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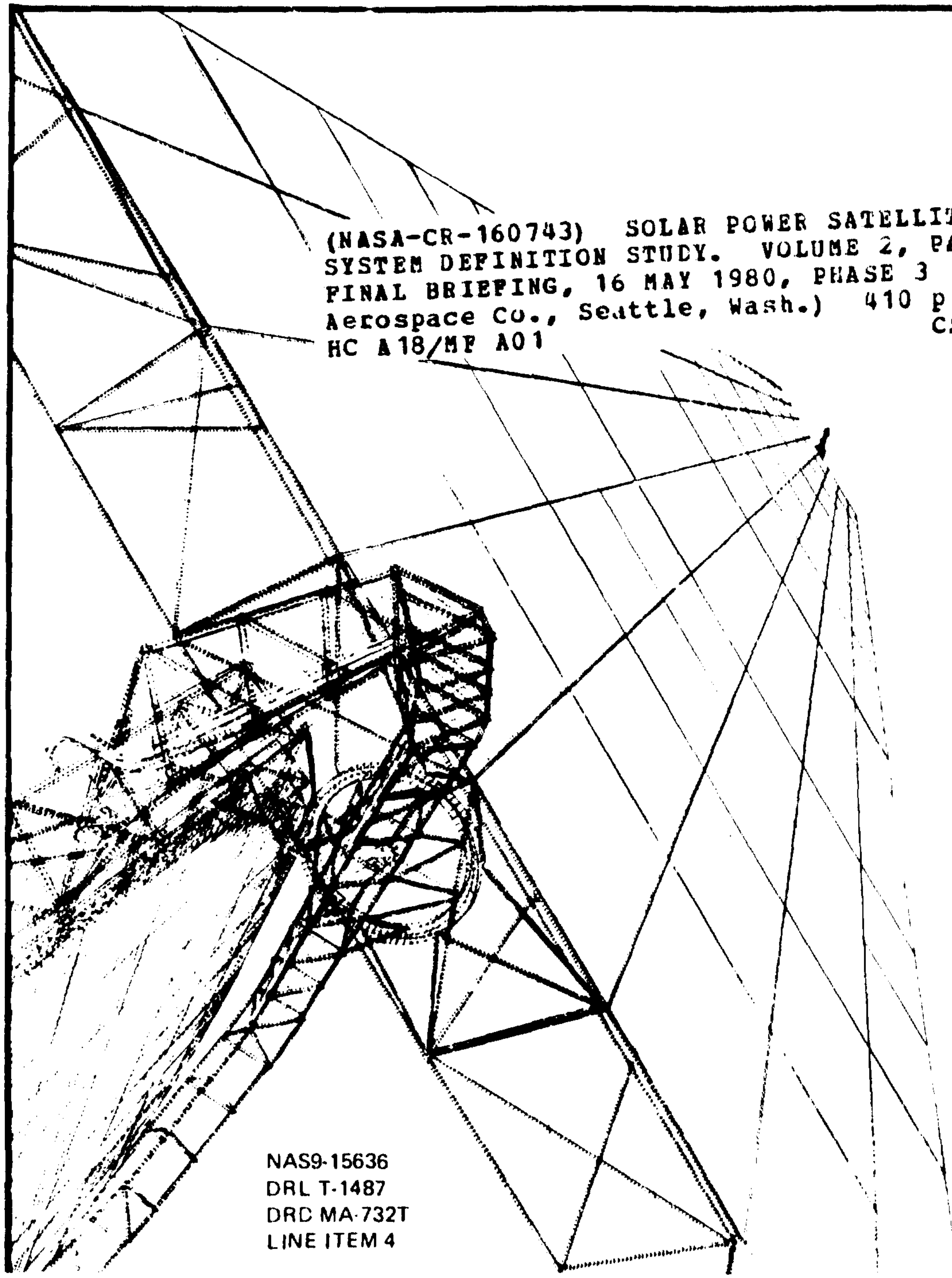

Solar Power Satellite System Definition Study

BOEING

GRUMMAN

MSNW

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

D180-25969-2

SOLAR POWER SATELLITE SYSTEM DEFINITION STUDY

PART III
FINAL BRIEFING
D180-25969-2
MAY 16, 1980

BOEING AEROSPACE COMPANY
P.O. BOX 3999
SEATTLE, WASHINGTON 98124

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FOREWORD

Phase III of the Solar Power Satellite System Definition Study investigated alternatives to the reference SPS systems defined in earlier phases. Three principal alternative technologies were investigated. The first was laser power transmission; laser systems and satellite configurations were developed and analyzed to assess the viability of this power transmission technology as either an alternative or supplement to the reference microwave power transmission system.

The second investigation included three transportation issues: (a) investigation of a shuttle-derived transportation system intended to reduce non-recurring costs for SPS transportation development; (b) examination of a smaller, heavy-lift launch vehicle with the same end in mind. (A significant part of the smaller, heavy-lift vehicle investigation was assessment of the operational penalties that might arise because of reducing payload bay size and lift capability.) and (c) a sensitivity analysis of the electric orbit transfer vehicle with particular attention directed to effects of higher solar cell temperatures in lower Earth orbits and also to the eventuality of having to operate the EOTV without solar array annealing.

The third investigation was an update of a previous analysis of solid state power transmission with attention to the design details of the solid state transmitter and further analysis of the power distribution system.

The study effort included two subcontracts. Grumman analyzed space construction considerations for each major task area. Their results are included in each task presentation at the appropriate location. Their conclusions and recommendations are included at the end of their solid-state SPS construction analysis. Math Science Northwest assisted in laser power transmission analyses. Their results were incorporated into the laser task results.

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AGENDA

Executive Summary	- G. Woodcock
Solid State SPS Analysis	- G. Woodcock
	- R. McCaffrey
Space Transportation Analysis	- G. Woodcock
	- R. McCaffrey
Laser SPS Analysis	- G. Woodcock
	- R. McCaffrey

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LASER POWER TRANSMISSION

Laser power transmission for the solar power satellite offers a number of potential advantages. In addition to the possibility of providing small power blocks because of the relatively short wave length of lasers, this transmission means provides an option to the reference microwave system which avoids microwave environmental issues. One of the laser options investigated even offers the possibility of eliminating the solar array from the reference system by direct conversion of sunlignt into laser energy. The known disadvantages and problems with the laser system include a lower efficiency than the microwave system, a perception that lasers are weapons systems, concerns over weather and atmospheric absorption of these short wave lengths and in many instances a complexity that is comparable to the old thermal engine satellite options involving complex configurations, with large fluid loops and pumping machinery.

LASER POWER TRANSMISSION

ADVANTAGES

- SMALL POWER BLOCKS - 10 - 100 Megawatts
- NO MICROWAVE ENVIRONMENTAL ISSUES
- NO IONOSPHERE HEATING
- SYNERGISTIC TECHNOLOGY
- POSSIBLE ELIMINATION OF SOLAR ARRAY

DISADVANTAGES

- LOW EFFICIENCY (?)
- "WEAPON" CONCERNS
- WEATHER/ATMOSPHERE ABSORPTION
- COMPLEXITY

LASER CHARACTERISTICS

The characteristics of lasers are summarized on the facing page. The free electron laser, although in some senses it can be considered as a normal laser, is different in that the extremely low entropy of the relativistic electron beam offers a system which in principle should be able to reach quite high efficiencies of conversion of electron beam power to light power.

LASER CHARACTERISTICS

NORMAL LASERS

- CHARACTERIZED BY CREATION OF A NON-EQUILIBRIUM EXCITED STATE WHICH DECAYS BY EMISSION OF RADIATION.
- OPTICAL RESONATOR CAUSES STIMULATION OF DECAY EMISSION AND FORMATION OF COHERENT BEAM.
- LASANT OPTIONS: GASES, LIQUIDS, SOLIDS
- PUMPING OPTIONS: ELECTRICAL, OPTICAL, CHEMICAL, GAS DYNAMIC

FREE-ELECTRON LASER

- LIGHT EMISSION BY INTERACTION OF A RELATIVISTIC ELECTRON BEAM WITH AN ALTERNATING MAGNETIC FIELD. ELECTRON BEAM CAN BE CONSIDERED A "NON-EQUILIBRIUM EXCITED STATE."

LASER OPTIONS - FIRST SCREENINGS

A wide variety of laser systems exist. In fact it has been said that almost anything can be made to laze. Of the better known types of lasers, three were selected for analysis and several others rejected for the reasons stated on the facing page.

LASER OPTIONS FIRST SCREENING

OPTION	SELECTED BECAUSE	REJECTED BECAUSE
GLASS OR RUBER LASERS		LOW EFFICIENCY; MASSIVE
CHEMICAL LASERS		NOT SUITED FOR STEADY-STATE OPERATION
EXCIMER LASERS		LOW EFFICIENCY
SOLID-STATE LASERS		LOW POER PER DEVICE; LOW VOLTAGE; COMPLEXITY
GAS DYNAMIC LASERS		LOW EFFICIENCY & MASSIVE
GAS ELECTRIC DISCHARGE LASERS	POTENTIAL FOR HIGH POWER AND FAIR EFFICIENCY	
GAS OPTICALLY-PUMPED LASERS	ELIMINATION OF SOLAR ARRAY	
FREE-ELECTRON LASER	POTENTIAL FOR HIGH POWER AND GOOD EFFICIENCY	

GAS LASER OPTIONS

Carbon dioxide and carbon monoxide gas lasers may be pumped either directly by sunlight or using an electric discharge. Gas dynamic pumping is also possible, but was eliminated from consideration as stated on the previous chart. The CO lasers operate on a series of lines in the 5 m wavelength range. The bare efficiency of CO lasers, i.e., the light output divided by electric discharge power input to the gas, can be quite high. System efficiency estimates include parasitic loads, such as gas pumping, thermal radiator fluid circulation, and other penalties. A further discriminator exists in propagation effects. The CO laser suffers substantial absorption by water vapor bands in the atmosphere. The CO_2 laser wave length is long enough to escape most of the absorption. If an isotope laser is used to shift the wave length away from the CO_2 atmosphere absorption band, quite high propagation efficiencies can be achieved in clear weather. A final consideration is lasing temperature. For the CO laser to reach high efficiency, it must operate at a low lasing temperature whereas the CO_2 laser can operate at near room temperature.

GAS LASER OPTIONS

- SOLAR PUMPED OR ELECTRIC DISCHARGE

	CO	CO_2
WAVELENGTH	~ 5 μM	~ 10 μM
EFFICIENCY (BARE)	~ 50%	~ 25%
ELECTRIC DISCHARGE SYS EFF'Y	~ 85%	~ 85%
SOLAR-PUMPED SYS EFF'Y	~ 60%	~ 30%
PROPAGATION	~ 55%	~ 90%
LASING TEMPERATURE	60-80 K	300 K

LASER POWER LINK CHARACTERISTICS - CO VERSUS CO_2

The facing page provides additional information on the transmission effectiveness for various locations and for various numbers of receiving sites. The statistics for numerous receiving sites assumes that the sites are far enough apart such that the cloud cover is not statistically correlated. This ordinarily will require separation of well over hundred kilometers. The average transmission given is for vertical transmission. For the typical slant range of the SPS, the transmission will be on the order of 10 percentage points less for the 60% efficient CO laser lines and 1-2 percentage points less for the high efficiency isotopic CO_2 lines.

LASER POWER LINK CHARACTERISTICS: CO vs CO_2

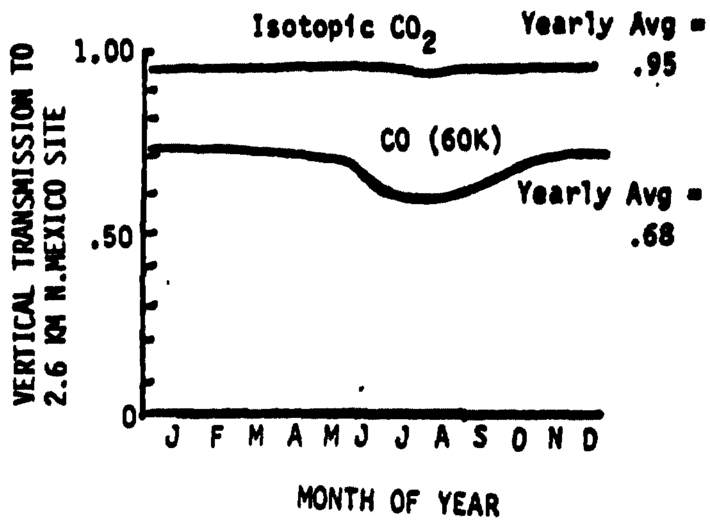
NOTE: BEST SITES ASSUMPTION -
ARID, 2.6 KM ALTITUDE SITE (TYPICAL OF GOOD LOCATIONS IN NEW MEXICO + NEVADA)

- CLOUD COVER

NUMBER OF RECEIVING SITES	AVERAGE YEARLY AVAILABILITY
1	.65
2	.878
3	.957
4	.985

- ATMOSPHERIC TRANSMISSION

Laser Type	Lasant	Receiver Altitude	Vertical Yearly Avg. Transmission
Non-Isotopic CO_2	N.A.	2.6 km	.56
Isotopic CO_2	N.A.	2.6 km	.95
"	N.A.	1.3 km	.90
CO	60 K	2.6 km	.68
CO	70 K	2.6 km	.67
CO	80 K	2.6 km	.56

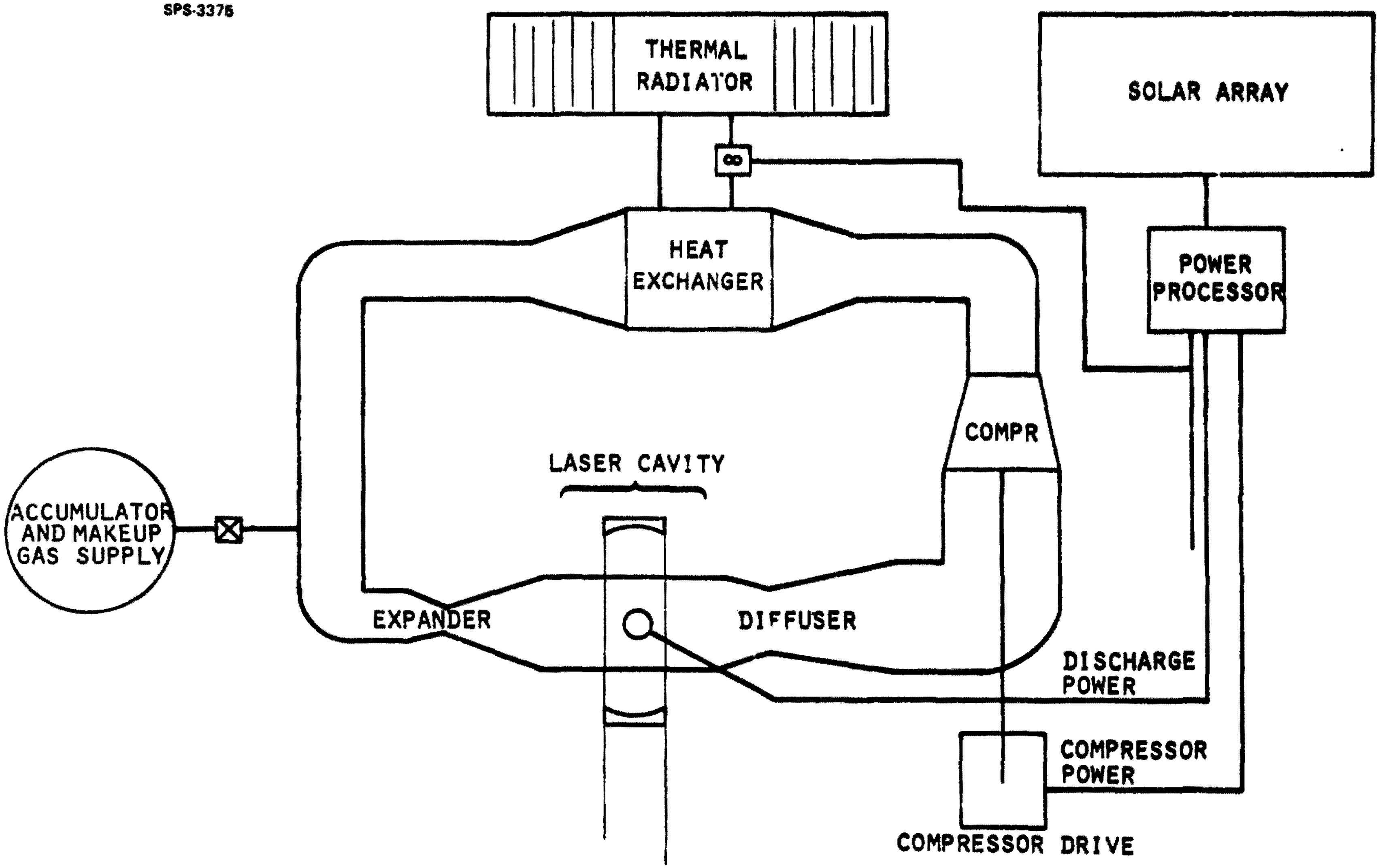


- PATH INCLINATION DERATING $T(\Theta) \approx [T(0)]^{\sec\theta}$

ELECTRIC DISCHARGE LASER SCHEMATIC

The electric discharge laser requires a gas loop to circulate gas and provide some refrigeration, a laser cavity including optics and the electric discharge equipment to pump the gas, a heat exchanger and thermal radiator system for waste heat removal, a solar array and power processor to provide power to the systems, and, finally, an accumulator and makeup gas supply to supply any makeup gas required due to leakage. In the schematic shown on the facing page, it is assumed that the gas flow through the laser cavity is supersonic. Subsonic lasers can also be constructed.

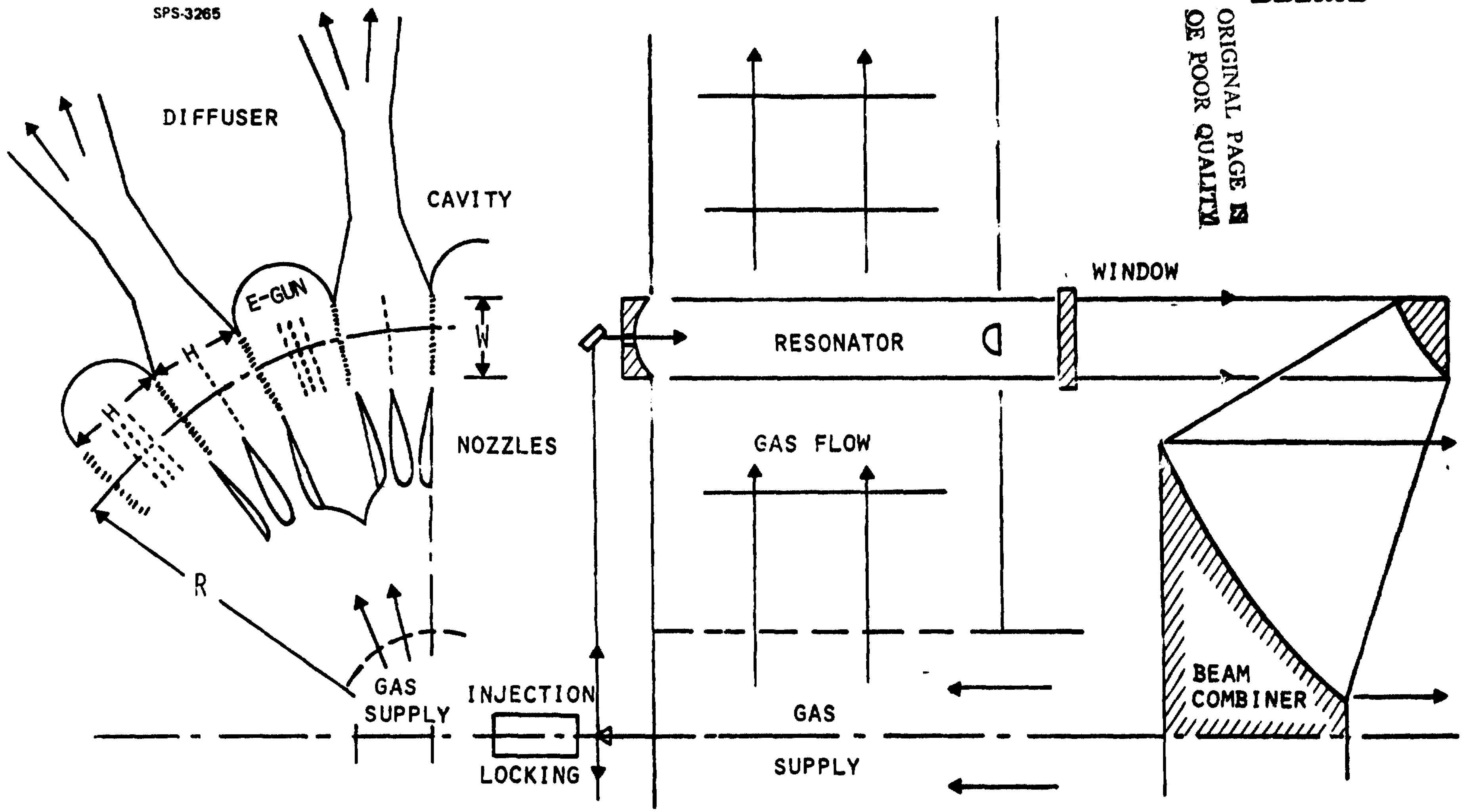
ELECTRIC DISCHARGE LASER SCHEMATIC



ELECTRICAL DISCHARGE LASER CONFIGURATION FOR SPS

The illustration on the facing page shows how the lasers would actually be grouped together and combined to form a single beam of the desired power level. In this configuration, the gas flow through the multiple laser cavities is radially outward.

ELECTRICAL DISCHARGE LASER CONFIGURATION FOR SPS



CO REFRIGERATION

Because of the severe radiator mass penalties associated with low temperature radiation, it is important to provide a degree of refrigeration, especially for the CO systems or the lasent must be in the range 60K to 80°K. Two options exist: first, a supersonic flow laser as illustrated earlier; and second, the use of a refrigeration machine to provide a low circulating gas temperature in a subsonic laser system.

CO REFRIGERATION

- o SUPERSONIC FLOW

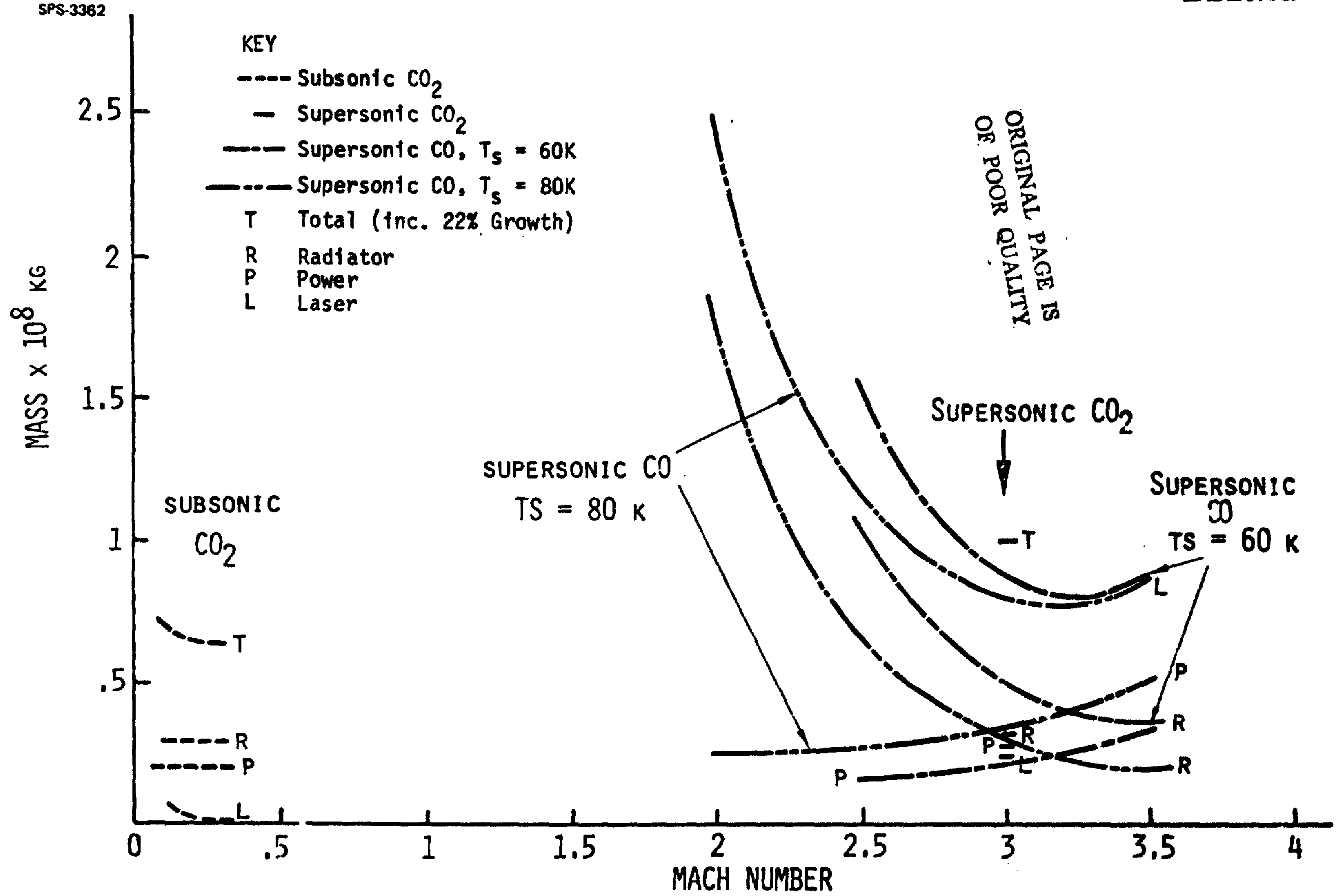
- o REFRIGERATION MACHINE

1 GIGAWATT ELECTRIC DISCHARGE LASER - MASSES VERSUS MACH NUMBER

The various laser flow option system masses were parameterized as a function of Mach number in the laser cavity region. Subsonic CO_2 lasers may be reasonably competitive because of the relatively high lasant temperture. For CO lasers, supersonic flow is essential. The tradeoff between pumping power and radiator temperature reaches a minimum at a Mach number slightly in excess of 3.

1 GW EDL LASER SPS MASSES VS MACH NUMBER

SPS-3362

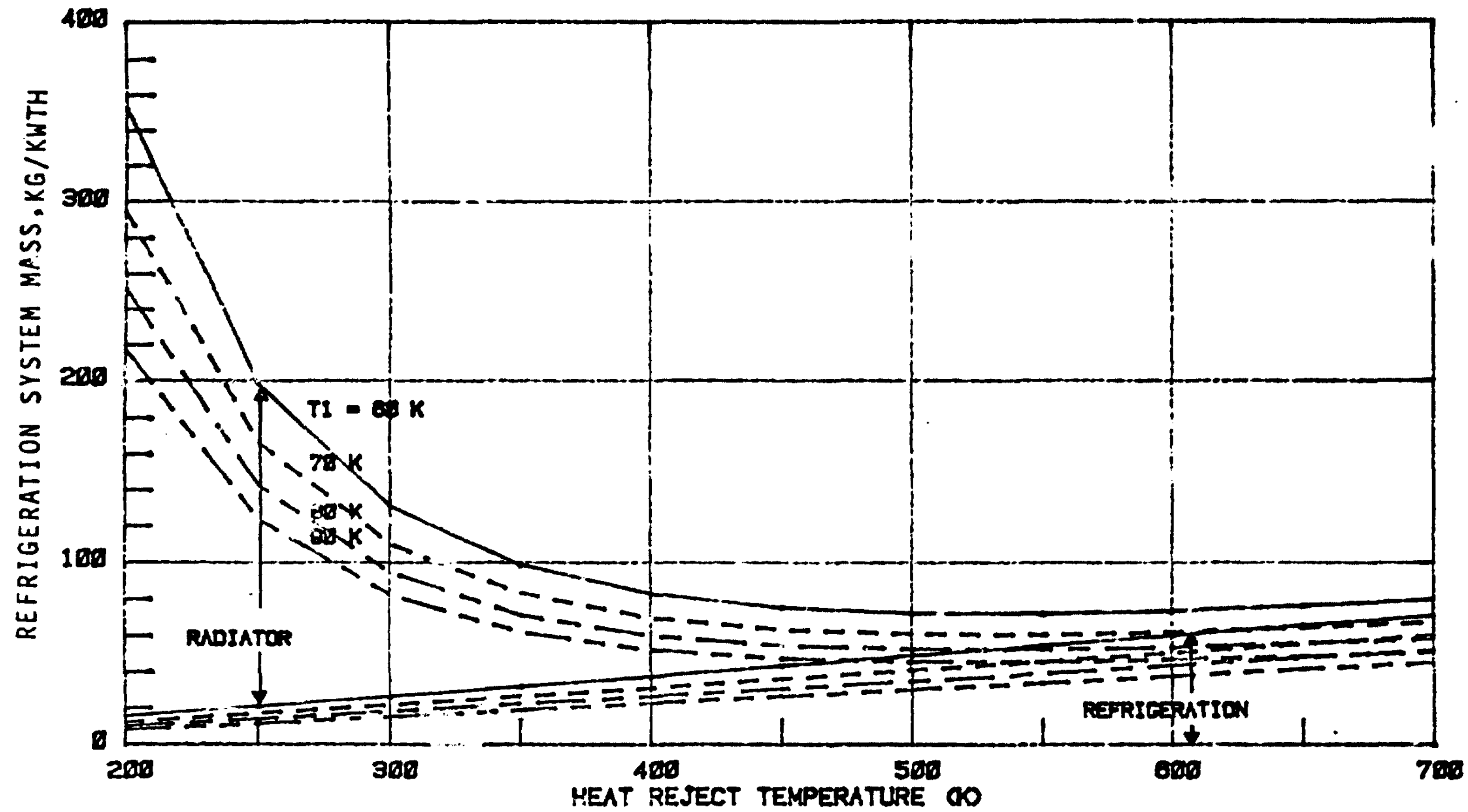


LASER REFRIGERATION OPTIMIZATION

For the CO laser, if one uses a refrigeration machine with subsonic flow, one finds an optimum at a heat reject temperature of about 500°K. Because of the refrigeration power, the heat rejection system actually rejects about 10 times as much heat as is generated in the laser itself. Thus the refrigeration option is more massive than the supersonic flow option because in the supersonic flow instance the situation in the laser cavity is not an equilibrium thermodynamic state and one does not actually pump heat from the low lasant temperature.

LASER REFRIGERATION OPTIMIZATION

SPS-3254



ELECTRIC DISCHARGE GAS LASER RESULTS

A summary of the findings for the electric discharge gas lasers is presented. The main finding is that because of their generally low radiator temperatures they have large and massive radiators that compound the mass and cost multipliers caused by their low (circa 20%) efficiencies.

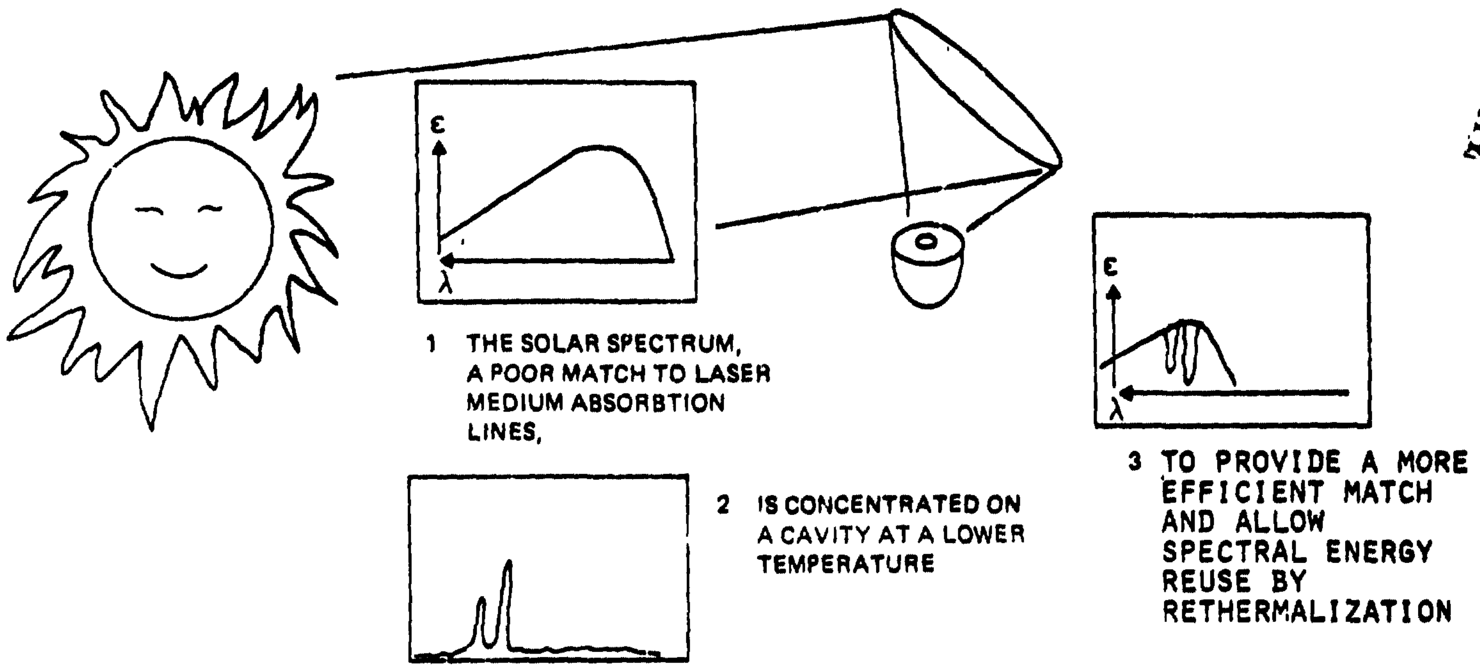
ELECTRIC DISCHARGE GAS LASER RESULTS

- VERY MASSIVE
- LOW EFFICIENCY
- PUMPING MACHINERY & OTHER COMPLEXITY
- STRONG TECHNICAL BASE
- LOW ABSORPTION WITH CO_2 ISOTOPE
- COULD IMPROVE MARKEDLY WITH NOVEL THERMAL RADIATOR

INDIRECT OPTICALLY PUMPED LASER PRINCIPLES

Optical pumping of lasers occurs on relatively narrow resonance lines at which the lasant absorbs energy to raise it to the excited state. If sunlight is concentrated directly upon a lasant, the laser absorbs the solar spectrum only on those resonant lines and the efficiency of utilization of sunlight is very low, typically less than 1%. Selective concentrators have been suggested as a way to make a reasonable directly pumped optical laser, but with realistic concentrator masses, this option is quite unattractive. By employing a cavity absorber to rethermalize the solar spectrum in the infrared range, a more efficient match to the absorption lines of CO or CO_2 may be provided and because of continuous energy exchange between wave lengths in a thermal cavity, efficient absorption of the solar energy by the lasent is possible. This is called the indirectly optically pumped laser.

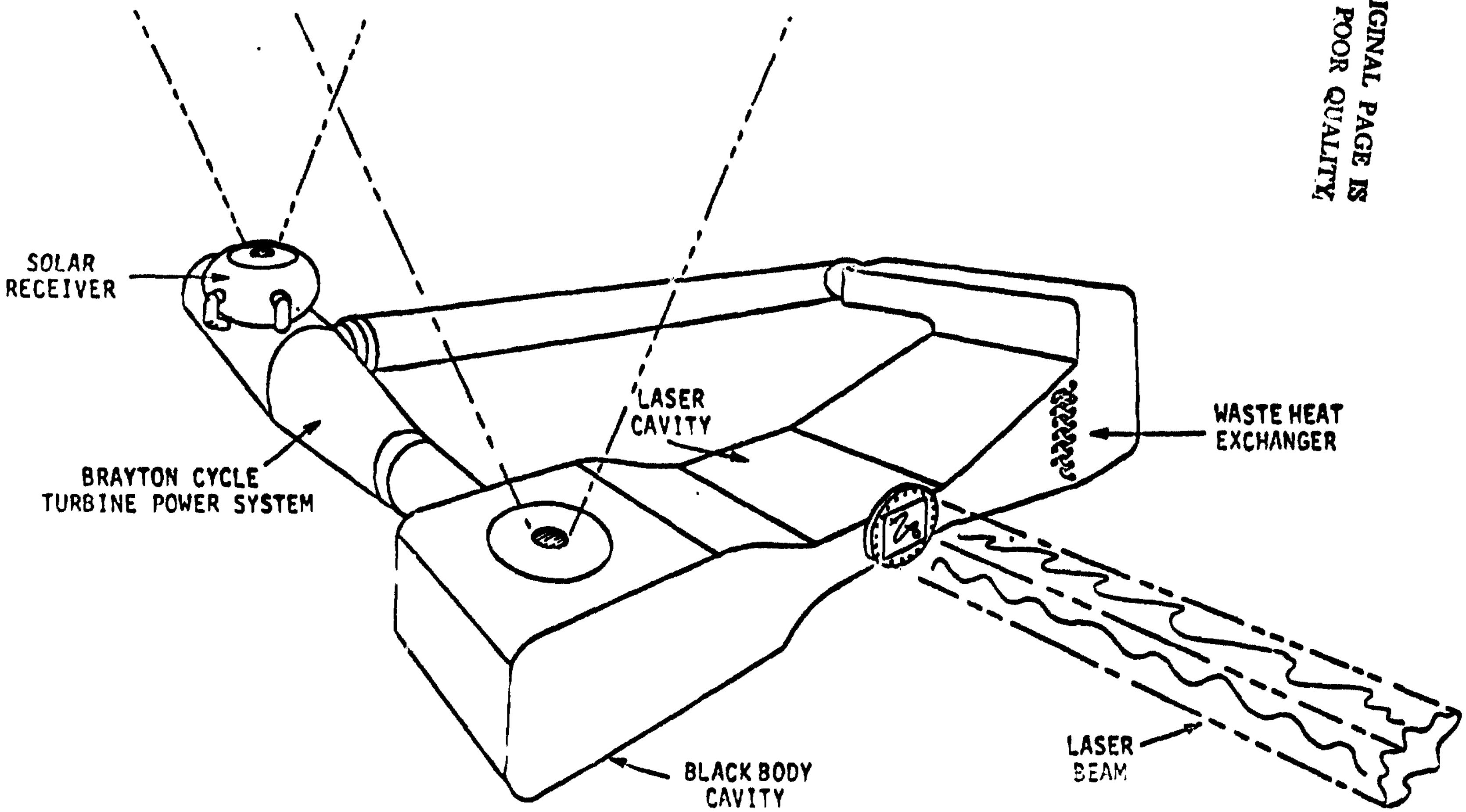
INDIRECT OPTICALLY PUMPED LASER PRINCIPLES



CO SOLAR PUMPED LASER

A cycle schematic for the indirect optically pumped laser is illustrated here. Like the electrically discharged laser, a circulating gas loop is used with a laser cavity, a heat exchanger, and a pumping system. Pumping power may be derived either from a solar array or from a thermal powered loop. For the configuration selected, it makes sense to use a thermal power loop to avoid a rotary joint system for getting electric power to the laser system.

CO SOLAR PUMPED LASER

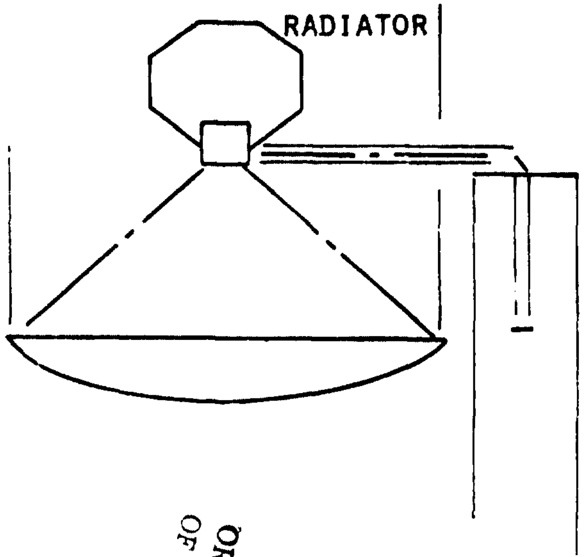


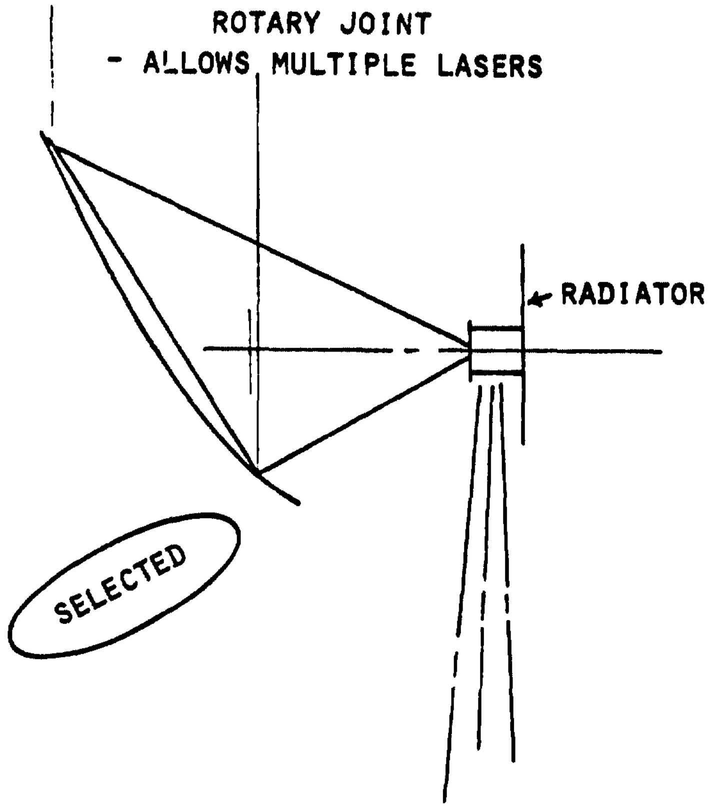
INDIRECT OPTICALLY PUMPED LASER CONFIGURATION OPTIONS

As is the case for microwave systems, a rotary joint between the sunlight collected by the SPS and the powered beam sent down by the SPS is necessary. In the case of the optically pumped laser, this rotary joint may be an optical/mechanical rotary joint. The two options are use of an optical rotary joint for the incoming sunlight or for the outgoing laser power. Geometric considerations limit the number of lasers to two for a case using a laser optical rotary joint. Since the solar pumped lasers may be limited in power to a few megawatts, the concentrator optical rotary joint was selected since this allows as many lasers as one may wish to have attached to the cavity which is then fixed with respect to earth pointing.

IOPL LASER OPTIONS

(NOT TO SCALE)



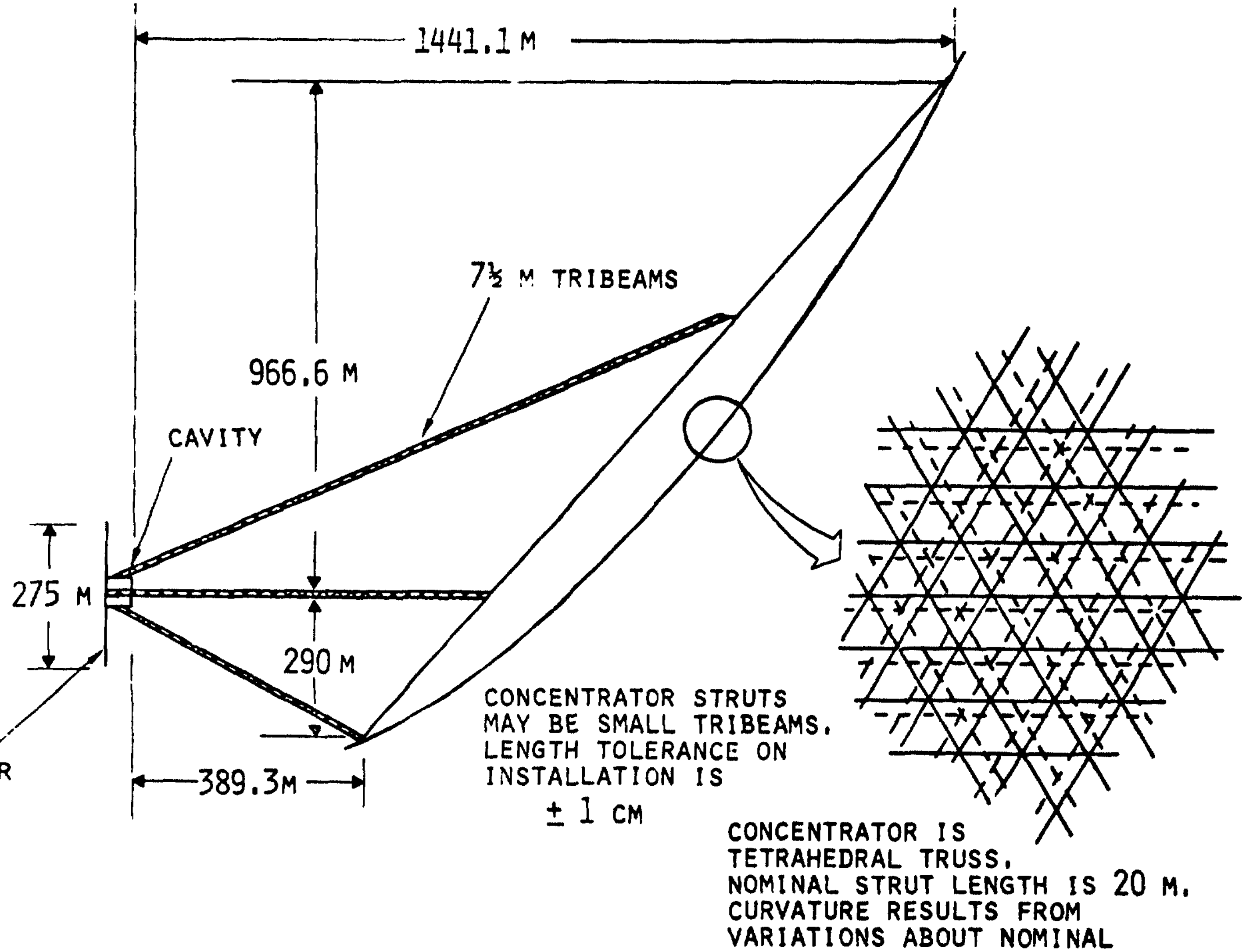


INDIRECTLY OPTICALLY PUMPED LASER SPS GENERAL ARRANGEMENT

Based on the preceding considerations, a general configuration was developed as illustrated in order to carry out a construction analysis. This configuration was sized for a light input to the thermal cavity of approximately 1 gigawatt with an estimated output of between 100 and 200 megawatts of laser light power. The concentrator itself is a segment of an off-axis parabaloid. It is made of a tetrahedral truss graphite structure with the length of each truss member selected to provide the required curvature. Based on earlier studies of achievable mechanical precision of such structures, it appears that the reflector surface of aluminized kapton could simply be stretched between the structural elements so that individually adjustable pointable facets are, strictly speaking, not required. However, for a conservative approach to the analysis here individually controlled, hex faceted reflectors like those proposed for the earlier Boeing solar thermal power satellite are baselined.

