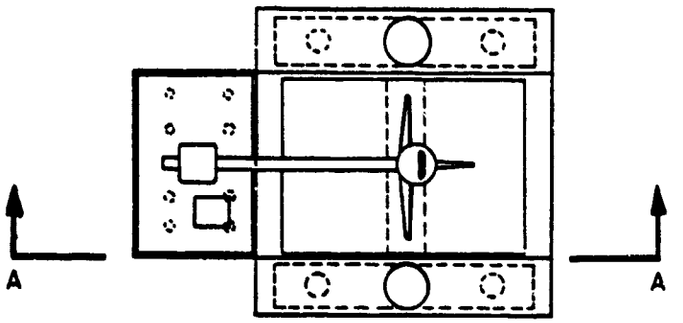
FIGURE 4.1 RUNWAY, FLOTATION, MOORING-SEMISUBMERSIBLE CONCEPT

COST DEVELOPMENT METHODOLOGY

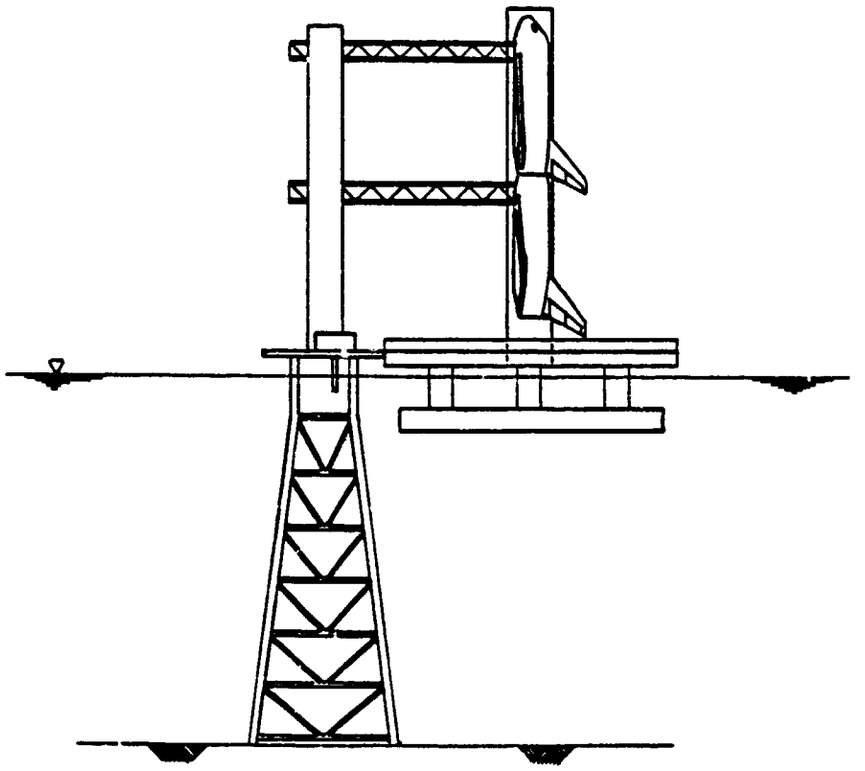
OSC - SEMI - SUBMERSIBLE PLATFORMS

LAUNCH PLATFORM

- WEIGHT ESTIMATE - COMPONENTS FROM RUNWAY
- COST ESTIMATE
  - DECKS @ $2000/L.T.
  - COLUMNS @ $4000/L.T.
  - PONTOONS @ $4000/L.T.
  - MOORING EQUIPMENT @ $3000,000/STATION



PLAN



VIEW A-A

LAUNCH PLATFORM
(VEHICLE ERECTED FOR LAUNCH)

COST DEVELOPMENT METHODOLOGY

OSC - SEMI - SUBMERSIBLE PLATFORMS

HEAVILY LOADED PLATFORMS *

- COST ESTIMATE - PLATFORM COST = (RUNWAY COST) (X) $\left(\frac{\text{PLATFORM AREA}}{\text{RUNWAY AREA}}\right)$

$$X = \left(\frac{\text{LAUNCH PLATFORM COST}}{\text{RUNWAY COST}}\right)\left(\frac{\text{RUNWAY AREA}}{\text{LAUNCH PLATFORM AREA}}\right)$$

$$= \left(\frac{143.2}{1432}\right)\left(\frac{300 \times 15000}{500 \times 500}\right) = 1.8$$