INDIRECTLY OPTICALLY PUMPED LASER SPS GENERAL ARRANGEMENT

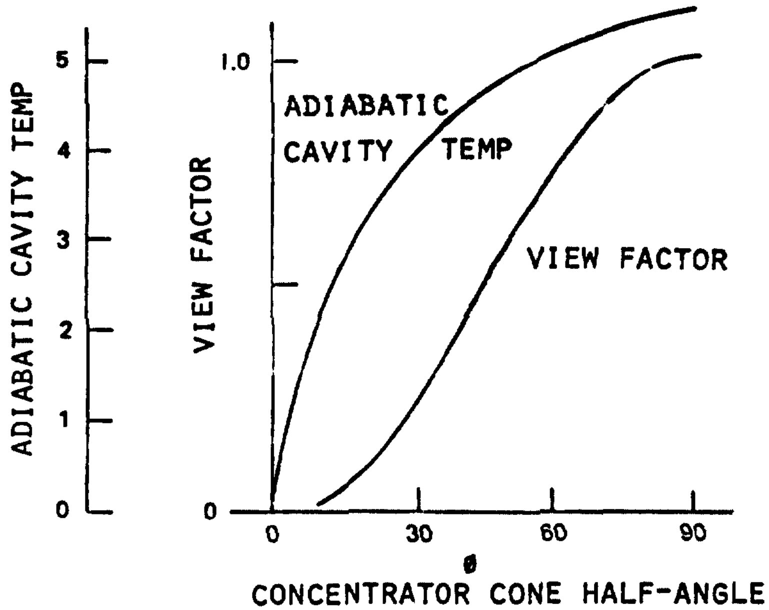
SPS-3240



CAVITY SOLAR IMAGED VIEW FACTOR AND WALL TEMPERATURE AS A FUNCTION OF CONE ANGLE

As one increases the sunlight concentrator cone angle of sunlight concentrated into the caivity, the apparent view factor from the cavity of the solar surface temperature increases to a figure approaching 1 or a concentrator cone half angle of 90°. Given a view factor, one may calculate an adiabatic cavity temperature one which would be reached if no energy were extracted from the cavity. Efficiency considerations dictate an adiabatic cavity temperature on the order of twice the operating temperature with heat extraction. Math Science Northwest has estimated a desirable operating temperature of about 1750K. This leads to an adiabatic temperature of about 3500K and suggests a concentrator half angle on the order of 30 to 35°. A figure of 0.6 radians, approximate 35°, was selected for configuration analysis.

CAVITY SOLAR IMAGE VIEW FACTOR AND WALL TEMPERATURE AS A FUNCTION OF CONE ANGLE

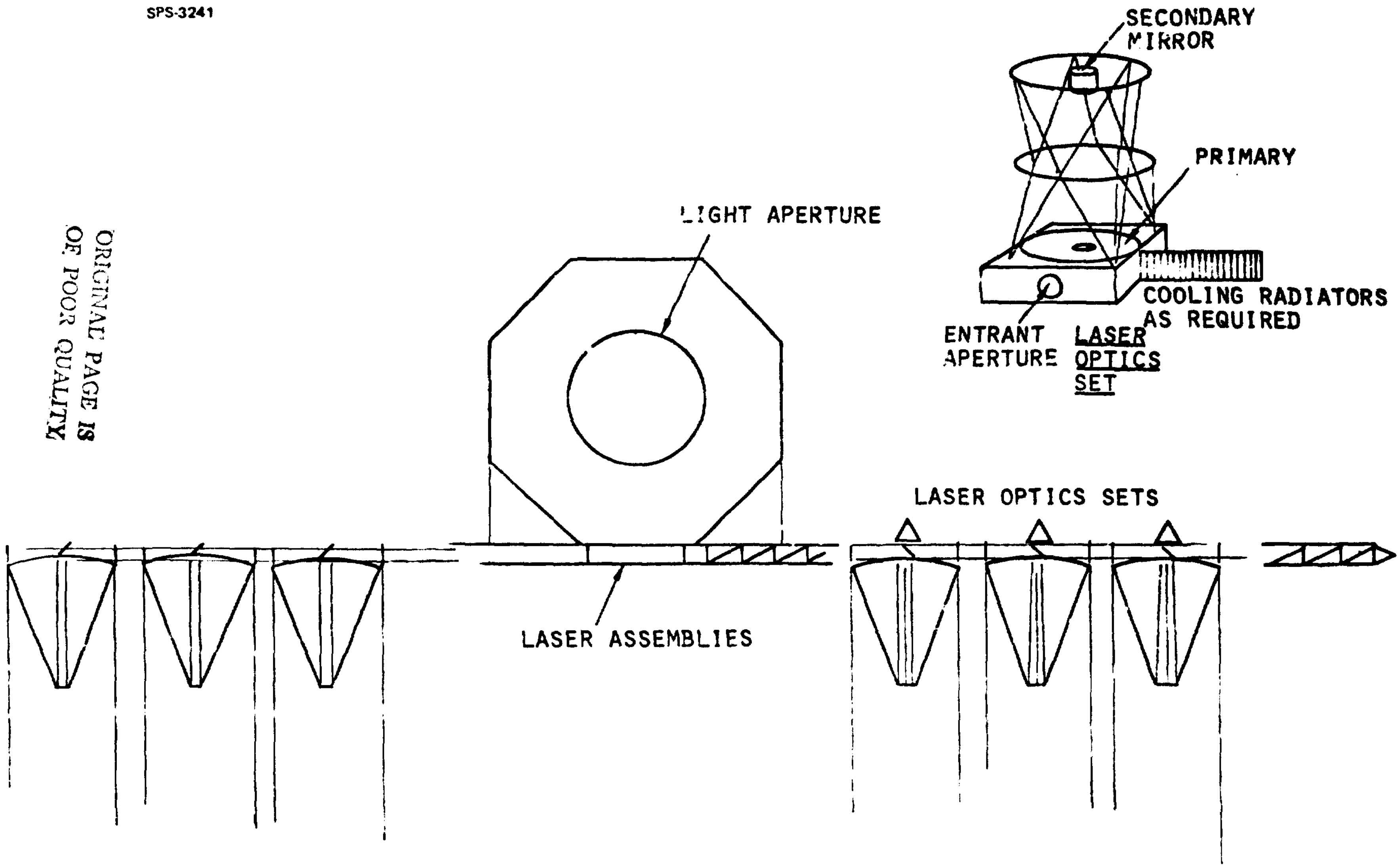


INDIRECTLY OPTICALLY PUMPED LASER SPS CAVITY AND LASER ARRANGEMENT

On the facing page is illustrated the contemplated arrangement of lasers and laser telescopes in order to provide multiple laser power beam transmission from the optically pumped laser satellite. It is essential to keep the laser gas circuit and cavity assemblies as close to the aperture as possible in order that lasant pumped in the cavity can be circulated immediately to the optical laser cavity before it depopulates.

The telescope assemblies use turning mirrors to turn the laser light toward the Earth. The laser telescopes must be articulated in order to accommodate the seasonal movement of the Sun as the laser satellite with its concentrator must be flown perpendicular to the ecliptic plane rather than perpendicular to the orbit plane as is done with the reference microwave systems.

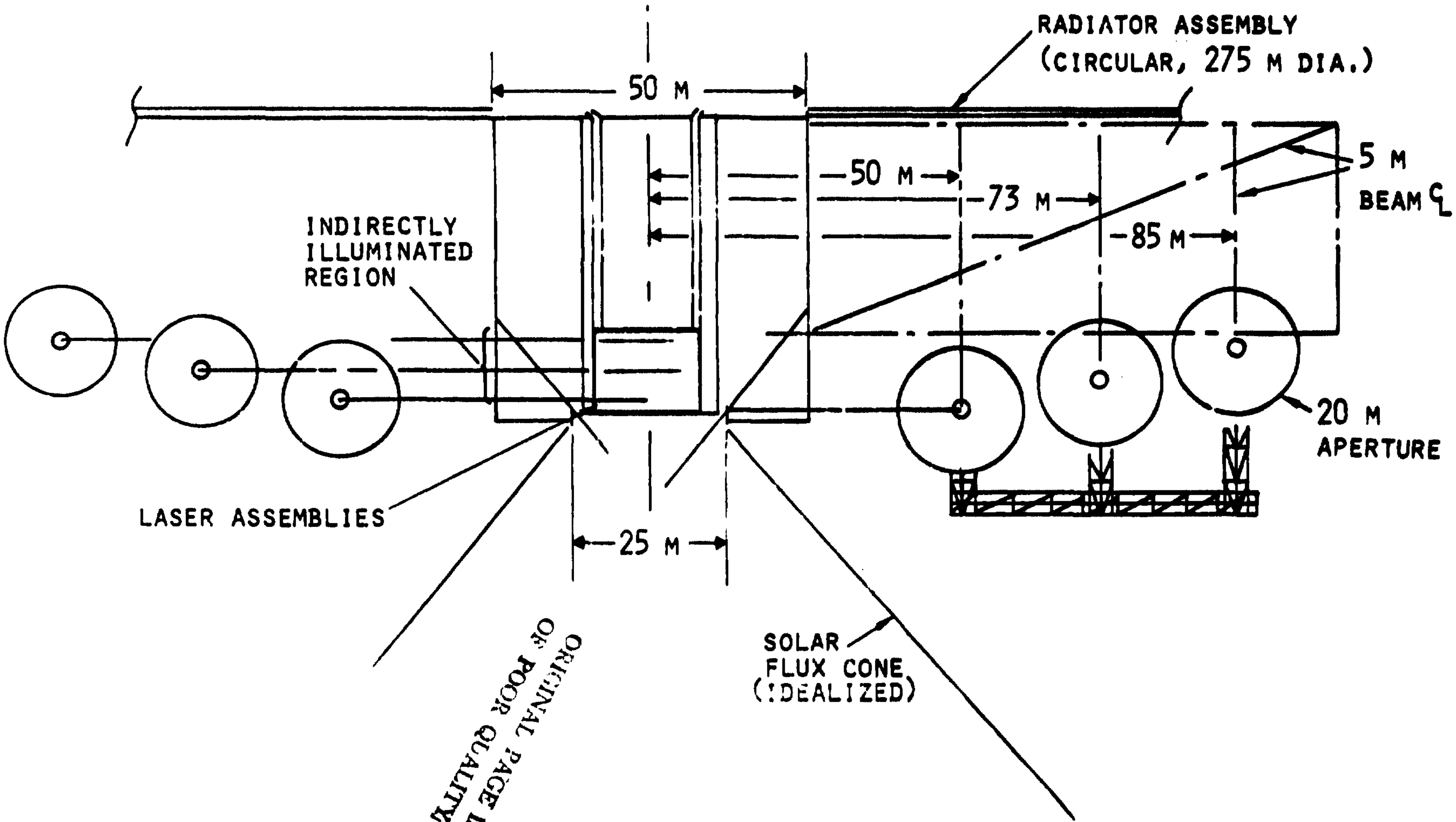
INDIRECTLY OPTICALLY PUMPED LASER SPS CAVITY AND LASER ARRANGEMENT



'NDIRECTLY OPTICALLY PUMPED LASER SPS CAVITY AND LASER ARRANGEMENT

The other view of the arrangement shown on the previous chart is presented here.

INDIRECTLY OPTICALLY PUMPED LASER SPS
CAVITY AND LASER ARRANGEMENT



INDIRECT OPTICALLY PUMPED LASER SPS CONSTRUCTION REQUIREMENTS & ISSUES

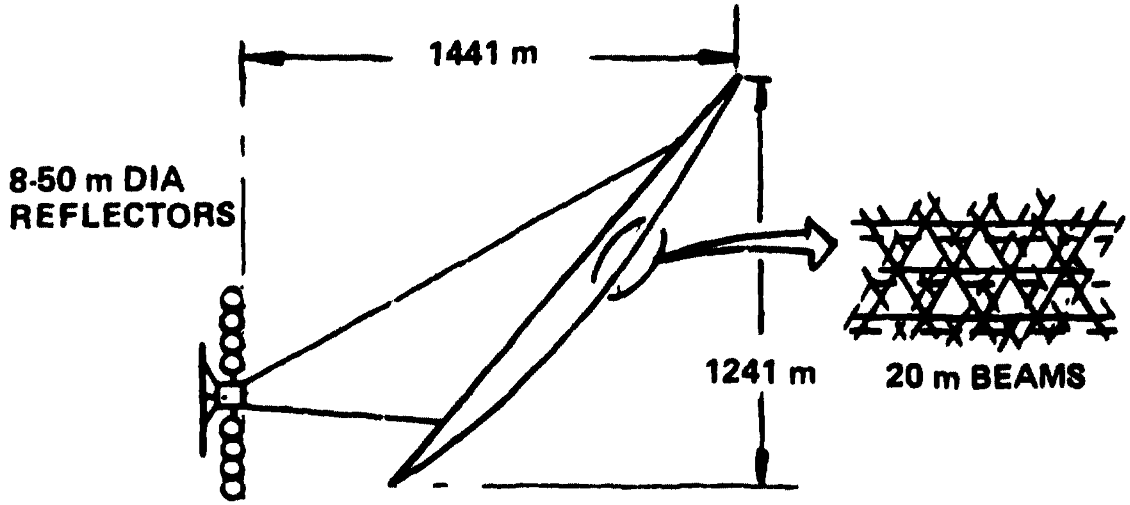
The 100 MW Indirect Optically Pumped Laser (IOPL) Solar Power Satellite (SPS) is to be constructed entirely in GEO and is to be assembled in accordance with the major groundrules and constraints for the reference construction base wherever possible. That is, to use contiguous assembly facilities, operate two 10-hour/shifts/day at 75% efficiency, and so on, appears reasonable. The 10 GW annual production goal however, may be inappropriate for the 100 MW power category.

The IOPL-SPS features an off-axis parabolic concentrator with a black body cavity, radiator, and eight laser reflectors as defined by recent Boeing data. The solar concentrator is designed with a tetrahedral structure and is assumed to be covered with adjustable reflective facets similar to those used on early solar thermal SPS concept (Refer to Report D180-20689-3).

As in the reference SPS, a broad range of technology issues (most of which are beyond the scope of this study) must be addressed to cover all aspects of the laser SPS construction process. If this concept is to be studied further, the satellite construction approach must be reexamined for the solar concentrator, laser 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 assembling and installing the major subsystems (i.e., facets, lasers, bases reflectors and radiators) 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.

INDIRECT OPTICALLY PUMPED LASER SPS CONSTRUCTION REQUIREMENTS & ISSUES

- 10 GW ANNUAL CONSTRUCTION GOAL ?



- IOPL-SPS CONCEPT INFORMATION (BOEING DATA FAX No. 24 ON 3/14/80 & NO. 39 ON 3/18)

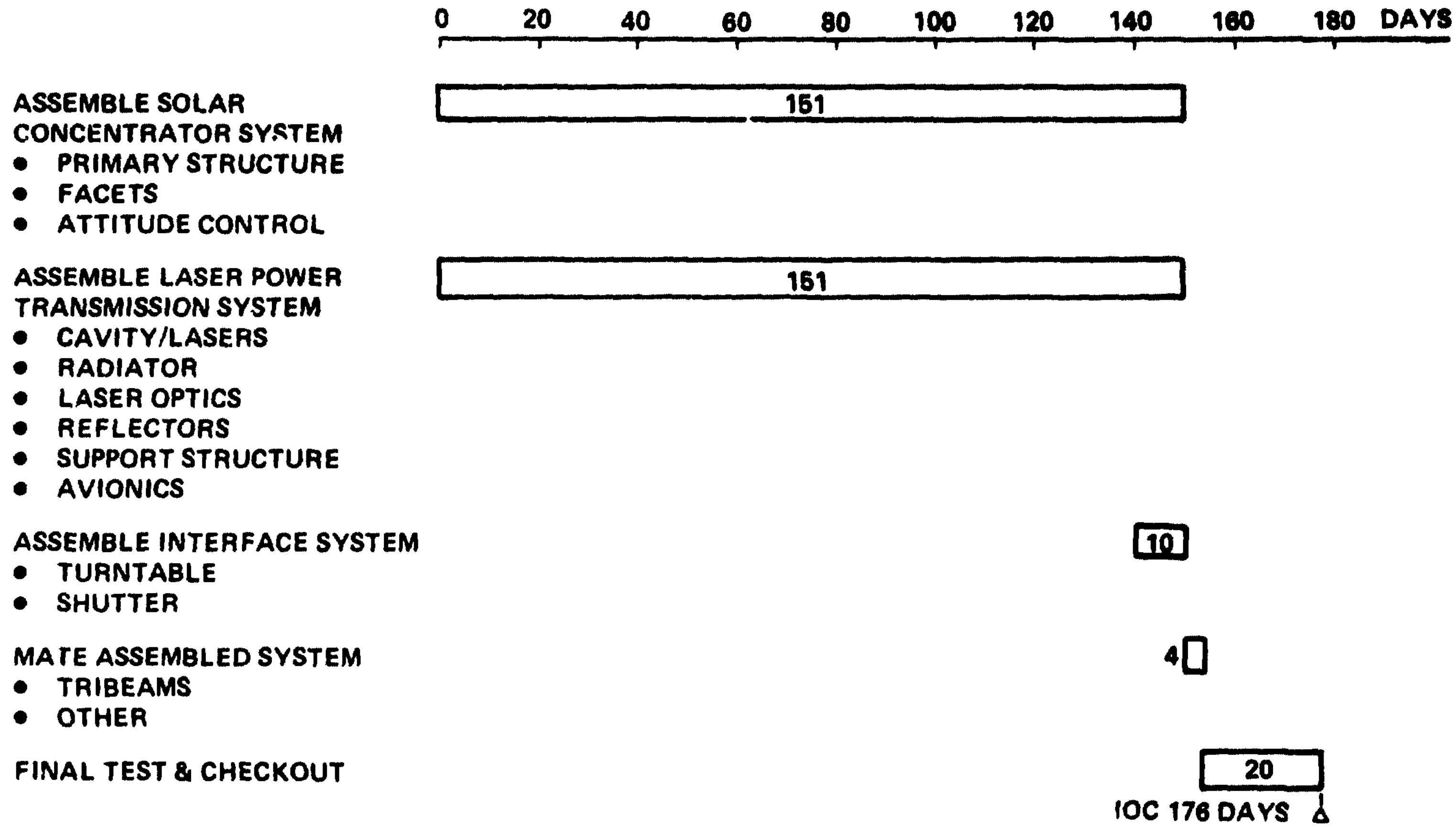
- LASER SPS CONSTRUCTION ISSUES
  - SATELLITE CONSTRUCTION APPROACH
  - STRUCTURAL ASSEMBLY METHODS
  - SUBSYSTEM INSTALLATION TECHNIQUES
  - CONSTRUCTION EQUIPMENT REQMTS
  - SATELLITE SUPPORT & BASE INTERACTIONS
  - HANDLING & MATING LARGE SYSTEM ELEMENTS
  - IN-PROCESS INSPECTION & REPAIR
  - FINAL TEST & CHECKOUT

0580-036W

INDIRECT OPTICALLY PUMPED LASER SPS CONSTRUCTION TIMELINE

The timeline for constructing the 100 MW IOP Laser SPS is shown on the facing page. As in the reference system, it features parallel assembly of the solar concentrator system and the laser power transmission system. The interface system is constructed as needed for final systems mating. The times for interface assembly, systems mating, and final test and checkout are assumed to be the same as the reference system. However, the longer time shown for assembling the two major systems was determined from analysis of concentrator assembly operations.

INDIRECT OPTICALLY PUMPED LASER SPS CONSTRUCTION TIMELINE



GRUMMAN

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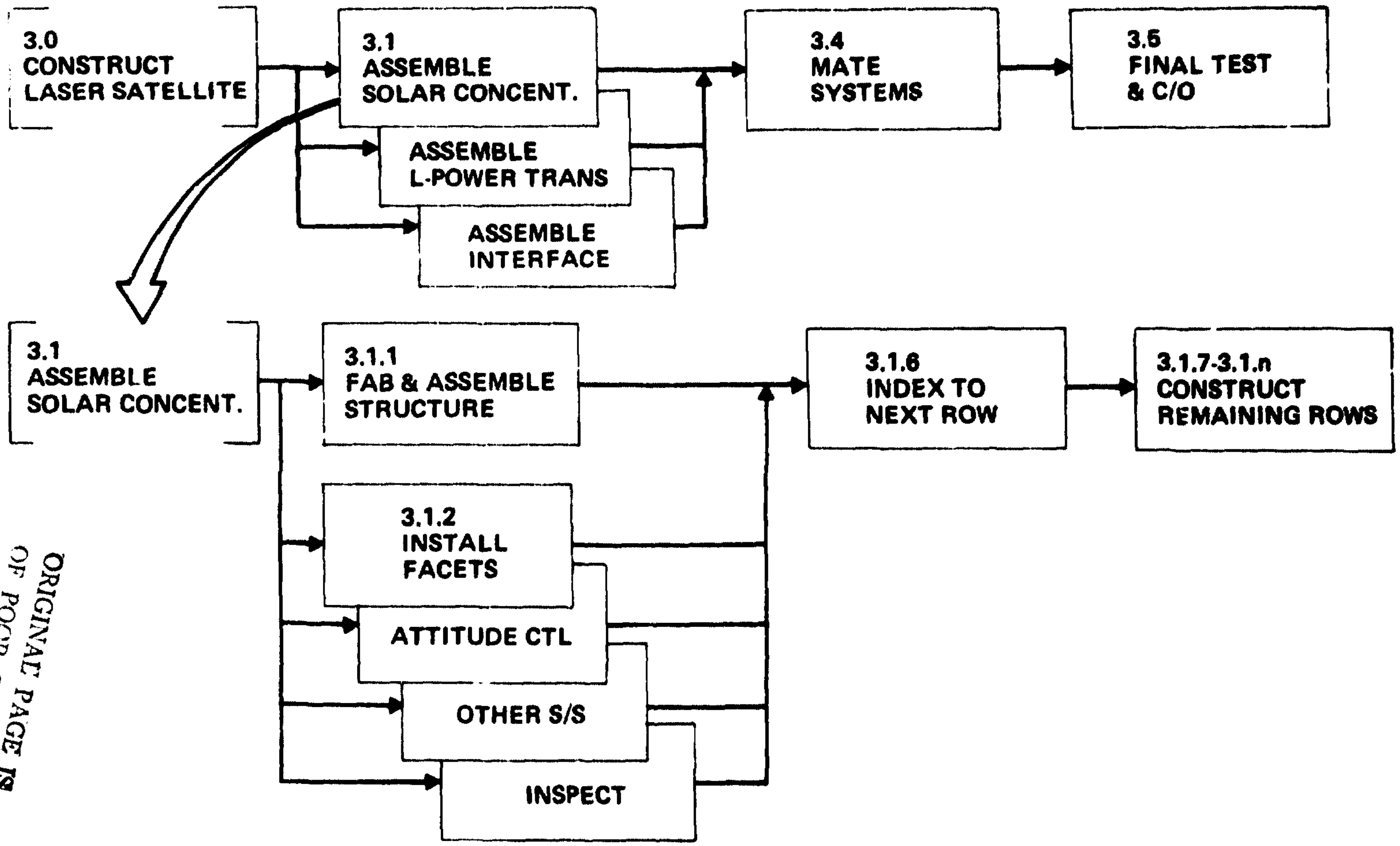
LASER SPS CONSTRUCTION OPERATIONS ANALYSIS

Construction of the 100 MW IOP Laser SPS follows the same sequence as the reference 5 GW Microwave SPS. The construction operations for the solar concentrator system received the major emphasis and were analyzed from the top down.

A breakdown of the assembly operations for the Laser SPS Solar Concentrator system is shown by the abbreviated flow illustrated on the lower half of the facing page. This assembly activity includes the fabrication and assembly for the first row of primary structure (3.1.1). It also includes the parallel installation and inspection of other subsystems during the construction process. These subsystems include the installation of facets (3.1.2) attitude control, etc. When each row is assembled, the concentrator is indexed (3.1.6) away to allow the second row to be added. The remaining rows of the concentrator are constructed in a like manner.

LASER SPS CONSTRUCTION OPERATIONS ANALYSIS



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IOP LASER CONCENTRATOR ASSEMBLY OPTIONS

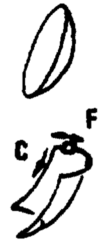
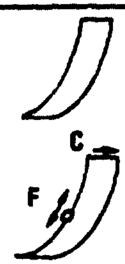
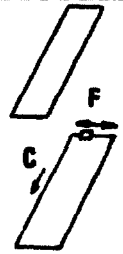
This SPS system definition calls for a concentrator with the shape of an offset paraboloid segment. To build this shape with maximum repeatability requires a facility indexing along a parabolic curved track, building as it goes a row of varying geometry structural bays assembled from beams of varying lengths. At completion of a row, the structure is indexed outboard, ready for assembly of the next row. Each row is repeatable but owing to the variation in beam lengths, as much as 50% above or below the 20 m nominal, the assembly facility must be large enough to handle beams up to 30 m long. Indexing the paraboloid shape structure as it is built, requires curved support arms, each of which is a different radius from another. Steerable facets, which provide the reflective surface, are mounted to primary structure node points but, due to the varying geometry of structural units, the nodes do not provide a regular pattern. Therefore, to minimize concentrator surface, the facets must vary in size to match the node pattern. An alternate is to provide a secondary structure which provides regular pattern mounting points for constant size facets. Concentrator area is the minimum necessary.

Since steerable facets will be used in any event to provide the parabolic reflective surface, then a more simply built structure on which to mount them can be considered. A segment of a sphere which approximates the paraboloid segment can be built by a facility indexing along a circular track to follow the same construction procedure as the paraboloid. Here, however, support arms for the indexing concentrator have the same radius. Variation in primary structure beam length is ±10%, much less than the parabolic structure. The structure bay varies progressively in geometry over half of one row then reverses the variation over the remainder of the row. This total variation is repeated for each row. Spherical concentrator structure area must be about 10% larger than a tailored parabolic area since the facets must be spaced to reflect into the paraboloid focus, as shown on the following chart. To keep this area increase to a minimum requires, again, a secondary structure on which to mount constant size facets or no secondary structure but facets varying in size to suit primary structure geometry. An alternate is to use constant size facets but increase the concentrator area to provide the necessary facet mounting points. The construction timeline is affected by the size as well as the variation in structure unit geometry.

Simplifying the construction base even further leads to the other two structural shape options shown on the chart, a parabolic trough and a flat surface. These require up to 40% larger concentrator areas with little reduction in base complexity. One other option is to dispense with the separately mounted, steerable facets and mount reflective sheet directly to the primary structure. This greatly increases the accuracy with which the structure must be built and dictates that it be a segment of a parabola, a much more complex construction operation. This option requires further study.

The selected option is the spherical segment concentrator which uses constant size facets but no secondary structure. Its small area penalty has little impact on production.

IOP LASER CONCENTRATOR ASSEMBLY OPTIONS

	PARABOLOID SEGMENT		SPHERE SEGMENT			PARABOLIC TROUGH			FLAT		
• CONCENTRATOR STRUCTURE SHAPE • CONCENTRATOR INDEXING (F = FACILITY C = CONCENTRATOR)											
• CONCENTRATOR SUPPORT	MULTI-CURVE		SINGLE-CURVE			STRAIGHT			STRAIGHT		
• PRIMARY STRUCTURE – BEAM LENGTH VARIATION (20 m NOMINAL)	~ ± 50%		~ ± 10%			~ ± 10%			NONE		
• SEPARATE FACET SIZE	SAME	VARIED	SAME	SAME	VARIED	SAME	SAME	VARIED	SAME	SAME	VARIED
• SECONDARY STRUCTURE	YES	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO
• CONCENTRATOR AREA INCREASE	NORM	NORM	<10%	10%	<10%	<20%	20%	<20%	<40%	40%	<40%

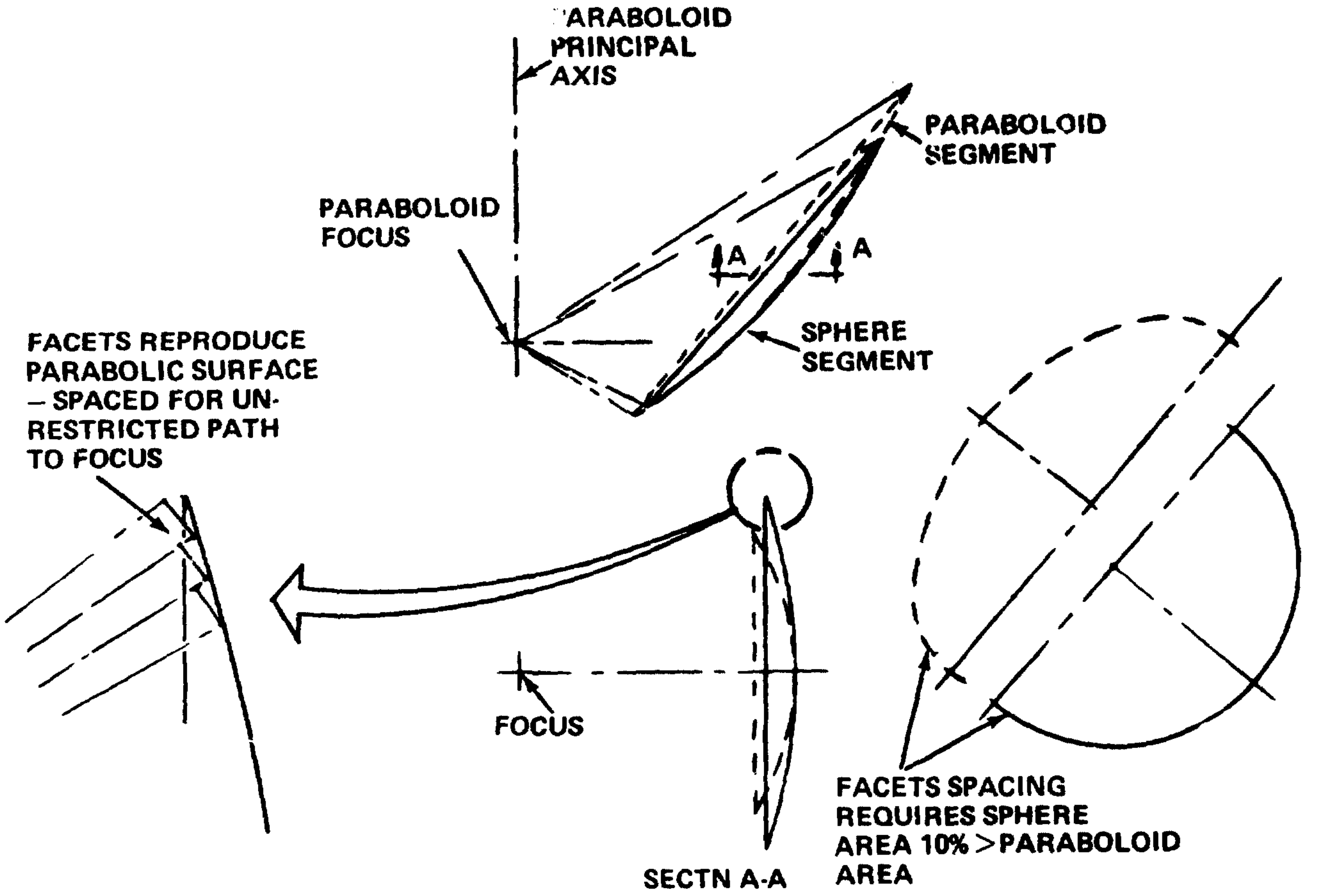
IF FACETS REQD
MINIMAL IMPACT
ON ASSEMBLY FACILITY
& CONCENTRATOR
AREA

0580-060W

PARABOLIC CONCENTRATOR SURFACE MOUNTED ON SPHERICAL SEGMENT

A parabolic surface for the concentrator is provided by separate steerable facets mounted on a spherical segment structure. This figure shows the paraboloid shape (dotted lines) superimposed on a comparable spherical surface (solid lines). In a section through the principal axis of the paraboloid, the surfaces are fairly close in form but in a section normal to the principal axis, they diverge quite a bit either side of a common centerline. This divergence in surfaces requires that the spherical surface be large enough to mount the facets at a spacing which provides unrestricted reflective paths to the parabola focus. The area of the spherical surface is, therefore, larger than the corresponding parabolic surface. The additional area is, of course, a function of the geometries.

PARABOLIC CONCENTRATOR SURFACE MOUNTED ON SPHERICAL SEGMENT



0580-037W

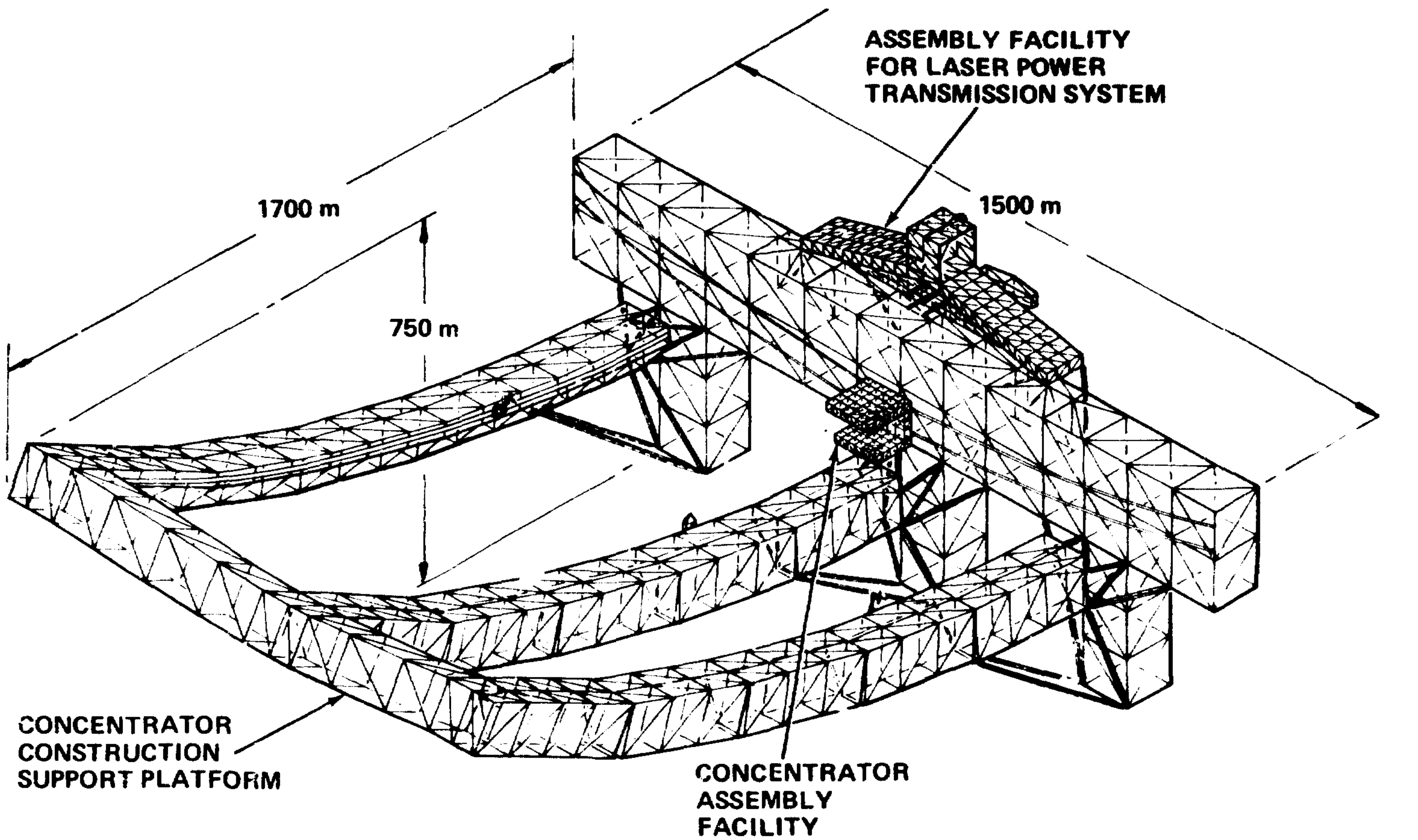
INDIRECT OPTICALLY PUMPED LASER SPS CONSTRUCTION BASE

The largest construction job in this SPS system is to build the concentrator, which has to provide a surface with the shape of an offset paraboloid segment. To provide this surface, steerable facets are mounted to a primary structure which, for ease of construction, is a spherical segment. This concentrator is similar in size to the solid state SPS antenna and it features tetrahedral construction. The construction philosophy for building this concentrator is similar to that of the solid-state antenna in as much as an assembly facility indexes across a platform, building rows of structure and installing facets as it goes. At completion of each row, the completed structure is indexed outboard ready for assembly of the next row. The assembly facility runs on a curved track to provide the spherical shape of the structure. Arms, to support the growing structure, provide curved tracks for indexing supports.

The energy conversion and transmission equipment is built in a facility which is mounted on the concentrator construction base. Here, the laser cavity, radiator, turntable, shutter assembly and the 50 m diameter reflectors with their support structures, are assembled.

For final assembly, the laser power transmission assembly is located in its correct operational position, relative to the concentrator, by an arm pivoted from the base. Struts to join the concentrator to the transmission assembly are then fabricated and installed.

INDIRECT OPTICALLY PUMPED LASER SPS CONSTRUCTION BASE

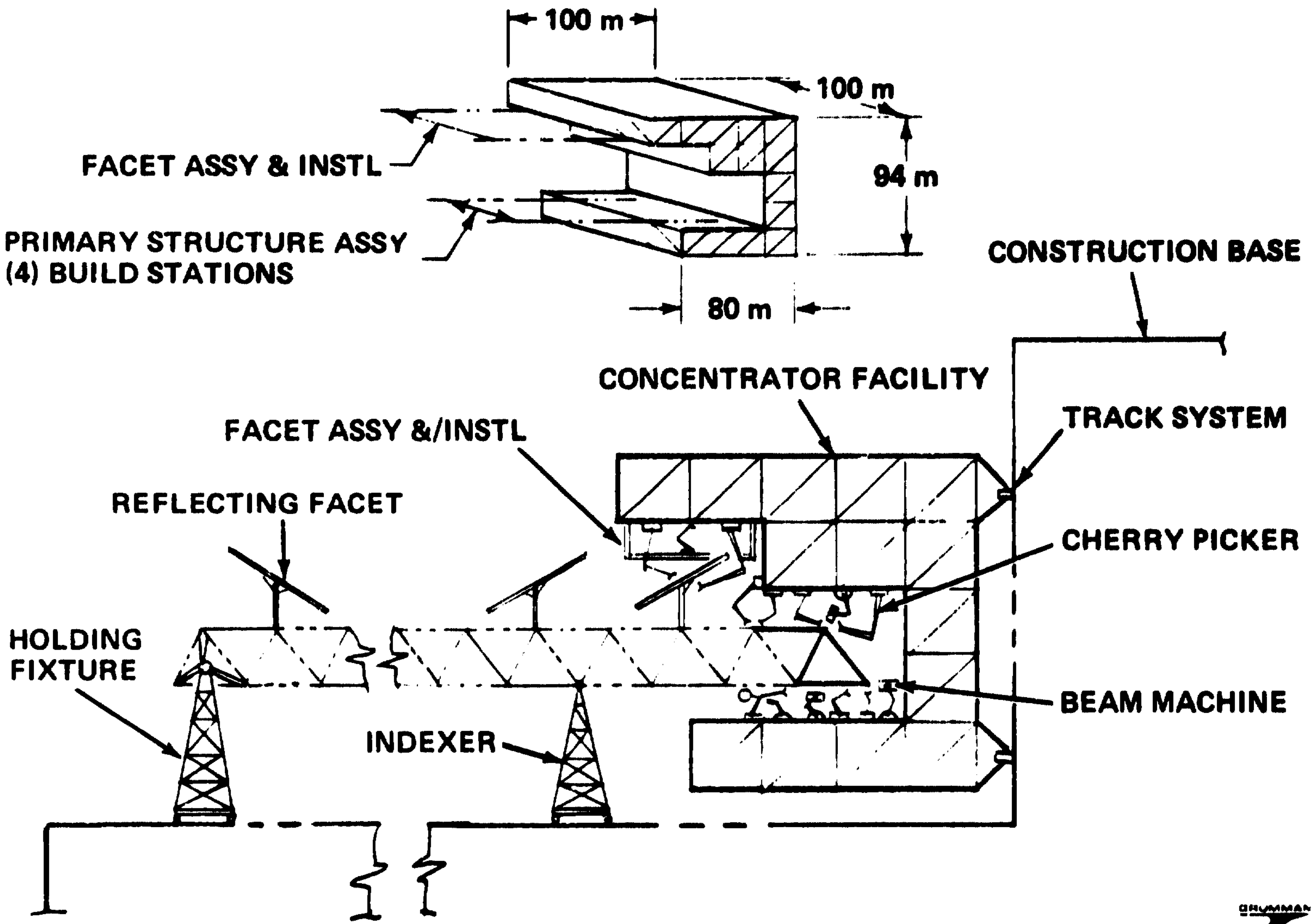


0580-061W

CONCENTRATOR ASSEMBLY FACILITY

The 'C' shaped mobile facility, 94 m high x 100 m wide x 100 m long, is shown mounted to the construction base via an indexing track system which allows the facility to index from side to side to build the rows of structural bays of the spherical shaped concentrator. The assembly facility covers four bays of the concentrator structure and builds in two directions. The inboard low bay area of the facility provides four stations for building the concentrator structure. Located at these stations are 1.5 m beam machines for the fabrication of the structural beams and 30 m cherry pickers for the alignment and assembly of the beams. In parallel with the building of the structure, the concentrator reflecting facets are assembled in the facet assembly station located in the outboard upper high bay of the facility. The facet assemblies are then installed on the completed structural bays.

CONCENTRATOR ASSEMBLY FACILITY



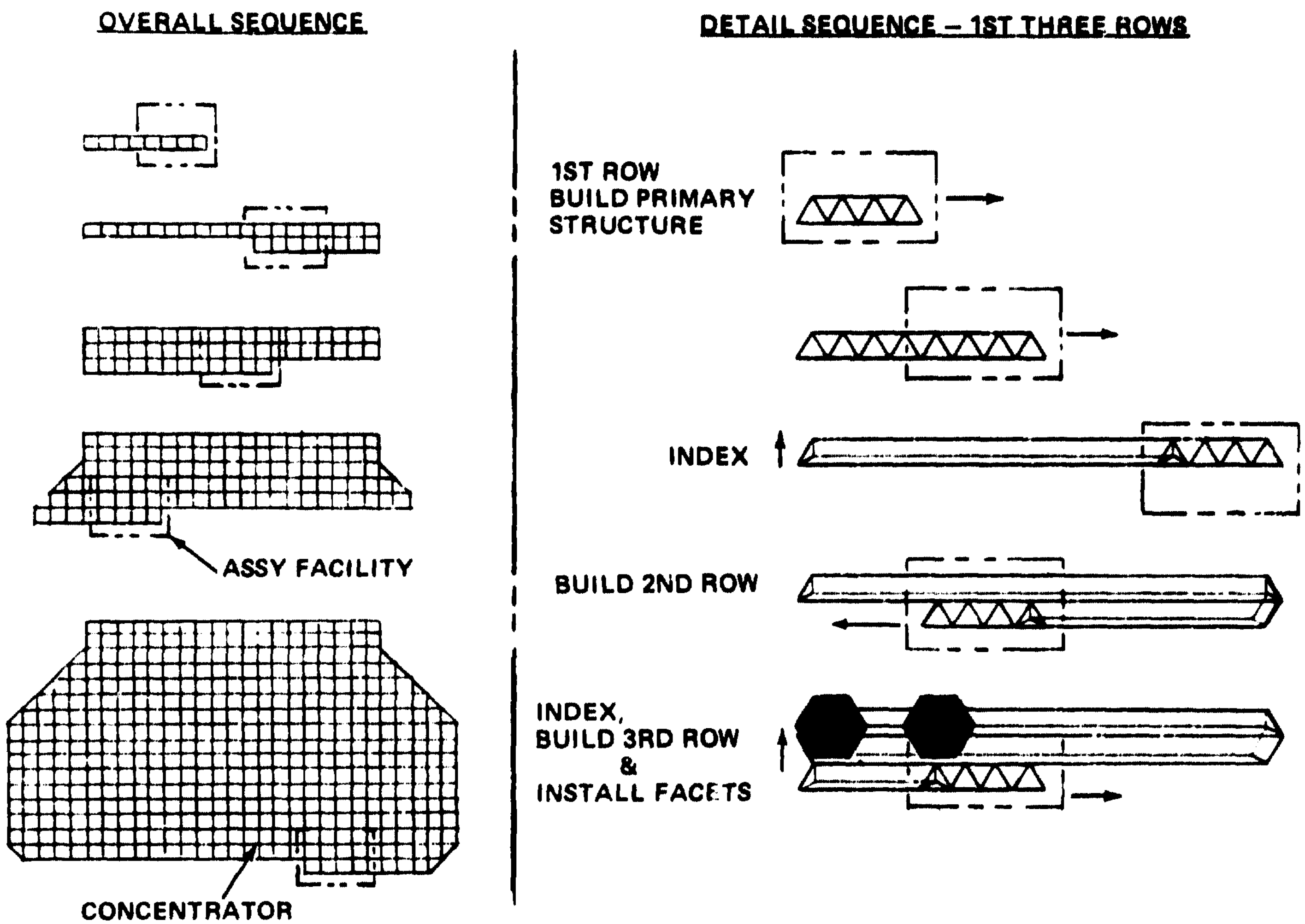
0580-052W

CONCENTRATOR CONSTRUCTION SEQUENCE

Shown on the facing page is the overall assembly sequence which is to build the concentrator in repeatable rows of structural bays. The facility indexes across the construction base via a track system to fabricate and assemble the first row as it goes. The completed row, supported by two holding fixtures mounted to a track on the construction base, is then indexed forward for one row width. The facility is then indexed back along the track building the second row onto the first row, during this second construction pass. This process is repeated until the concentrator is completed.

Taking a more detailed look at the sequence as it builds the first rows, the facility starts by building primary structure for the first four bays of the first row. The facility then indexes four bay lengths, then builds the structure for the next four bays. This is repeated until the first row is completed. The first row is then indexed forward one row. The facility then builds four bays of the second row on to the first row, it is then indexed back four bay lengths to build that structure. The process is repeated, with each completed row indexed forward on the construction base and the facility building as it is indexed from side to side, until the start of the third row. With the start of the third row, the reflecting facets, which have been assembled in the high bay area of the facility, are installed on the completed rows of the concentrator. Two of the hexagon shaped facets are installed for each of the following four structural bays. This process is repeated until the concentrator structure is completed and approximately 1500 facets installed.

CONCENTRATOR CONSTRUCTION SEQUENCE



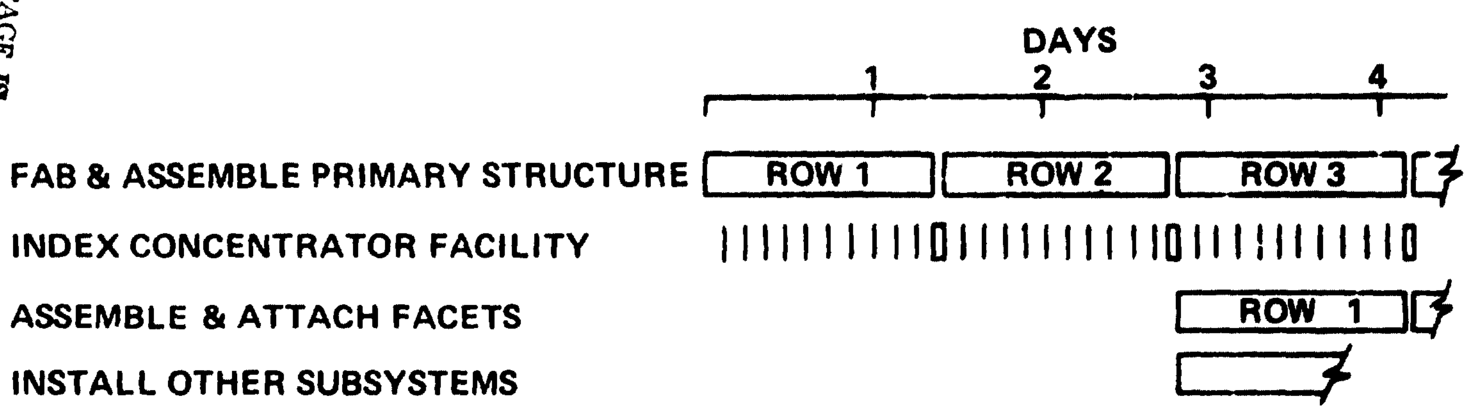
0580-064W

CONCENTRATOR ASSEMBLY TIMELINE

The facing page shows the timeline for assembling the first three rows of the solar concentrator system. As previously described, the concentrator assembly facility builds the structure in progressive steps and sequentially installs the required subsystems. There are 44 tetrahedral bays in the first row of construction, which are built four at a time. The entire concentrator has 4656 tetrahedral bays. By building 4 bays at a time, fabricating 2 beams with each beam builder at 1.5 m pm, and considering related operations (e.g. setup, joining, indexing, etc) this completed structure is estimated to take 148 days.

Sequential installation of the reflective facets and other subsystems parallels the assembly of the third structural row near the start of day 3, as shown. Hence the total assembly time is 151 days.

CONCENTRATOR ASSEMBLY TIMELINE



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0580-067W

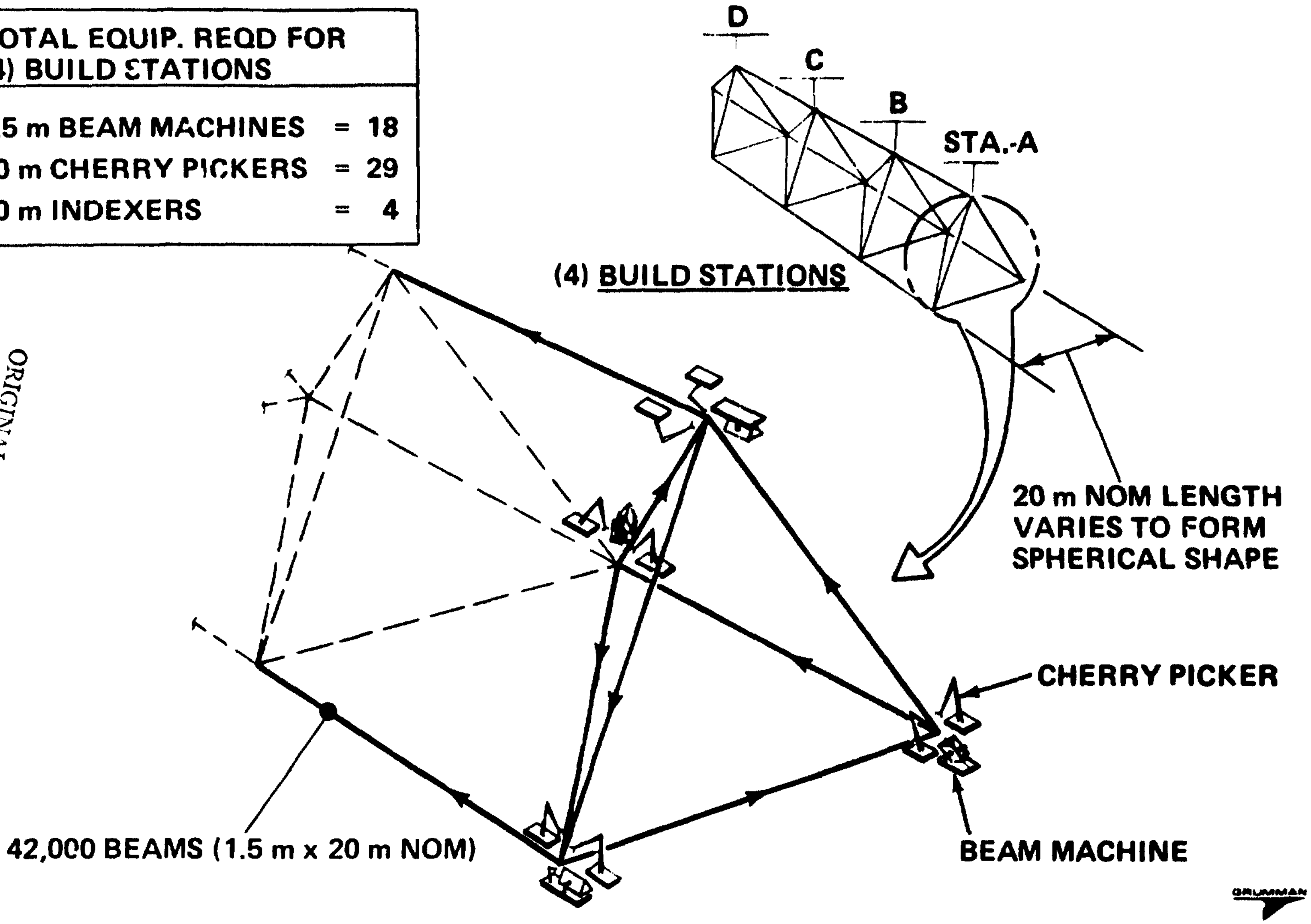
CONCENTRATOR STRUCTURE FABRICATION & ASSEMBLY

The assembly facility provides four build stations for the fabrication and assembly of the concentrator primary structure. The concentrator consists of approximately 42,000 (1.5 m x 20 m (nominal)) beams assembled to form the tetrahedron structure of the spherical concentrator. The facing page illustration identifies the equipment needed for the fabrication and assembly of the structure at one of the four build stations. As shown, each beam machine fabricates two of the 1.5 m x 20 m beams required and the cherry pickers are used for the alignment and assembly of the beams.

Eighteen 1.5 m beam machines, twenty-nine 30 m cherry pickers and four 10 m indexers are required to support the four build stations for the fabrication and assembly of four structural bays of the concentrator.

CONCENTRATOR STRUCTURE FABRICATION & ASSEMBLY

TOTAL EQUIP. REQD FOR (4) BUILD STATIONS		
1.5 m BEAM MACHINES	=	18
30 m CHERRY PICKERS	=	29
10 m INDEXERS	=	4



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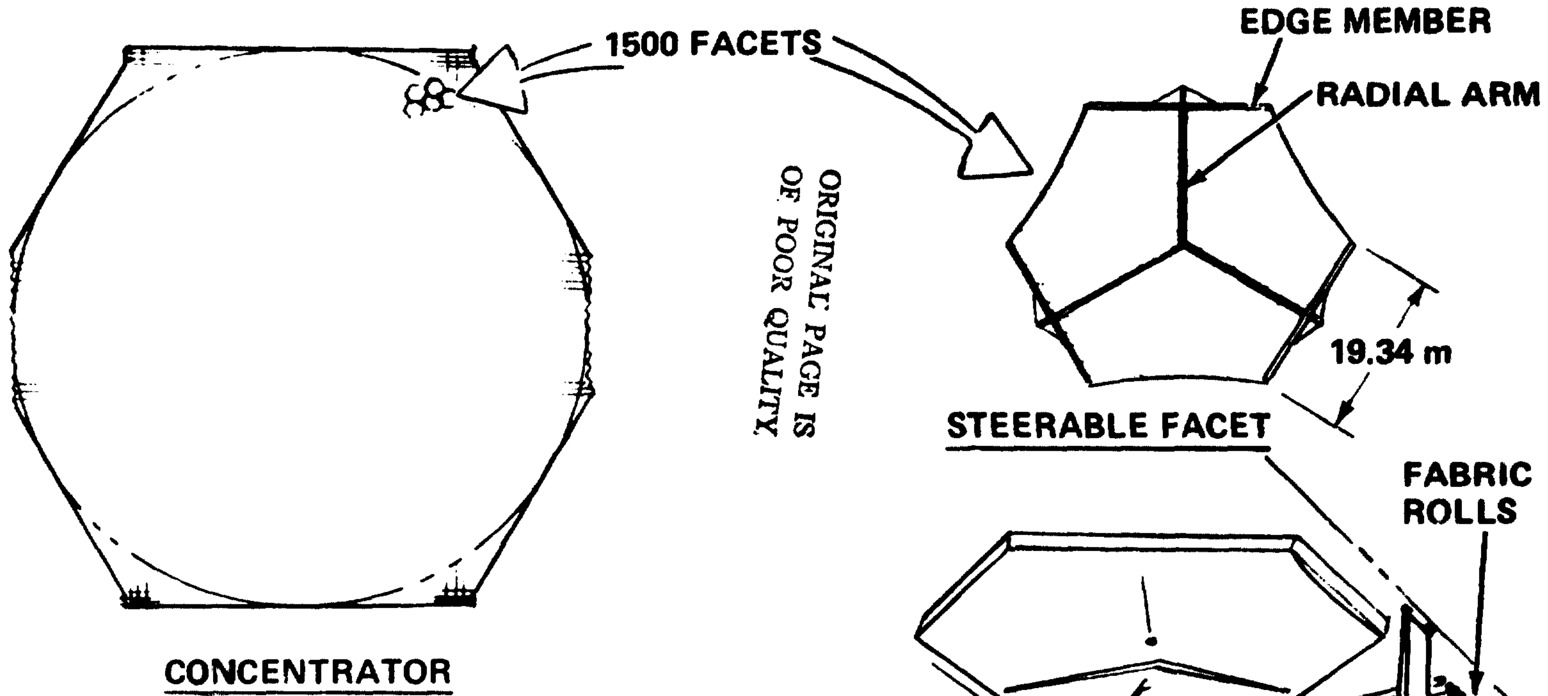
0580-050W

CONCENTRATOR FACET INSTALLATION REQUIREMENTS

The concentrator reflecting surface is provided by the use of approximately 1500 reflecting facets as shown in the facing page illustration. The hexagon shaped facets are assembled in the facet assembly station located in the high bay area of the concentrator facility. The operations at the assembly stations consists of assembling the three radial support arms, edge members, tension bridles and the pre-cut reflecting film. The completed facet assembly is then attached to a central mounting post which has been attached to the tetrahedron structure of the concentrator.

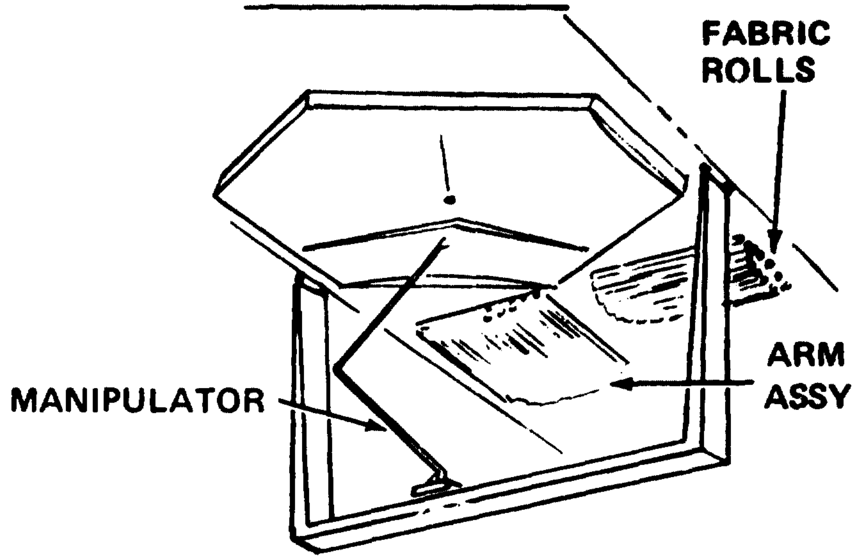
CONCENTRATOR FACET INSTALLATION REQUIREMENTS



CONCENTRATOR

STEERABLE FACET

MAJOR ASSY TASKS
• ASSEMBLE SUPPORT STRUCTURE • ATTACH REFLECTOR SHEET ASSY • INSTALL CENTRAL MOUNTING POST • ATTACH FACET ASSEMBLY TO POST



FACET ASSEMBLY STATION

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IOP LASER POWER SATELLITE ASSEMBLY FUNCTIONS

In considering the complexity of laser power satellite assembly operations. this chart opposite lists the gross elements comprising a satellite and identifies the assembly functions necessary for each. The functions are classified as structural. mechanical. electrical. fluid and optics.

All elements require structure assembly and, with the exception of basic structural subassemblies, they all require electrical assembly. Many mechanisms are involved in these elements, and each must be assembled and installed. Fluids are expected to be in self-contained subunits which need no open fluid connections. Optical assemblies will require alignment by adjustment as they are assembled, or during checkout.

These operations are diverse, and in some cases, require dedicated equipments which have yet to be defined.

IOP LASER POWER SATELLITE ASSEMBLY FUNCTIONS

IOP LASER SPS ELEMENTS	STRUCTURAL	MECHANICAL	ELECTRICAL	FLUID	OPTICAL
• SOLAR CONCENTRATOR					
– PRIMARY STRUCTURE	•				
– FACETS	•	•	•		•
– ATTITUDE CONTROL	•	•	•	TANKS	
• LASER POWER TRANSMISSION					
– CAVITY	•		•		
– LASER UNITS	•	•	•	SEALED	•
– SUPPORT STRUCTURE	•				
– RADIATORS	•	•	•	SEALED	
– LASER OPTICS	•	•	•		•
– LASER REFLECTORS	•	•	•		•
– ELECTRICAL POWER	•		•		
– AVIONICS	•		•		
• INTERFACE					
– TURNTABLE	•	•	•		
– SHUTTER	•	•	•		
– TRIBEAMS	•				

DIVERSE ASSEMBLY OPERATIONS TO BE PERFORMED

ORIGINAL PAGE IS OF POOR QUALITY

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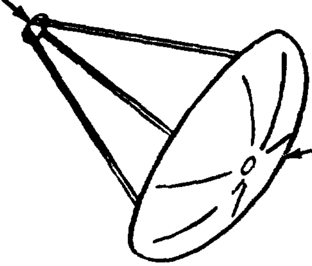
0580-044W

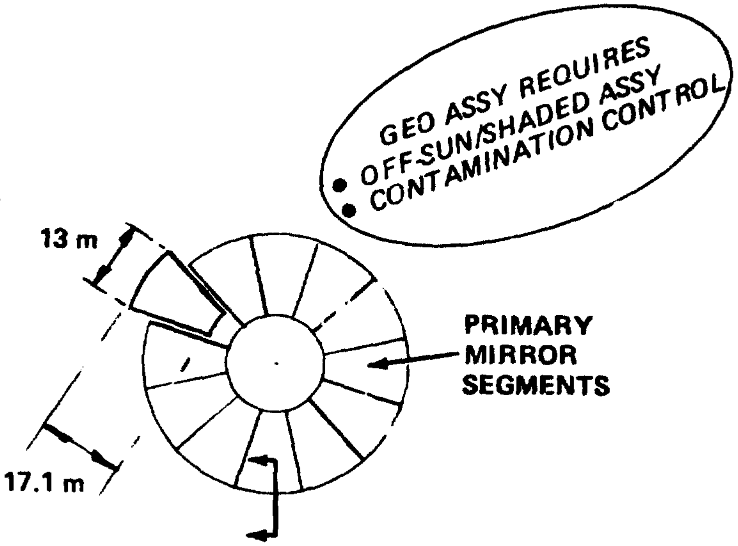
LASER REFLECTOR ASSEMBLY REQUIREMENTS

As presently configured, the laser power transmission system has eight reflectors transmitting to the ground. This chart shows the main subassemblies of a reflector and identifies gross assembly operations for building the reflectors from gound-fabricated components. The primary mirror is 50 m in diameter and is an assembly of segments, each of which has a primary structure, supporting adaptive optics. A secondary mirror is supported from the primary mirror by struts.

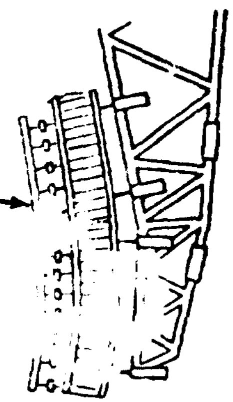
Assembly should be done out of the sun and, to this end, a shading facility is provided on the construction base. Contamination control during assembly is necessary to ensure satisfactory operational performance.

LASER REFLECTOR ASSEMBLY REQUIREMENTS





REFLECTOR ASSY OPERATIONS
• PRIMARY MIRROR SEGMENTS • SECONDARY MIRROR/STRUCTURE • OPTICAL SENSOR SUBSYS • POINTING/TRACKING SUBSYS • CHECKOUT & TEST



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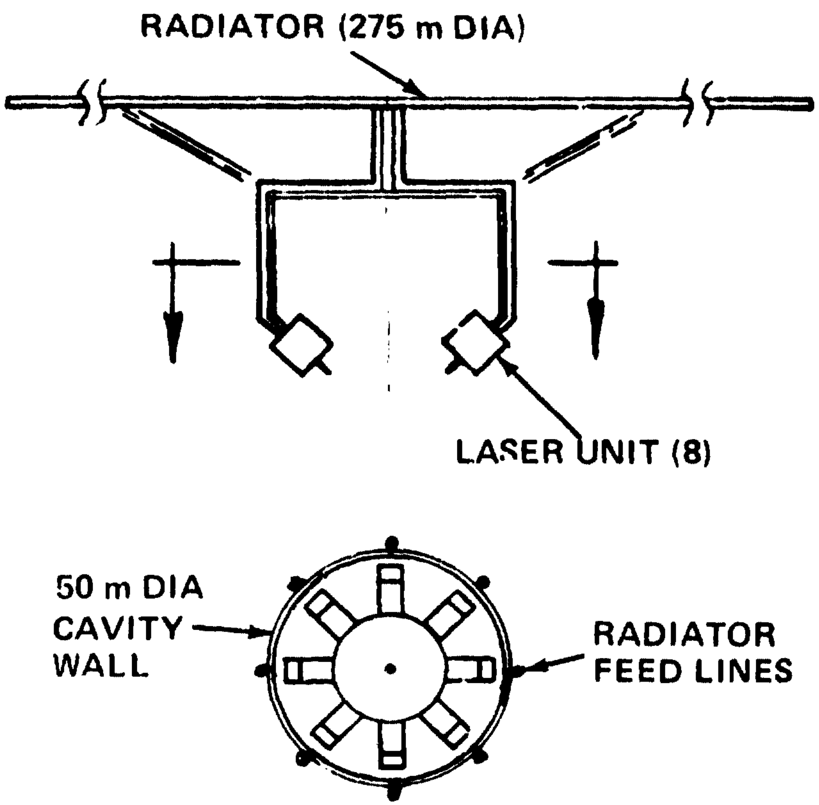
0580-043W

LASER CAVITY ASSEMBLY REQUIREMENTS

The laser cavity assembly comprises a cavity wall lined with a pyralitic material and assembled from segments. Eight laser units are mounted around the cavity opening. A radiator, fed from the lasers, is mounted to the cavity unit by support struts. Gross assembly operations are listed for building the cavity and its appendages from ground-fabricated subassemblies.

LASER CAVITY ASSEMBLY REQUIREMENTS



COMPLEX SYSTEMS INTEGRATION & CHECKOUT

CAVITY ASSY OPERATIONS
• CAVITY SEGMENTS
• LASER UNITS (MODULAR OR WHOLE)
• LASER HEAT PIPES
• RADIATOR SEGMENTS
• RADIATOR SUPPORT STRUCTURE
• CHECKOUT & TEST

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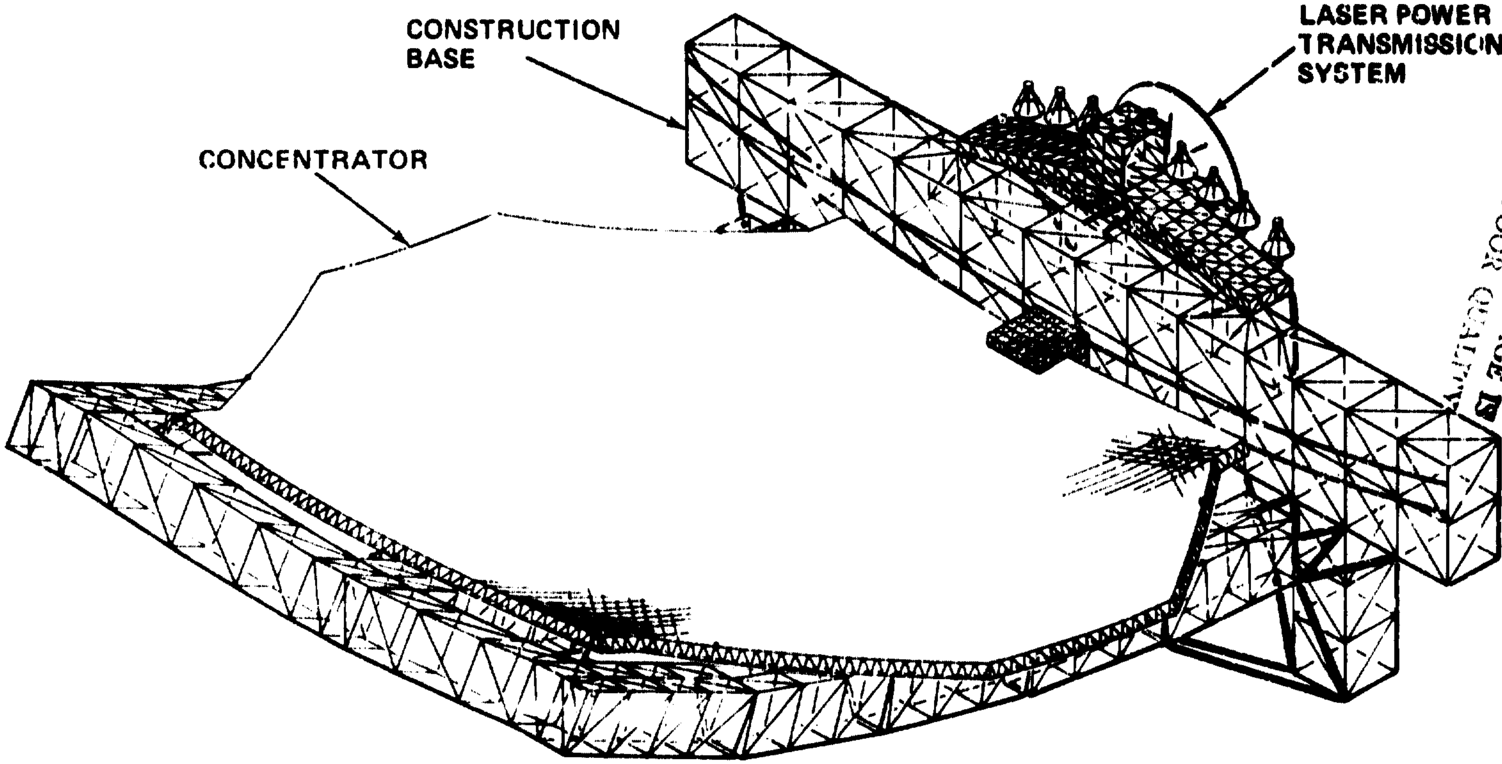
LASER SPS — CONSTRUCTION COMPLETED

This illustration shows the two main systems assemblies of the SPS (the concentrator and the laser power transmission) in their construction facilities, ready for final assembly operations. The concentrator assembly facility is indexing back to its stowed location.

LASER SPS-CONSTRUCTION COMPLETED



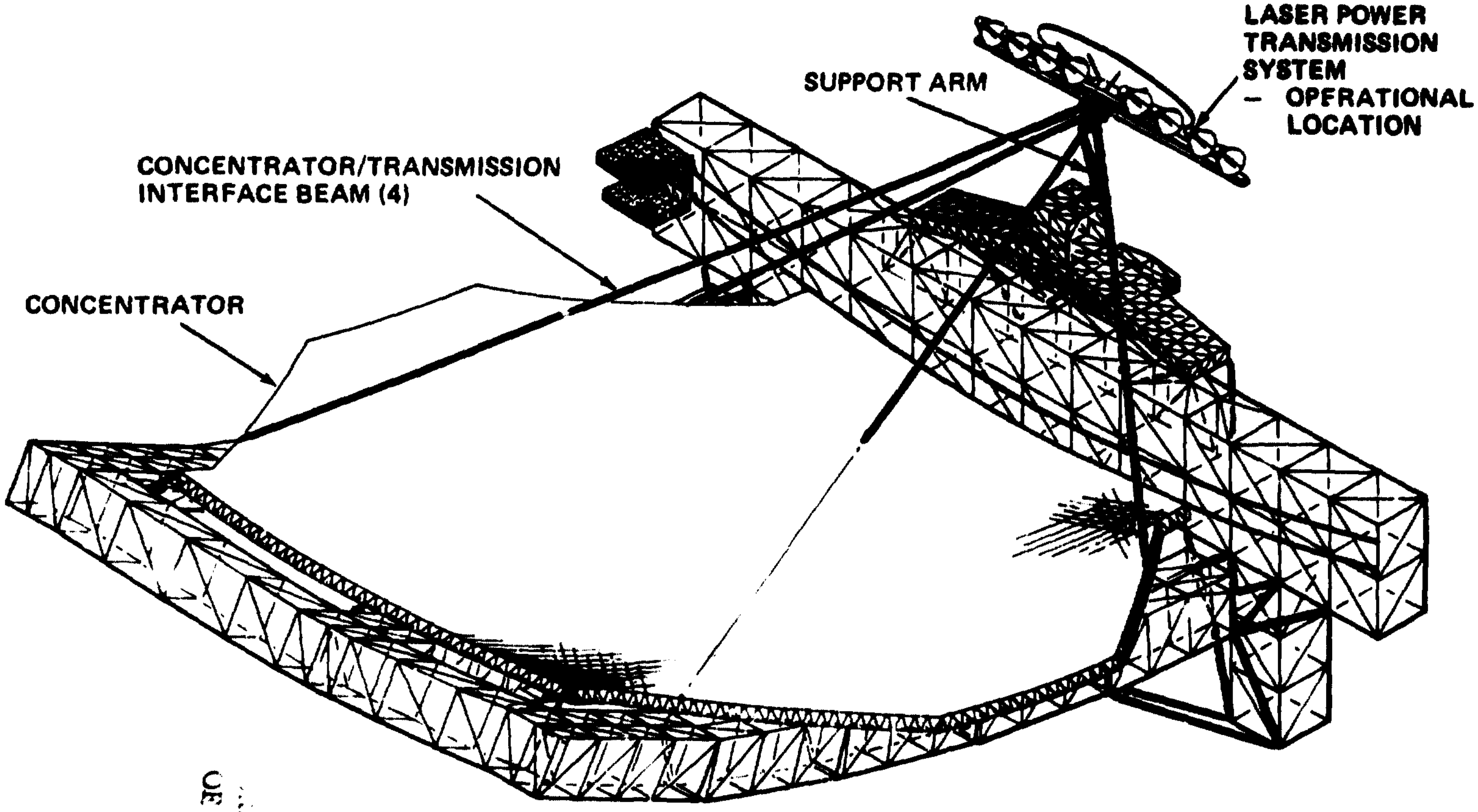
0580-063W

LASER SPS – FINAL SYSTEMS MATING

Before mating the laser power transmission system to the concentrator, it must first be located in its operational position. This is accomplished by a support arm, part of the construction system, which first attaches to the the transmission at its shutter assembly mounts, then pivots to position it at the operational location, as shown on this illustration.

A small platform, mounting a 7.5 m beam, is located at the tip of the support arm where it attaches to the transmission. With the beam machine aimed at one of the four interface beam attachment points on the concentrator, a beam is fabricated to arrive at this attachment point where it is mated to the concentrator. The other end of the beam attaches to the transmission assembly at the shutter mount. This process of beam machine alignment, beam fabrication, and installation is repeated for the three other interface beams.

LASER SPS-FINAL SYSTEMS MATING



0580-062W

IOP LASER SPS CONSTRUCTION EQUIPMENT

This chart lists the construction equipment, identified to date, for building the IOP Laser SPS concept. A breakdown of the equipment used to assemble the solar concentrator is shown together with related mass and cost estimates. The large number of 1.5 m beam builders and 30 m cherry pickers reflects the impact of building 4 bays at once to shorten the overall assembly time. The 7.5 m beam builder which fabricates the interface tribeam supports is also included. However, available study resources precluded equivalent analysis to define the full array of equipment needed to assemble the laser power transmission system and the elements of the interface system. As previously shown, many diverse construction operations must be performed to assemble all of the elements in these systems. Although a breakdown of the power transmission/interface assembly equipment remains to be developed, it is believed that the total mass and cost of these items will be similar to those for building the concentrator.

IOP LASER SPS CONSTRUCTION EQUIPMENT

REF BASE DELTA
- -26 MT
- +$1580M

CONSTRUCTION AREA/EQUIPMENT	QTY	MASS, MT	COST, $M
• CONCENTRATOR ASSEMBLY			
– BEAM BUILDERS			
1.5 m GIMBAL MANNED	18	72	724
1.5 m MOBILE MANNED	2	8	79
7.5 m MOBILE MANNED	1	11	58
– CHERRY PICKERS			
30 m	29	72.5	621
45 m	6	18	128
– INDEXERS			
10 m } SINGLE SUPPORT	8	8.7	26
45 m } SINGLE SUPPORT	6	7.8	21
60 m MULTI-SUPPORT	2	16	14
– FACET ASSEMBLY STATION	1	3	21
SUBTOTAL		217 MT	$1692M
• PWR TRANSMISSION/INTERFACE ASSY			
– UNDEFINED EQUIPMENT FACTOR (100%)	TBD	217	1692
TOTAL		434 MT	$3384M

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0580-045W

IOP LASER CONSTRUCTION BASE CREW COMPARISON

This chart shows a comparison of crew operations staffing for the reference GEO base and for the laser construction base. Each base operates on two 10 hour shifts per day and have similar organizations.

Construction of the solar concentrator requires nearly three times as many people as for assembling the reference energy conversion system because it has a denser structure and requires more construction equipment. The diverse construction operations for assembling the laser power transmission system, however, have not been analyzed to the point where the sequence of operations and required equipments are defined. At this juncture it is believed that the crew needed to assemble the laser power transmission system will lie somewhere between 50% and 100% of the total crew for solar concentrator assembly. The remaining construction operations (i.e., subassembly factory, maintenance, logistics and test/Q.C.) are assumed to be the same for both concepts. In addition, the base operations and base management crew operations are also the same. However, the larger construction crew for the laser SPS also requires more people for base support (i.e., utilities, hotel, food service, etc).

IOP LASER CONSTRUCTION BASE CREW COMPARISON

CREW OPERATION	REFERENCE GEO BASE		LASER CONST BASE		
CONSTRUCTION OPERATIONS	258		377		
– ENERGY CONVERSION SYS		42		–	
– SOLAR CONCENTRATOR SYS		–		116	
– ANTENNA		42		–	
– POWER TRANSMITTER		–		87	75% SOLAR CONC
– SUBASSEMBLY FACTORY		48		48	
– MAINTENANCE		40		40	
– LOGISTICS		44		44	
– TEST/QC		42		42	
BASE OPERATIONS	84		84		
BASE SUPPORT	84		108		
BASE MANAGEMENT	18		18		
TOTAL CREW	444		587		
△ CREW	–		143		

0580-046W

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IOP LASER SPS CONSTRUCTION BASE IMPACTS

The impact of IOP Laser SPS construction is summarized on the facing page in terms of penalty (or gain) to the reference GEO base mass, cost, and productivity.

The reference base is not suitable for building this small Laser SPS concept. An entirely different and much smaller construction base is needed. However, there are many diverse laser satellite assembly tasks to be performed on this smaller base, which leads to a larger crew size (587 vs 444). Hence, more habitats are required than for the reference 4 bay end builder. Although, the total mass of the laser base is significantly less, the net effect increases the GEO base investment cost and annual operations cost as shown. For the IOP Laser Construction base defined, it was not practical to accelerate the concentrator assembly operation further to complete construction in less than 176 days. Consequently, productivity of the laser construction base is 2% of the reference. It is possible, however, that an alternate structural concept and another more highly automated construction facility could build the entire satellite a great deal faster.

IOP LASER SPS CONSTRUCTION BASE IMPACTS

BASE PRODUCTIVITY
– IOP LASER SPS = 0.2 GW/YR
– REFERENCE SPS = 10 GW/YR

GEO BASE ELEMENT	Δ MASS, MT	Δ COST – 1979 $M DDT&E	UNIT COST
• WORK FACILITIES			
– STRUCTURE	-2167	-34	-250
– CONSTRUCTION EQUIPMENT	- 26	0	1580
• CREW SUPPORT FACILITIES			
– 2-17 m DIA HABITATS	486		770
• WRAPAROUND FACTORS			
– DEVMT 127%		-43	
– PROD. 47%			987
TOTAL	-1707 MT	-$77M	$3087M

$\underbrace{-\$77M \quad \$3087M}_{\$3010M}$

ANNUAL OPERATIONS INCREASE:

SALARIES & TRAINING (+143)		212
RESUPPLY	+363 MT/YR	204
		$416M/YR

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0580-047W

OPTICALLY PUMPED GAS LASER RESULTS

A summary of the optically pumped laser results is presented here.

OPTICALLY-PUMPED GAS LASER RESULTS

- LESS MASSIVE THAN EDLS
- ELIMINATES SOLAR ARRAY
- EFFICIENCY UNCERTAIN; NEEDS MORE DETAILED ANALYSIS AND EXPERIMENTAL WORK
- COMPLEX AND EXPENSIVE TO CONSTRUCT
- SOME PUMPING MACHINERY
- POTENTIAL FOR MARKED IMPROVEMENT IF TECHNOLOGY BREAKS FAVORABLY
- TECHNOLOGY EMBRYONIC BUT BASED ON WELL-UNDERSTOOD LASANTS

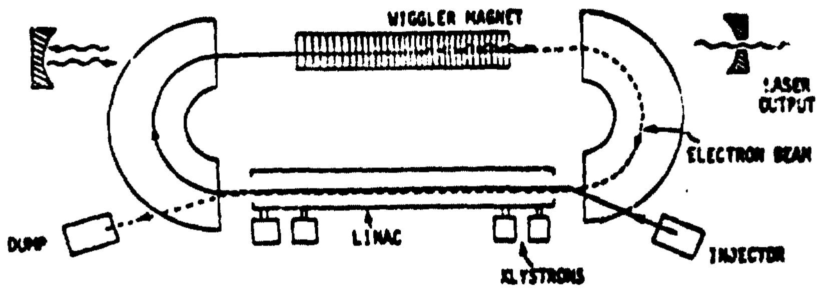
FREE ELECTRON LASER CANDIDATES

Many concepts have been developed for free electron lasers. Three of the options are shown on the facing page. The "Catalac" laser uses a one and a half pass system through the wiggler magnet to improve efficiency. The double free electron laser uses a long wave length free electron laser to create a virtual wiggler magnet which then extracts energy and short wave lengths from the high power electron beam. This concept was viewed as unnecessary for pursuit in the present study because it is suited mainly to extracting very short wavelengths (approximately 1 micron). nally, a storage ring free electron laser utilizes a simple magnetically contained storage ring to recirculate the electron beam through the wiggler magnet so that a relatively small extraction of energy per electron beam can still provide reasonable efficiencies.

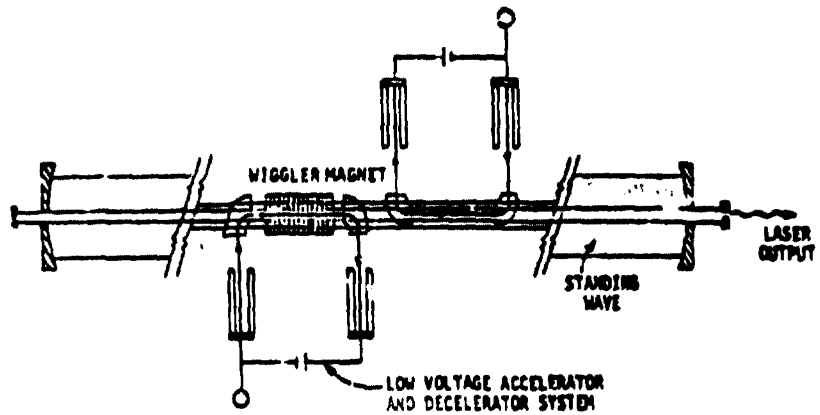
The simplest free electron laser concept is a straight through concept in which the electron beam is accelerated into a high extraction wiggler magnet which extracts as much laser energy as possible in a single pass. The spent beam is then collected by a collector from which the waste electron beam energy must be collected as thermal energy and dissipated to space through a thermal radiator system. Indications are that the straight through system may achieve efficiencies as high as 50% without the complexities of the recirculating systems. Furthermore, recent study of electron beam thermalization has raised a current controversy regarding achievable efficiencies of recirculating beam FEL's.

FREE ELECTRON LASER CANDIDATES

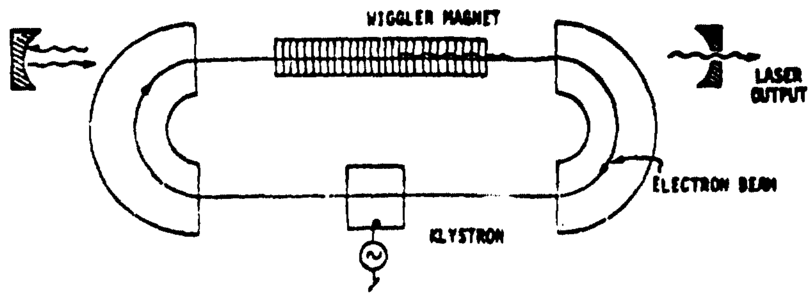
CATALAC FEL



DOUBLE FEL



STORAGE RING FEL



SINGLE PASS FREE ELECTRON LASER

The facing page presents a summary efficiency chain and mass estimating rationale for the single pass free electron laser SPS.

SINGLE PASS FREE-ELECTRON LASER

EFFICIENCY ESTIMATE

POWER	AT	EFFICIENCY
1 GW	GROUND	
1.25 GW	ON RCVR	.80 IR/ELECTRICITY
1.3158	INTO ATM	.95
2.6315	E-BEAM	.50 E-BEAM/LIGHT
3.289	EL. PWR	.8 ELEC./E-BEAM
3.46	ARRAY OUTPUT	.95 UNCONDITIONED-CONDITIONED POWER
24.73	SUNLIGHT	.14 SUNLIGHT - CONDITIONED ELEC.

= 4% vs 7% FOR MICROWAVE

MASS ESTIMATE

ITEM	FACTOR	BASIS	ESTIMATE (MT)
OPTICS	3 KG/KW_{TH}	100 KW_{TH}	30
LASER & CAVITY OPTICS	0.1 KG/KW_L		100
RADIATOR & COOLING	0.4 KG/KW_{TH}	1.3×10^6 KW_{TH}	520
HOUSING & MOUNTING	25%		160
KLYSTRONS & E-OPTICS	1 KG/KW_E	3.289×10^6 KW_E	3,289
POWER PROCESSING	2 KG/KW_E & 15%	3.280×10^6 KW_E	987
POWER CONDUCTORS	0.125 KG/KW_E	3.289×10^6 KW_E	411
SOLAR ARRAY	3.3 KB/KW_E	3.46×10^6 KW_E	11,418
STRUCTURES	19 KM^2	19/50 REF (4,654)	1,768
			18,683 TONS

FREE ELECTRON LASER RESULTS

A summary of the free electron laser results is presented on the facing page. The free electron laser appears to be the most attractive of the options investigated to date. However, the technology is very embryonic and its attractiveness depends on achieving high extraction of light energy from the electron beam. Experiments to validate the possibility of high efficiency should be relatively inexpensive to conduct.

FREE-ELECTRON LASER RESULTS

FREE-ELECTRON LASER

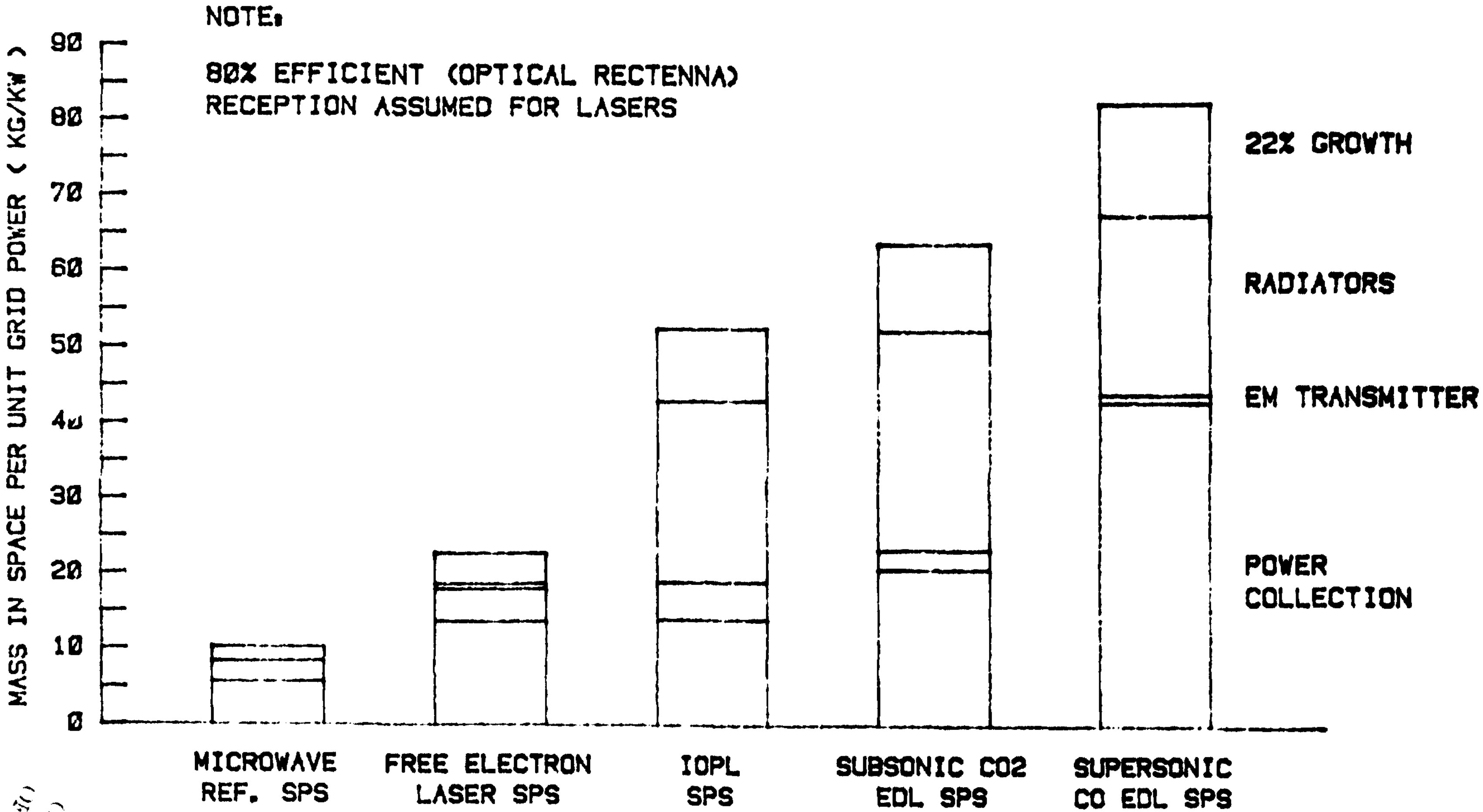
- NO MOVING PARTS (EXCEPT OPTICS)
- NO FLUID CIRCUITS
- EFFICIENCY UNCERTAIN BUT BELIEVED POTENTIALLY FAIR TO GOOD
- LEAST MASSIVE OF THE LASER OPTIONS IF EFFICIENCY ESTIMATES VALID
- SCALING UNCERTAIN BUT HIGH POWER BELIEVED POSSIBLE
- TECHNOLOGY EMBRYONIC

LASER SPS OPTION MASSES COMPARED

The masses in space required for 5 gw of delivered electric power are composed for the 4 major laser SPS concepts assessed in this study. The free electron laser (with 50% extraction assumed) is clearly the best SPS laser option. However, due to its power conversion efficiency penalty of a factor of 2 with respect to the microwave reference SPS, it is also that much more massive.

LASER SPS OPTION MASSES COMPARED

SPS-3424

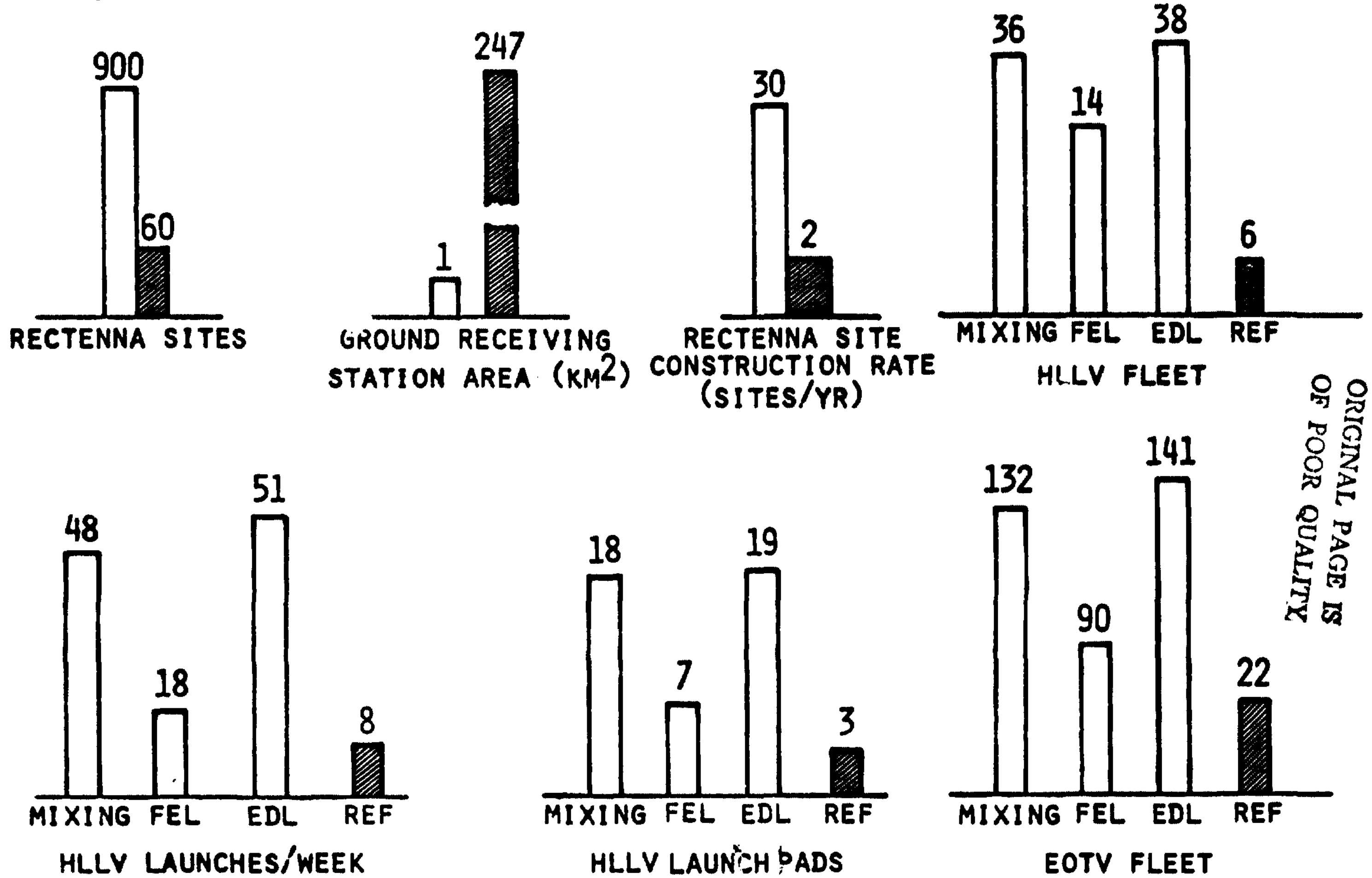


LASER SPS OPERATIONAL FACTORS

The following two charts summarize laser SPS operational factors. The factors for the EDL's and FEL's are extrapolated from the reference system data base; specific construction analyses were no conducted.

Due to the facts that the laser SPS's are more massive per unit power and have lower power per link than the microwave reference system, more of every component of the SPS system will be required.