* HYDROGEN PLATFORM
OXYGEN PLATFORM
POWER STATION

COST DEVELOPMENT METHODOLOGY

OSC - SEMI - SUBMERSIBLE PLATFORMS

OTHER PLATFORMS *

- COST ESTIMATE - RATIO RUNWAY COSTS TO AREAS

* INDUSTRIAL AREA
LOADING AREA
FUEL FACILITY
AIRPORT TERMINAL
LIVING FACILITIES
DOCKS
LAUNCH SITE

ADDITIONAL SYSTEM COST COMPONENTS

OSC - SEMI - SUBMERSIBLE PLATFORMS

MOORING PILE INSTALLATION

- DRILLSHIP
  - MOBILIZATION, $1,000,000
  - DEMOBILIZATION, $1,000,000
  - DAY RATE, $50,000/DAY
- ANCHOR PILES
  - QUANTITY, APP. 450
  - INSTALLATION RATE, 1 PER DAY
  - WEATHER AND EQUIPMENT FACTOR, 1
  - COST, 450 x 2 x 50,000 = $45,000,000

TOTAL - $47,000,000

ADDITIONAL SYSTEM COST COMPONENTS

OSC - SEMI - SUBMERSIBLE PLATFORMS

OFFSHORE MODULAR PLATFORM INTEGRATION

- REQUIREMENTS - Platform Dimensions Exceed Building Capabilities (Approximately 300' x 300')
- COMPONENT % INCREASE - Assumed @ 25% Structure Cost
  - Runway
  - Industrial Area
  - Loading Area
  - Launch Platform
  - Living Facilities
  - Docks

  Subtotal $2,638,600,000
- COMPONENT INCREASE - $659,700,000

ADDITIONAL SYSTEM COST COMPONENTS

OSC - SEMI - SUBMERSIBLE PLATFORMS

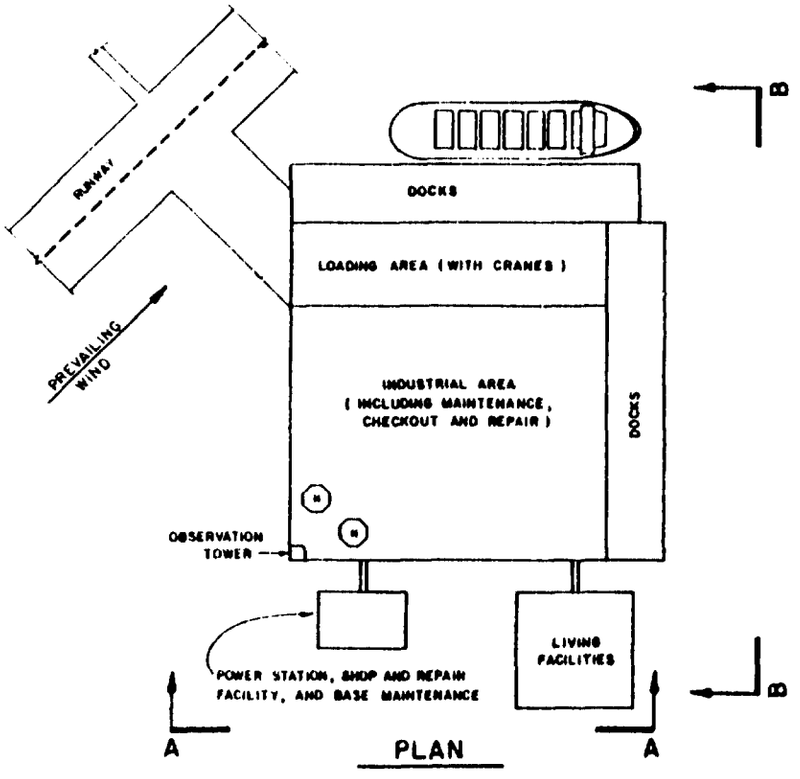
STANDARDIZED COMPONENTS AND TECHNIQUES

- SIGNIFICANCE
  - REDUCED HANDLING
  - REDUCED PRODUCT VARIATION
  - REDUCED REWORK
  - INCREASED PRODUCTIVITY
- COST CHANGE
  - INCREASING REDUCTION THROUGHOUT PROGRAM
  - AVERAGE APPROXIMATELY 15%
- COST DECREASE - (3,005,000,000) (.15) = $450,750,000