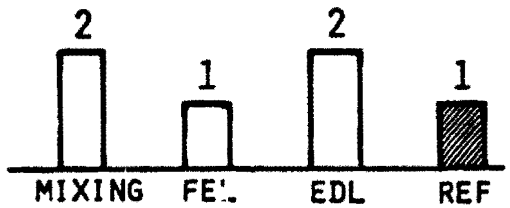
LASER SPS OPERATIONAL FACTORS



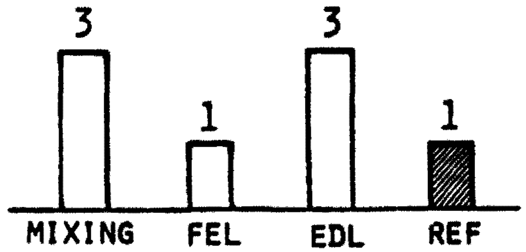
LASER SPS OPERATIONAL FACTORS (CONT)

The greater construction effort required for the more massive laser SPS's is illustrated.

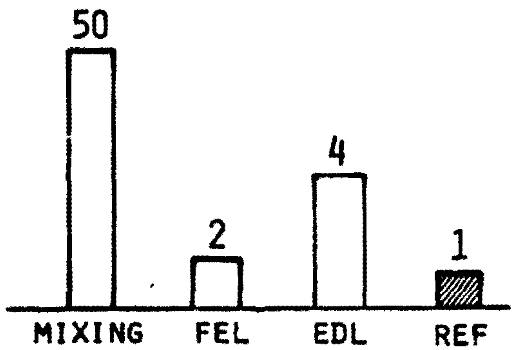
LASER SPS OPERATIONAL FACTORS



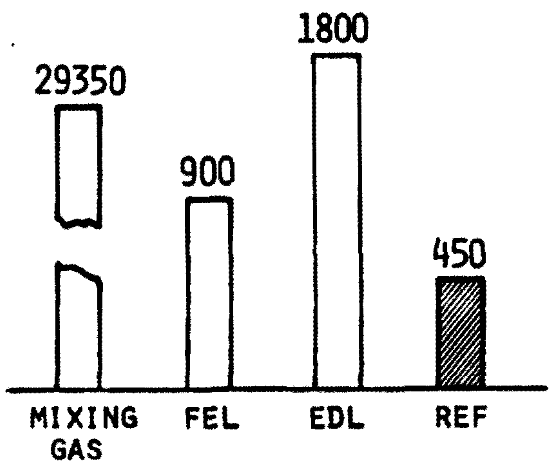
NO. OF LEO BASES



NO. OF EOTV'S STATIONKEEPING W/EACH LEO BASE



NO. OF GEO BASES



CONSTRUCTION CREW

LASER SPS OPERATIONAL FACTORS

On the following pages, the operational factors by which the various SPS laser concepts differ are listed by category.

LASER SPS OPERATIONAL FACTORS

SPS-3[illegible]

OPERATIONAL FACTOR	LASER SATELLITE CONCEPTS			LASER RECTENNA CONCEPTS	
	MIXING GAS	FEL	EDL	PHOTOVOLTAIC	POWER TOWER
o INDUSTRIAL COMPLEX/SURFACE TRANSPORTATION					
. Primary Industrial Capacity Needs	. Kapton . Graphite Fibers . Laser Optics	. Solar Array . Graphite Fibers . Klystrons . Laser Optics	. Solar Array . Graphite Fibers . Laser Optics	. Solar Array . Fresnel Lens or Optical Diodes	
. Surface Transportation	(ADDITIONAL MASS OF MATERIALS TO BE TRANSPORTED WILL NOT STRAIN THE CURRENT TRANSPORTATION SYSTEM)				
o RECTENNA CONSTRUCTION					
. No. of 1 GW sites				300	300
. Size of Sites				(1 x 1 km?) 320 x 320 m + Radiators + Switchyard + Exclusion Boundary	(1 x 1 km?) 320 x 320 m + Radiators + Switchyard + Exclusion Boundary
. No. of Sites to Bring On Line Each Year				10	10

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LASER SPS OPERATIONAL FACTORS

SPS-3352

OPERATIONAL FACTOR	LASER SATELLITE CONCEPTS			LASER RECTENNA CONCEPTS	
	MIXING GAS	FEL	EDL	PHOTOVOLTAIC	POWER TOWER
o RECTENNA CONSTRUCTION - Cont.					
. Construction Complexity Factors				. Lens and support structure could be automated. . May need superconductors.	. Need portable heliostat assy. factory. . Power tower does not lend itself to high-rate construction
o LAUNCH AND RECOVERY SITE					
. <u>Mass Laser</u> SPS					
. Microwave-to-Ref. Mass Ratio	6	2.25	6.4		
. No. of 400 MT HLLV's in fleet	36	14	38		
. No. of Launches per Week	48	18	51		
. No. of Launch Pads	18	7	19		
. Location of Launch Site	(NONE OF THESE COULD BE SUPPORTED BY KSC-- WOULD HAVE TO GO TO OFFSHORE OR EQUATORIAL SITES)				

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LASER SPS OPERATIONAL FACTORS

OPERATIONAL FACTOR	LASER SATELLITE CONCEPTS			LASER RECTENNA CONCEPTS	
	MIXING GAS	FEL	EDL	PHOTOVOLTAIC	POWER TOWER
o LEO BASE					
. EOTV Fleet Size	132	50	141		
. Time required to construct EOTV fleet at 8 vehicles/ year rate	16.5 yrs	6.25 yrs	17.6 yrs		
. No. of LEO Bases required to construct EOTV fleet within 9 years (vehicle life)	2	1	2		
. No. of HLLV docking ports	18 (9 on each base)	7	19 (10 on each base)		
	(HAVING HLLV DOCKING PORTS ON MULTIPLE SIDES OF THE BASE WILL PRESENT SIGNIFICANT APPROACH/DEPARTURE OPERATIONAL PROBLEMS)				
. No. of EOTV's in stationkeeping positions	6 (could pose an operational problem)	2-3	6-7 (could pose an operational problem)		

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LASER SPS OPERATIONAL FACTORS

OPERATIONAL FACTOR	LASER SATELLITE CONCEPTS			LASER RECTENNA CONCEPTS	
	MIXING GAS	FEL	EDL	PHOTOVOLTAIC	POWER TOWER
o SPACE TRANSPORTATION					
. No. of EOTV's in pipeline	132	50	141		
. No. of POTV's in pipeline	120	4	8		
. No. of Cargo Tugs	12 @ LEO 12 @ GEO	6 @ LEO 6 @ GEO	12 @ LEO 12 @ GEO		
o GEO BASE					
. No. of Construction Bases Req'd to Bring 10 GW Capacity On-Line Each Yr	50	2	2		
. Construction Crew Size at Each Base	587	450	900		
. Total Number of Construction Crew	29,350	900	1,800		

* Penalty is small compared to Mixing Gas IOPL

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LASER SPS OPERATIONAL FACTORS

OPERATIONAL FACTOR	LASER SATELLITE CONCEPTS			LASER RECTENNA CONCEPTS	
	MIXING GAS	FEL	EDL	PHOTOVOLTAIC	POWER TOWER
o MAINTENANCE					
. Primary Maintenance Tasks	. Lasant fluid changeout . Radiator system maint. -Pumps -Fluid Leaks . Lasant intercavity tube cleaning . Optics cleaning	. Klystron changeout (30 tubes) . Optics cleaning . Radiator system maint. -Pumps -Fluid Leaks	. Cathode changeout . Makeup gas replenishment . Waste gas removal	. Lens Cleaning	. Reflector cleaning . Turbo-machinery maint.
. Significant Operational Problems	. What to do with degraded lasant gases? . How much time must be allowed to cool system before maint. crews can work? . Maint. access to interior of cavity.		. What to do with waste gases?		

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SPS-3357

LASER SPS OPERATIONAL FACTORS

BOEING

OPERATIONAL FACTOR	LASER SATELLITE CONCEPTS			LASER RECTENNA CONCEPTS	
	MIXING GAS	FEL	EDL	PHOTOVOLTAIC	POWER TOWER
o UTILITY GRID					
. Input to Grids in "Small" Increments				100 MW → 1 GW	100 MW → 1 GW
. Intermittent Input Due to Weather					
. (Other Power Input Interruptions Essentially The Same as for Microwave SPS)					
. Rectennas will be Predominantly Located in Arid Locations					
. Smaller Unit Size Allows Rectennas to be Located Near to Population Centers					
. Tolerance to Winds, Earthquakes, Ice, Snow, Etc.				. Fresnel Lens will be susceptible to damage	. Should be easier to protect heliostats from damage.

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LASER SPS OPERATIONAL FACTORS

SPS-3359

OPERATIONAL FACTOR	LASER SATELLITE CONCEPTS			LASER RECTENNA CONCEPTS	
	MIXING GAS	FEL	EDL	PHOTOVOLTAIC	POWER TOWER
o COMMAND CONTROL . Increased Number of Space Vehicles and Bases Will Demand Much More Complex C&C System. (Space Traffic Control, Tracking and Comm, Base Support C&C, etc.) . Will Require 10 times the Numberof Orbital Slots					

LASER POWER RECEIVER TYPES

The types of laser power receivers considered in that study and their anticipated efficiencies are listed.

LASER POWER RECEIVER TYPES

LOW INTENSITY (LESS THAN 5 SUNS AVERAGE POWER/AREA)

- PHOTO CELL
  - EFFICIENCY ~ 40%
- POWER TOWER
  - EFFICIENCY ~ 60%
  - HARDWARE CURRENTLY UNDER CONSTRUCTION CAN BE USED
- OPTICAL RECTENNA
  - MUST BE PULSED FOR EFFICIENCIES UP TO > 90%

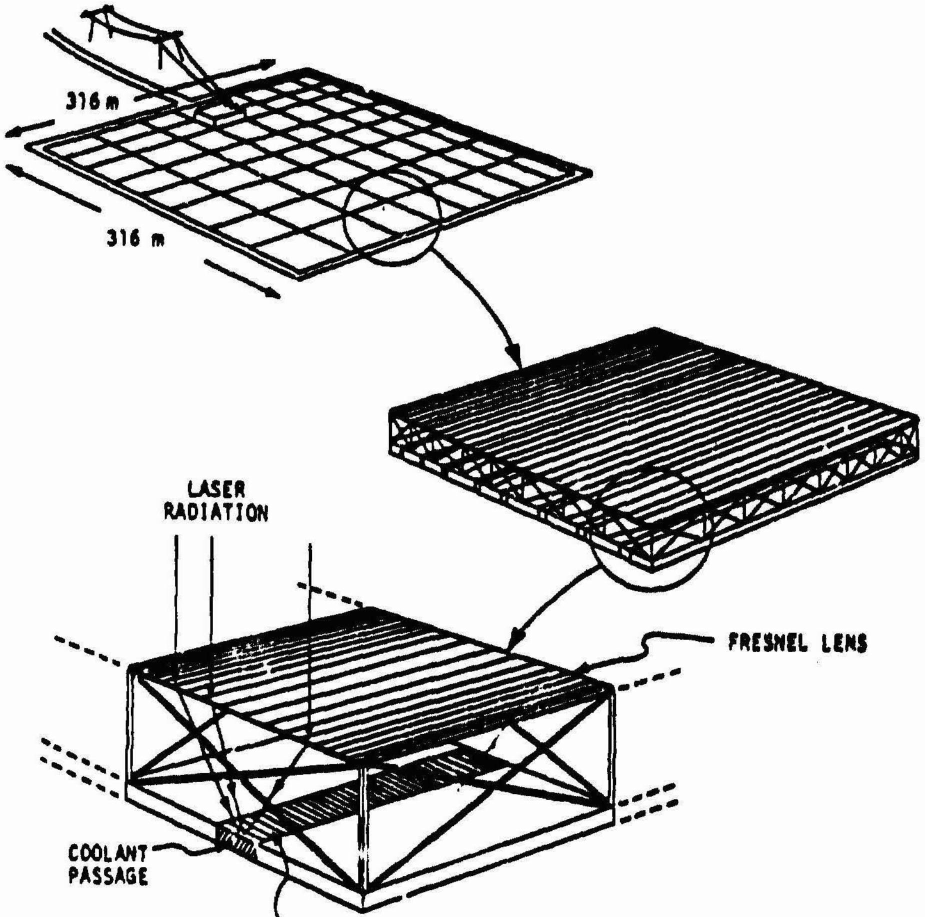
HIGH INTENSITY (OVER 5 SUNS, DANGEROUS)

- PARABOLIC CONCENTRATOR
  - EFFICIENCY ~ 60%

PHOTOCELL RECEIVER

Mass produced plastic Fresnel lens could be used to concentrate laser power on strips of water cooled photocells underneath.

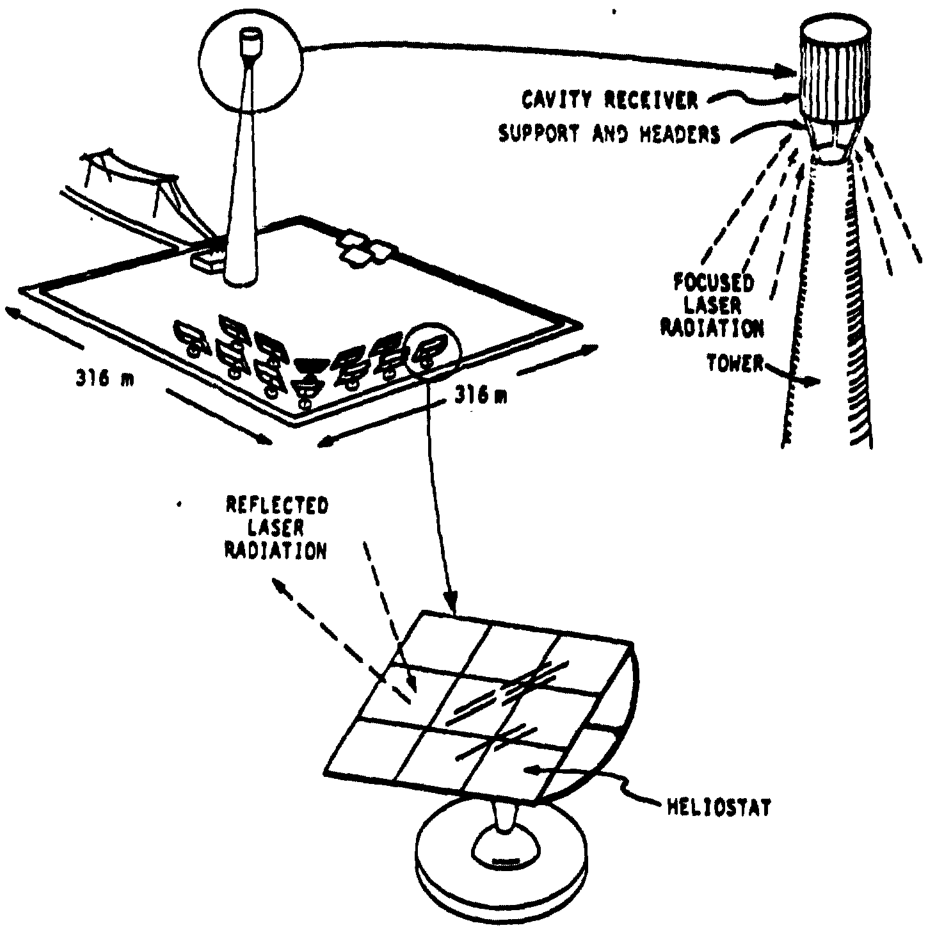
PHOTOCELL RECEIVER



POWER TOWER RECEIVER

This concept is almost identical to the solar power towers now under investigation by DOE and being constructed at several desert locations. The laser power from the SPS has a smaller divergence angle than sunlight, is of 5 times the intensity and is constant over the course of the day.

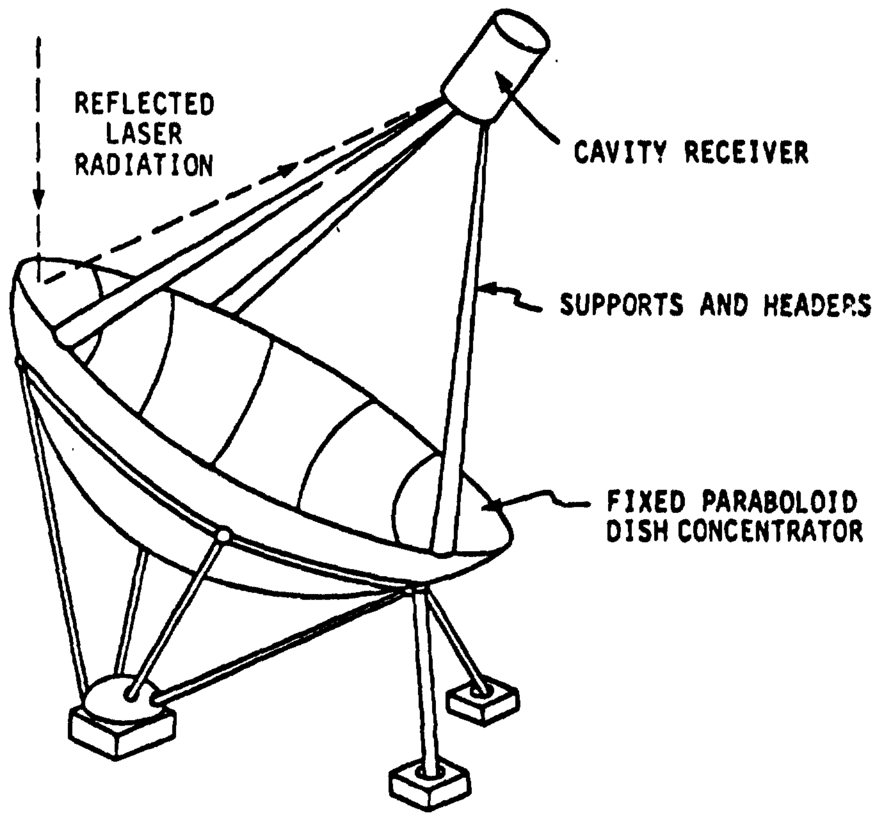
POWER TOWER RECEIVER



SINGLE HIGH INTENSITY RECEIVER

This concept, not a recommended option for beam safety reasons, is a data point representing what a high intensity laser beam receiver might look like.

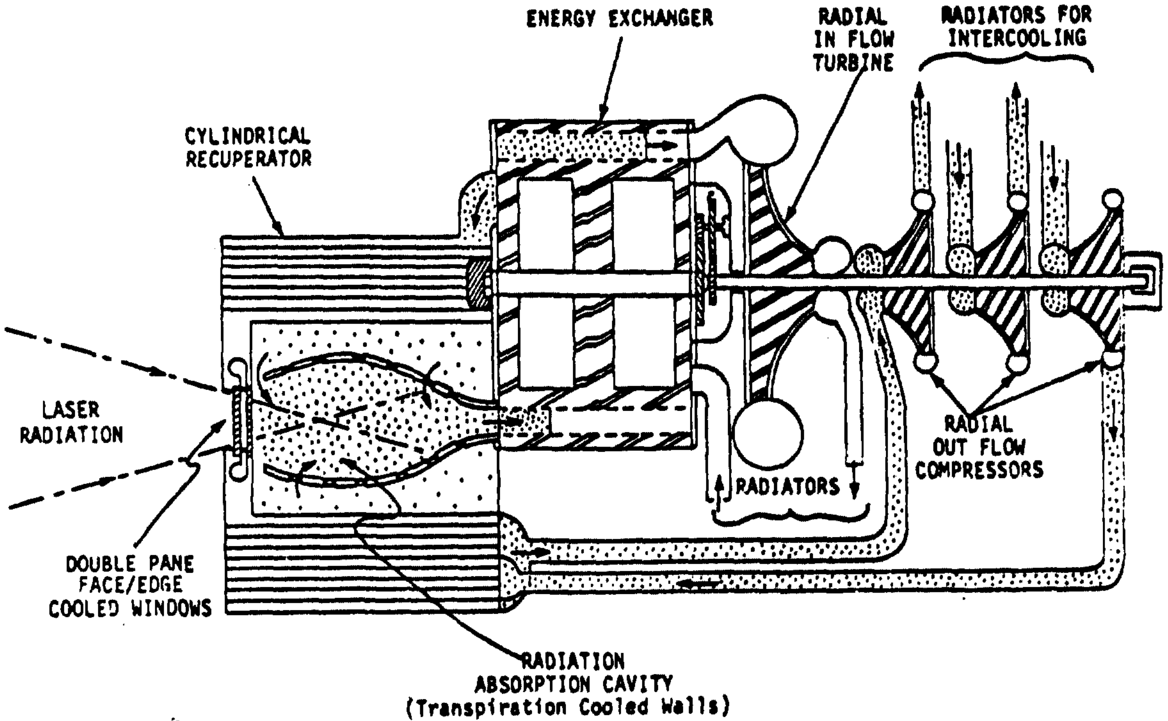
SINGLE HIGH INTENSITY RECEIVER



SCHEMATIC CROSS-SECTIONAL VIEW

The power head at the focus of either the high intensity receiver or the power tower is expected to be a design similar to this.

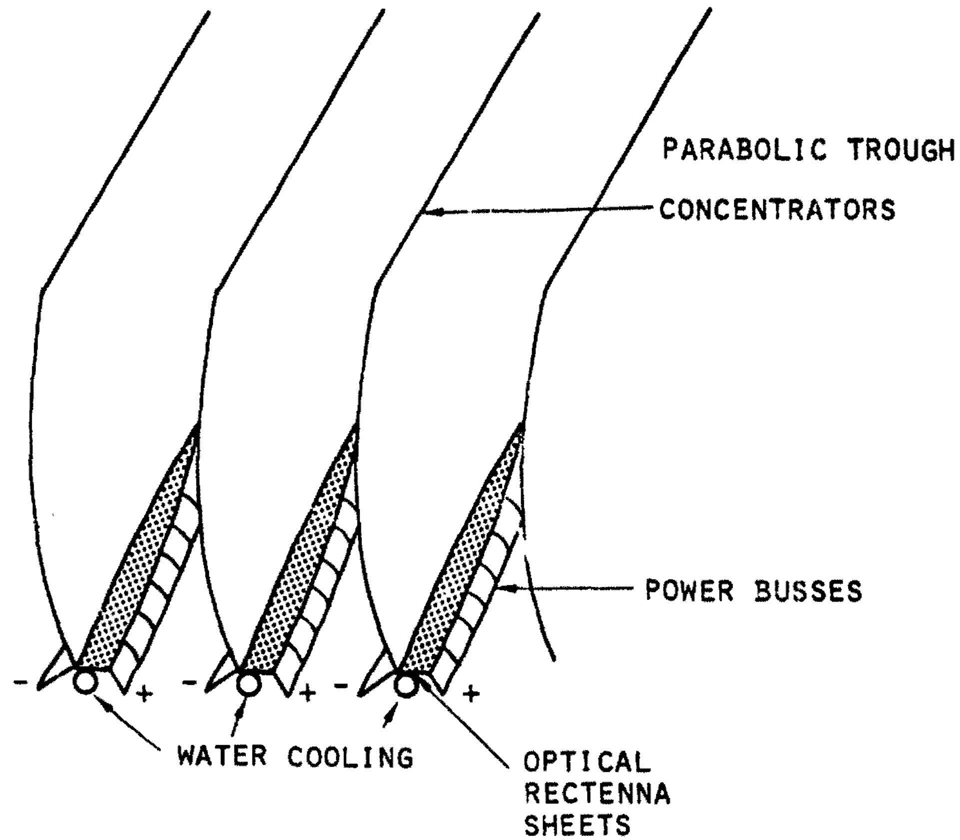
SCHEMATIC CROSS-SECTIONAL VIEW OF ABSORPTION CAVITY, ENERGY EXCHANGER/TURBINE LASER DRIVEN HEAT ENGINE



OPTICAL RECTENNA CONFIGURATION

The optical rectenna is a microminature 10 micron wavelength dipole receiver and rectifier diode entirely analogous to the microwave rectenna in principle of operation. The method of fabrication is by semiconductor processing and lithography on silicon sheets. The sheets are mounted on water cooled plates at the base of a factor of 30 parabolic trough concentrator and connected to positive and negative power busses that run alongside.

OPTICAL RECTENNA CONFIGURATION



OPTICAL RECTENNA PRELIMINARY CHARACTERISTICS

Preliminary optical rectenna diode performance based on the constant forward voltage diode drop approximation is shown. Neither concentration or pulse factor alone will suffice for high efficiency - a concentrator ratio of 30-100 with a pulse factor of 1000 to 10,000 is needed. However, the result is the most efficient laser receiver concept proposed to date.

OPTICAL RECTENNA PRELIMINARY CHARACTERISTICS

- DIODE OUTPUT VOLTAGE

$$V = \left((P/A)\, Z_0 \right)^{1/2} \lambda$$

Power/Area — Free Space Impedance — Wavelength

- APPROXIMATE RECTENNA EFFICIENCY DUE TO FORWARD DIODE DROP LOSSES

$$\eta_{forward} = (V - V_{forward})\, V^{-1}$$

for Silicon diodes $V_{forward} = .6$ volts

- RESULTS OF CONCENTRATING ON DIODES AND PULSING LASER

CONCENTRATION	PULSE FACTOR	V (VOLTS)	$\eta_{FORWARD}$
1	1	.014	0
20	1000	1.94	.69
30	1000	2.38	.75
100	1000	4.34	.86
300	1000	7.52	.92
300	10000	23.8	.975

LASER CONCLUSIONS

Our conclusions on use of laser for SPS power transmission are listed.

LASER CONCLUSIONS

- BEST LASER OPTIONS ARE WITHIN A FACTOR OF 2 OF REFERENCE SYSTEM SPECIFIC MASS & COST.
- CAN PROVIDE SMALL (< 100 MW) BLOCKS OF POWER WITHOUT LOSS OF COST-EFFECTIVENESS.
- GROUND RECEIVER CAN BE EFFICIENT WITHOUT DANGEROUS INTENSITIES.
- AVAILABILITY BETTER THAN GROUND SOLAR BUT, NOT AS GOOD AS MICROWAVE SPS.
  - DOESN'T SHUT OFF AT NIGHT, BUT
  - CAN'T GET THROUGH INCLEMENT WEATHER
- SMALL RECEIVERS POSSIBLE (HUNDREDS OF METERS DIAMETER AT 1 GW).
- MOST PROMISING AREAS FOR REASEARCH
  - FREE-ELECTRON LASER
  - OPTICALLY-PUMPED LASER
  - MICRO-RECTENNA

LASER RESEARCH RECOMMENDATIONS

Because it is the most promising SPS laser candidate, the FEL deserves a more detailed study, particularly with regard to achievable beam power extractions.

LASER RESEARCH RECOMMENDATIONS

FREE-ELECTRON LASER

- DETAILED TRADEOFF OF SINGLE-PASS VS STORAGE RING

  KEY ISSUES:

KEY ISSUES	
. MAGNET WEIGHTS . BEAM RECONSTITUTION . POWER PROCESSING (LASER IS PULSED) . BEAM LEAKAGE	STORAGE RING
. HIGH-EXTRACTION WIGGLER . POWER PROCESSING (LASER IS PULSED) . SPENT BEAM DISSIPATION	SINGLE-PASS
. SCALING & POWER LIMITS . OPTIMIZATION . OPTICS SURVIVAL	BOTH

- HIGH-EXTRACTION & POWER PROCESSING EXPERIMENT PROGRAMS

LASER RESEARCH RECOMMENDATIONS (CONT)

Despite the generally unfavorable preliminary results in this study, the indirectly optically pumped laser still has potential for improvement. To realize this a more detailed investigation of the laser cycle needs to be done.

The optical rectenna is a good candidate for a small experimental program, as are band-gap matched photovoltaics.

Finally, a laser SPS grid integration study is needed to assess compatibility with electric utilities.

LASER RESEARCH RECOMMENDATIONS

OPTICALLY-PUMPED LASER

- DETAILED PHYSICS, THERMODYNAMICS & KINETICS MODELING: DESIGN TO OPTIMIZE LASER CIRCUIT & ASSESS SCALING.
- PUMPING & GAIN EXPERIMENTS
- SEARCH FOR BETTER CATALYSTS

GROUND RECEIVER

- ANALYZE & TEST MICRO-RECTENNA WITH CONCENTRATION & PULSING
- ANALYSE & TEST MATCHED PHOTOVOLTAICS

GENERAL

- DETAILED SCENARIO ANALYSIS TO ASSESS LOAD-CARRYING CAPACITY FOR VARIOUS REGIONS.

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TRANSPORTATION ANALYSES

Three separate transportation analyses were conducted. A study was made of a shuttle-derived heavy lift and orbit transfer system, attempting to make maximum use of existing or modified space shuttle hardware. In addition, a significant effort was invested in the definition of a small heavy lift launch vehicle, sized to roughly one third the liftoff mass of the present reference SPS HLLV. The third analysis, still in progress, is a sensitivity study of the electric orbit transfer vehicle, examining its sensitivity to thermal effects in low Earth orbit, radiation degradation, and use of alternative propellants.

TRANSPORTATION ANALYSES

- SHUTTLE-DERIVED SPS TRANSPORTATION
- SMALL HEAVY LIFT LAUNCH VEHICLE
- ELECTRIC ORBIT TRANSFER VEHICLE SENSITIVITIES

SHUTTLE-DERIVED SPS TRANSPORTATION

The goal of the shuttle-derived SPS transportation system was to minimize transportation development cost. The question related to this goal was determination of the recurring cost for SPS production if this transportation system were adopted. The concept involves use of shuttle orbiters and external tanks both for Earth-to-orbit and for orbit-to-orbit transportation. In order to reduce costs and increase performance, a new booster is to be designed and developed.

SPS-3274

SHUTTLE-DERIVED SPS TRANSPORTATION

GOAL: MINIMIZE DEVELOPMENT COST

APPROACH:

- o USE SHUTTLE ORBITER AND ET
- o PROVIDE NEW BOOSTER TO INCREASE PERFORMANCE AND DECREASE COSTS

PROBLEMS WITH THE ORIGINAL CONCEPT

This concept was developed by the Johnson Space Center. An initial configuration was provided as a part of the Phase III task statements. The configuration had certain known problems. First of all, very little volume was available for SPS hardware payloads. These hardware payloads are relatively low in density and require a low density payload bay to achieve efficient transportation operations. Further, the original concept included a redesign of the satellite, fairly complex construction operations, and raised certain questions as to whether the large sections of satellite built at low Earth orbit could be transported to GEO. Thirdly, accommodations for crew delivery from LEO to GEO were not provided. Finally, the system included a ballistic booster. Earlier studies of ballistic versus winged boosters had indicated that winged systems would provide lower transportation costs due to more rapid turnaround operations.

PROBLEMS WITH THE ORIGINAL CONCEPT

- NO VOLUME FOR PAYLOAD.
- SATELLITE MUST BE REDESIGNED AND PARTIALLY BUILT AT LEO, PARTIALLY AT GEO.
- NO VOLUME FOR LEO-GEO CREW.
- BALLISTIC BOOSTER WITH HIGH STAGING VELOCITY REQUIRES EXTENSIVE SEA RECOVERY OPERATION.

WORKAROUNDS

A revised configuration was developed that included a redesign of the external tank and the use of a fly-back booster. It had also been suggested that the orbiter be redesigned to provide increased payload accommodations. This, however, appeared to be in conflict with the desired objective of minimizing development costs. If one were to redesign the orbiter and provide a new booster, one would, in effect, have a small heavylift launch vehicle. That option was studied as another part of the transportation task.

WORKAROUNDS

- o REDESIGN ORBITER
- o REDESIGN ET (REQUIRED IN ANY EVENT)
- o USE FLYBACK BOOSTER

MODIFIED SHUTTLE SPS TRANSPORTATION SYSTEM

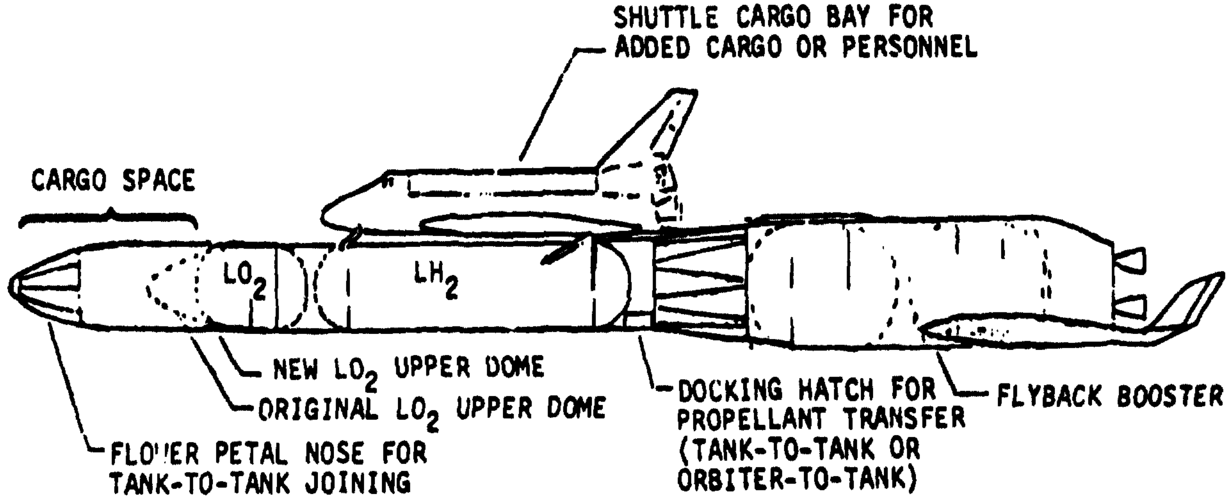
Shown here are the principal features of the modified system. Cargo space is provided in the external tank. The shuttle cargo bay provides sufficient volume for personnel accommodation. The flyback booster and interstage structure provide for launch of the shuttle and external tank to the proper staging conditions.

Cargo is launched to low Earth orbit with the configuration illustrated. Some of the external tanks with cargo space are to be used for orbit-to-orbit transportation. These are provided with better thermal insulation for roughly two weeks' stay time in low Earth orbit. Additional launches with relatively conventional external tanks bring propellant to low Earth orbit to fill the orbit transfer ET systems. The relatively high performance of the large flyback booster allows the system to arrive in orbit with substantial propellant remaining in the external tank. This is then transferred to the orbit transfer ET's until they are fully loaded with propellant.

In order to provide an adequate mass fraction for orbit transfer and allow the shuttle orbiter to go along as a propulsion system and crew transfer system, several external tanks are docked together end-to-end to provide a very large orbit transfer system with great propellant mass.

MODIFIED SHUTTLE SPS TRANSPORTATION SYSTEM

CARGO LAUNCH CONFIGURATION



FEATURES OF REVISED SYSTEM

The principal features of the revised system are tabulated here. Note that three types of external tanks are required. All cargo for launch from Earth to orbit is housed internally to the external tank payload bay. For orbit transfer, this is not necessary and cargo brought to Earth orbit by those external tanks not configured for orbit transfer will be stored externally to the orbit transfer ET's for the orbit transfer.

FEATURES OF REVISED SYSTEM

- CARGO SPACE IN ET ALLOWS DELIVERY OF CARGO TO GEO & ALL CONSTRUCTION AT GEO.
- ADEQUATE VOLUME CAN BE PROVIDED.
- ORBITER BAY AVAILABLE FOR PERSONNEL
- THREE ET VERSIONS

  (1) "REGULAR" - PROPELLANT DELIVERY TO LEO - MODIFIED ONLY FOR PROPELLANT ACQUISITION AND TRANSFER

  (2) CARGO TO LEO - CARGO BAY ADDED

  (3) LEO-GEO
    - CARGO BAY
    - FLOWER PETAL NOSE
    - BETTER INSULATION

OPTIMIZATION QUESTIONS

A number of questions have been raised as to how to configure this system for minimum cost. The three principal variables are the booster size and attendant staging velocity, booster flyback optimization, and the number of external tanks to be provided for each transfer flight. Crew accommodations in the orbiter were a secondary question.

OPTIMIZATION QUESTIONS

- BOOSTER SIZE/STAGING VELOCITY
- BOOSTER FLYBACK OPTIMIZATION
- ET'S PER TRANSFER FLIGHT
- CREW ACCOMMODATIONS
- COST

ISAIAH: WHAT IT IS

In order to conduct the optimization analysis, the Isaiah Systems Modeling Software System was employed. The Isaiah software, in effect, allows one to very quickly develop a computer program to analyze a complex systems model by standardizing those things that normally cause most of the difficulty in developing computer models.

ISAIAH - WHAT IT IS

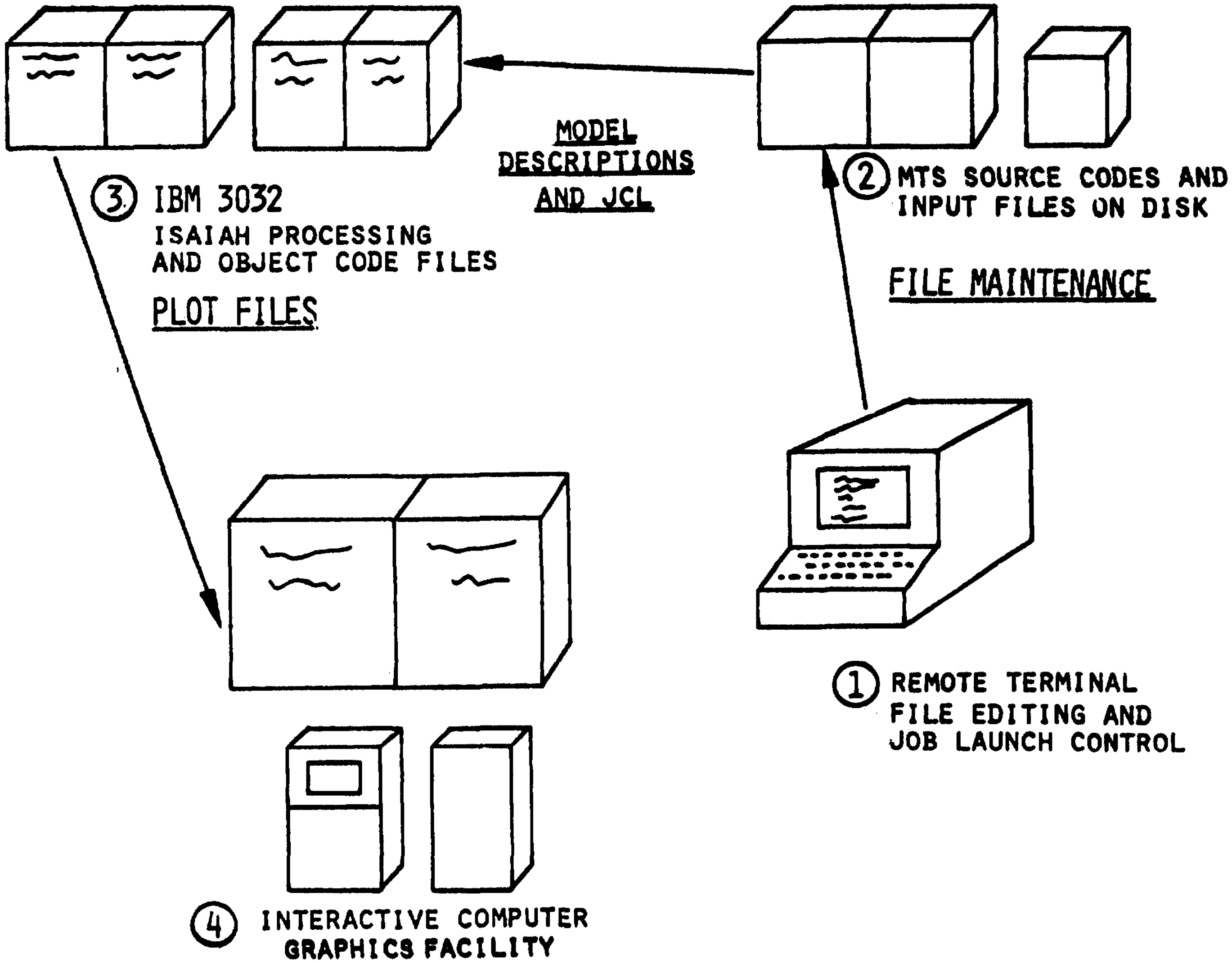
- STANDARDIZED, STRUCTURED PROCEDURE AND SOFTWARE SYSTEM FOR INTERRELATIONSHIPS AND SENSITIVITY ANALYSIS
  - MODELING METHODOLOGY
  - INPUT LANGUAGE
  - INTERNAL LOGIC
  - DIAGNOSTICS
  - OUTPUT FORMATTING
  - PLOT ROUTINES

- NINETY PERCENT OF THE CODE AND 95% OF THE TROUBLE IN A LARGE COMPUTER PROGRAM IS INPUT, OUTPUT, LOGIC STRUCTURE, AND FILE HANDLING. THE RATIO IS SOMEWHAT WORSE IF COMPUTER GRAPHICS IS USED. WITH THE ISAIAH METHODOLOGY ALL OF THIS STUFF IS ALREADY THERE AND DOESN'T NEED CHANGING.

ISAIAH COMPUTER HOOKUP

The Isaiah System operates with the computer network at the Boeing Kent Space Center. The system is accessible through remote terminals and all card image files are maintained on disk files to avoid card deck handling. The software runs on a large IBM mainframe and plot files are transmitted to the interactive computer graphics facility for rapid plotting of results.

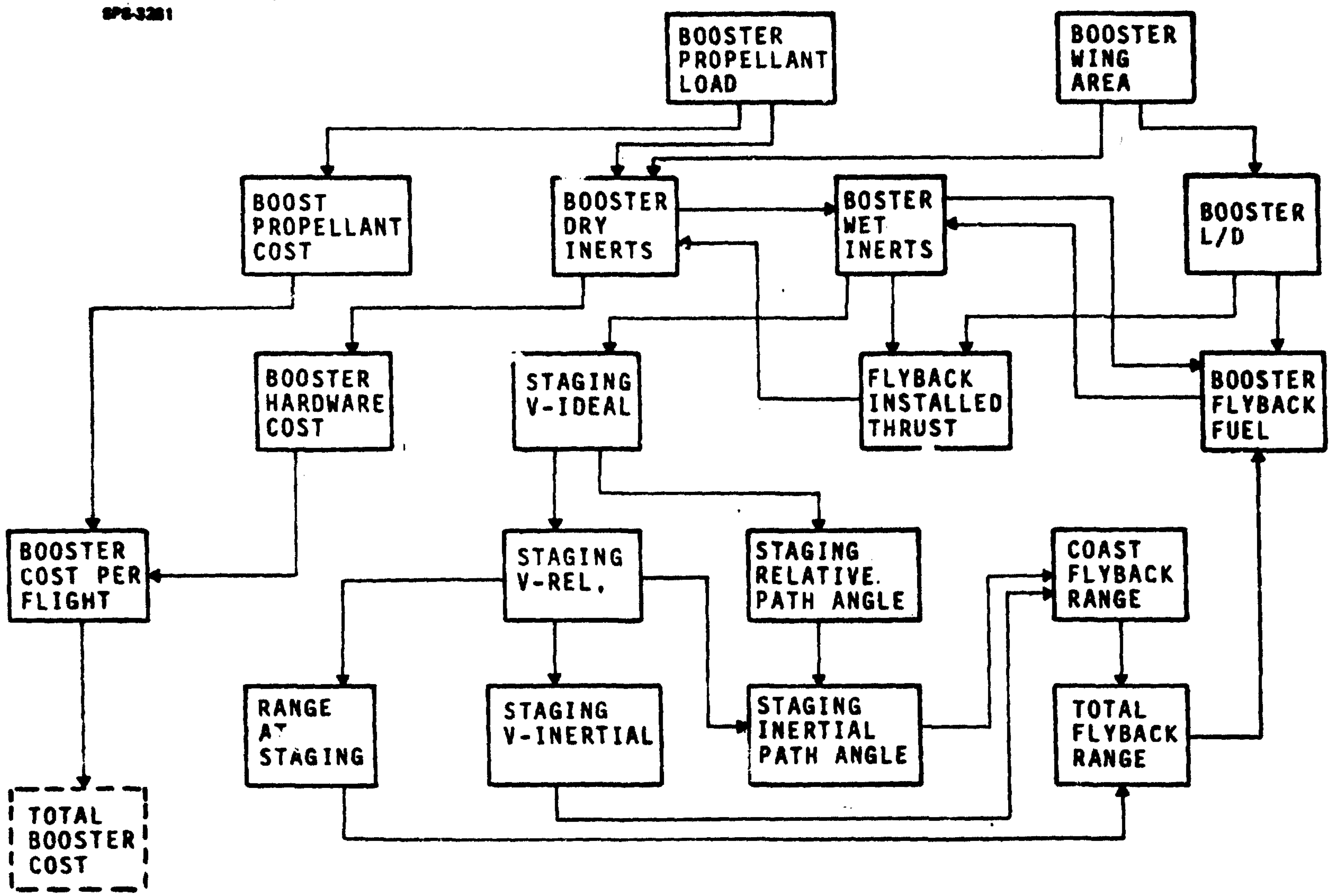
ISAIAH COMPUTER HOOKUP



SHUTTLE DERIVED SYSTEM OPTIMIZATION (BOOSTER)

The systems model is summarized on the facing page. This segment of the model includes the booster flyback optimization with principal variables being the booster wing area, dry inerts, and the booster propellant load and staging velocity. The iterations implied in the network are handled automatically with the Isaiah software.

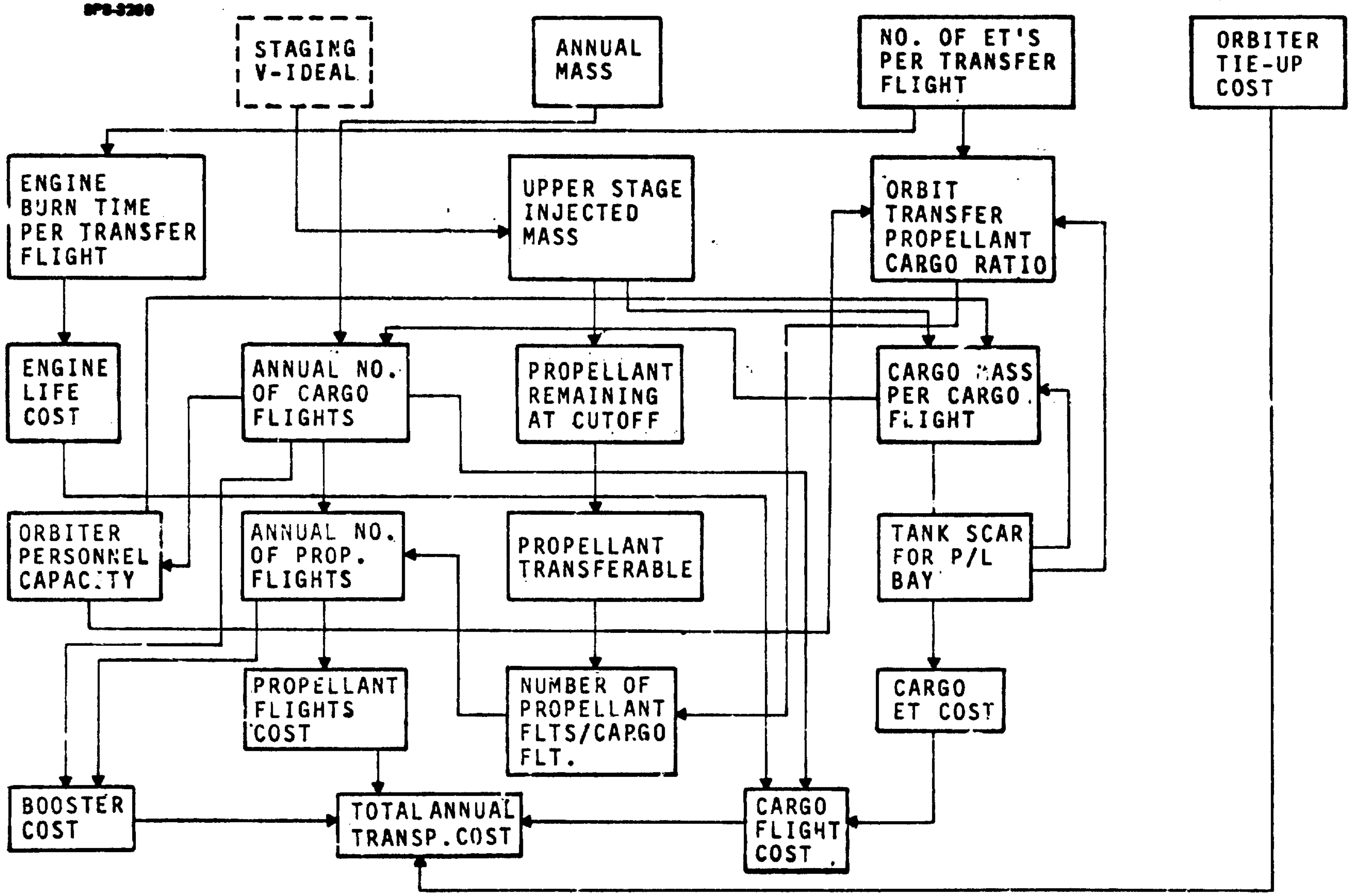
SHUTTLE -DERIVED SYSTEM OPTIMIZATION (BOOSTER)



SHUTTLE DERIVED SYSTEM OPTIMIZATION (UPPER STAGES AND TOTAL)

The analysis of the upper stages is diagramed on the facing page. As the ideal staging velocity increases, the upper stage injected mass increases thus increasing the cargo mass and the propellant deliverable. However, as the ideal staging velocity increases, larger and larger boosters are required so one would expect a minimum cost point.

SHUTTLE-DERIVED SYSTEM OPTIMIZATION (UPPER STAGES & TOTAL)

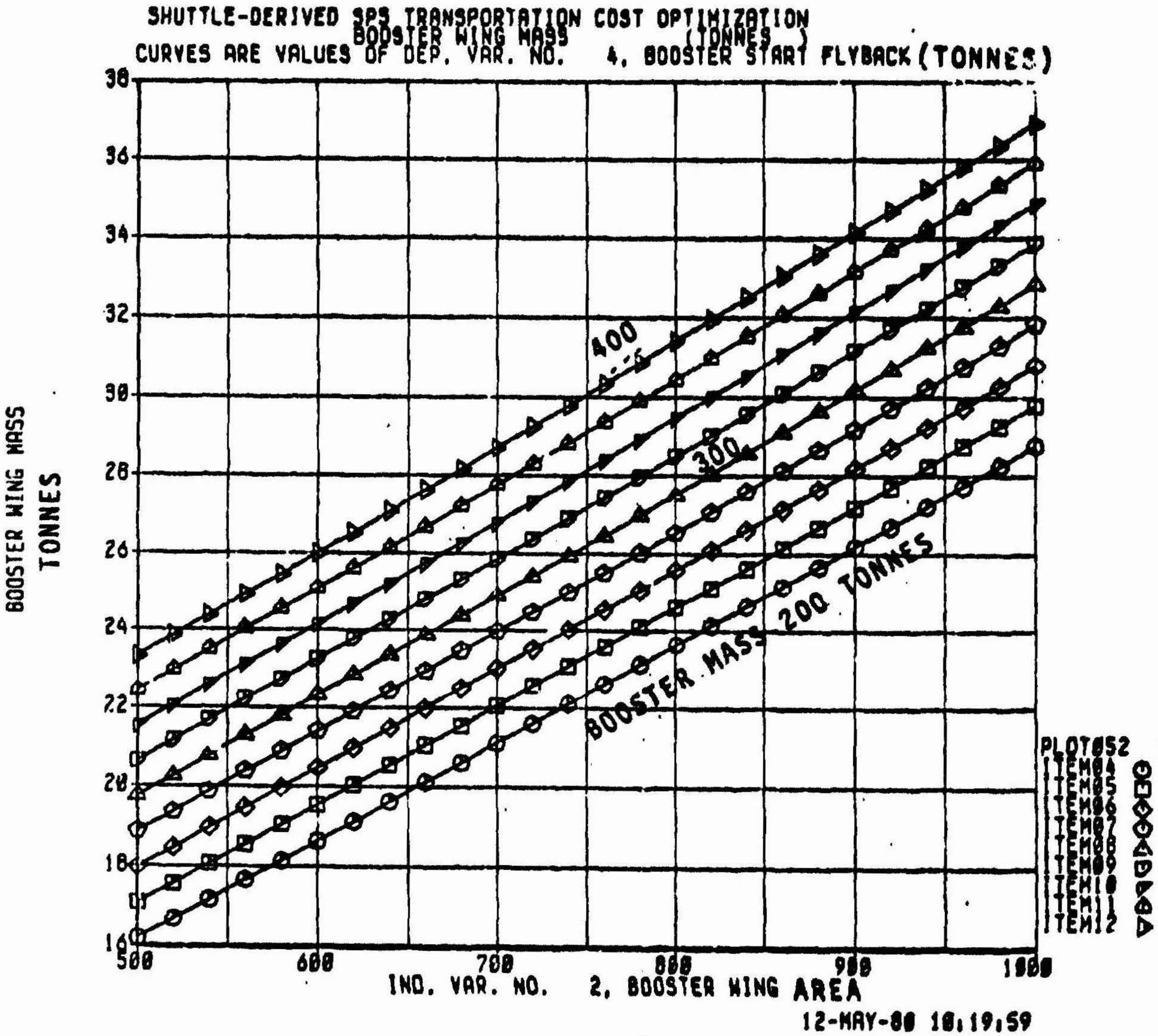


MODEL INPUTS

Plo' .ed here is the estimated relationship of booster wing mass to the booster mass and booster-wing area. This is a key relationship for establishing the flyback optimization.

MODEL INPUTS

SPS-3404

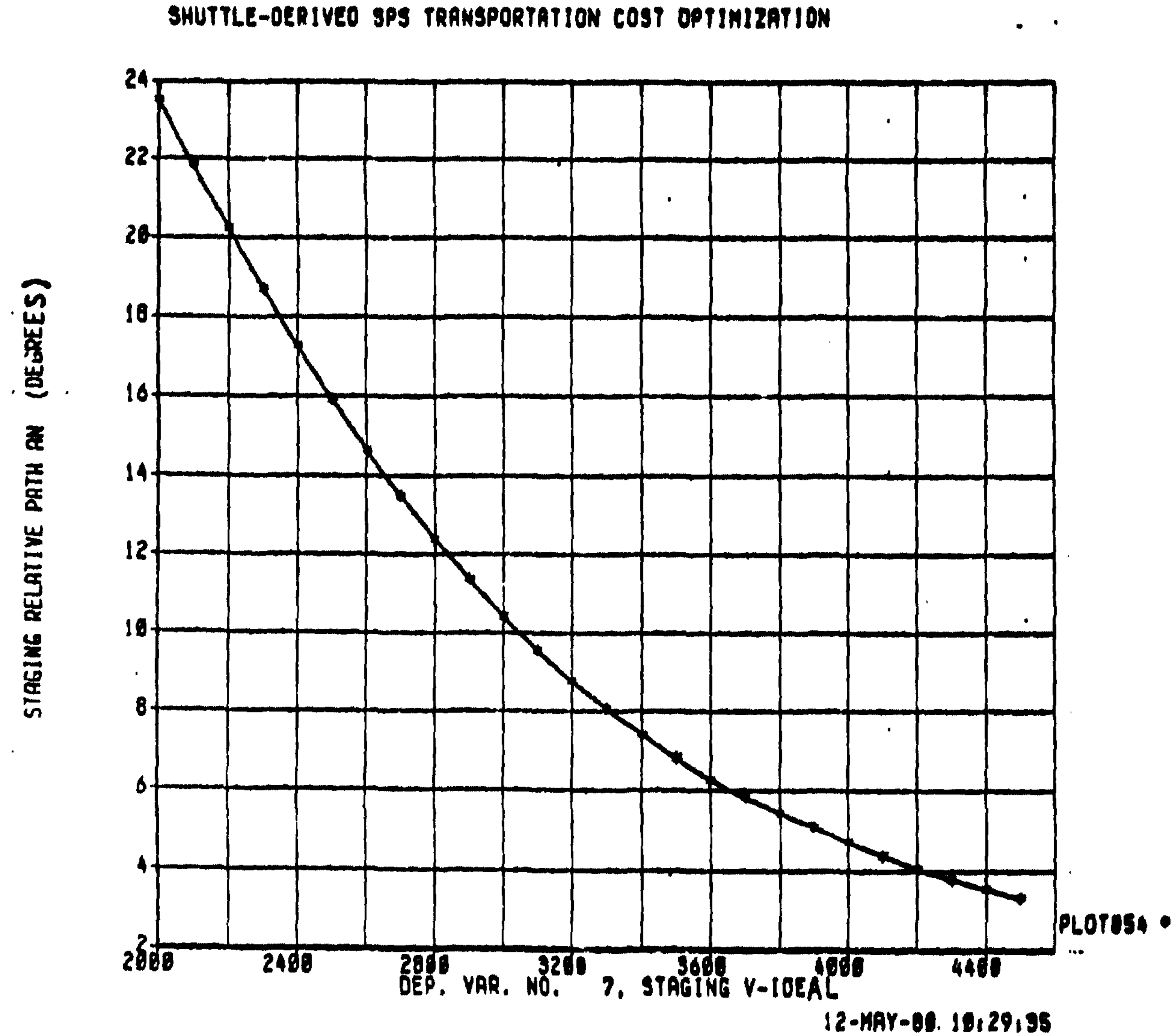


MODEL INPUTS (CONTINUED)

The staging relative path angle decreases with increasing staging velocity; the path angle is important in establishing flyback range.

MODEL INPUTS (CONT'D)

SPS-3406

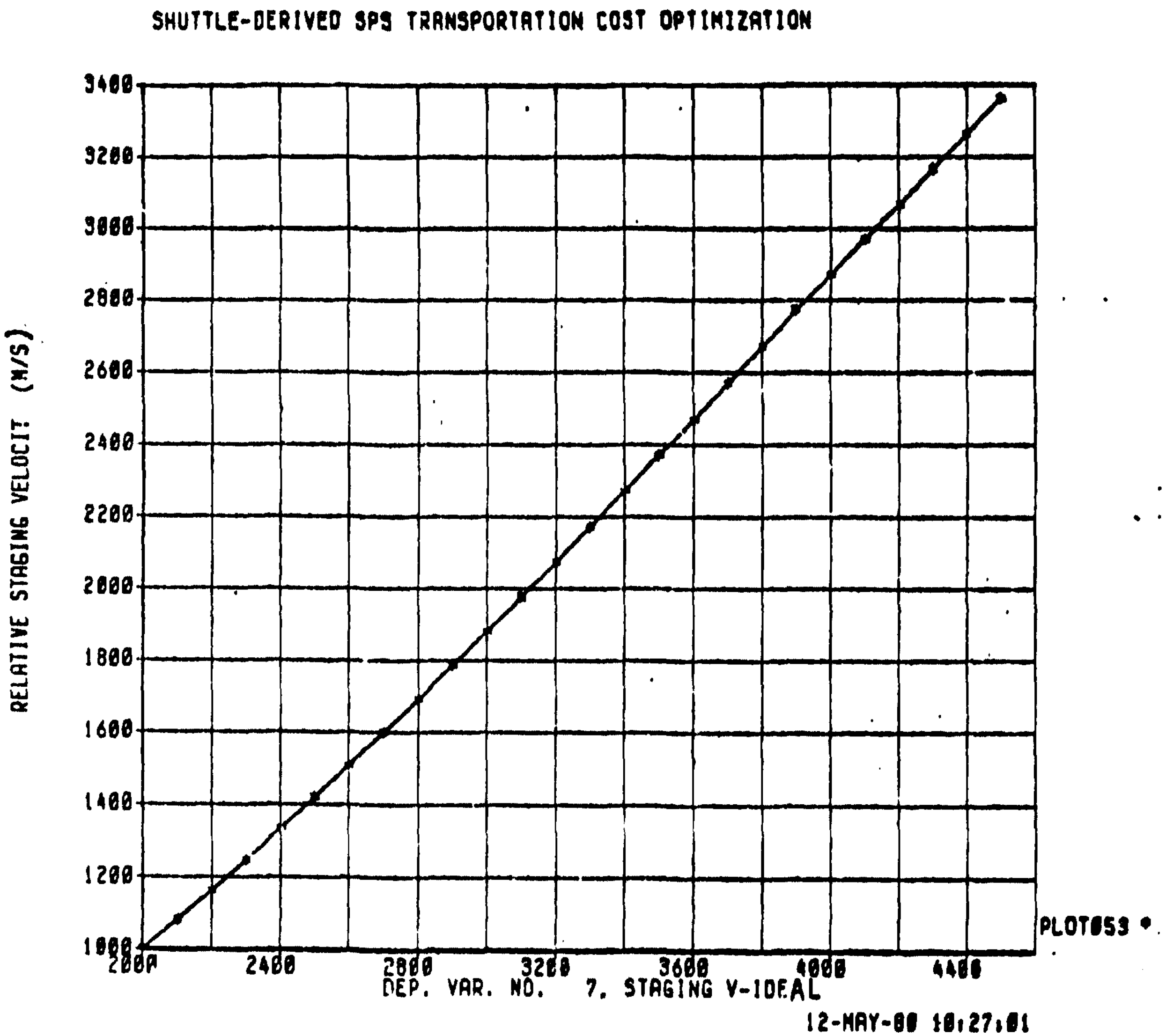


MODEL INPUTS (CONTINUED)

Shown here is the relationship of relative staging velocity to ideal staging velocity.

MODEL INPUTS (CONT'D)

SPS-3408

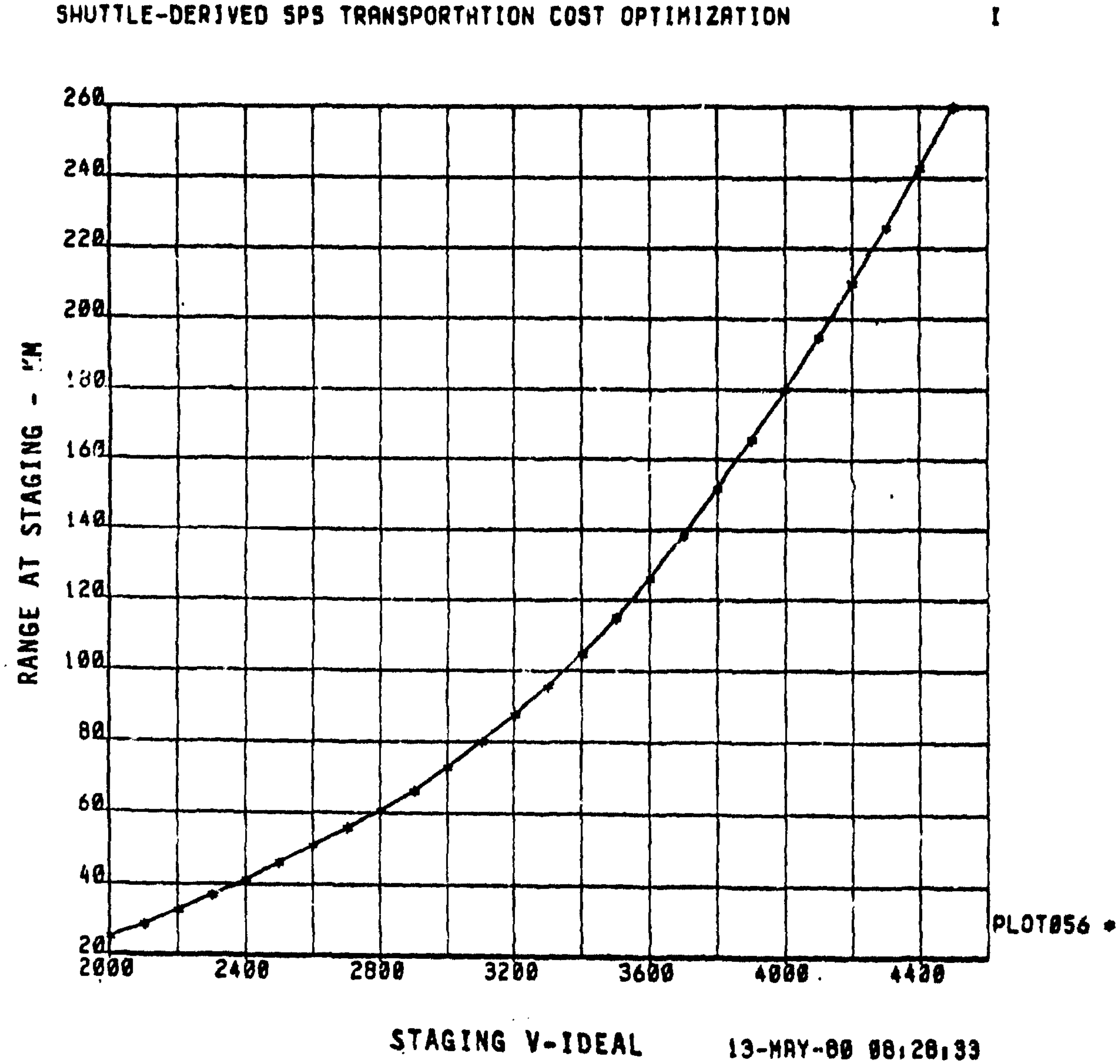


MODEL INPUTS (CONTINUED)

The flyback range is composed of two principal components: the range at staging and the coast range after staging. Shown on this chart is the range at staging as a function of ideal staging velocity. On the next chart, the coast and flyback range as a function of path angle and inertial staging velocity is shown.

MODEL INPUTS (CONT'D)

SPS-3407



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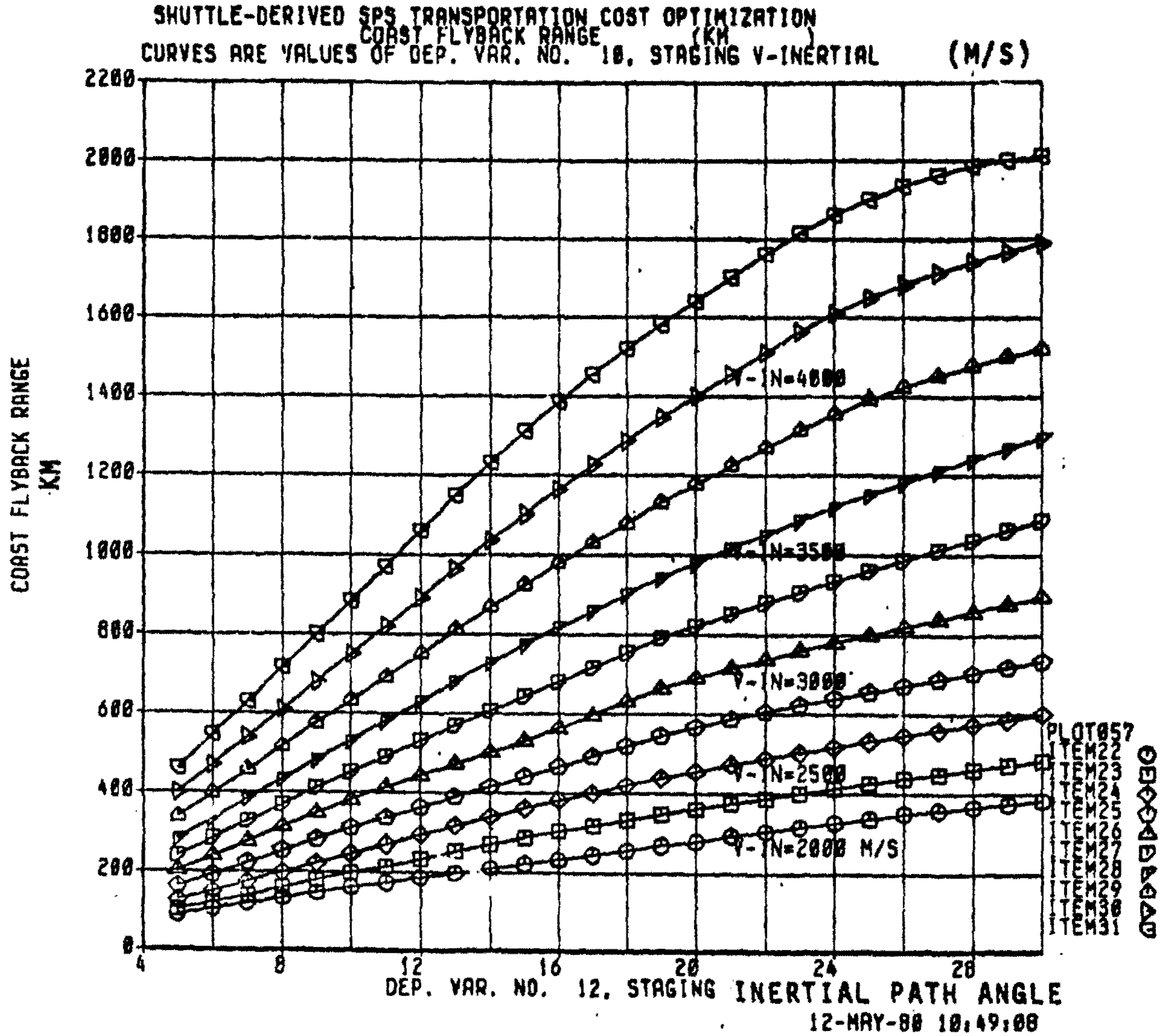
MODEL INPUTS (CONT'D)

SPS-3408

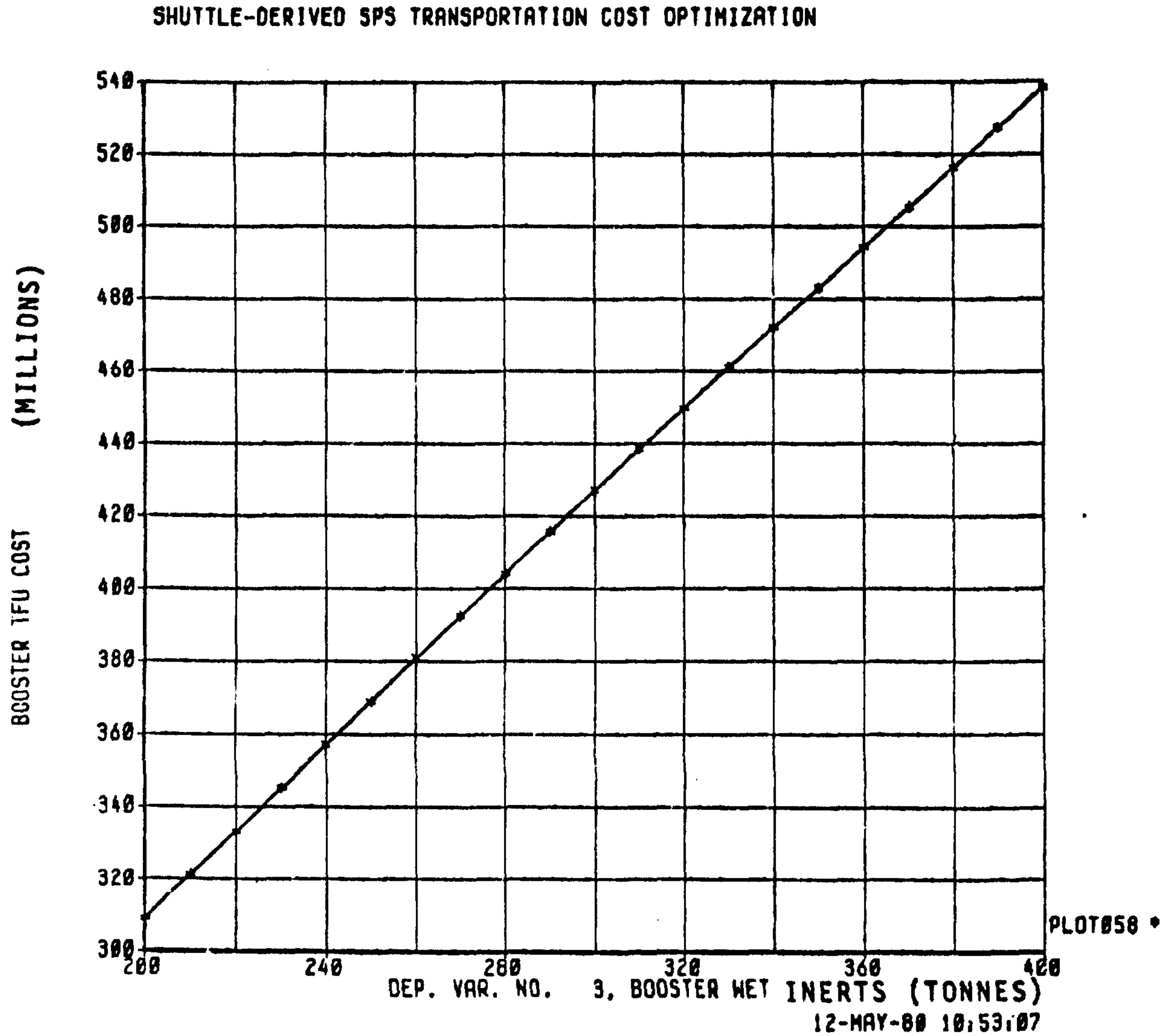


MODEL INPUTS (CONTINUED)

The booster theoretical first unit cost is modeled as dependent upon the booster wet inert weights (booster inerts including residual ascent propellants but not including flyback propellant). The model included learning curve relationships to allow the booster average unit cost to be computed from the theoretical first unit cost.

MODEL INPUTS (CONT'D)

SPS-3409

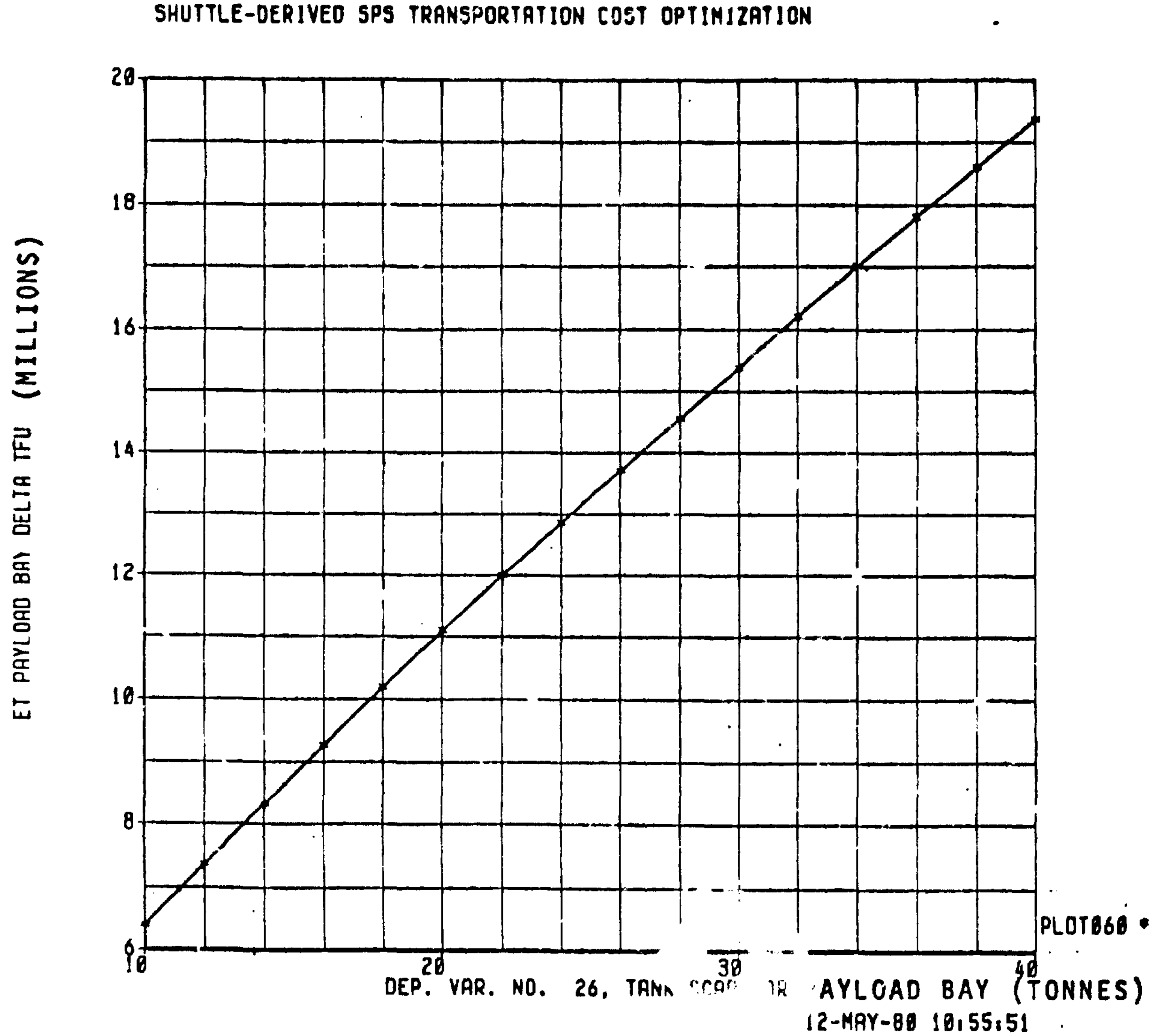


MODEL INPUTS (CONTINUED)

ET costs were computed based on the theoretical first unit for the basic ET and on a delta theoretical first unit for the additional mass of payload bay which in turn depends upon the payload deliverable per flight.

MODEL INPUTS (CONT'D)

SPS-3411

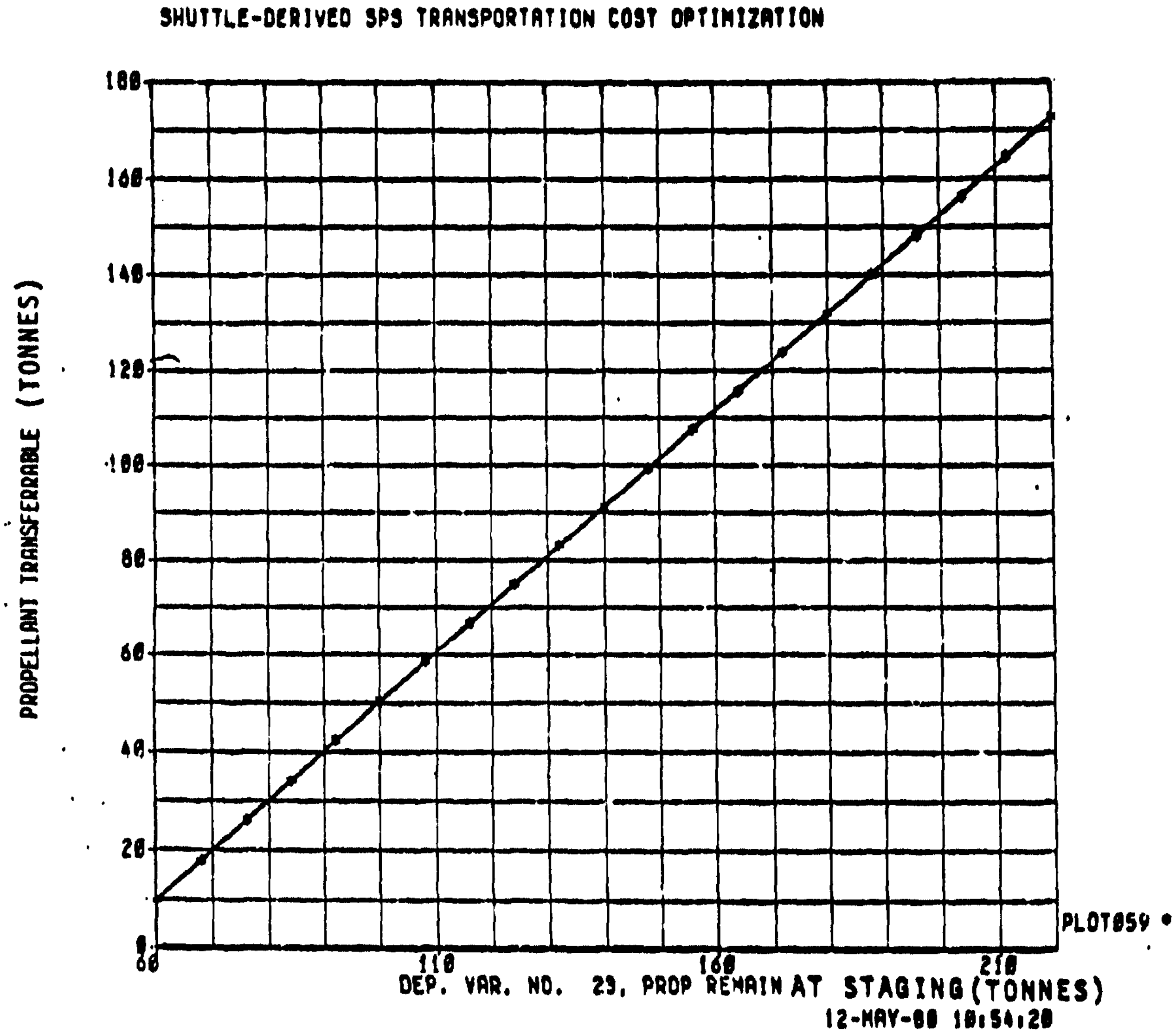


MODEL INPUTS (CONTINUED)

The propellant transferrable is dependent upon the propellant remaining at staging. For relatively low values of propellant remaining, very little propellant is transferrable since most of it will be vaporized by the tank vapor residuals and the tank wall mass.

MODEL INPUTS (CONT'D)

SPS-3410

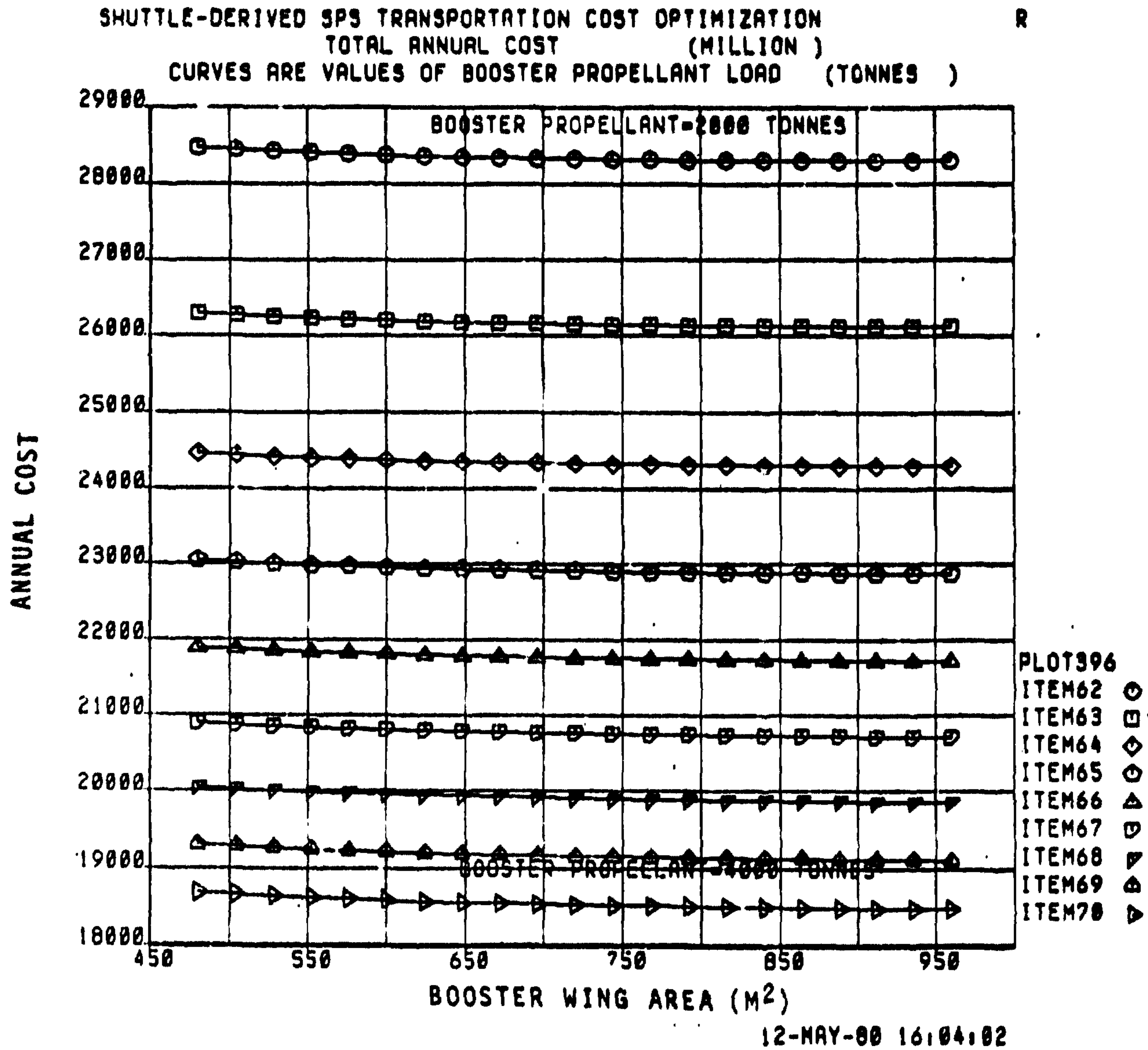


WING AREA EFFECTS

The first run of the model examined the importance of booster wing area. Wing area was found not to be a very important parameter. For further investigations, wing area was fixed at 1,000 square meters.

WING AREA EFFECTS

SPS-3412

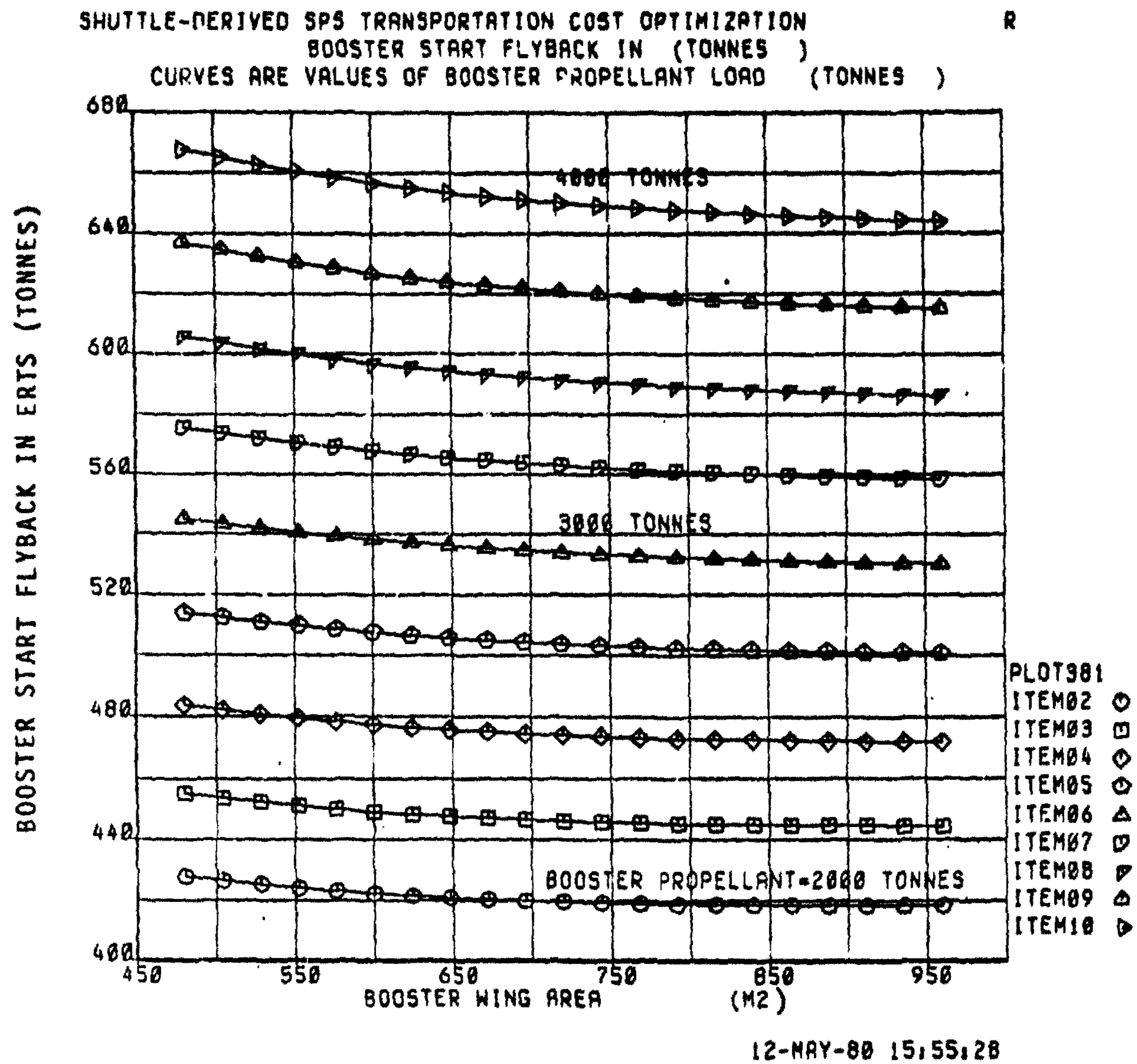


BOOSTER START FLYBACK INERTS

The larger wing areas actually reduce booster start flyback inerts as the improvement and L/D is more important than the increase in wing mass.

BOOSTER START FLYBACK INERTS

SPS-3423



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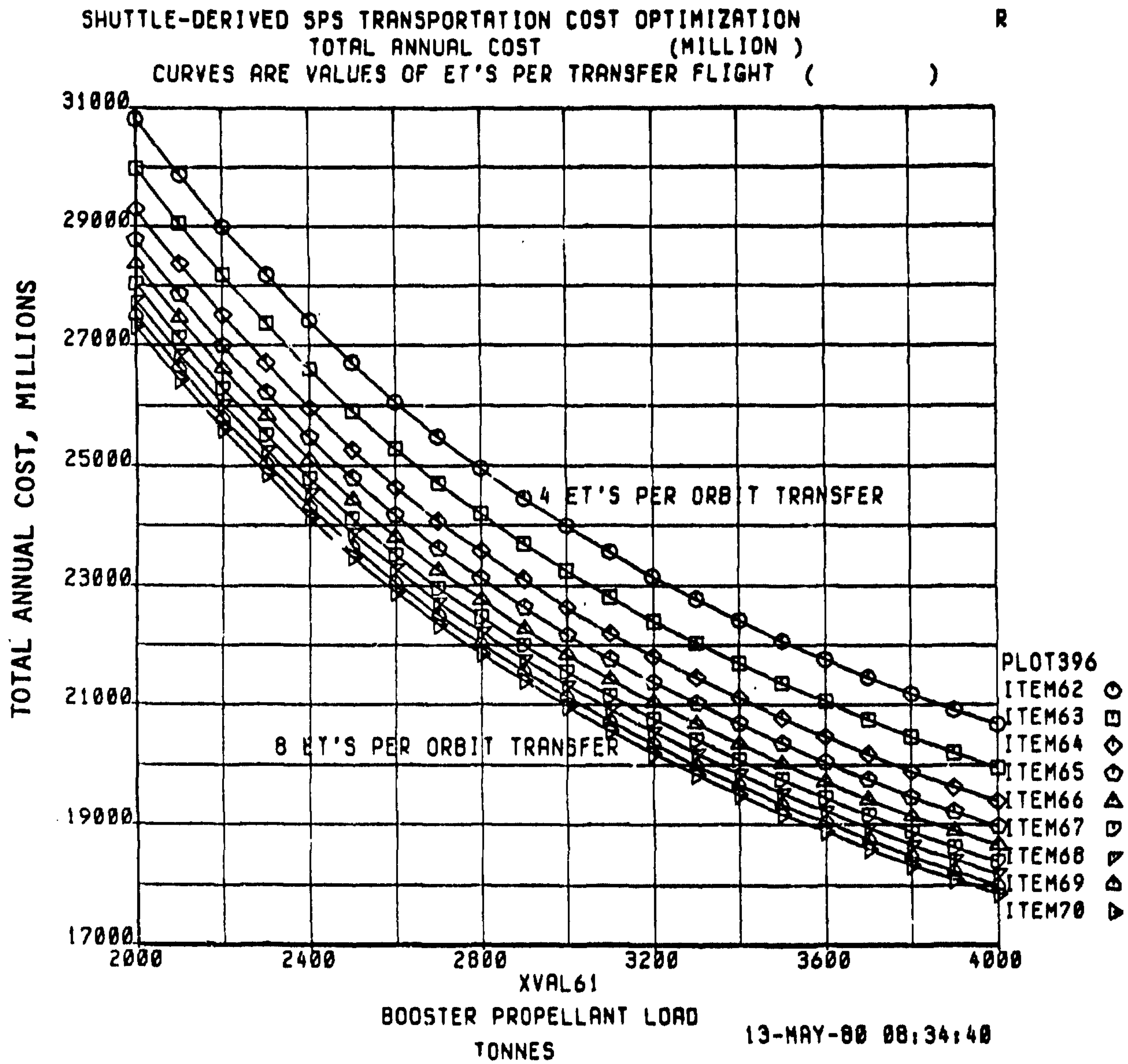
TOTAL ANNUAL COST

Displayed here is the total annual cost for construction of two SPS's per year as a function of booster propellant load and number of ET's per orbit transfer. It is evident that large boosters are important and that using at least six ET's per orbit transfer is desirable.

TOTAL ANNUAL COST

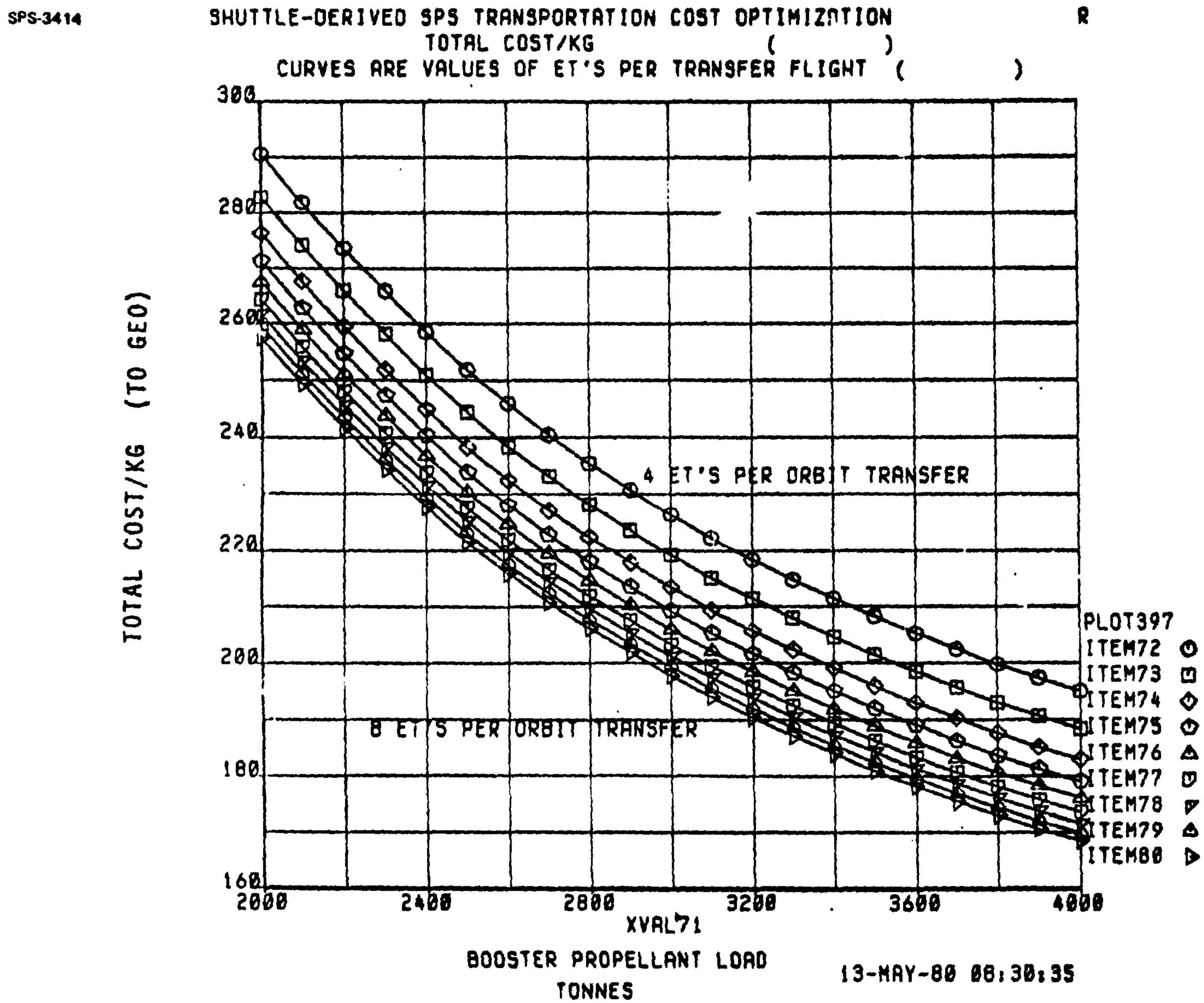
SPS-3413



TOTAL COST PER KILOGRAM

The same data are displayed here in terms of cost per kilogram.