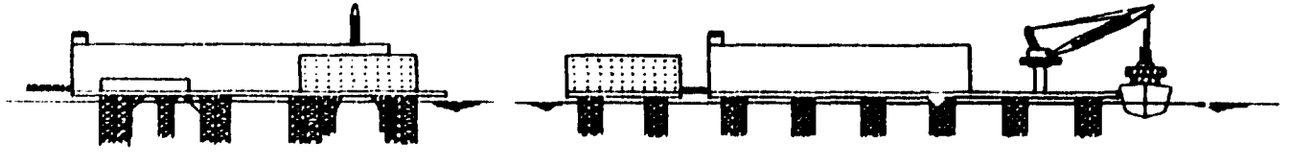
OSC - SEMI - SUBMERSIBLE PLATFORMS
REVISED SUMMARY COST ESTIMATE

STRUCTURE		$3,005,000,000
MOORING PILE INSTALLATION	+	47,000,000
OFFSHORE MODULAR PLATFORM INTEGRATION	+	659,700,000
STANDARDIZED COMPONENTS AND TECHNIQUES	-	450,750,000
TOTAL		$3,260,950,000

INDUSTRIAL COMPLEX, POWER, AND LIVING FACILITIES

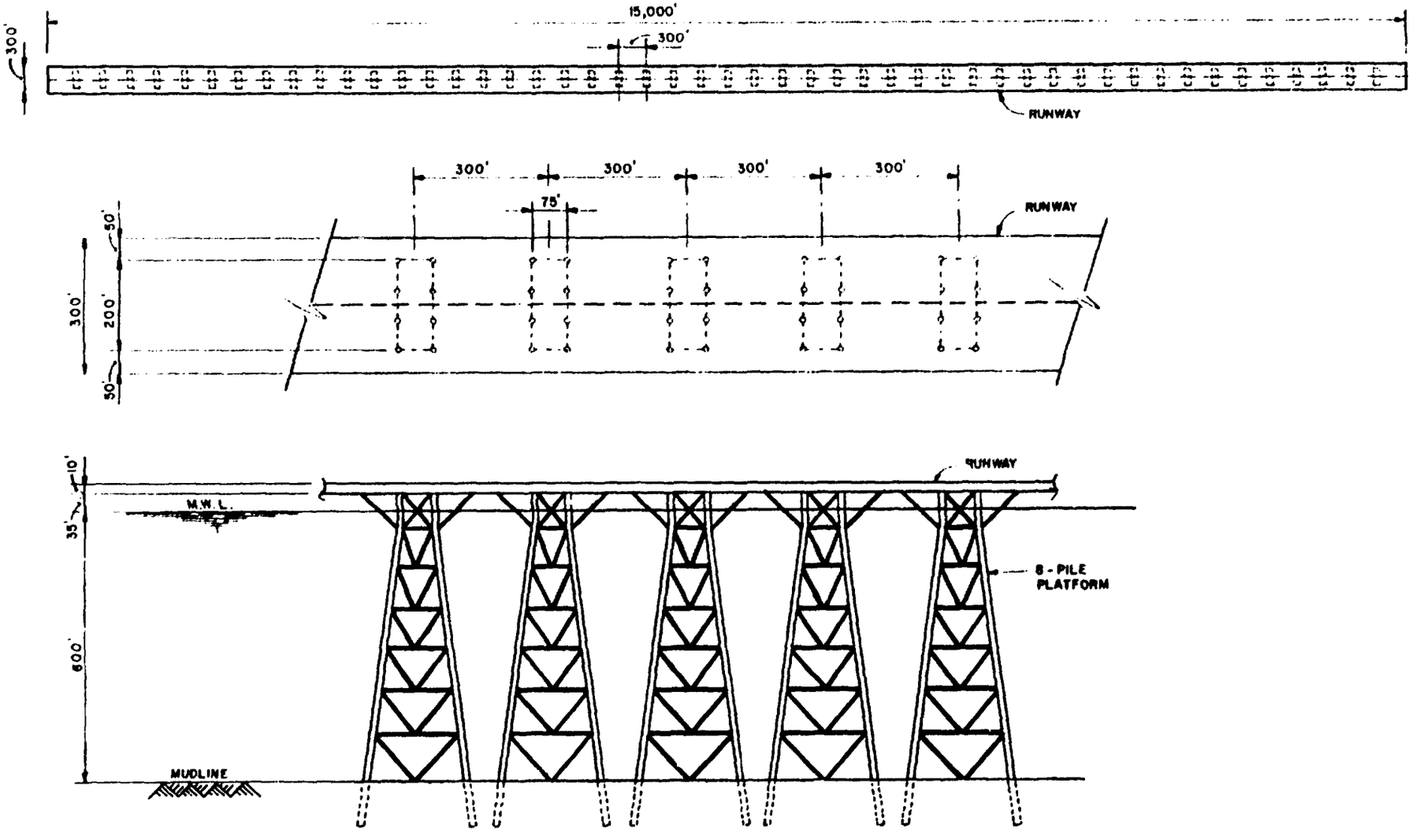