TOTAL COST/KG

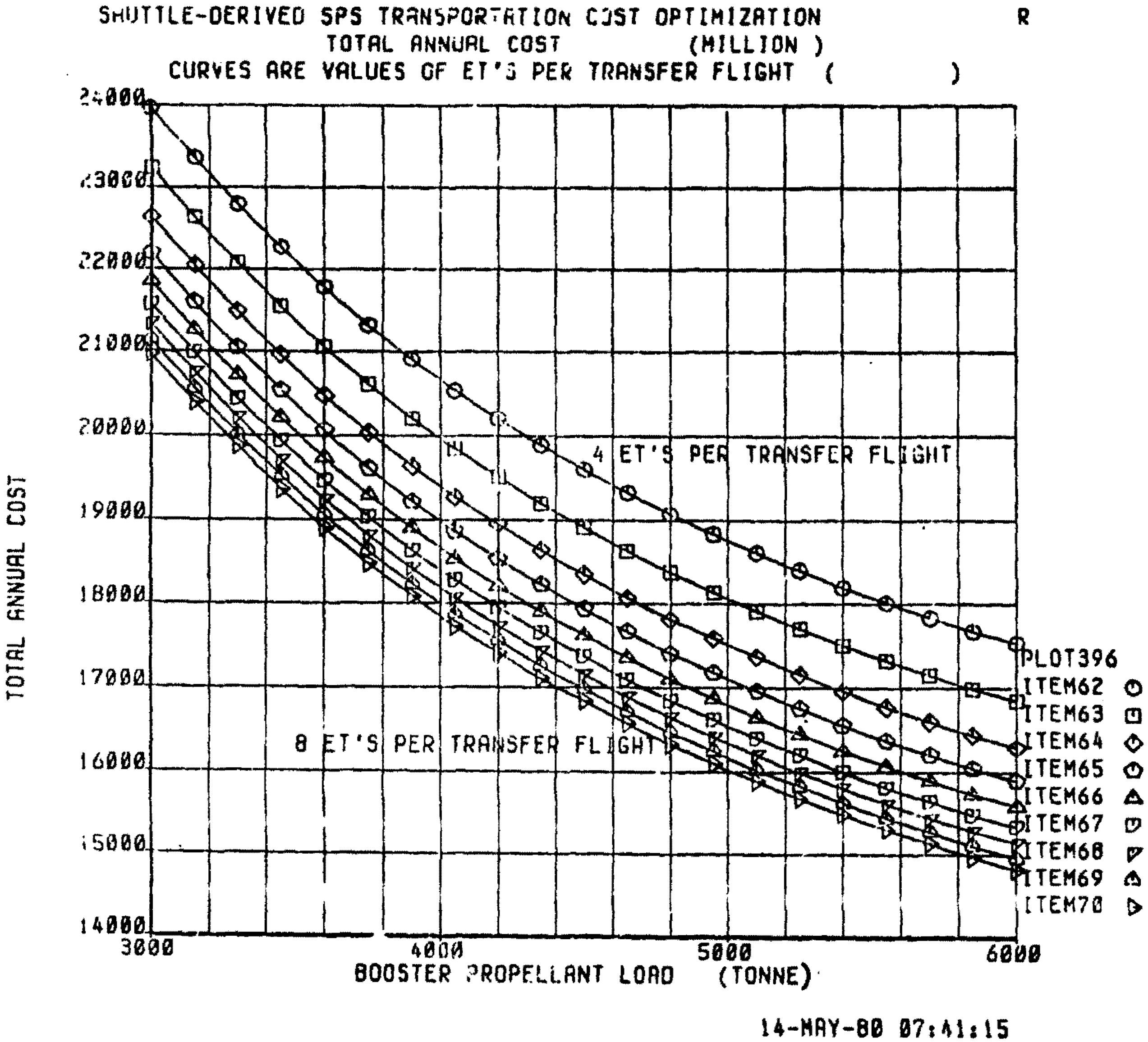


TOTAL ANNUAL COST FOR LARGE BOOSTERS

The previous case was rerun for larger booster propellant loads showing some additional reduction in total annual cost up to 6,000 ton boosters. The total annual cost here is about twice that for the small HLLV whereas the booster size is approaching the booster for the large HLLV which had a propellant load of about 7,000 metric tons.

TOTAL ANNUAL COST FOR LARGE BOOSTERS

SPS-3428



SHUTTLE DERIVED DEVELOPMENT REQUIREMENTS

A number of developmental requirements are necessary in order to implement the shuttle derived system. Several changes to the external tank are required and orbiter crew accommodations of up to 30-40 crew are needed for the orbit transfer. These crew accommodations can be provided in the payload bay. A new large booster is required and the orbiter/external tank flight operations technology involved in transferring propellant and flying LEO to GEO orbit transfers must also be developed.

SPS

SHUTTLE-DERIVED DEVELOPMENT REQUIREMENTS

SPS-3419

BOEING

- ET CARGO BAY (CARGO ET'S ONLY)
- ET IMPROVED INSULATION (ORBIT TRANSFER ET'S)
- ET DOCKING (ORBIT TRANSFER ET'S)
- ET PROPELLANT TRANSFER EQUIPMENT
  (PROPELLANT ET'S AND
  ORBIT TRANSFER ET'S)
- ORBITER CREW ACCOMMODATIONS ≈ 30 TO 40
- NEW BOOSTER 5000 TO 6000 TONNES GROSS BOOSTER MASS
- ORBIT IN ET FLIGHT OPERATIONS

RESULTS

The dominant results are summarized here. The recurring cost is estimated as about twice that of the small heavy lift launch vehicle and the DDT&E, including the large booster and the ET mods is estimated at 60 to 70 percent of the small heavy lift launch vehicle. The shuttle derived system optimizes with payload to orbit per flight in the range of 300 tons. This payload capability is too large for many other applications, a criticism also directed at the large SPS reference heavy lift launch vehicle.

It is recommended that the small heavy lift launch vehicle should be selected as the SPS reference system. That small vehicle is described in the following briefing material. The shuttle derived concept, however, should be retained as an option for further consideration and reexamined in light of shuttle operating experience after a few shuttle flights have been accomplished.

RESULTS

- NEED ABOUT 25 ORBITERS TO HANDLE LAUNCH RATE

- RECURRING COST ≈ 2X SMALL HLLV

- DDT&E ≈ 60%-70% OF SMALL HLLV

- RECOMMENDATION: SELECT SMALL HLLV AS SPS REFERENCE SYSTEM

SMALL HEAVY LIFT LAUNCH VEHICLE

Discussion of the small HLLV considers the vehicle design aspects, then the operations analyses assess the effects of the small HLLV.

SPS-3279

SMALL HLLV

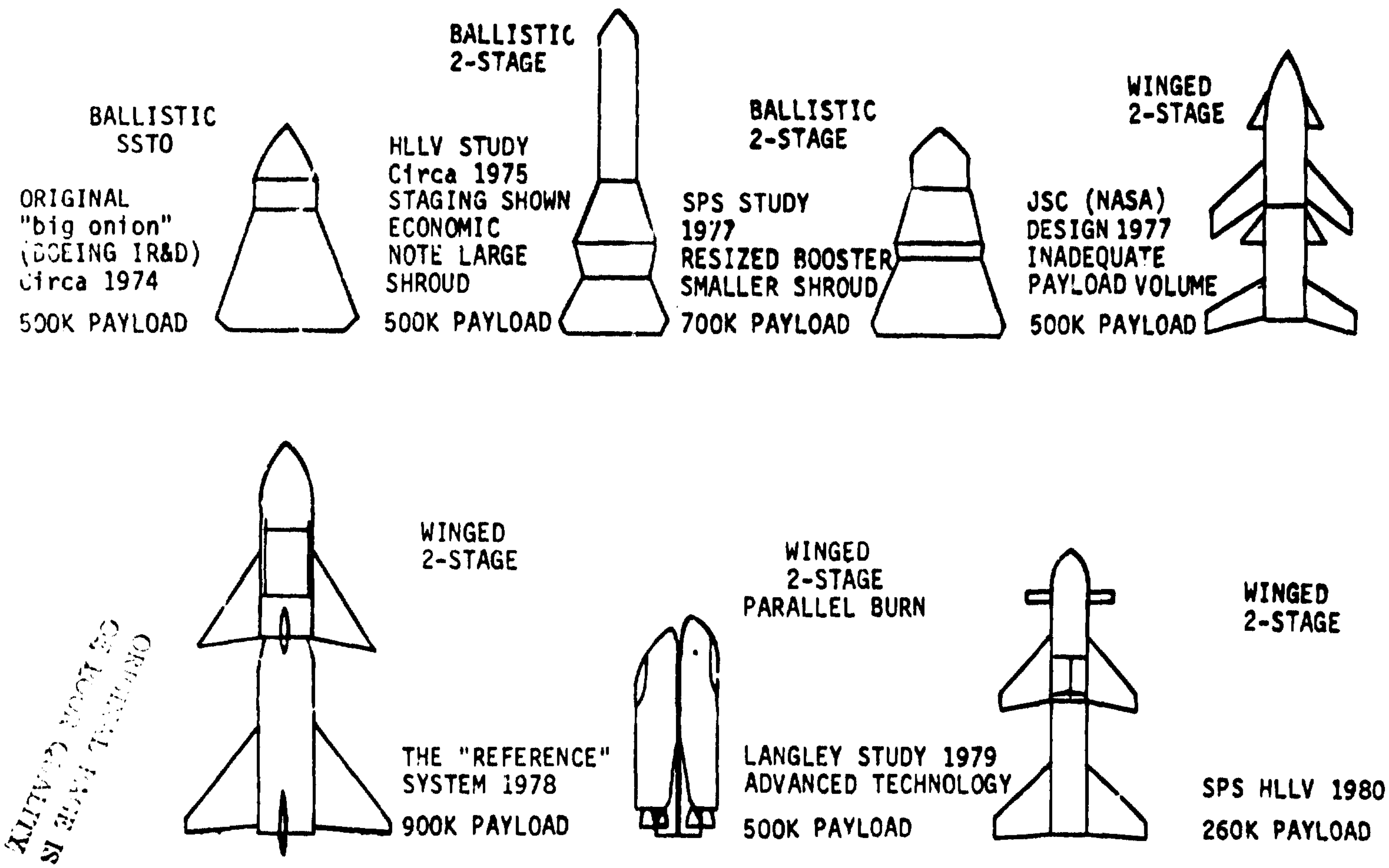
- o SIZE AND CONFIGURATION SELECTION
- o VEHICLE ANALYSIS

SPS LAUNCH VEHICLE CONCEPT EVOLUTION

The earliest studies of large launch vehicles were conducted in the mid-1960's during the development of Saturn V. With the initiation of shuttle development, such studies were for a time dropped. As concept development for the solar power satellite began, there again developed an interest in large launch vehicles. Boeing developed a concept of a 500,000 lb. payload single stage-to-orbit ballistic vehicle in 1974. It used dual-fuel propulsion with oxygen-hydrocarbon and oxygen-hydrogen engines. A later study, funded by NASA-JSC and MSFC, examined heavy lift launch vehicles and concluded that staged ballistic configurations would have a cost advantage over single staged systems. At that time SPS payloads were thought to have very low density, on the order of 20 killograms per cubic metre. Consequently, the configurations of that time period employed very large expendable shrouds.

Development of space fabrication concepts improved the payload density to about 75 killograms per cubic metre and the launch vehicles were resized in response. JSC, in 1977, developed a winged vehicle concept for horizontal land landing. A comparative assessment of this versus the sea-landing ballistic system showed that the land lander would be operationally perferable and about equal in cost to the ballistic system, but that the specific configuration had inadequate payload volume. It was subsequently reconfigured to increase payload volume and became the reference system. Later studies have examined parallel burn vehicles, as well as a smaller heavy lift system for SPS application. The smaller heavy lift vehicle is the subject of this presentation.

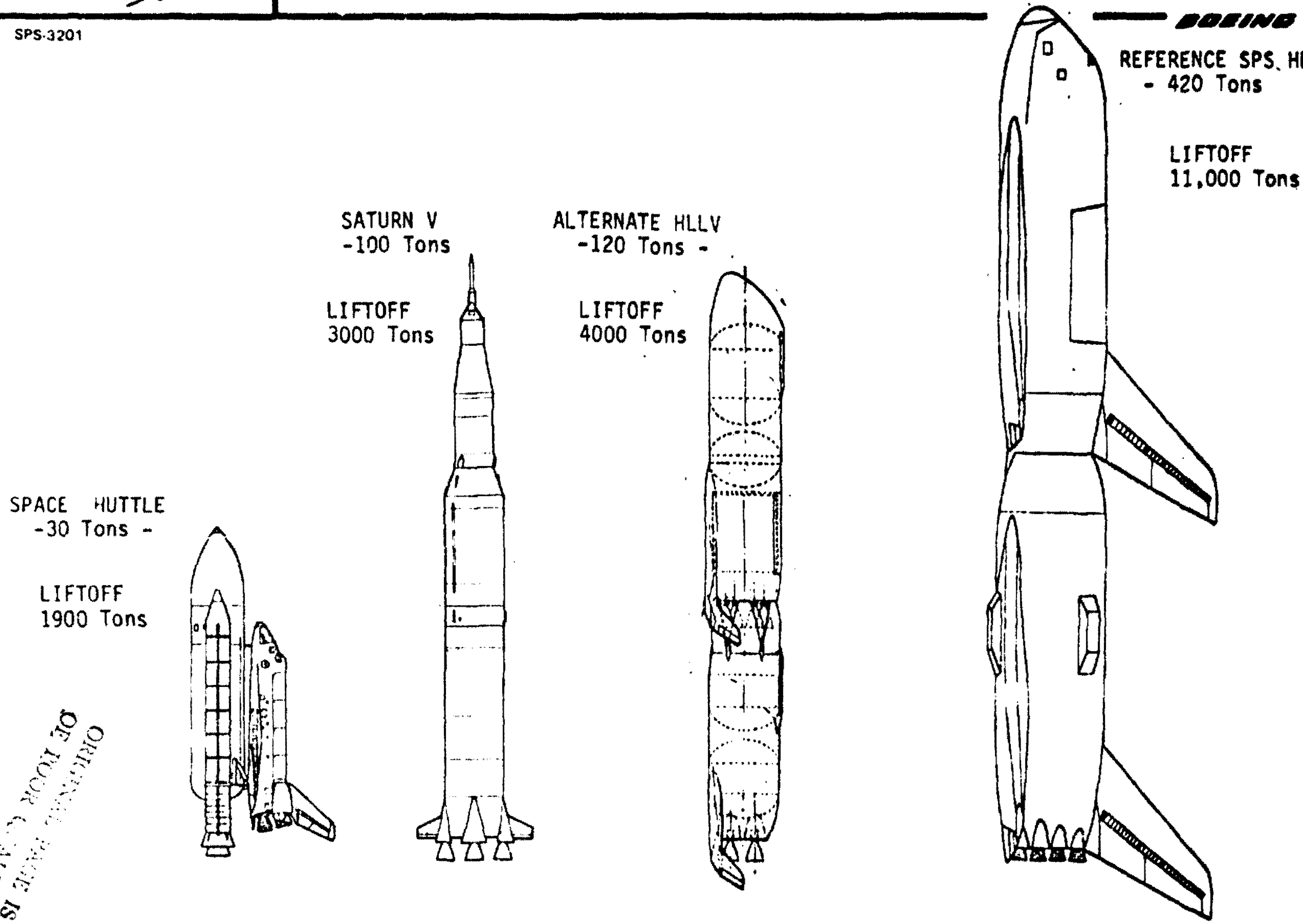
SPS LAUNCH VEHICLE CONCEPT EVOLUTION



LAUNCH SYSTEMS - SIZE COMPARISONS

The small or alternate HLLV is shown to correct scale on this figure with the shuttle, the Saturn, the reference SPS HLLV, and the 747 commercial aircraft. As is evident, the small HLLV is much nearer in size to large airframes that have been built.

LAUNCH SYSTEMS SIZE COMPARISON



SPS LAUNCH VEHICLE TECHNOLOGY ASSUMPTIONS

The technology assumption used for the SPS HLLV studies are summarized on the facing page. In general, these represent evolutionary technology growth from space shuttle. The last item, on-board built-in test and fault isolation test, is intended to provide rapid assessment of vehicle maintenance requirements to minimize turnaround time.

SPS-3318

BOEING

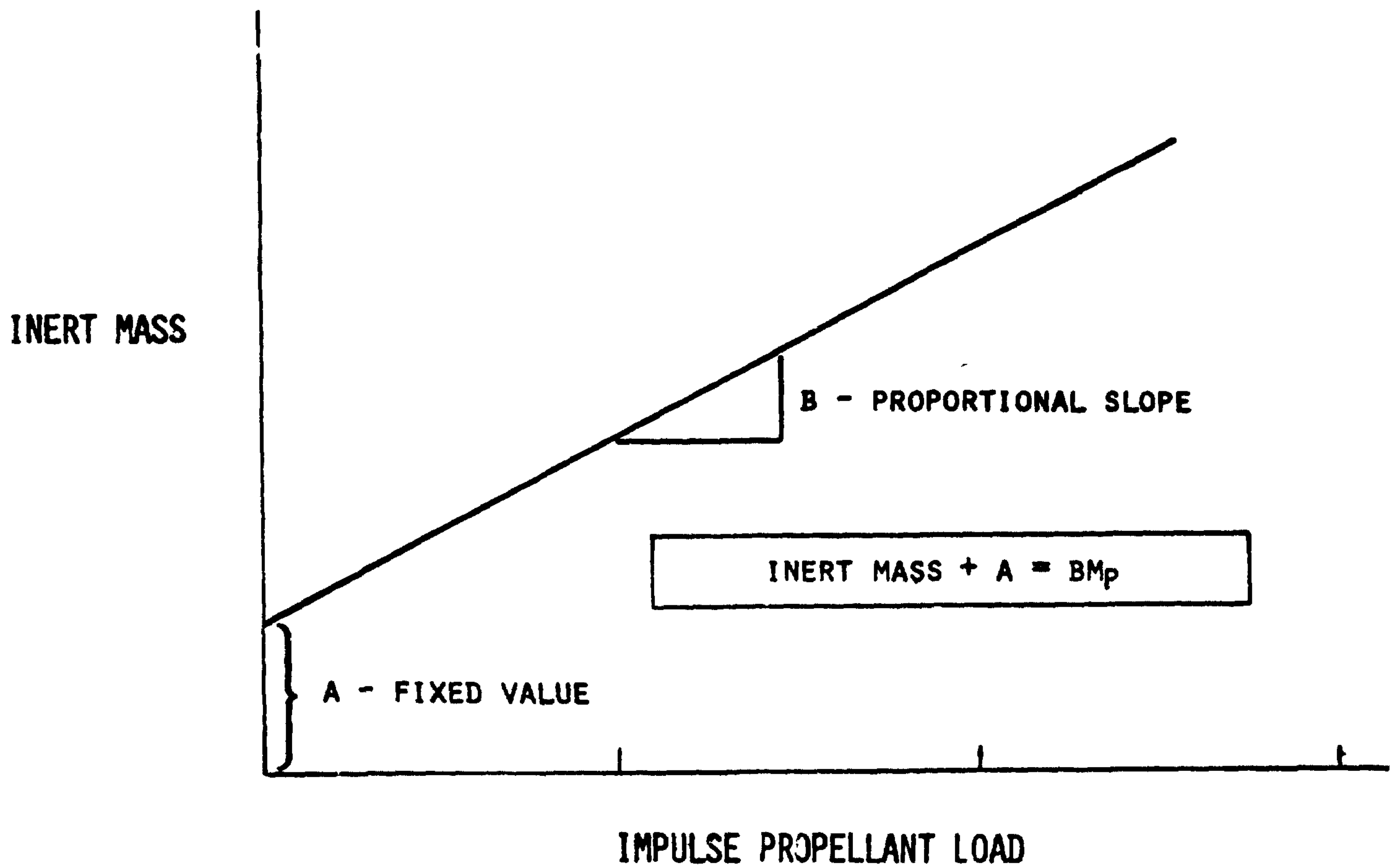
SPS LAUNCH VEHICLE TECHNOLOGY ASSUMPTIONS

- ENGINE TECHNOLOGY CONSISTENT WITH SPACE SHUTTLE MAIN ENGINE SPECIFICATION
- CRYOGENIC ORBIT MANEUVERING PROPULSION
- IN SOME CASES, CONTROL-CONFIGURED AERODYNAMICS
- STATE-OF-THE-ART ALUMINUM TANKS: TITANIUM WHERE WARRANTED FOR AERO SURFACES: MODERATE USE OF COMPOSITES IN UNHEATED, DRY STRUCTURE
- SERVICEABLE SHUTTLE-TYPE THERMAL PROTECTION FOR ORBITERS
- REUSABLE LH_2 INSULATION
- SUBSYSTEMS GENERALLY CONSISTENT WITH SHUTTLE STATE-OF-ART
- EVOLUTIONARY IMPROVEMENTS IN SUBSYSTEMS SERVICEABILITY
- ONBOARD BIT/FIT

INERT MASS SCALING

The small HLLV was initially scaled using an inert mass scaling technique that represents the inert mass of each stage as a function of a fixed value and a proportional slope. The inert mass increases with propellant load, but because it starts with a fixed value at zero propellant load, we find that the propellant fraction or "lambda-prime" improves as the vehicle becomes larger.

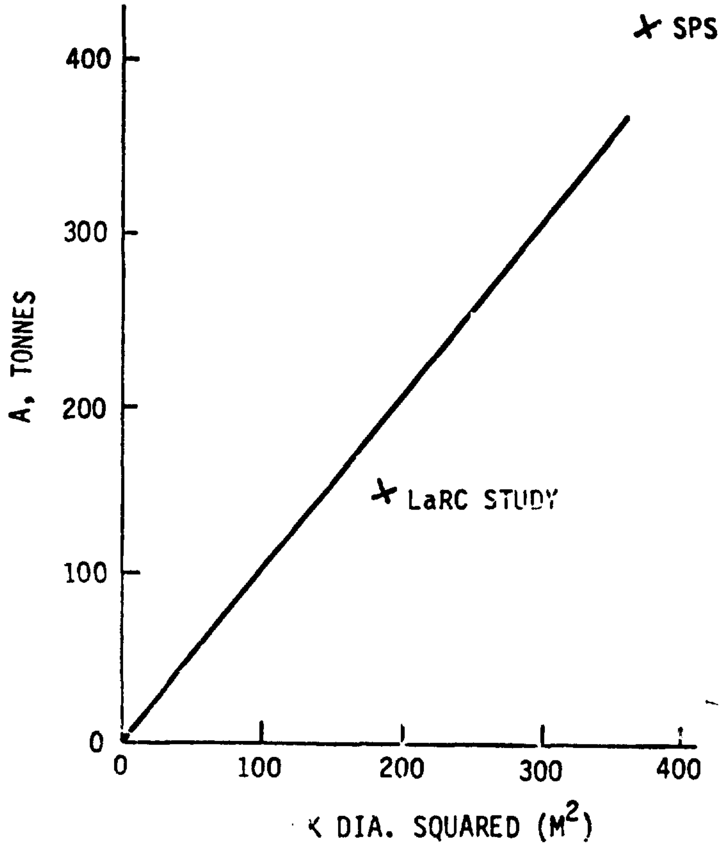
INERT MASS SCALING



"A" PARAMETER SCALING

Examination of a number of earlier vehicle designs indicated that the so-called fixed value "a" is fixed only for a constant tank diameter and that as the vehicle tank diameter increases, the value of "a" should be scaled proportionately. This scaling approximation was used to select an "a" value for the small HLLV of approximately 140,000 killograms.

"A" PARAMETER SCALING



SCALING ASSUMPTIONS

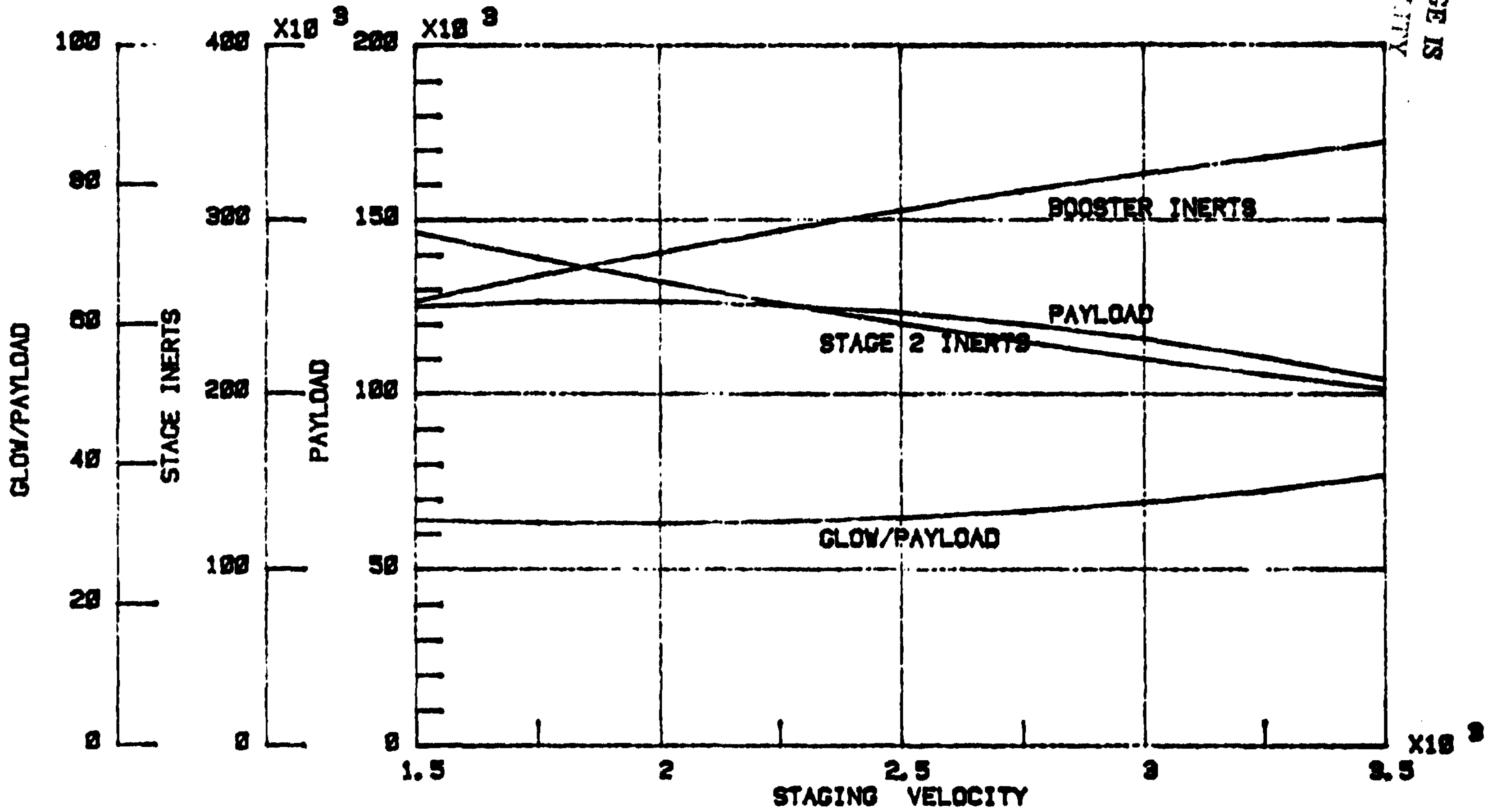
- CONSTANT TANK DIAMETER
- "NORMAL TECHNOLOGY GROWTH
- LO_2 - LCH_4 BOOSTER
- LO_2 - LH_2 BOOSTER

SERIES BURN GLOW = 4E6

Given the inert mass scaling factors for each stage, it was possible to carry out simple parametrics to ascertain the variation of payload and other important parameters with ideal staging velocity. This analysis assumed the total ideal delta V to low Earth orbit to be 9200 metres per second and examined the variation of vehicle parameters with staging velocity. As indicated, the maximum payload occurs with relatively low velocities.

SPS-3206

SERIES BURN - GLOW = 4E6

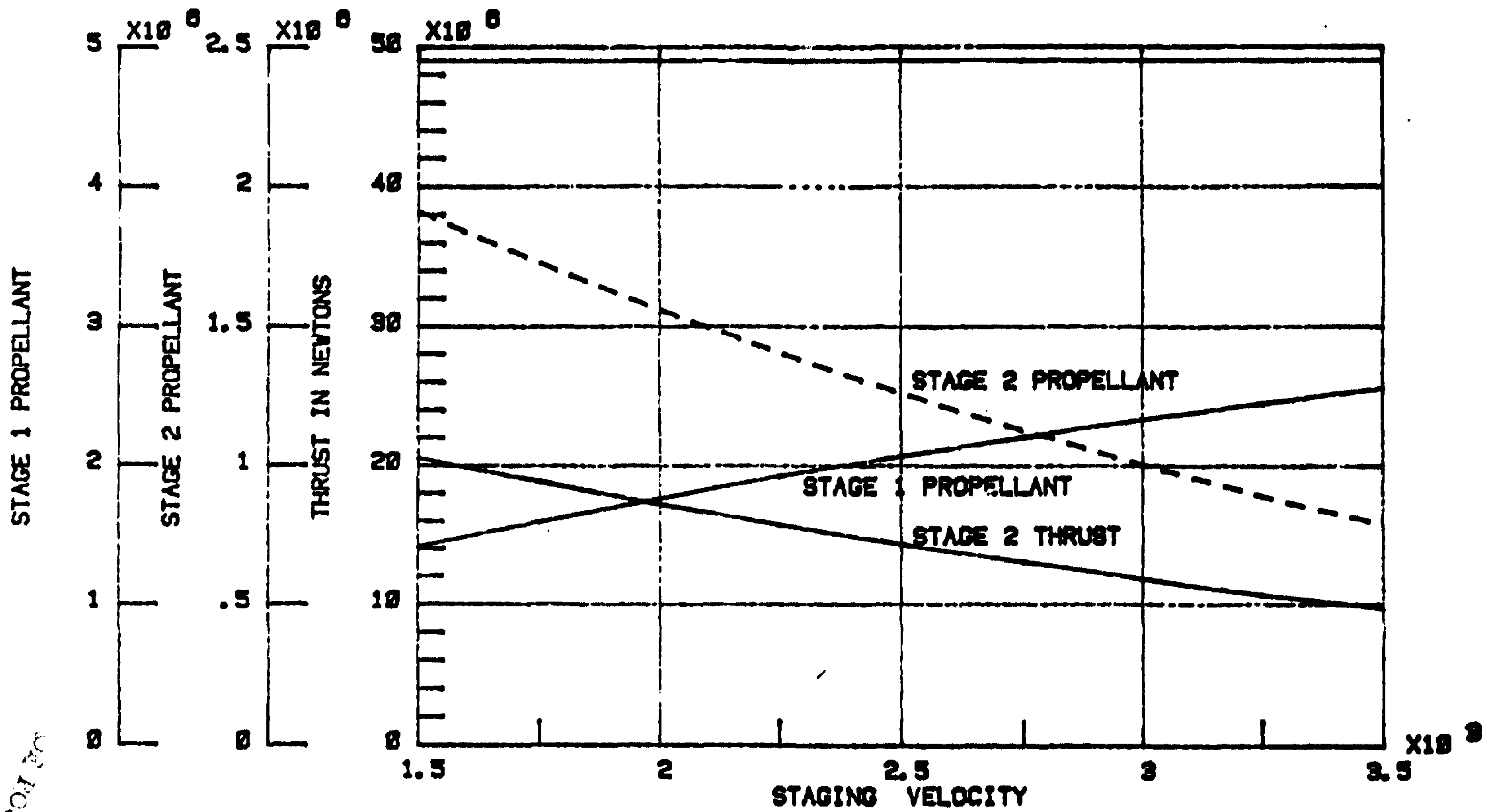


VARIATION OF PROPELLANT LOAD WITH STAGING VELOCITY

In order to geometrically configure the vehicle, it is essential that the first stage propellant load be approximately twice that of the second stage propellant load. This result is obtained because the propellants for the booster are comparitively dense and the booster does not include a payload bay. With first stage propellant loads less than twice than those of the second stage, the booster tends to become too short to be a reasonable aerodynamic configuration.

SPS-3204

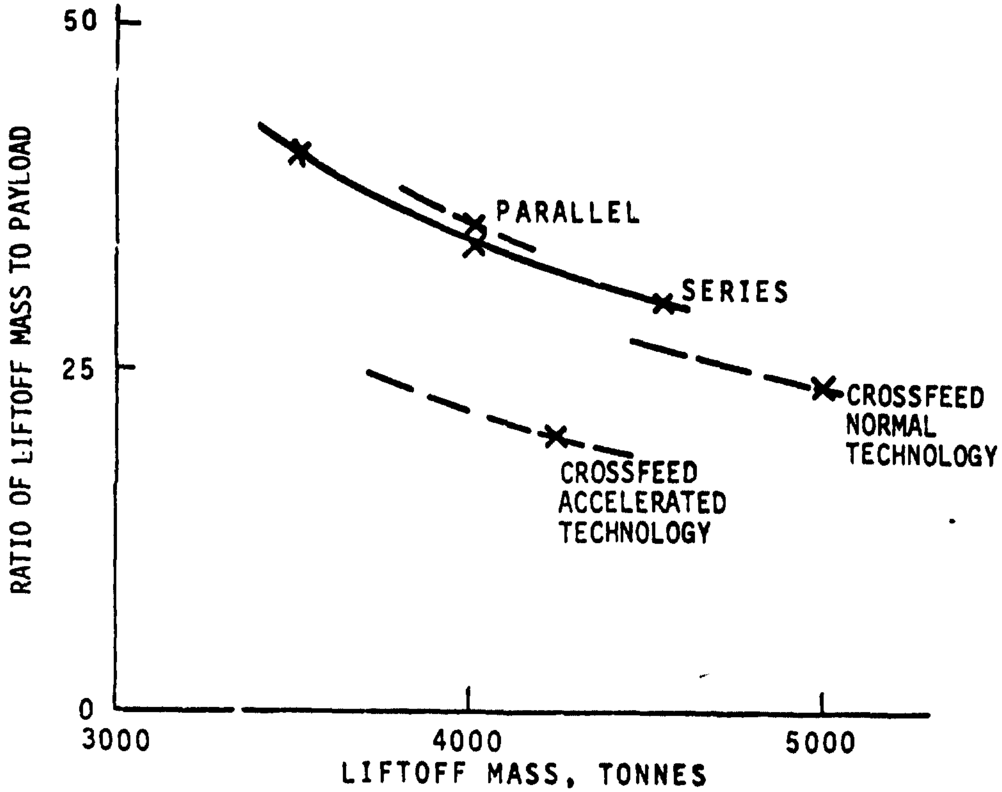
VARIATION OF PROPELLANT LOAD WITH STAGING VELOCITY



MASS TRENDING

Parametric studies, such as shown on the previous two charts, were developed for a range of lift-off masses. The result was the trends illustrated here. The series burn configuration offered slightly better performance than parallel-burn without crossfeed. The use of crossfeed with parallel burn improves vehicle performance. Two point designs from the recent Langley study of "Technology Requirements for Earth-to-GEO Transportation," are shown for comparison with implied trending lines. The improvements attainable through crossfeed and accelerated technology are illustrated.

MASS TRENDING

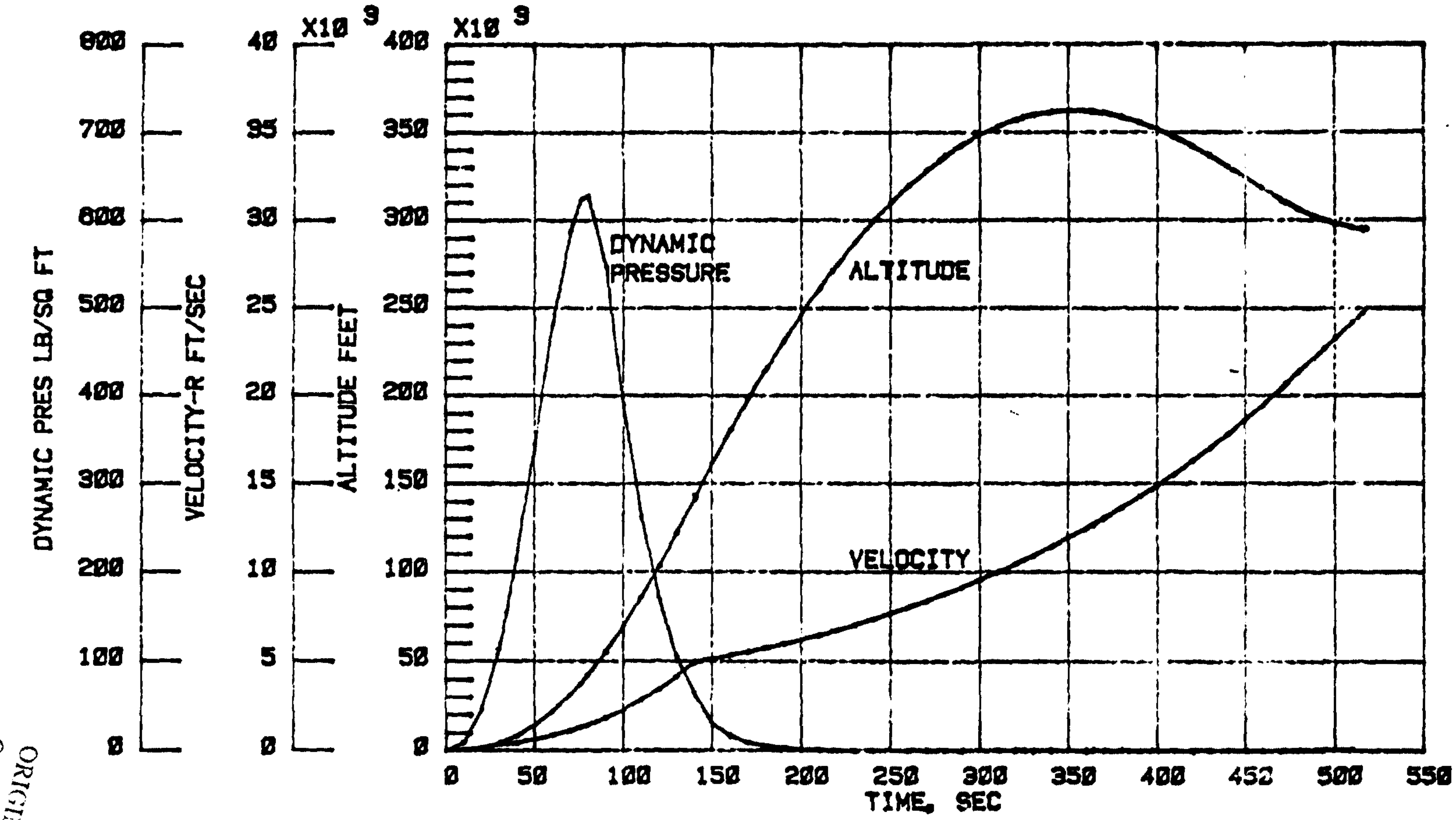


SMALL HLLV REFERENCE TRAJECTORY

With propellant loads and lift-off mass selected, a variety of trajectories were run in order to select a reference trajectory. The selected reference case employed injection at 90 killometers and a real staging velocity of approximately 5,000 ft/sec.

SMALL HLLV REFERENCE TRAJECTORY

SPS-3200



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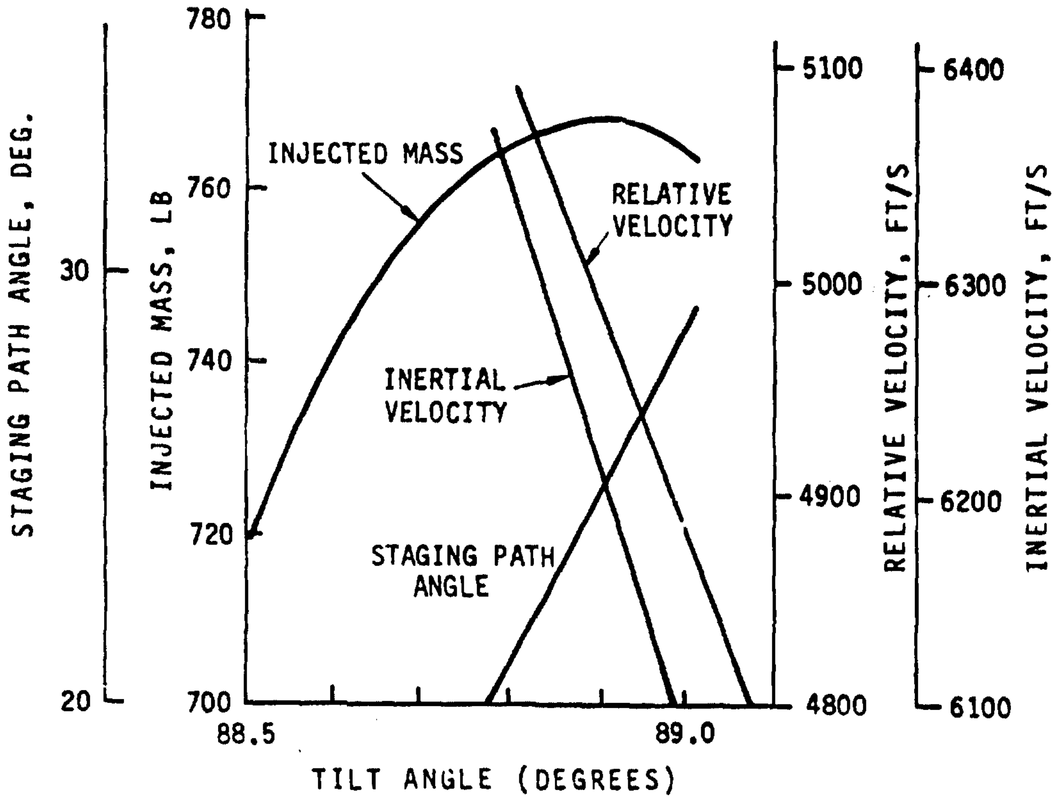
STAGING POINT VARIATION AND INJECTED MASS

Shown here is the parametric study that resulted in selection of the reference trajectory. The most important parameter is the booster tilt angle. The tilt point occurs at approximately 60 metres/sec vertical velocity. This effects the staging path angle and attitude. The maximum occurs when the combined losses for the two stages are minimized.

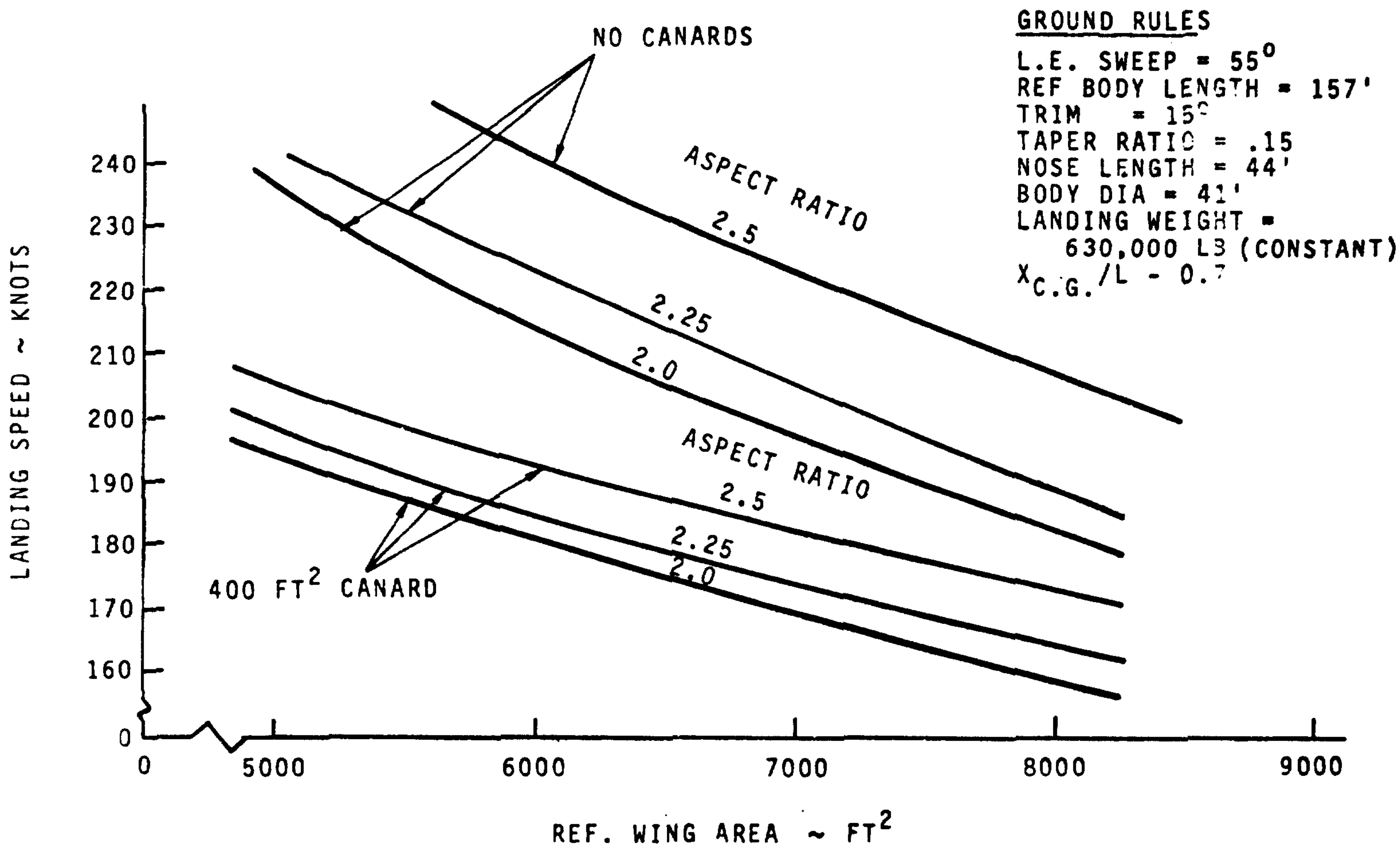
STAGING POINT VARIATION AND INJECTED MASS



BOOSTER AERO SUMMARY LANDING SPEED

A further parametric study was conducted to select the reference wing area. Wing area was dictated by landing speed with a desire to maintain landing speed at no more than 165 knots. The result was a selection of a reference wing area of 8200 ft^2 with a canard for subsonic trim.

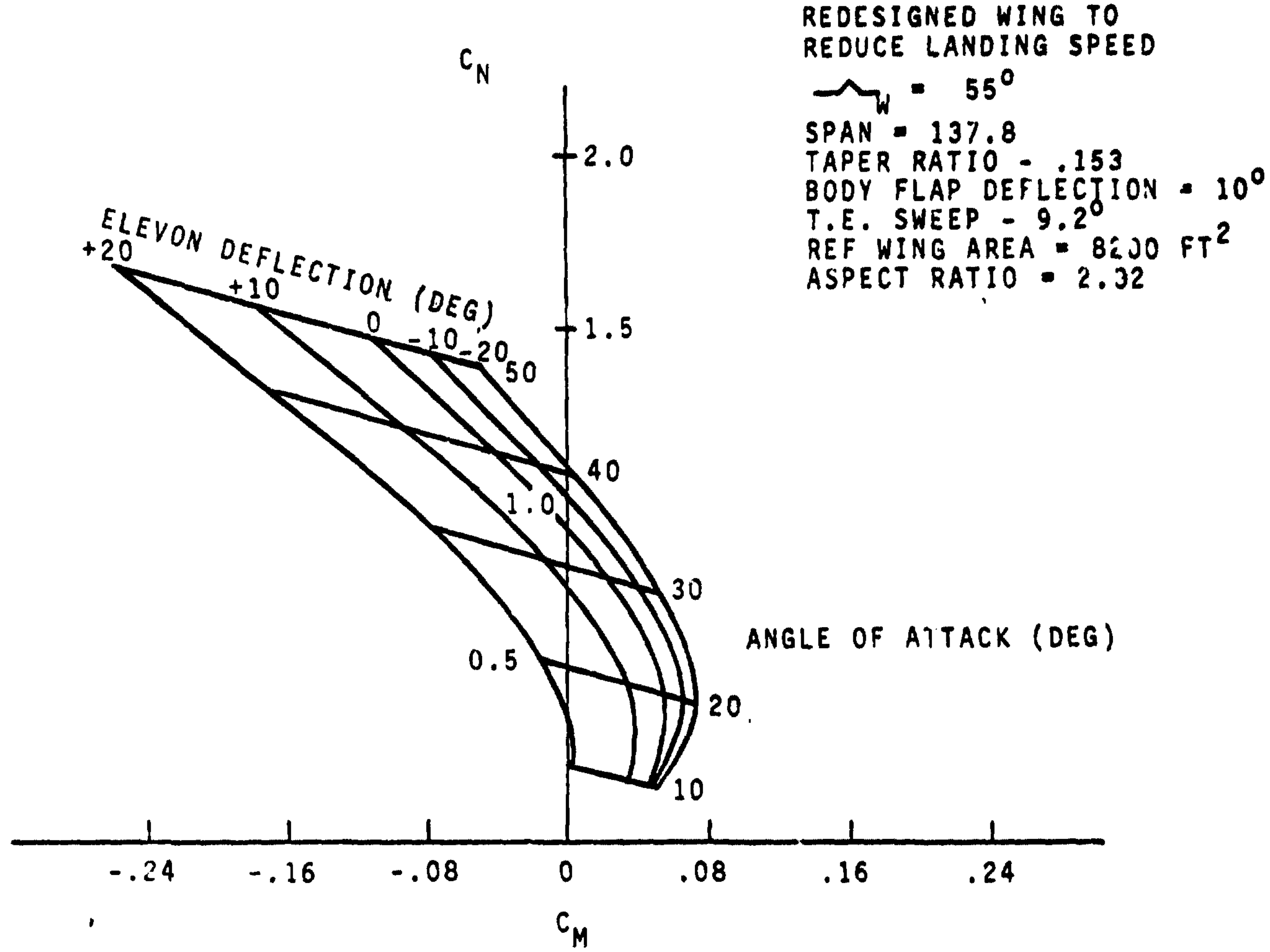
BOOSTER AERO SUMMARY LANDING SPEED



BOOSTER AERO SUMMARY HYPERSONIC TRIM

A hypersonic trim investigation showed that the vehicle could be trimmed between 30 and 40 degrees angle of attack with reasonable aileron deflections.

BOOSTER AERO SUMMARY HYPERSONIC TRIM

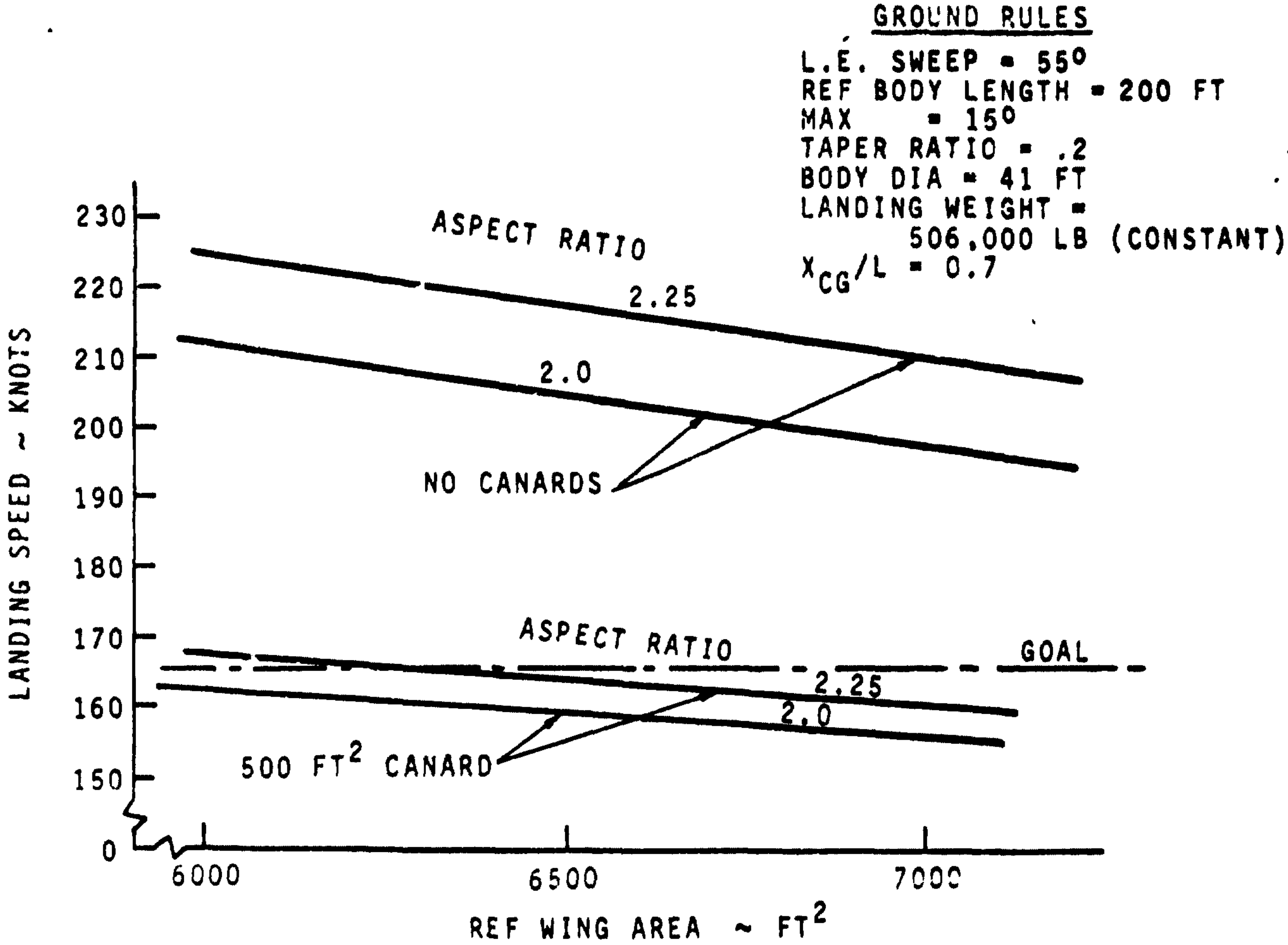


EFFECT ON REF WING AREA AND ASPECT RATIO ON SPS ORBITER LANDING SPEED

The orbiter wing area was also selected for landing speed of 165 knots. Again, a canard was used for subsonic trim to avoid large wing areas.

EFFECT OF REF WING AREA AND ASPECT RATIO ON SPS ORBITER LANDING SPEED

SPS-3282



SUMMARY OF RESULTS OF INITIAL ITERATION ON SPS BOOSTER/ORBITER AERODYNAMICS

The next four charts summarize the results of the aerodynamics investigations.

SPS-3301

SUMMARY OF RESULTS OF INITIAL ITERATION ON SPS BOOSTER/ORBITER AERODYNAMICS

- BOOSTER
  - INITIALLY DEFINED CONDITIONS
    - WEIGHT AT START OF FLYBACK
      320 TONNES = 704,000 LBS
    - FLYBACK RANGE
      250 KM + 20 MINUTES RESERVE
    - C.G.
      $X_{C.G.}$/BODY LENGTH = 0.7
    - DRAWING OF CONFIGURATION
  - ADDITIONAL CONDITIONS DEFINED
    - LANDING
      - ANGLE OF ATTACK = 15^{o} MAX
      - SPEED = 165 KTS MAX.
    - HYPERSONIC TRIM
      - TRIM BETWEEN 30^{o} & 50^{o} ANGLE OF ATTACK
      - TRIM WITHOUT POSITIVE ELEVON DEFLECTION
  - RESULTS
    - LANDING SPECIFICATIONS CONTROL WING AREA
      - ORIGINAL WING REF AREA FROM DWG ≅ 6000 FT^2
      - REQUIRED WING REF AREA ≅ 8000 FT^2

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SUMMARY OF RESULTS OF INITIAL ITERATION ON SPS BOOSTER/ORBITER AERODYNAMICS (CONT'D)

SPS-3283

- O BOOSTER
  - . RESULTS
    - \- FLYBACK
      - . $C_{D_0} \cong .032$ (BASED ON WING REF AREA)
      - . ASSUME FLYBACK OCCURS AT $L/D)_{MAX}$ AND 10,000 FT ALTITUDE
      - . ASSUME TSFC = 0.8 FOR FLYBACK ENGINES
      - . CONCLUSIONS
        - O $L/D)_{MAX} = 6.73$
        - O 67,000 LB FUEL REQD. (INCLUDING 20 MINUTES RESERVES)
        - O VELOCITY = 500 KM/HR
        - O WING LOADING AT START OF FLYBACK $\cong$ 95 LB/FT^2
        - O 105,000 LB THRUST REQD. AT START OF FLYBACK
    - \- HYPERSONIC TRIM

      BOOSTER WILL TRIM AT 35^0 ANGLE OF ATTACK WITH 0 ELEVON DEFLECTION

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SUMMARY OF RESULTS OF INITIAL ITERATION ON SPS BOOSTER/ORBITER AERODYNAMICS (CONT'D)

SPS-3302

- ORBITER
  - INITIALLY DEFINED CONDITIONS
    - LANDING WEIGHT = 230 TONNES - 506,000 LB
    - X_{CG}/BODY LENGTH = 0.7
    - DRAWING OF CONFIGURATION
  - ADDITIONAL CONDITIONS DEFINED
    - LANDING ANGLE OF ATTACK = 15° (MAX)
    - LANDING SPEED = 165 KTS (MAX)
  - RESULTS
    - ORIGINAL WING REF AREA OF ~5600 FT^2 WAS A LITTLE LOW FOR LANDING
    - RECOMMENDED WING/CANARD CONFIGURATION
      - REF WING AREA = 6180 FT^2
      - REF WING ASPECT RATIO = 2.25
      - REF WING TAPER RATIO = .186
      - WING L.E. SWEEP - 55°
      - WING T.E. SWEEP = 12°
      - CANARD AREA = 500 FT^2
      - LANDING TRIM CL = 0.88
      - ELEVON/WING RATIO = .12
      - ELEVON DEFLECTION = 11°

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SPS-3303

SUMMARY OF RESULTS OF INITIAL ITERATION ON SPS BOOSTER/ORBITER AERODYNAMICS

(CONT'D)

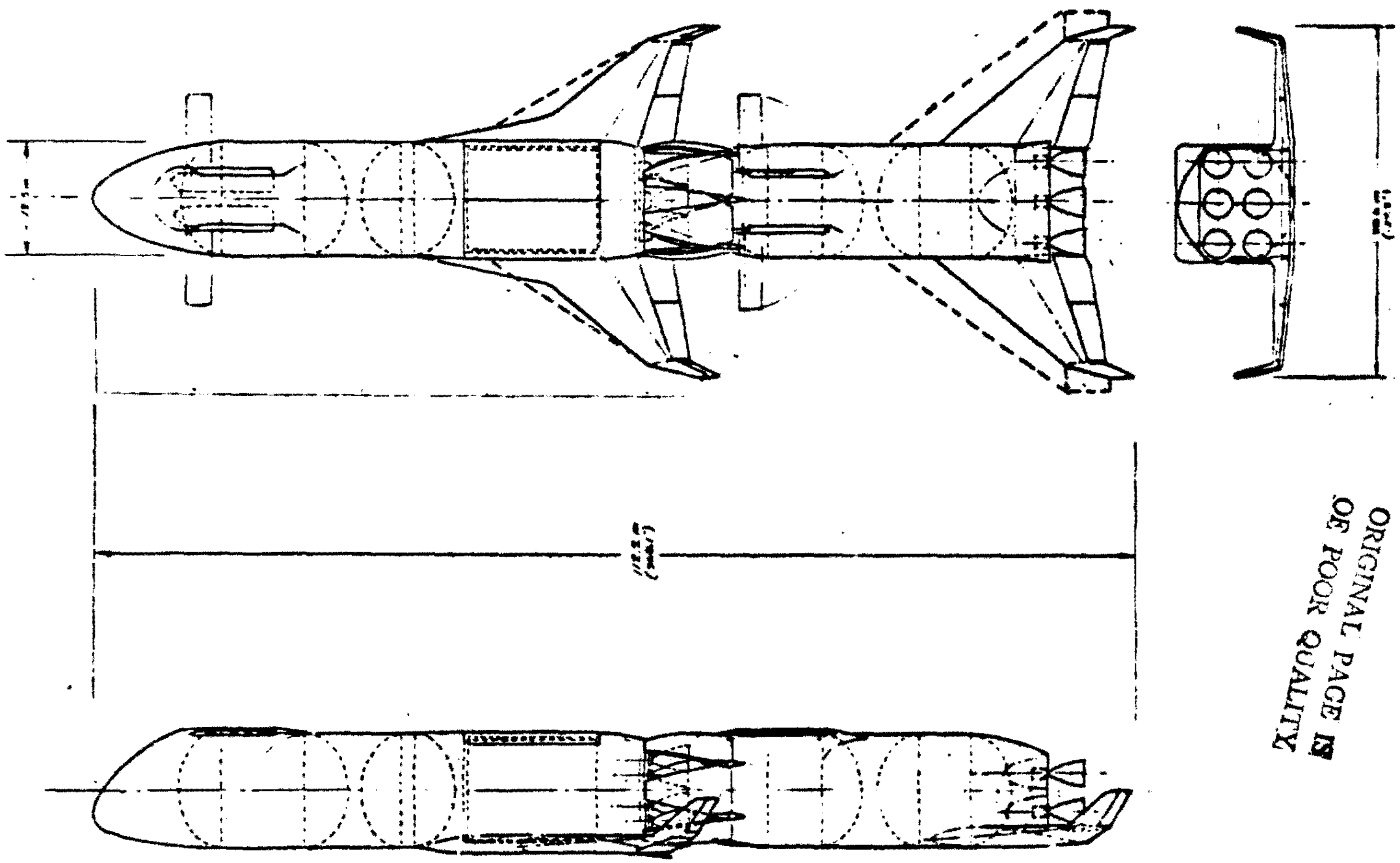
- o BOOSTER
  - RESULTS
    - RECOMMENDED WING/CANARD DESIGN

      REF AREA = 8200 FT^2
      ASPECT RATIO = 2.32
      L.E. SWEEP = 55°
      TAPER RATIO = .15
      T.E. SWEEP = 9.2°
      CANARD AREA = 400 FT^2
      LANDING TRIM CL = .83
      ELEVON/WING AREA = .12
      ELEVON DEFLECTION = 7.6°

SMALL HLLV WING RESIZE

Illustrated here are the revised wing areas as compared to the original wing areas, shown on the original configuration. Revised wing areas are shown as dotted lines.

SMALL HLLV - WING RESIZE



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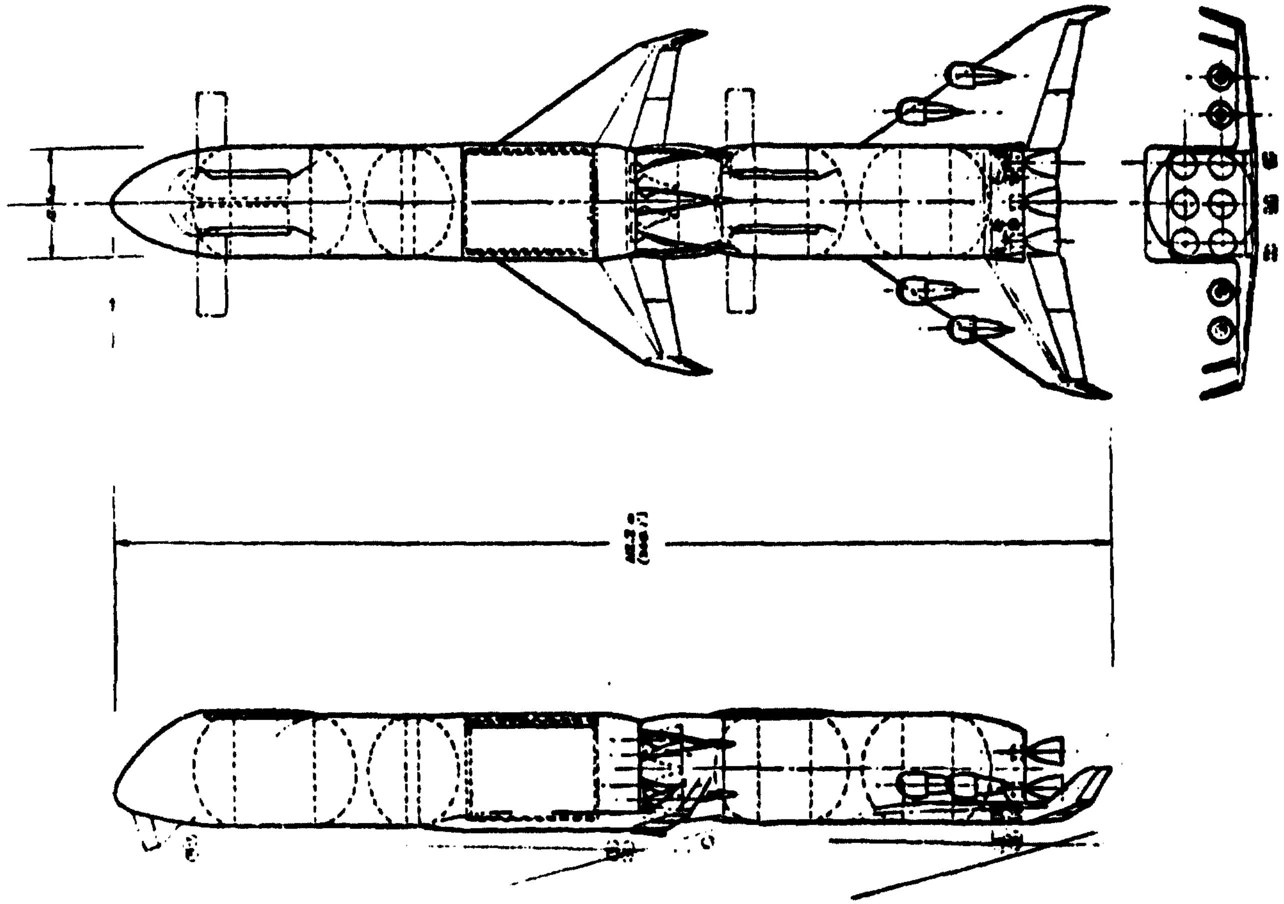
SPS HLLV SELECTED CONFIGURATION

The small HLLV final configuration is shown here. The orbiter includes a swept-back delta wing with a small subsonic foldout canard. The payload bay is aft of the propellant tanks and is 11 metres square by 14 metres long. The orbiter uses six space shuttle main engines with extended exit bells. Four of the six engines are gimbaled; the center two are fixed. The upper stage also uses a small yaw ventral for head-end steering to improve controllability in yaw.

These vehicles are control configured in yaw, thus eliminating the large vertical tail. Elimination of the vertical tail assists in balancing the vehicle and makes practical an aft payload bay on the orbiter. The booster employs a "flower-petal" opening nose with a truss structure as an interstage structure. This approach avoids expendible interstage hardware and allows the second stage engine start sequence to be initiated during the first stage tail-off as the open nose allows room for gas venting during the start sequence. After stage separation, a simple hinged actuator mechanism closes the nose to a streamlined, aerodynamic configuration.

The booster employs six oxygen-methane engines of approximately 1835 K/lb thrusts. Four high thrust air-breather engines are mounted on top of the wings for fly-back. The air-breather engine inlets are closed by a blow-off cover until subsonic transition at which time the engines undergo start sequence. Engine location was selected to avoid flow attachment to either the wing or the body as a flow attachment will result in higher drag during the fly-back.

SMALL HLLV UPDATED CONFIGURATION



SMALL HLLV MASS PROPERTIES

The next five pages present the mass statement for the small HLLV, based on the final configuration. The estimated payload based on the detailed mass statement is 126 metric tons as compared to a parametric figure of 120 metric tons.

SPS-3331

SMALL HLLV MASS PROPERTIES
BOOSTER P.1

	KG	LBM
STRUCTURE-AEROSURFACES	28,235	62,245
WING	25,509	56,236
CANARD	1,452	3,200
TIPLETS	1,020	2,249
YAW VENTRAL	254	560
STRUCTURE - BODY & TANKS	69,107	152,357
NOSE	9,761	21,519
NOSE GEAR SUPPORT	693	1,528
METHANE TANK	9,684	21,349
OXYGEN TANK	13,610	30,006
INTERTANK	10,592	23,353
AFT BAY & FAIRINGS	10,513	23.178
THRUST STRUCTURE	8,130	17,924
BODY FLAP	1,860	4,100
FAIRINGS	4,264	9,400
TPS	0	0
MECHANISMS	9,043	19,936
LANDING GEAR	8,090	17,836
DRAG DEVICE	953	2,100
MAIN PROPULSION	68,750	151,596
ROCKET ENGINES	50,000	110,229
ENGINE ACCESSORIES	6,250	13,779
PROPELLANT SYSTEMS	12,500	27,588

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SMALL HLLV MASS PROPERTIES
ORBITER P.1

STRUCTURE-AEROSURFACES	22,552	49,720
WING	20,135	44,390
CANARD	1,560	3,440
TIPLETS	635	1,400
YAW VENTRAL	222	490
STRUCTURE-BODY & TANKS	66,328	146,211
NOSE	2,440	5,380
NOSE GEAR SUPPORT	529	1,166
LH_2 TANK	10,928	24,093
LO_2 TANK	11,719	25,835
INTERTANK	6,231	13,737
PAYLOAD BAY BODY SECTION	10,282	22,668
PAYLOAD BAY DOORS	2,255	4,971
AFT BODY	10,979	24,204
THRUST STRUCTURE	3,390	7,473
BODY FLAP	2,270	5,000
FAIRINGS	2,137	4,700
CREW CAB STRUCTURE	3,168	6,984
INDUCED THERMAL PROTECTION	19,923	43,922
WING RSI	4,799	10,580
BODY RSI	10,136	22,345
TANK SIDEWALL PANELS	1,571	3,465
WING TIPLETS RSI	386	850
LH_2 INTERNAL INSULATION	2,169	4,782
PROPELLANT PURGE, VENT, & DRAIN	862	1,900

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SMALL HLLV MASS PROPERTIES

ORBITER P.2

MECHANISMS	7,198	15,869
LANDING GEAR	6,439	14,196
DRAG DEVICE	759	1,573
MAIN PROPULSION	31,694	69,873
SSME's	19,336	42,630
ACCESSORIES	2,077	4,580
AFT BODY PROPELLANT SYSTEM	7,008	15,450
DELIVERY LINES & PROP.MGT	3,273	7,213
AUXILIARY PROPULSION	4,090	9,018
OMS PROPULSION SYS (DRY)	2,548	5,618
RCS PROPULSION SYS (DRY)	1,542	3,400
SUBSYSTEMS	9,960	21,958
FLIGHT CONTROL	1,270	2,800
AVIONICS	1,978	4,360
EC/LSS	1,339	2,952
ELECTRIC POWER	5,373	11,846
CREW & PAYLOAD ACCOMMODATIONS	3,652	8,053
PERSONNEL PROVISIONS	305	674
FURNISHINGS	411	907
PAYLOAD PROVISIONS	1,380	3,042
CREW & ACCESSORIES	1,556	3,430
GROWTH	14,519	32,009
TOTAL DRY WITH CREW	179,916	396,633

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SMALL HLLV MASS PROPERTIES
BOOSTER P.2

AUXILIARY PROPULSION	30,615	67,495
FLYBACK ENGINES	25,000	55,115
FUEL SYSTEM	3,039	6,700
RCS	2,576	5,680
SUBSYSTEMS	7,804	17,205
AUXILIARY POWER	703	1,550
ELEC. CONV. & DISTR.	2,667	5,880
FLT CONTROL ACTUATION	2,073	4,570
FLIGHT CONTROL SYSTEM	1,111	2,450
AVIONICS	1,000	2,205
EC/LSS	250	550
GROWTH	21, 355	47,083
TOTAL DRY	234,909	517,917
FLUIDS	61,466	135,506
BIAS PROPELLANT	11,300	24,911
PRESSURANT	11,300	24,911
RESIDUALS & TRAPPED	8,475	18,684
FLYBACK FUEL	30,391	67,000
NET INERTS	296,375	653,423
IMPULSE PROPELLANT	2,260,000	4,982,396
BOOSTER LIFTOFF MASS	2,556,375	5,635,819

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SMALL HLLV MASS PROPERTIES
ORBITER & INTEGRATED VEHICLE

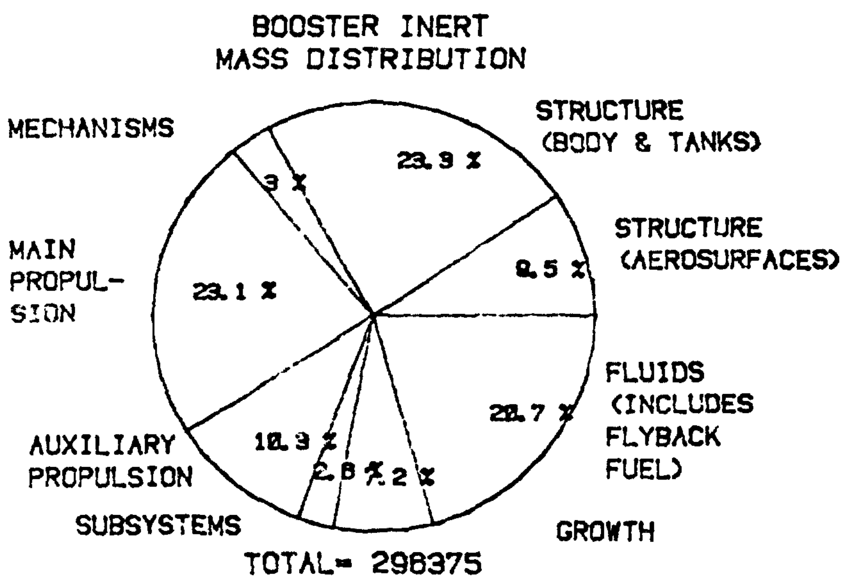
FLUIDS & GASES	41,734	92,008
OMS PROPELLANT	28,263	62,309
OMS RESERVES & RESIDUALS	2,826	6,231
FUEL CELL REACTANT	254	560
TRAPPED MAIN PROPELLANT & PRESSURANT	10,391	22,908
TOTAL INERTS	221,650	488,641
ASCENT PAYLOAD	126,260	278,359
TOTAL ORBITER INJECTED	347,910	767,000
IMPULSE PROPELLANT	1,130,000	2,491,198
ORBITER AT LIFTOFF	1,477,910	3,258,198
BOOSTER AT LIFTOFF	2,556,375	5,635,819
VEHICLE AT LIFTOFF	4,034,285	8,894,017

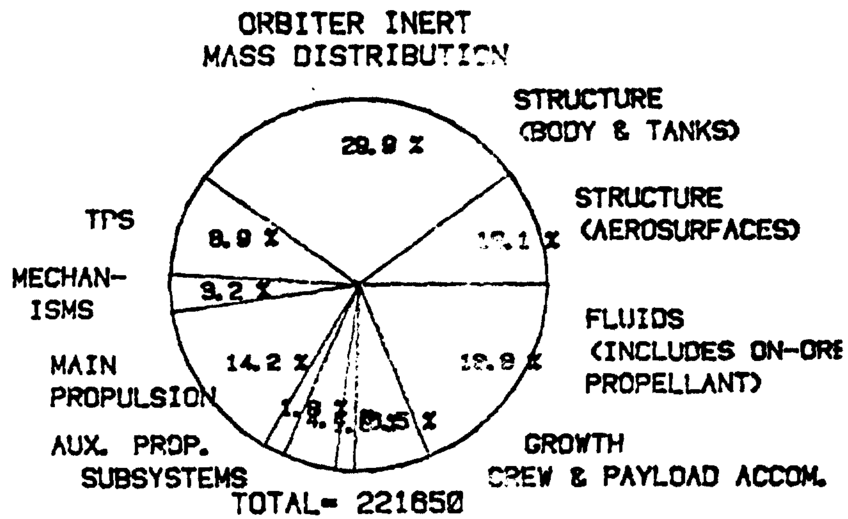
SMALL HLLV INERT MASS DATA

The pie charts show a summary of the inert mass of the two stages. The pie chart areas are proportional to the total inert mass of each stage.

SMALL HLLV INERT MASS DATA

SPS-3320





HLLV FLEET SCENARIO

The SPS transportation and construction system interrelated transportation operations scenario material presented in the reference system description report from Phase II has been incorporated into software so that trade studies can be run. Shown here is the HLLV fleet scenario for the small HLLV. Note the increased numbers of flights and the increased production rate.

SMALL HLLV TRANSPORTATION SCENARIO

HLLV FLEET

PROGRAM YEAR	NO. OF SPS'S	TOTAL PAYLOAD CONSTR	TOTAL PAYLOAD MAINT	HLLV FLIGHTS CONSTR	HLLV FLIGHTS MAINT	TOTAL FLIGHTS	BOOSTERS REQD	ORBITERS REQD	BOOSTER BUYS	ORBITER BUYS	CREW CAP. REQD
1	0	27364	0	69.7	2.0	71.7	1	2	2.2	3.2	2.8
2	0	6149	154	63.0	0.0	63.0	1	1	0.2	0.2	3.2
3	1	35027	2877	330.5	4.4	334.9	4	5	4.1	4.1	1.6
4	2	102624	6724	982.9	6.7	989.5	12	15	11.3	13.3	1.6
5	4	135515	4300	1308.8	19.3	1328.1	16	20	8.4	9.4	1.7
6	6	134723	7768	1308.6	34.3	1342.9	16	20	4.5	4.5	1.8
7	8	134741	9387	1308.7	49.4	1358.1	16	20	4.5	4.5	1.9
8	10	134757	10684	1308.8	61.0	1369.9	16	20	4.6	4.6	2.0
9	12	134774	12196	1309.0	77.0	1385.9	16	21	4.6	5.6	2.1
10	14	134792	13923	1309.1	91.2	1400.2	17	21	5.7	4.7	2.2
11	16	134917	15712	1309.3	103.9	1413.2	17	21	4.7	4.7	2.3
12	18	134825	16732	1309.3	118.7	1428.1	17	21	4.8	4.8	2.4
13	20	134843	18265	1309.5	130.8	1440.3	17	21	4.8	4.8	2.4
14	22	134862	19991	1309.6	149.0	1458.6	17	22	4.9	5.9	2.5
15	24	134877	21289	1309.7	160.7	1470.4	17	22	4.9	4.9	2.6
16	26	134895	22908	1309.8	173.7	1483.6	18	22	5.9	4.9	2.7
17	28	135021	24912	1310.0	190.8	1500.8	18	22	5.0	5.0	2.8
18	30	134928	25825	1310.1	202.4	1512.5	18	22	5.0	5.0	2.9
19	32	134946	27337	1310.2	214.3	1524.6	18	23	5.1	6.1	2.9
20	34	134963	28956	1310.3	231.4	1541.7	18	23	5.1	5.1	3.0
21	36	134982	30596	1310.5	246.6	1557.1	18	23	5.2	5.2	3.1
22	38	134998	31894	1310.6	258.3	1568.9	19	23	6.2	5.2	3.2
23	40	135015	33406	1310.7	272.2	1582.9	19	23	5.3	5.3	3.2
24	42	135142	35517	1310.9	288.4	1599.3	19	24	5.3	6.3	3.3
25	44	135050	36537	1311.0	301.2	1612.1	19	24	5.4	5.4	3.4
26	46	135066	37942	1311.1	315.9	1627.1	19	24	5.4	5.4	3.4
27	48	135083	39453	1311.2	327.9	1639.1	19	24	5.5	5.5	3.5
28	50	135102	41180	1311.4	344.1	1655.4	20	25	6.5	6.5	3.6
29	52	135118	42498	1311.5	355.9	1667.4	20	25	5.6	5.6	3.6
30	54	135244	44503	1311.7	372.9	1684.6	20	25	5.6	5.6	3.7
31	56	135154	45737	1311.7	386.0	1697.7	20	25	5.7	5.7	3.8
32	58	135170	47034	1311.9	399.6	1711.5	20	25	5.7	5.7	3.8
33	60	135187	48646	1312.0	411.6	1723.6	20	26	5.7	6.7	3.9

TOTAL FLIGHTS: 45744.7

TOTAL BOOSTERS BOUGHT: 173.482

TOTAL ORBITERS BOUGHT: 179.482

VEHICLE QUANTITIES

Vehicle quantities were derived from the scenario data on the preceding page. The scenario analysis establishes the number of vehicles required for the initial fleet. Spares were added to this. Engines and auxiliary propulsion were independently estimated. Since the engines follow a different learning curve than the airframes, it is necessary to discretely estimate engine costs. The scenario results also determine the number of new vehicles required for life cycle operations. An additional set of equivalent vehicles is required to maintain spares and maintenance. The figures used were based on the same assumptions as used to cost the reference HLLV.

VEHICLE QUANTITIES

INITIAL FLEET & SPARES	BOOSTER	ORBITER
AIRFRAME	17	22
MAIN ENGINE	102	133
AUX. PROPULSION	70	22
LIFE CYCLE		
NEW VEHICLES		
AIRFRAME	173	179
MAIN ENGINE	1041	1077
AUX. PROPULSION	694	179
SPARES & MAINTENANCE		
AIRFRAME	174	174
MAIN ENGINE	2744	2744
AUX. PROPULSION	101	174

SMALL HLLV INHERITANCE

It was estimated that the small HLLV would inherit several subsystems and technologies that could be used with suitable modifications. The principal ones are indicated on the facing page.

SMALL HLLV INHERITANCE

FROM SHUTTLE

- o ORBITER MAIN ENGINES
- o THERMAL PROTECTION SYSTEM
- o AVIONICS & POWER
- o CREW SYSTEMS
- o REACTION CONTROL SYSTEM

FROM OTV

- o ORBIT MANEUVER ENGINES

FROM MILITARY OR COMMERCIAL AIRCRAFT

- o BOOSTER FLYBACK ENGINES

SMALL HLLV COST SUMMARY

Cost estimating factors are summarized here. The top part of the table indicates the DDT&E costs. The center part shows the commonality credits from the shuttle and OTV, and the bottom summarizes the theoretical first unit costs and learning slopes for vehicle production.

SMALL HLLV COST SUMMARY

	DDT&E	
	BOOSTER	ORBITER
AIRFRAME	1977	3120
MAIN ENGINE	1619	215
AUXILIARY PROPULSION	151	26
SUBSYSTEMS	316	381
GROUND & FLIGHT TEST VEHICLES	704	525

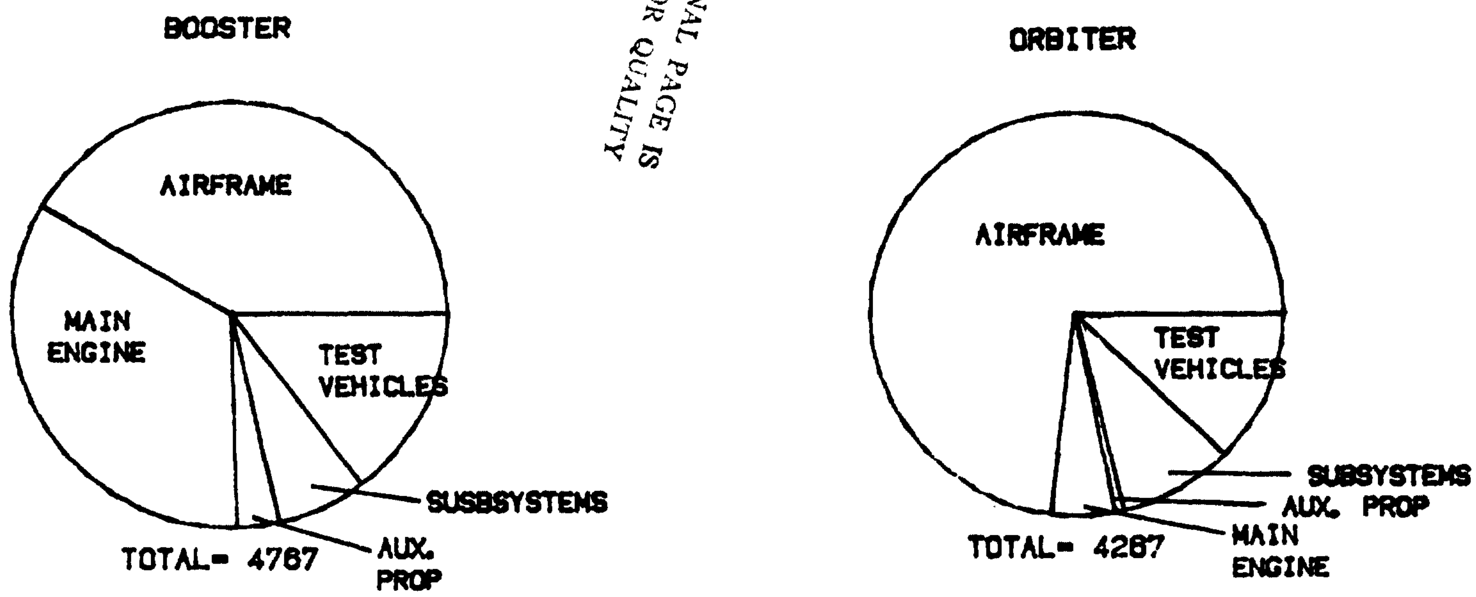
	ORBITER COMMONALITY CREDITS (DDT&E)
MAIN ENGINE	0.95 (SSME)
OMS	0.8 (OTV)
RCS	0.5 (SHUTTLE)
ELECTRIC POWER / AVIONICS / EC/LSS	0.7 (SHUTTLE)

	PRODUCTION			
	BOOSTER		ORBITER	
	TFU	SLOPE	TFU	SLOPE
AIRFRAME & SUBSYSTEMS	178	.85	187	.85
MAIN ENGINE (6 PER STAGE)	32	.90	18	.90
AUXILIARY PROPULSION	4.5 (4 REQ'D)	.88	5.1	.88

SMALL HLLV DEVELOPMENT COSTS

The development cost figures from the previous chart are shown in pie chart fashion here. Note that totals are also indicated. The relatively small main engine contribution for the orbiter results from the assumption that the space shuttle main engine is to be used essentially as is.

SMALL HLLV DEVELOPMENT COST



COST PER FLIGHT

The principal contributors to cost per flight are enumerated on the facing page.

COST PER FLIGHT (1500/YR)

SPS-3416

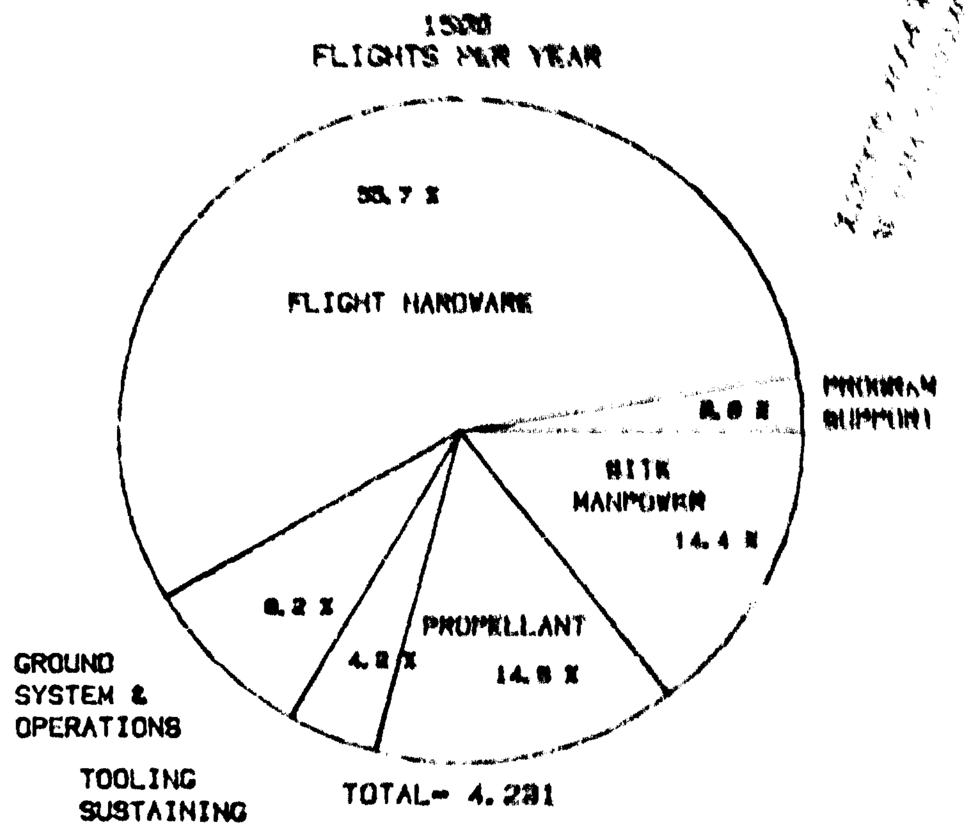
ITEM	COST IN MILLIONS (79$)
PROGRAM SUPPORT	.113
FLIGHT HARDWARE	2.359
GROUND SYSTEM & OPS	0.35
TOOLING SYSTEMS	0.18
PROPELLANT	0.617
SITE MANPOWER	0.612
	4.231

SMALL HLLV COST PER FLIGHT

The scenario indicated a nominal launch rate of 1500 flights per year. The program average cost per flight is shown here in pie chart fashion. As was true for the reference HLLV, flight hardware for amortization of vehicles and spares and maintenance dominates the total. Ground system and operations include those people directly involved in vehicle turnaround operations. Site manpower and program support are indirect people chargeable to launch operations. Tooling sustaining reflects a 10% a year figure based on initial tooling costs. Finally, propellants were costed as they were costed for the reference HLLV.

SMALL HLLV COST PER FLIGHT

SPS-3428



EFFECTS OF SMALL HLLV ON PAYLOAD PACKAGING

The next section of this presentation discusses the effects of the small HLLV on the SPS operations. Two kinds of effects were investigated. First, those on the systems operations that could influence system cost, and secondly, environmental effects as compared to the large HLLV.

THE EFFECTS OF A SMALL HLLV ON

PAYLOAD PACKAGING, SPS CONFIGURATION,

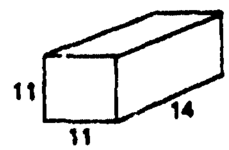
GROUND AND SPACE FACILITIES, AND

OPERATIONS.

SMALL HLLV PACKAGING PARAMETERS

The nominal small HLLV payload parameters that were given are as follows:

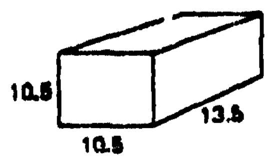
Cargo Bay Envelope



Payload Mass — 120 mT

Following the guidelines established in previous packaging analyses (Reference: Section 5 in the Phase II Operations and Systems Synthesis document, D180-25461-3), we have discounted these parameters to allow for packaging and pallets. The working parameters become the following:

Max. Envelope of Components



Max. Payload Mass (Without Packaging) — 108 mT

This table lists the total payload that needs to be delivered to LEO for each year of the SPS commercial program. This total payload includes components, spare parts, crew supplies and propellants used at both LEO and GEO. This table also lists the corresponding number of mass-limited launches required per day and per week to deliver this payload.

SPS-3256

TABLE 1

THEORETICAL QUANTITY OF MASS-LIMITED LAUNCHES

SPS PROGRAM YR	TOTAL PAYLOAD (MT) [1]	THEORETICAL TOTAL NO. OF LAUNCHES (MASS-LIMITED) [2]	NO. OF LAUNCHES [3] PER DAY	NO. OF LAUNCHES [3] PER WEEK
1	15059	140	.38	2.66
2	17048	158	.43	3.01
3	47095	437	1.20	8.4
4	107633	997	2.73	19.11
5	138549	1283	3.52	24.64
6	137065	1270	3.48	24.36
7	138990	1287	3.55	24.85
8	140104	1297	3.55	24.85
9	141661	1312	3.59	25.13
10	155249	1438	3.94	27.58
11	156457	1449	3.97	27.79
12	158804	1471	4.03	28.21
13	148352	1374	3.76	26.32
23	162564	1506	4.12	28.84
33	179013	1658	4.54	31.78

[1] Reference: D180-25461-2, Table 1.3-16 (p. 216)

[2] Based on 108 MT net payload per launch (120 MT payload capability discounted 10% to allow for packaging)

[3] Based on 7 day per week launch schedule

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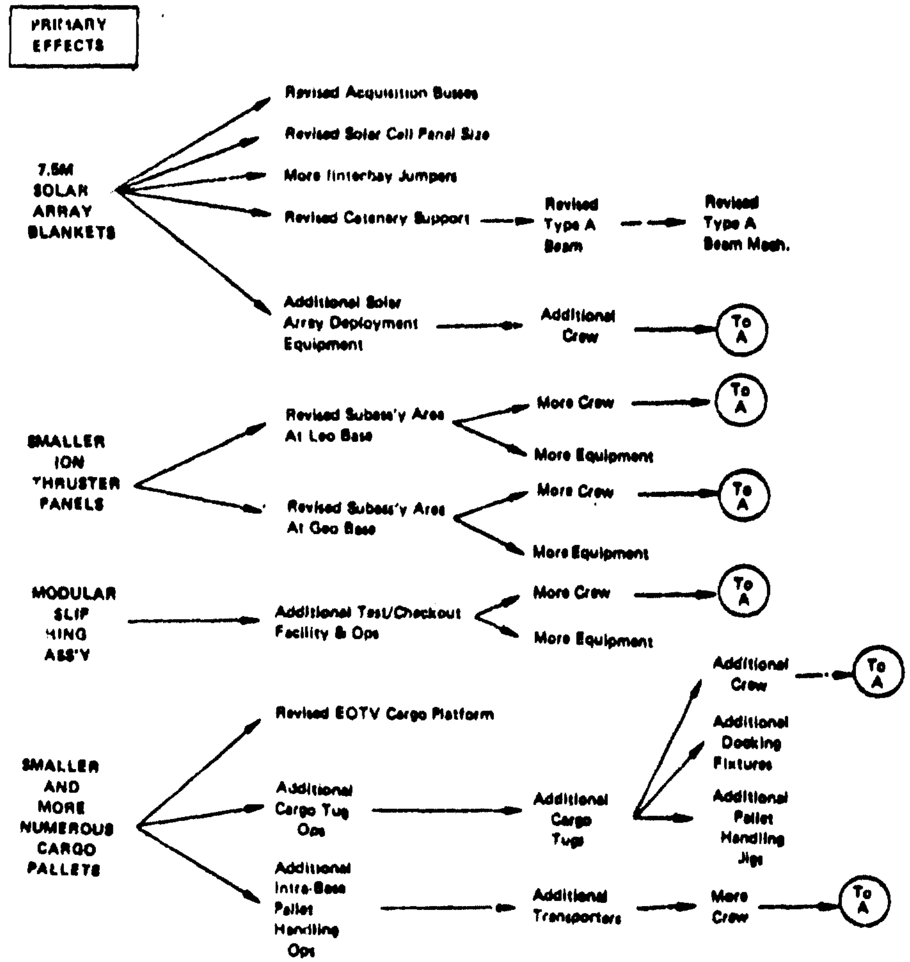
EFFECTS ON SPS PROGRAM ELEMENTS

The constraints identified in the previous section were used to define the effects on the various SPS program elements.