PLAN



VIEW A-A

VIEW B-B



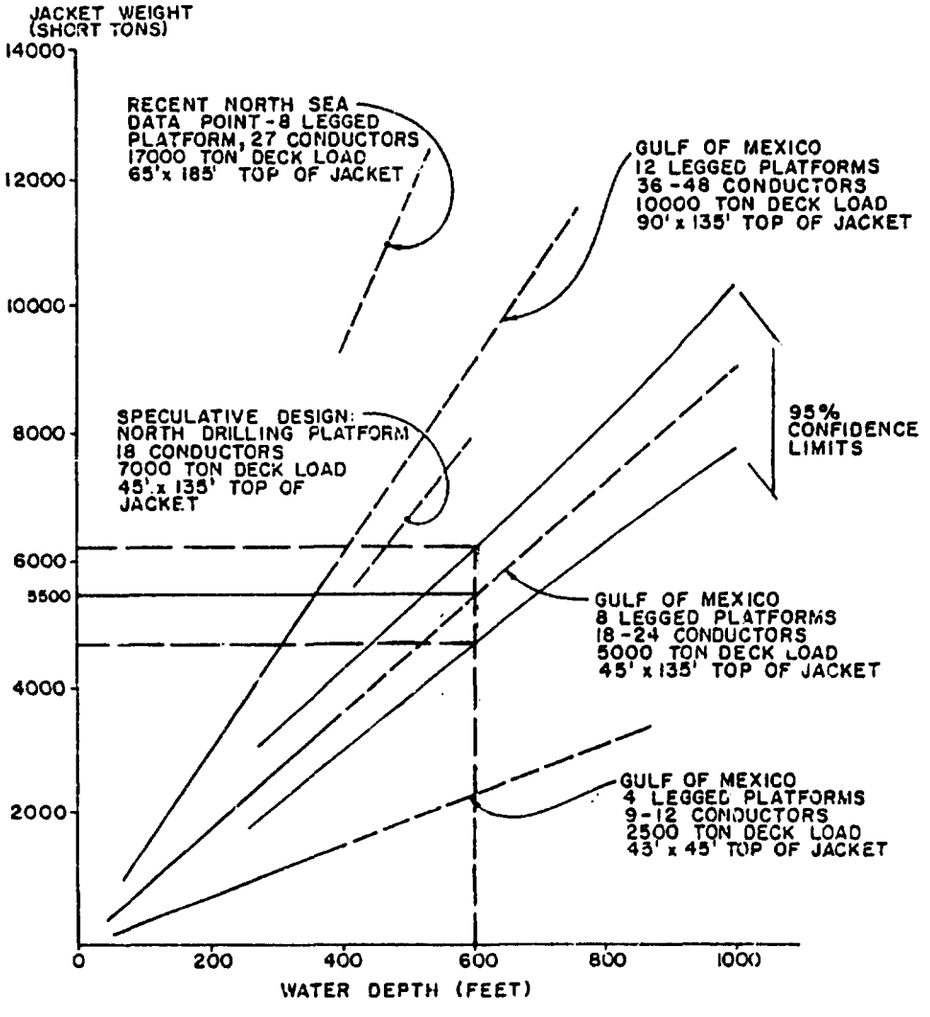
RUNWAY, PLATFORM STRUCTURE - PILE SUPPORTED CONCEPT

TYPICAL PLATFORM COST SUMMARY

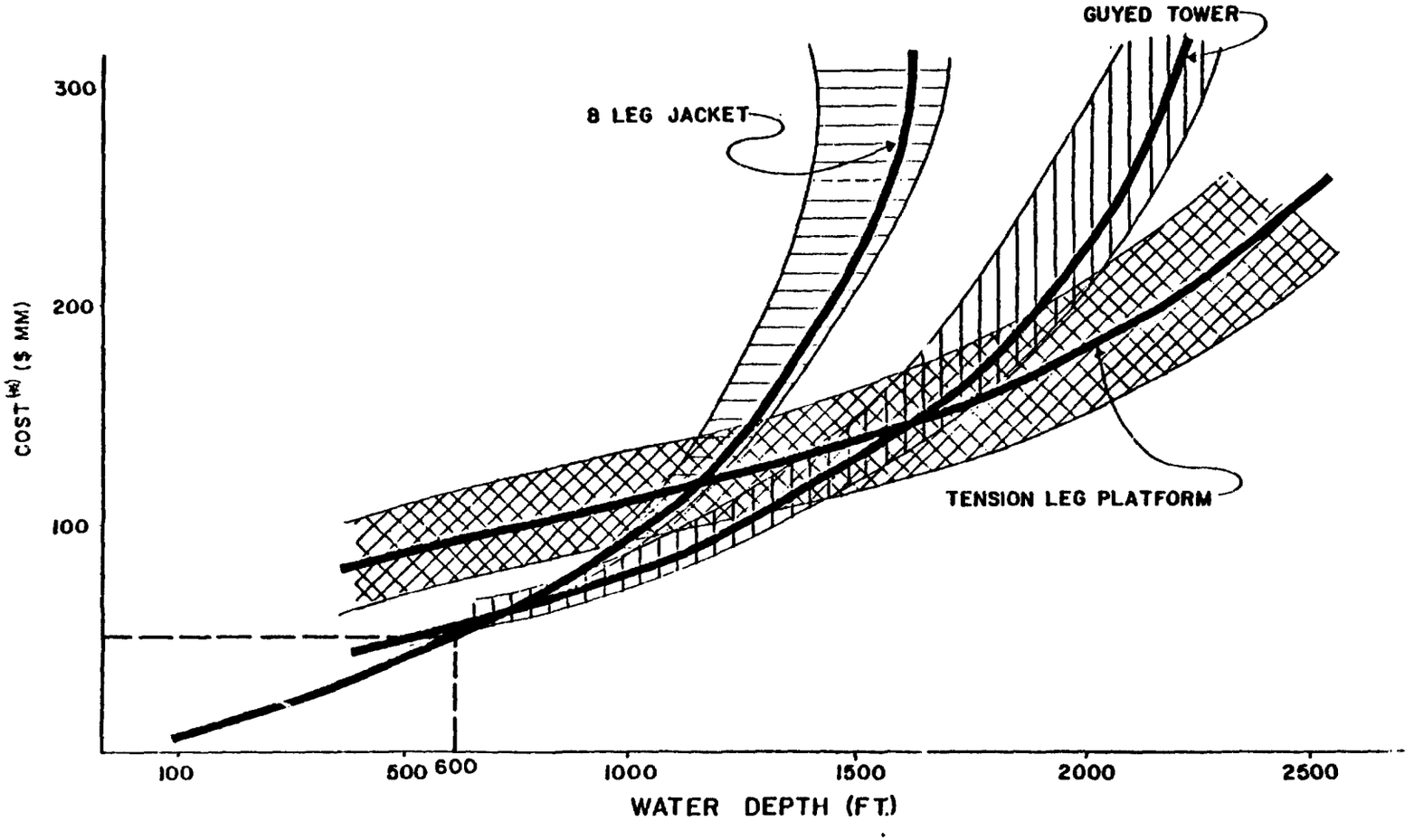
COMPONENTS	MAT'L COST ($/TON)	FAB COST ($/TON)	TOTAL COST ($/TON)	
			NOMINAL	RANGE
DECK	550	2450	3000	2500 - 4000
JACKET	500	1500	2000	1800 - 2300
PILING	500-	500+	1000	1000

TYPICAL PLATFORM COST SUMMARY

ITEM	PERCENT OF TOTAL	PERCENT OF TOTAL
MATERIAL		
DECKS	4.6	
JACKET	9.7	
PILING	8.0	22.3
FABRICATION		
DECKS	20.5	
JACKET	32.3	
PILING	10.3	63.1
INSTALLATION		
DECKS	3.8	
JACKET	2.4	
PILING	8.4	14.6
PLATFORM		100.0



EFFECT OF VARIATION IN
OPERATIONAL REQUIREMENT
ON JACKET TONNAGE



* DESIGN, FABRICATION AND INSTALLATION COST, EXCLUDING TOP SIDE EQUIPMENT AND FACILITIES.

- ORDER OF MAGNITUDE COST COMPARISON FOR DEEPWATER STRUCTURES IN THE GULF OF MEXICO

STATIONARY PILE SUPPORTED OSC COST ESTIMATE

NO.	FEATURE	NUMBER PER FEATURE			FACILITY COST (M$)		
		QUANTITY	JACKETS	BRIDGES	FABRICATION	INSTALLATION	TOTAL
1.	RUNWAY	1	40	40	$1400	$ 600	$ 2000
2.	INDUSTRIAL AREA (INCLUDING MAINTENANCE, CHECKOUT, AND REPAIR)	1	8	1	280	120	400
3.	LOADING AREA (WITH CRANES)	1	2	0	70	30	100
4.	LAUNCH PLATFORM*	3	0	0	400	29	429
5.	FUEL FACILITY	2	1	0	70	30	100
6.	HYDROGEN PRODUCTION	2	1	0	60	20	80
7.	LIQUID OXYGEN PRODUCTION	2	1	0	60	20	80

* SEMI - SUBMERSIBLE

STATIONARY PILE SUPPORTED OSC COST ESTIMATE (CONTINUED)

NO.	FEATURE	NUMBER PER FEATURE			FACILITY COST (M$)		
		QUANTITY	JACKETS	BRIDGES	FABRICATION	INSTALLATION	TOTAL
8.	AIRPORT TERMINAL, CONTROL AND OPERATION CENTER	1	1	1	$ 35	$ 15	$ 50
9.	POWER STATION, SHOP AND REPAIR FACILITY, AND BASE MAINTENANCE	1	1	0	45	15	60
10.	LIVING FACILITIES	1	1	1	55	15	70
11.	DOCKS	2	3	2	220	100	320
12.	LAUNCH SITE	4	1	0	70	30	100
13.	TUG TANKER/BARGE	4	0	0	108	20	128
	TOTAL STATIONARY PILE SUPPORTED OSC				$2873	$1044	$3917

OSC FEATURE COMPARISON

NO	FEATURE	QUANTITY	PILED COST	SEMI COST	PREFERRED CONCEPT
1.	RUNWAY	1	$2000	$1432.4	PILED
2.	INDUSTRIAL AREA (INCLUDING MAINTENANCE, CHECKOUT AND REPAIR AND OBSERVATION TOWER)	1	400	315.1	PILED
3.	LOADING AREA (WITH CRANES)	1	100	105.0	PILED
4.	LAUNCH PLATFORM	2 + SPARE	429	429.6	SEMI
5.	FUEL FACILITY	1 + SPARE	100	6.4	SEMI
6.	HYDROGEN PRODUCTION	1 + SPARE	80	45.8	SEMI
7.	LIQUID OXYGEN PRODUCTION	1 + SPARE	80	45.8	SEMI

OSC FEATURE COMPARISON (CONTINUED)

NO.	FEATURE	QUANTITY	PILED COST	SEMI COST	PREFERRED CONCEPT
8.	AIRPORT TERMINAL, CONTROL AND OPERATION CENTER	1	$ 50	$ 50.9	STUDY
9.	POWER STATION, SHOP AND REPAIR FACILITY, AND BASE MAINTENANCE	1	60	51.5	SEMI
10.	LIVING FACILITIES	1	70	203.7	PILED
11.	DOCKS	2	320	152.8	PILED
12.	LAUNCH SITE	2	100	38.2	STUDY
13.	TUG TANKER/BARGE (FOR CRYOGENIC WORK)	4	128	128.0	TUG/BARGE

ADDITIONAL WORK NEEDS TO BE DONE

- OTHER CONCEPTS AND COMBINATIONS
- OPTIMIZATION OF OSC FACILITIES AND SUPPORTS
- DEVELOPMENT OF LIFE CYCLE COSTS
- IMPACT OF THE OSC ON THE NASA SPACE PROGRAM
- SITING STUDY