The interactions of these effects are shown in the figure. It is seen that there are eight primary effects. It should be evident from this map that if any of the 8 primary effects can be alleviated, the secondary effects linked to them can also be eliminated. The possibilities for alleviating the primary effects are discussed in the following table.

SMALL HLLV OPERATIONAL EFFECTS TREE



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SMALL HLLV OPERATIONAL EFFECTS TREE - CONT.

SPS-3388

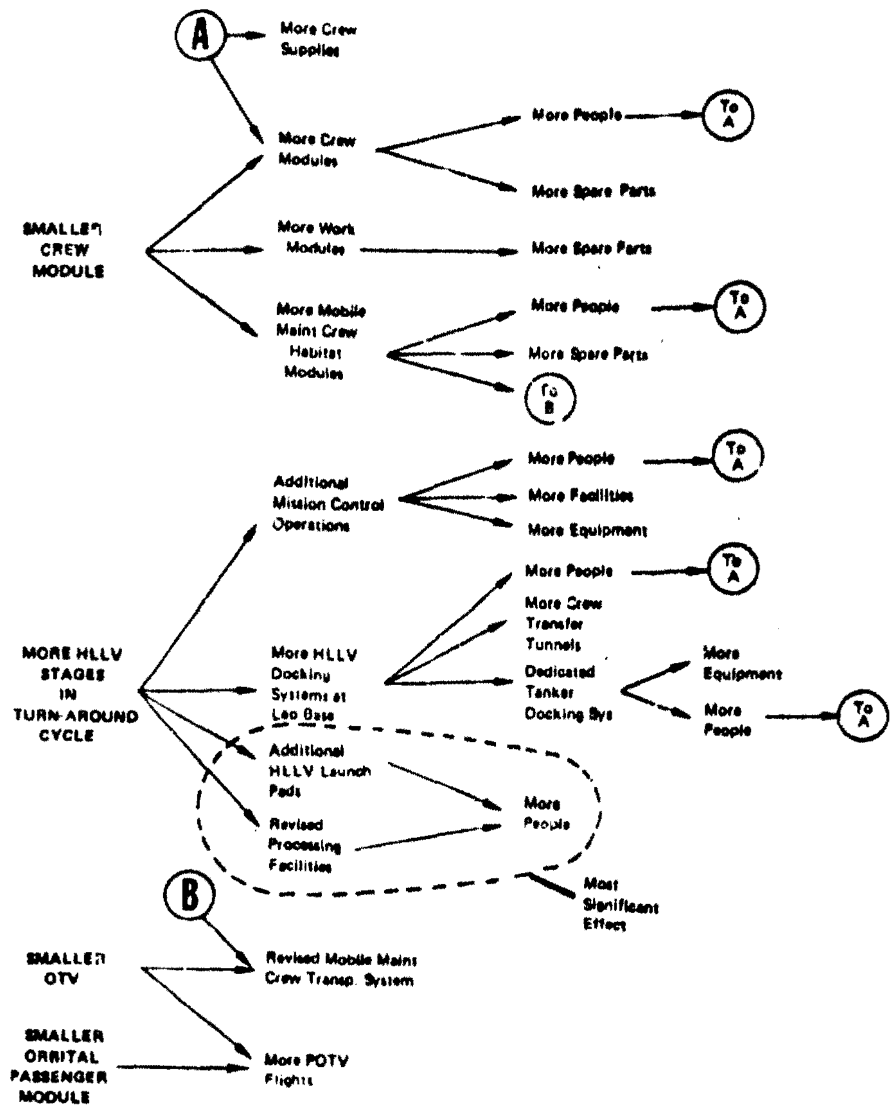

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TABLE 3
ANALYSIS OF PRIMARY EFFECTS

SPS-3293

EFFECT	ANALYSIS
o 7.5m Solar Array Blankets	o Anything less than 15m leads to problems. o If cargo bay could be in excess of 15m long and if the blankets could be shipped on end, then there would be no impact.
o Smaller Ion Thruster Panels	o The thruster panels were to be assembled from 2 subassemblies anyway, so having to assemble from 4 subassemblies is of only minor impact.
o Modular Slip Ring Assy's	o Anything less than 16m diameter is a problem. o The assembly could be knocked down into cylindrical quadrants.
o Smaller and More Numerous Cargo Pallets	o Smaller size units offset some of cost associated with having more units. o There is some quantity of additional units that could be tolerated before exceeding the capabilities of the presently defined set of handling equipment and crew.

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TABLE 3 (Continued)

ANALYSIS OF PRIMARY EFFECTS

SPS-3294

EFFECT	ANALYSIS
o Smaller Crew Modules	o The smaller HLLV leads to a 20 man crew habitat see Figure 2.
o More HLLV's	o With only 3 launch pads and a 7-day/2-shift launch schedule, only 1 or 2 more launches per week could be realistically scheduled. o Each launch pad can support only 2.5 launches per week (on a 7-day/2-shift schedule). o Going to a 3 shift schedule, 7 days per week, each launch pad can support 3.75 launches/week. o 6 pads will be required. (2 alternative arrangements of 6 HLLV launch pads at KSC are described in Appendix B) o A 7-day/week, 24 hr/day launch schedule will probably be environmentally unacceptable (noise level). Therefore, a remote, equatorial launch site would probably be required. o The largest cost associated with launch pads is the taxiways and offshore causeways and break waters (over 70% of cost). o The LEO Base will have to have at <u>least</u> 3 additional HLLV Docking Systems.

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TABLE 3 (Continued)
ANALYSIS OF PRIMARY EFFECTS

SPS-3295

EFFECT	ANALYSIS
o Smaller OTV	o Redesign OTV to be shorter and larger diameter and still keep baseline performance capability see Figure 3.
o Smaller Orbital Passenger Module	o Could redesign to a shorter, larger diameter stage with double deck to keep 75 passenger capacity, see Figures 4 and 5.

CARGO PACKAGING ANALYSIS

The primary objective of the cargo packaging analysis was to determine the configurations of the primary payloads for the small HLLV.

The cargo packaging data developed in Phase II of this study was used as the reference (see Table 5-1 in Section 5.0-Cargo Packaging, Volume III, Phase II Final Report, Operations and Systems Synthesis, D180-25461-3). This data was examined to find the components that 1) would be affected by the smaller cargo bay envelope, and 2) those that are either the most numerous, the most massive, and/or the largest (the so-called "primary payloads"). These components are identified in the following figures.

The only components that are repackaged significantly are the solar array blankets, the ion thruster panels, and the electrical rotary joint (slip ring) assembly.

FIGURE A-1
PRIMARY PAYLOADS

SPS-3219

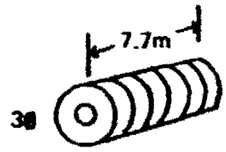
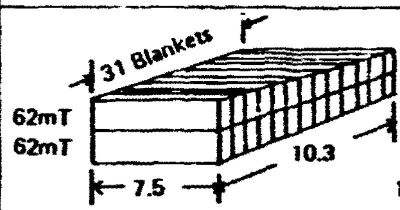
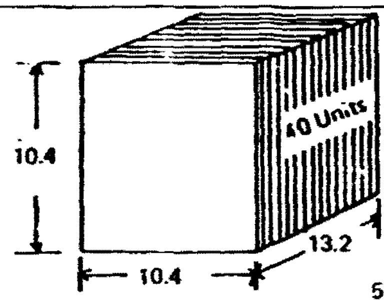
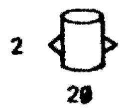
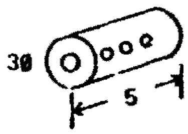
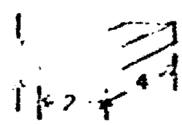
WBS	ITEM	SHIPPING UNIT CONFIGURATION	QTY SHIPPING UNITS/ YR
	SPS PRIMARY PAYLOADS		
1.1.1.1.1 1.1.2.1.1 1.1.2.1.2 1.1.6.1	Beam Machine Feedstock	 7.7m 3Ø 48.5 MT	365
1.1.1.3	Solar Array Blankets	 31 Blankets 62mT 62mT 10.3 7.5 124 MT	365
1.1.1.4.1	Power Busses	 3Ø 1 8.14 MT	365
1.1.2.2	Subarrays	 10.4 40 Units 13.2 10.4 56.6 MT	365
1.1.2.6.1	Ant Maint Systems		
	Cherrypickers	 2 2Ø	46
	Crew Bus	 3Ø 5	2
	Carriages Annealers (8) [illegible] (4) Docking (11) Cherrypickers (23) Cargo Handlers (4) Crew Bus (1) 51/SPS x2	 2 4	102

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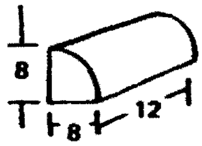
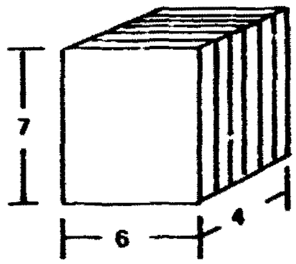
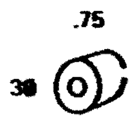
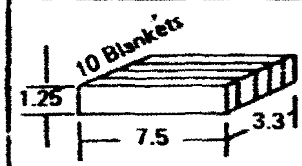
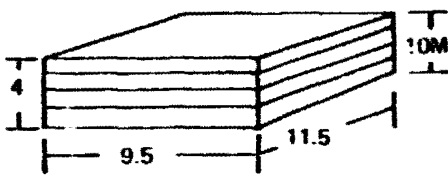
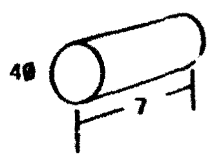
Fig A-1 - (Continued) Primary Payloads

WBS	ITEM	SHIPPING UNIT CONFIGURATION	QTY SHIPPING UNITS/ YR
1.1.6.2.3.1	Slip Ring Ass'y	 5MT	8
1.1.4	Thruster Panels	 5.6MT	1
1.3.2.1.1	**EOTV PRIMARY PAYLOADS** Beam Machine Feed Stock	 4.8 MT	120
1.3.2.3	Solar Array Blankets	 18.3 MT	345
1.3.2.4	Thruster Panels	 10MT	8
	Crew Supply Modules		48 (YR1) to 160 (YR33)

SPS-1220

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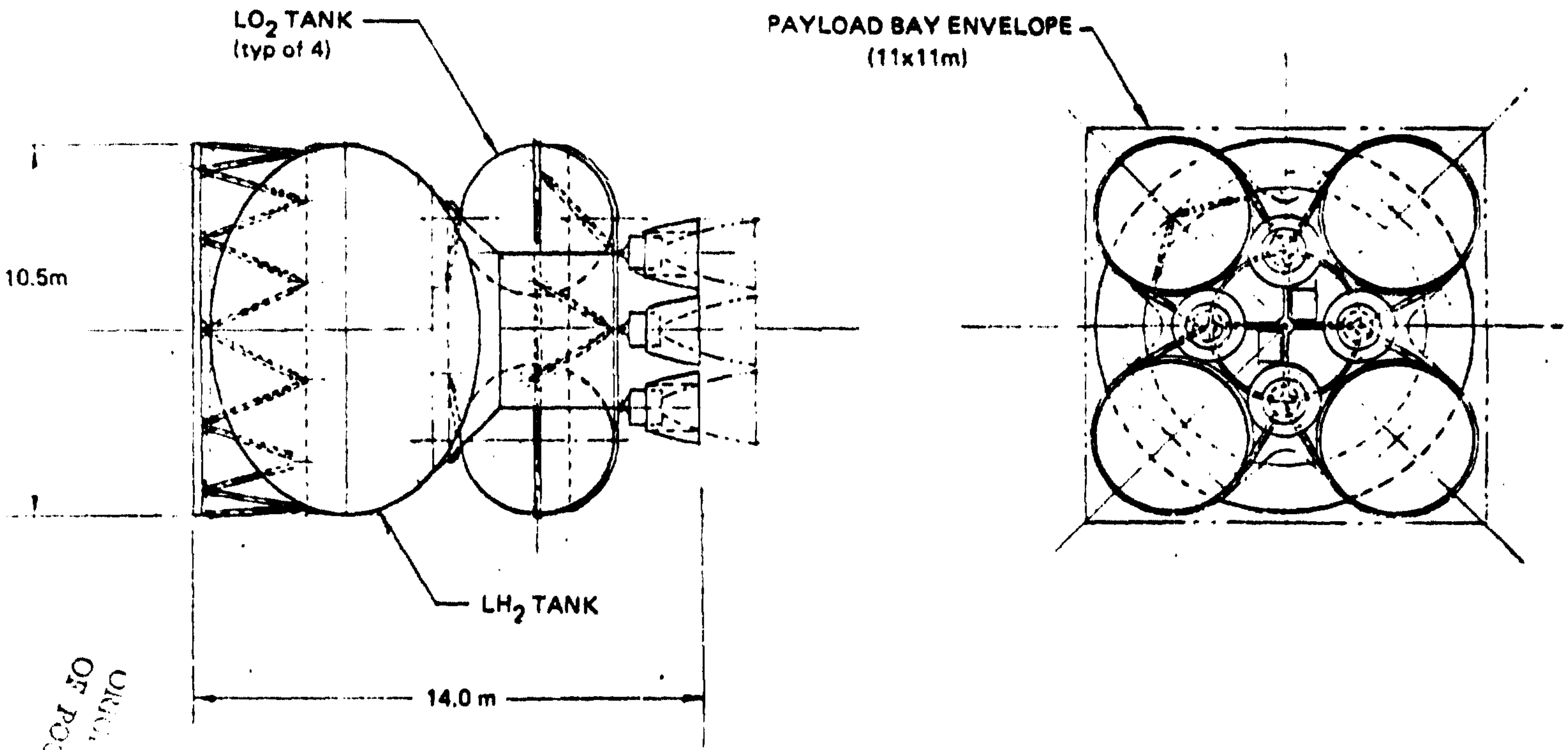
ORBITAL TRANSFER VEHICLE CONFIGURED TO FIT WITHIN A SMALL HLLV

The reference personnel orbit transfer vehicle employs a propellant loading of 200 metric tons. It is intended to be launched empty to minimize structural mass and refueled in space. In order to provide a 200 metric ton propellant volume within the payload bay envelope of the small HLLV, it was necessary to change to a short orbit transfer vehicle configuration with multiple liquid oxygen tanks. The configuration shown maintains the desired propellant loading and fits within the payload bay.

ORBITAL TRANSFER VEHICLE CONFIGURED TO FIT WITHIN A SMALL HLLV

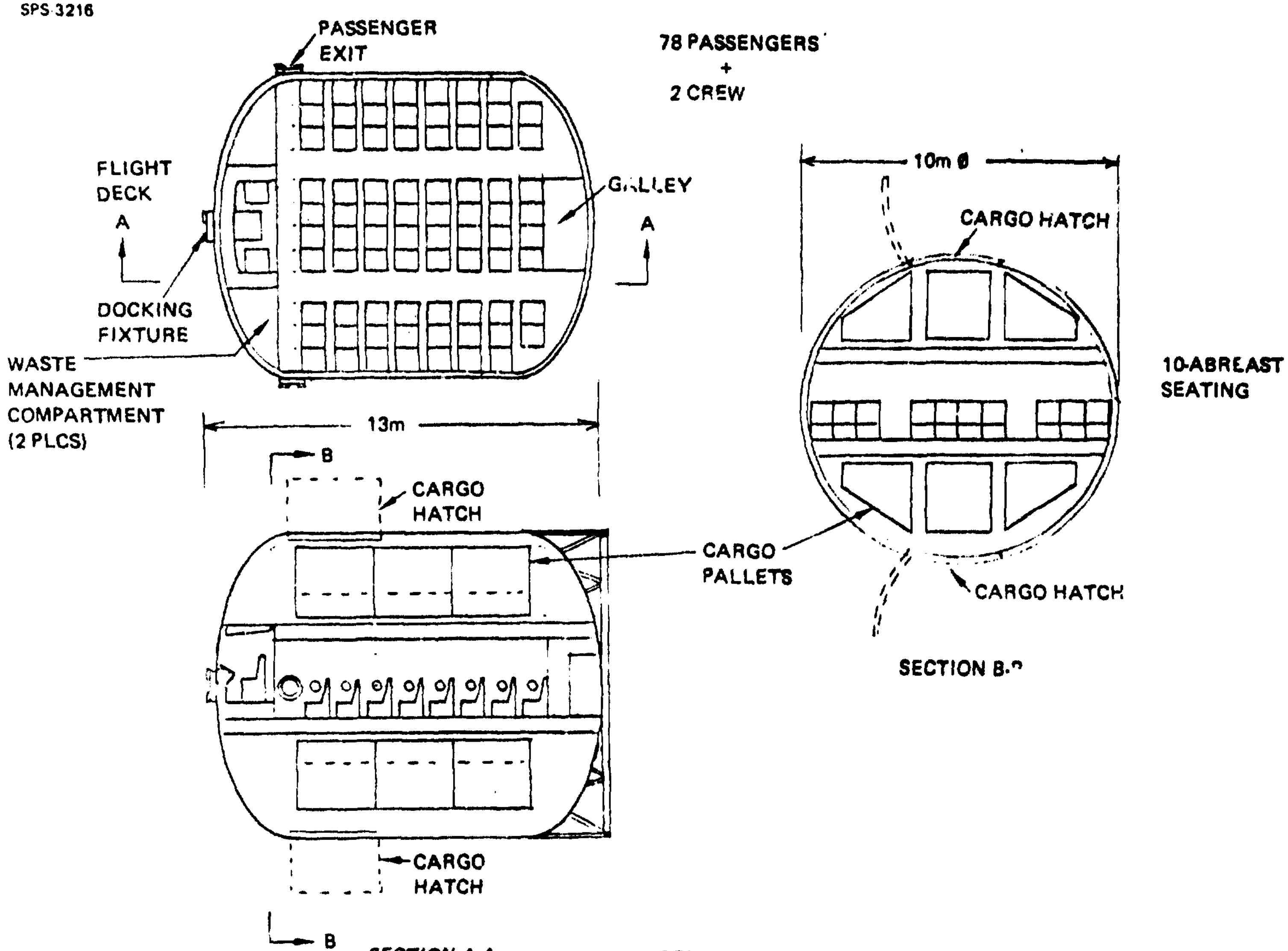


ORBITAL PASSENGER MODULE CONFIGURED TO FIT WITHIN A SMALL HLLV

A similar problem exists with the passenger module in that the earlier referenced passenger module was approximately 20 metres in length. In order to fit the smaller payload bay, it is necessary to employ the wide-body configuration. The wide-body configuration provides an advantage: the cargo carried externally in the earlier configuration can now be stowed internally in a manner similar to the cargo compartment of commercial jet aircraft.

ORBITAL PASSENGER MODULE CONFIGURED TO FIT WITHIN A SMALL HLLV

SPS-3216

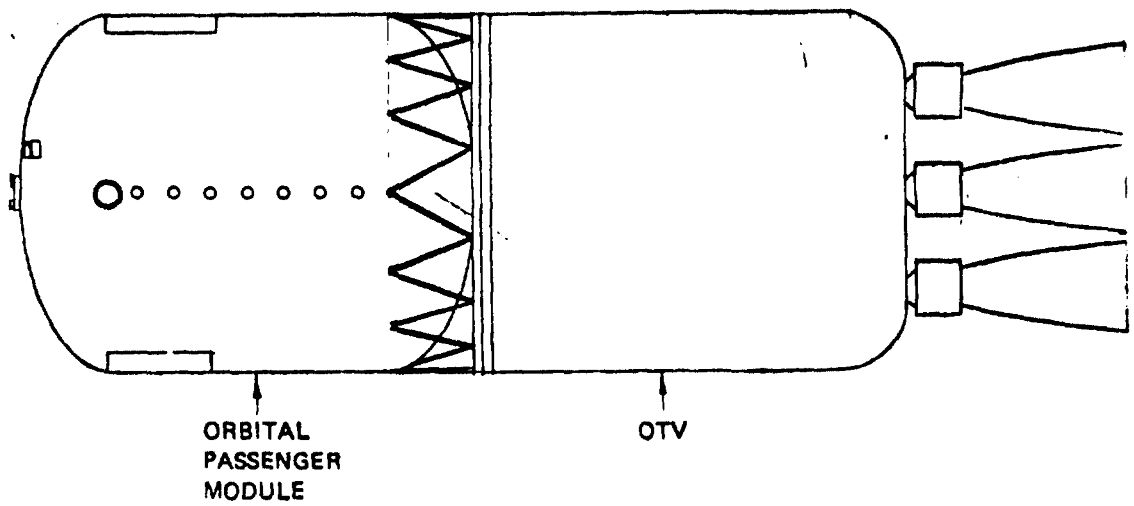


PERSONNEL ORBIT TRANSFER VEHICLE (POTV)

The passenger module and OTV propulsion stage must be launched separately, thus requiring two HLLV launches to deliver the entire POTV to low Earth orbit.

PERSONNEL ORBIT TRANSFER VEHICLE (POTV)

SPS-3215



SMALLER HLLV PAYLOAD EFFECTS ON GEO CONSTRUCTION BASE

Smaller HLLV payload capability covers a reduction in allowable cargo size and mass that can be delivered into low earth orbit. At the GEO Construction Base, however, the reduction in HLLV payload size will be important. The 11x11x14 m cargo bay limitation leads to alternate SPS construction requirements and impacts GEO base systems as shown on the facing page. When more construction tasks are [illegible]ded, extra equipment and/or work areas are needed. The smaller cargo bay also limits the size and hence the number [illegible] required pressure vessels for habitation and work support functions. A greater number of small cargo containers must be handled and distributed through the intra-base logistic network. All of the above leads to a larger crew, additional housing, more base support structure, etc.

SMALLER HLLV PAYLOAD EFFECTS ON GEO CONSTRUCTION BASE

- SMALLER HLLV PAYLOAD CAPABILITY
  - 11 X 11 X 14 m VS 17 m DIA X 23 m CARGO BAY
  - 120 MT VS 400 MT
- ALTERNATE SPS CONSTRUCTION REQUIREMENTS
  - 7.5 m VS 15 m SOLAR ARRAY BLANKETS
  - MODULAR VS ASSEMBLED SLIP RING DELIVERY
- GEO BASE SYSTEMS IMPACT
  - ADDED EQUIPMENT/WORK AREAS
  - SMALLER HABITATS & WORK MODULES
  - MORE INTRA-BASE LOGISTICS
  - LARGER WORK FORCE
  - ADDITIONAL BASE STRUCTURE

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GEO CONSTRUCTION OPERATIONS – IMPACT DUE TO SMALLER HLLV

The smaller HLLV cargo bay (11 m x 11 m x 14 m) affects GEO base operations for satellite construction and intra base logistics. Revised satellite construction requirements include smaller solar array blanket cannisters (7.5 m vs 15 m), modifications to solar blanket interfaces (e.g., support structure, acquisition buses, etc), and modular versus preassembled slip rings. These operations, which impose added equipments for the GEO base, are shown on the facing page. To maintain the 6 month reference construction schedule, twice as many cherry pickers are needed to install 88 versus 44 solar array blankets in each bay of the energy conversion system. No additional equipment is needed to handle the other subsystems which interface with the smaller solar array blankets. The level J subassembly factory must be expanded to accommodate the equipment needed to support the assembly and checkout of the modularized slip ring. Finally, it is estimated that four times as many cargo pallets must be docked/unloaded and handled. The equipment which must be added to the intra base logistic system is shown on the chart, together with total impact in mass and cost for all added equipment.

GEO CONSTRUCTION OPERATIONS IMPACT DUE TO SMALLER HLLV

REVISED OPERATIONS	GEO BASE SYSTEM IMPACT		
	ADDED EQUIPMENT	Δ MASS	Δ COST
• INSTALL 88 - 7.5 m SOLAR ARRAY BLANKETS/BAY (TWICE BASELINE)	(4) 30 m CHERRY PICKERS @ LEVEL H ANCHORS	10 MT	$ 87.6M
• ASSEMBLE & C/O MODULAR SLIP RING	(2) 30 m CHERRY PICKERS, RACKS & TOOLS, TEST & C/O EQUIP. @ LEVEL J FACTORY	15 MT	$ 97.6M
• DOCK/UNLOAD & HANDLE MORE NUMEROUS SMALL CARGO PALLETS (FOUR TIMES BASELINE)	(2) CARGO TUG DOCKING PORTS (2) CARGO PALLET HANDLING JIG (80) TRANSPORTERS (SMALL) @ LEVEL J	22 MT	$ 78.8M
		47 MT	$264M

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EFFECT OF SMALLER HLLV ON GEO BASE CREW OPERATIONS

GEO base crew operations also increases to support the added tasks for satellite construction and intra base logistics. It is estimated that 56 crewmen will be needed to cover the extra workload and furnish the required habitat and crew support services. A breakdown of these added crew operations is shown on the facing page together with the cost for annual operations.

EFFECT OF SMALLER HLLV ON GEO BASE CREW OPERATIONS

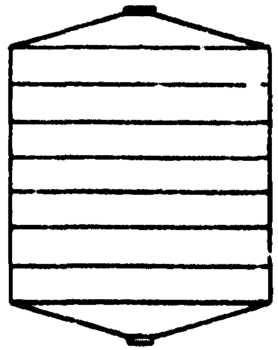
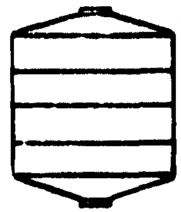
		CREWMEN
• BASELINE GEO CONSTRUCTION CREW		444
• ADDED CREW OPERATIONS		56
– SOLAR ARRAY INSTALLATION	8	
– SLIP RING ASSEMBLY & C/O	8	
– CARGO HANDLING & DISTRIBUTION	12	
– HABITAT & CREW SUPPORT (UTILITIES, HOTEL, FOOD MGT, MAINT, ETC)	28	
ADJUSTED BASE CREW		500
• OPERATIONS COST IMPACT		
– ADDED CREW SALARIES		$83.3M
– ADDED CREW SUPPLIES ($1.43M/MANYR)		$80.1
		$163.4M

IMPACT OF HLLV SIZE ON GEO BASE MODULES

One impact of the smaller HLLV is the reduced size of the crew support facilities for habitation and work-related activities. In the Phase II analysis of crew habitation requirements, it was judged that one module, sized for the larger HLLV (17 m dia x 23 m), could comfortably house 100 men. On a direct volume basis, five of the smaller modules (10.? m dia x 13.5 m) would provide approximately the same volume as one larger module. In fact, the equivalent volume ratio is probably greater than 5 to 1, since packaging given items into a smaller volume is less efficient than packaging the same items into a larger volume. This holds for all crew support facilities where the initial allocation of functional areas is either believed to be correct or is perhaps not well defined. The GEO base work modules for command and control, base maintenance, etc have yet to be analyzed. When the functional requirements for these activities are developed, the area needed for crew and equipment could either meet or exceed the current assumptions. Hence the 5 to 1 ratio is used to establish equivalent work modules for the smaller HLLV.

Crew habitation requirements, however, were examined in Phase II to the level of compartmental partitioning of major crew areas, considering furnishings and equipments. The larger crew module provided about 17.44 m^3 of free volume for each crew man. This is about ?.5 times Celentano's recommended free volume per man (7.08 m^3) for acceptable crew performance over 90 days. Therefore, a brief study was performed to take another look at the crew accommodation packaging arrangements for the smaller crew module. By reducing the free volume crew allocation to 10.35 m^3, we judge that 100 men can be adequately housed in three of the smaller modules. The distribution of crew quarters and other facilities are shown in the following chart.

IMPACT OF HLLV SIZE ON GEO BASE MODULES

	REFERENCE HLLV	'SMALLER' HLLV
		
• MODULE SIZE	17 m DIA X 23 m	10.5 m DIA X 13.5 m
• FREE VOL/MAN*	17.44 m^3	17.44 m^3
• MODULES/100 MEN	1	5
• FREE VOL/MAN*		10.35 m^3
• MODULES/100 MEN		3

CELENTANO 'PERFORMANCE': 90 DAYS = 7.03 m^3/MAN FREE VOL.

*FREE VOL ASSUMED TO BE 50% OF TOTAL VOLUME

'SMALLER' HLLV IMPACT
- WORK MODULES 5:1
- HABITATION MODULES 3:1

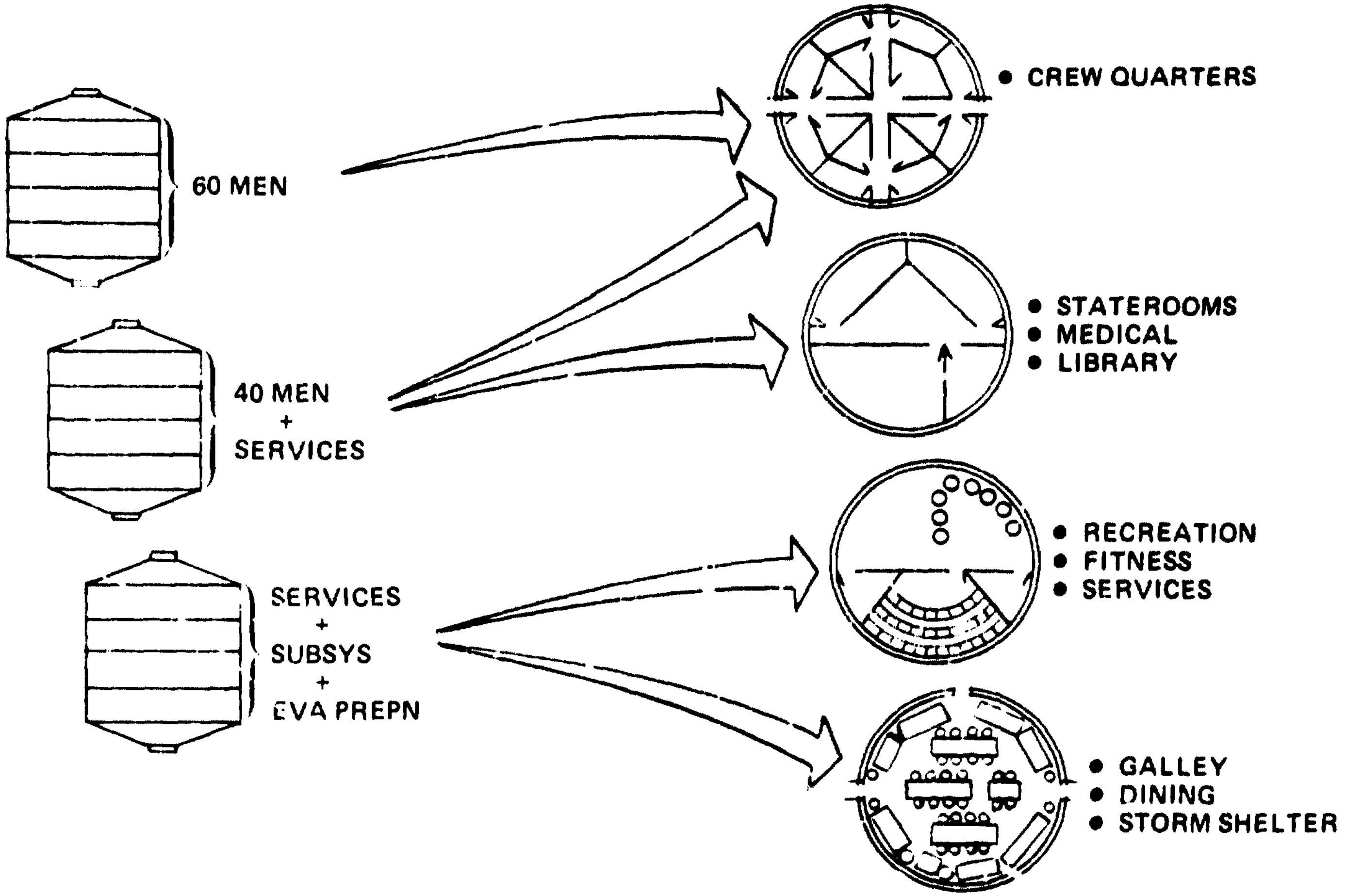
CREW MODULE SIZE FOR "SMALLER" HLLV LAUNCH (3 MODULES HOUSE 100 MEN)

Layout of the three habitation modules to house 100 men is shown here. Allowing for wall thickness, insulation and radiation protection, the inside diameter of each deck is 10 m and floor to ceiling height is 2.15 m. One module provides quarters for 60 men and each of the four decks has the same layout of 16 comparably sized quarters; except that on two of the decks, two quarters are eliminated on each to provide hygiene and waste management.

The second module has one deck of 14 quarters plus toilets, laid out as the first module, then two decks with 12 larger quarters each. A fourth deck provides medical facilities, a library and two staterooms for the two most senior officers.

The third module provides services on two of the four decks. One deck provides a gymnasium, a recreation lounge, a thirty seat theatre for movies, church services and meetings, a laundry and a hygiene/waste management facility. The other service deck has the galley, food storage for emergencies and eating accommodation for twenty-eight. Main food storage is in an attached logistics module. This deck also serves as the storm shelter with suitable distribution of equipments and wall thicknesses to provide protection. Taking the free area available for 100 men during solar storm conditions, area per man is 0.54 m^2 (5.8 ft^2) extending from floor to ceiling. The remaining two decks in this module house subsystems and EVA preparation.

CREW MODULE SIZE FOR 'SMALLER' HLLV LAUNCH – 3 MODULES HOUSE 100 MEN



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HLLV IMPACT ON GEO BASE CREW SUPPORT FACILITIES

A comparison of the estimates on GEO Base crew support facilities is shown on the facing page for the baseline and smaller HLLV payload modules. The number of crew habitats and related work modules are defined for support of GEO construction and SPS maintenance. When the appropriate small module to baseline module ratio is applied (i.e., 3:1 habitats and 5:1 work) 33 small modules (10.5 m dia) are required for initial GEO construction (vs 8 @ 17 m dia). Later in the program when 60 satellites have to be maintained, 99 of the smaller modules will be needed for habitation and work support functions. Comparative mass and cost data are shown on the chart. It should be noted that the cost penalty attributed to the smaller pressure vessel is probably too high since these cost data do not include the full benefit of production quantity learning.

HLLV IMPACT ON GEO BASE CREW SUPPORT FACILITIES

	BASELINE 17 m DIA X 23 m	SMALLER HLLV PAYLOAD 10.5 m DIA X 13.5 m	Δ MASS, MT	Δ COST, $
GEO CONSTRUCTION SUPPORT				
• CREW HABITATS	5	18		
– TOTAL (UNIT) MASS, MT	1215 (243)	1710 (95)	494	
– TOTAL (AVG UNIT) COST, 1979 $M	1923 (384.6)	4451 (247.3)		2528*
• WORK MODULES	3	15		
– TOTAL MASS, MT	413	807	393	
– TOTAL COST, $M	631	2028		1397*
SPS MAINTENANCE SUPPORT (20 TO 60 SATELLITES)				
• CREW HABITATS	4 TO 12	12 TO 36		
– TOTAL MASS, MT	972 – 2916	1140 – 3420	168 TO 504	
– TOTAL COST, $M	1538 – 4615	2967 – 8903		1429–4288*
• WORK MODULES	2 TO 6	10 TO 30		
– TOTAL MASS, MT	354 – 1062	692 – 2076	339 TO 1014	
– TOTAL COST, $M	646 – 1938	2077 – 6231		1431–4293*
		TOTAL Δ MASS	1393 TO 2405 MT	
*EXCLUDES FULL BENEFITS OF LEARNING		TOTAL Δ COST		$ 6785M TO $12506*

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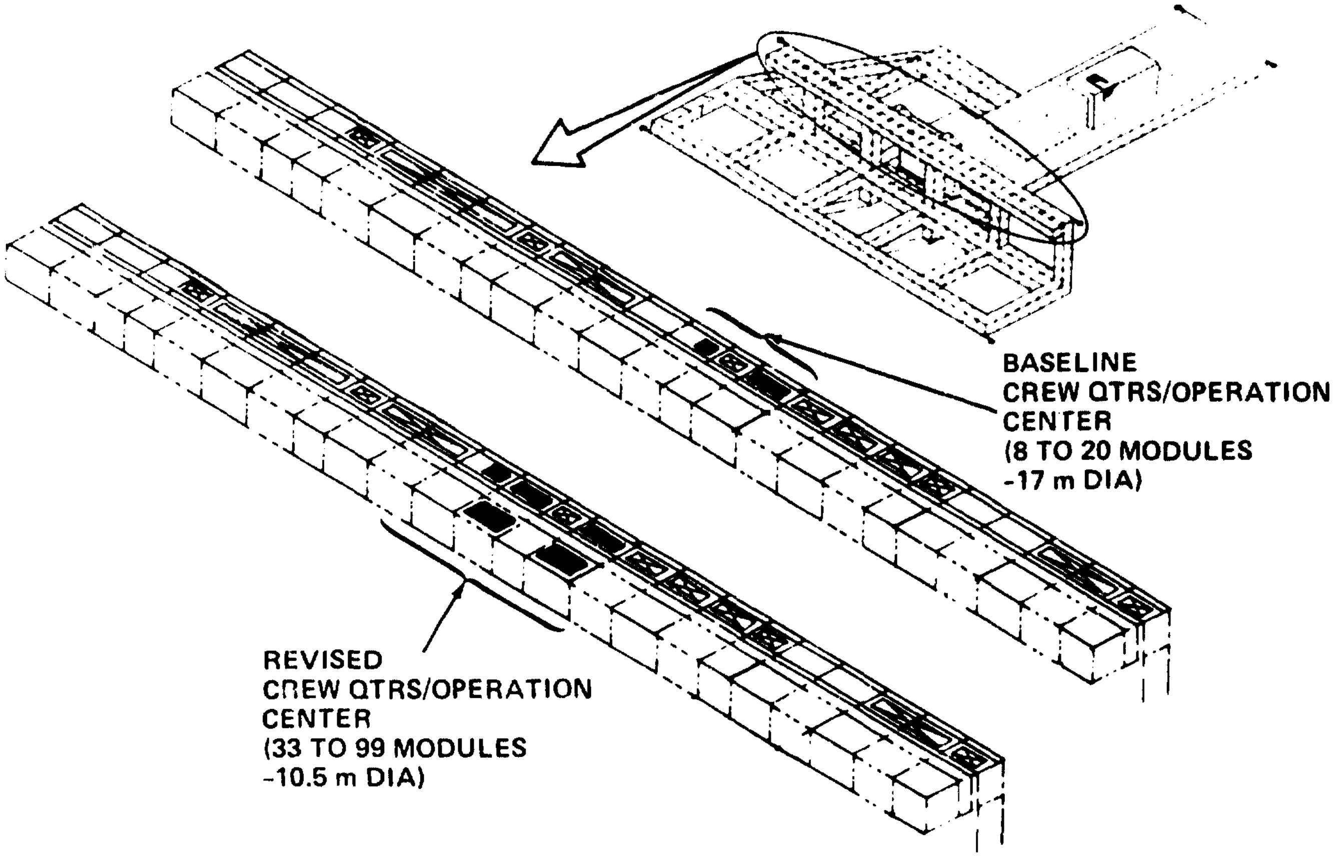
0580-033W

GEO BASE: LEVEL J FACILITIES – IMPACT OF SMALLER HLLV

The center of base activity occurs at the top deck, level J. Material and personnel are brought to this level from the LEO base; SPS service crews, with their materials, depart from here. In addition, numerous vertically moving transportation devices interface here with supplies and personnel for delivery to lower levels. The baseline level J has not changed from that reported in Phase 2 of the study.

In considering the impact of a smaller HLLV, its reduced payload capability results in a 13.5 m diameter module, instead of the baseline 17 m diameter, to provide crew quarters and operations center. As discussed in preceding charts, the ratios of smaller modules to baseline modules is 3:1 for crew habitats and 5:1 for work modules, thus needing more smaller modules to provide the same baseline facilities. For example, at the end of the 30 year reference scenario, the crew quarters/operations complex could grow to 99 modules. The chart illustrates that level J has ample area to mount as many small modules as needed.

GEO BASE: LEVEL J FACILITIES – IMPACT OF SMALLER HLLV



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0580-007W

NET IMPACT OF SMALLER HLLV ON GEO BASE

The net impact of the smaller HLLV on GEO base mass and cost is summarized. The reference work facilities must be revised primarily to support the added crew support facilities, accommodate extra construction equipment, enlarge cargo handling/distribution, and expand the subassembly factory. One benefit of the smaller crew module is that it provides a significant reduction in DDT&E expenditures which occur at the outset of the investment phase. It also provides a programmatic option that would make one crew module size serve needs for both the demonstration and investment phases of the program. In that event only one module would be developed and funded to meet earlier demonstration phase objectives. This option would then avoid $3.8B (with wraparound factors) for developing another small crew module for the investment phase.

It should be noted again that the crew module production costs are probably too low since they exclude the full benefits of high production learning. In addition, the range of crew modules costs cover an expenditure over 30 years with no discounting included.

NET IMPACT OF SMALLER HLLV ON GEO BASE

SMALL HABITAT OPTION
- KEY TO DEMO PHASE
- AVOID $3.8B INVEST.

GEO BASE ELEMENT	Δ MASS, MT	Δ COST 1979 $M DDT&E	PROD.
WORK FACILITIES			
– STRUCTURE	17	4	2
– CONSTRUCTION, EQUIPMENT	10	0	88
– CARGO HDLG/DISTRIBUTION	22	0	79
– SUBASSEMBLY FACTORIES	15	0	97
CREW SUPPORT FACILITIES			
– CREW QUARTERS (0 TO 60 SPS)	494 TO 998	-613	2528 TO 6816
– WORK MODULES	393 TO 1407	0	1397 TO 5690
WRAPAROUND FACTORS			
– DEVMT 127%		-773	
– PROD. 47%			1969 TO 6002
TOTAL	951 TO 2469 MT	-$1380M	$6160 TO 18770M

$\underbrace{\text{-\$1380M} \quad \text{\$6160 TO 18770M}}_{\text{\$4,780 TO \$ 17,390M}}$

ANNUAL OPERATIONS

SALARIES & TRAINING (+56 CREW)		83
RESUPPLY	142 MT/YR	80
		$163M/YR

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0580-034W

ALTERNATIVE LAUNCH AND RECOVERY SITE CONCEPTS

In the analysis of the effects of a small HLLV on the SPS program elements, it was found that the most significant effect would be on the launch and recovery site.

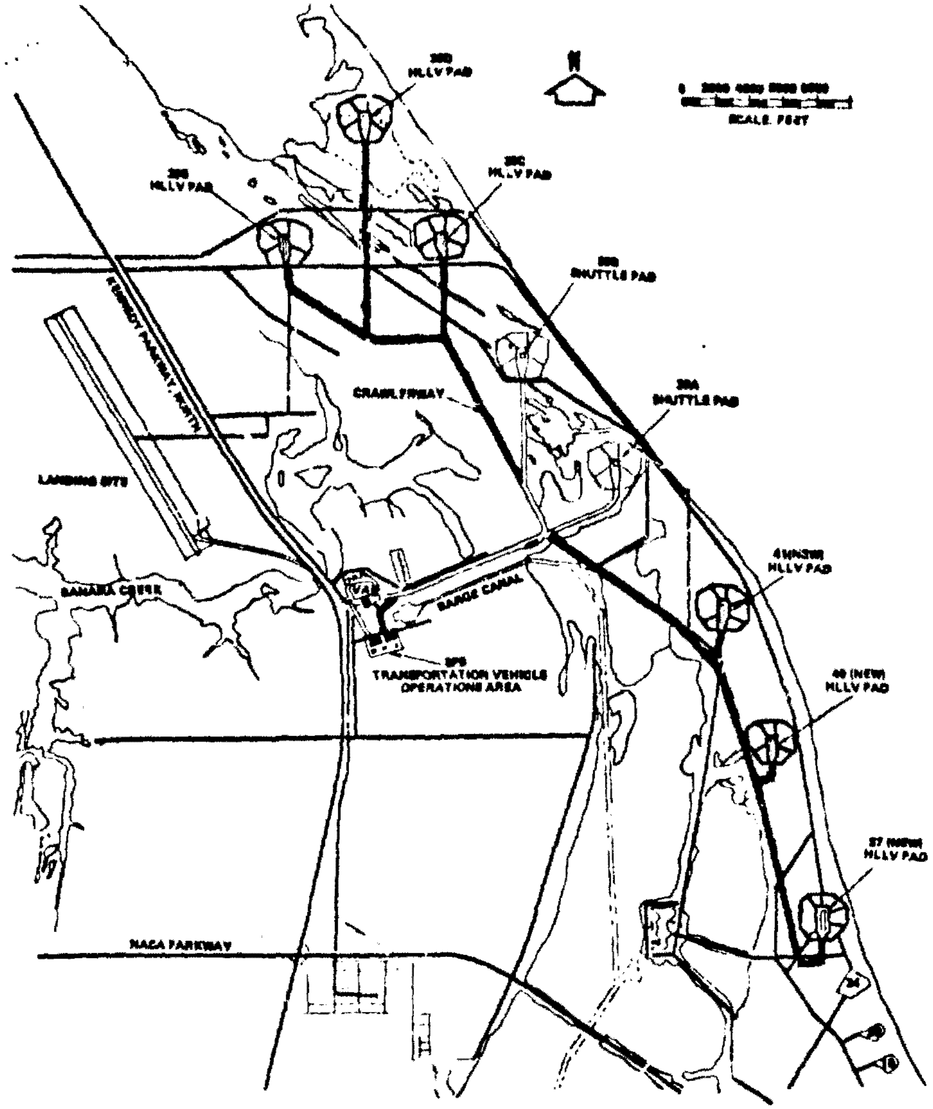
CALCULATION OF THE NUMBER OF LAUNCH PADS - It was shown that at year 12 (when 20 SPS's are in orbit, per year) that 1471 mass-limited flights would be required. Multiply this by 1.05 to account for non-optimal packaging and we get 1545 flights per year. The pad time per vehicle is 34 hours. This leads to the capability of each pad to support 257 flights per year (assuming 24 hours per day/365 days per year operatins). This results in a requirement for 6 launch pads for the small HLLV.

LAUNCH PAD LOCATIONS - If we assume that it will be environmentally acceptable to launch up to 5 vehicles per day every day of the week at KSC, then we are given the requirement to find space for 6 HLLV launch pads. In task 4210111, we found that for the small HLLV that the minimum pad separation distance required is 8000 ft.

We examined 2 possible arrangements of 6 HLLV launch pads at KSC that meet the 8000 ft separation requirement. This figure shows an off-shore arrangement similar to the baseline concept for the large HLLV. The next figure shows an arrangement where the 6 pads are located on-shore. In this arrangement, 3 of the HLLV pads will be at the 38C, 39D, and 39E pad locations (shown to be in locations previously reserved for them). The 3 additional HLLV pads are shown to be located at the 37, 40 and 41 pad locations. (It is assumed that the current user of these pads will no longer be operational or that they can be moved to other pad locations. In addition, pads 34, 20 and 19 will have to be decomissioned to provide the 8000 ft clearance).

ON-SHORE ARRANGEMENT OF SPS LAUNCH AND RECOVERY SITE FACILITIES AT KSC CONFIGURED FOR A SMALL HLLV

SPS-3217



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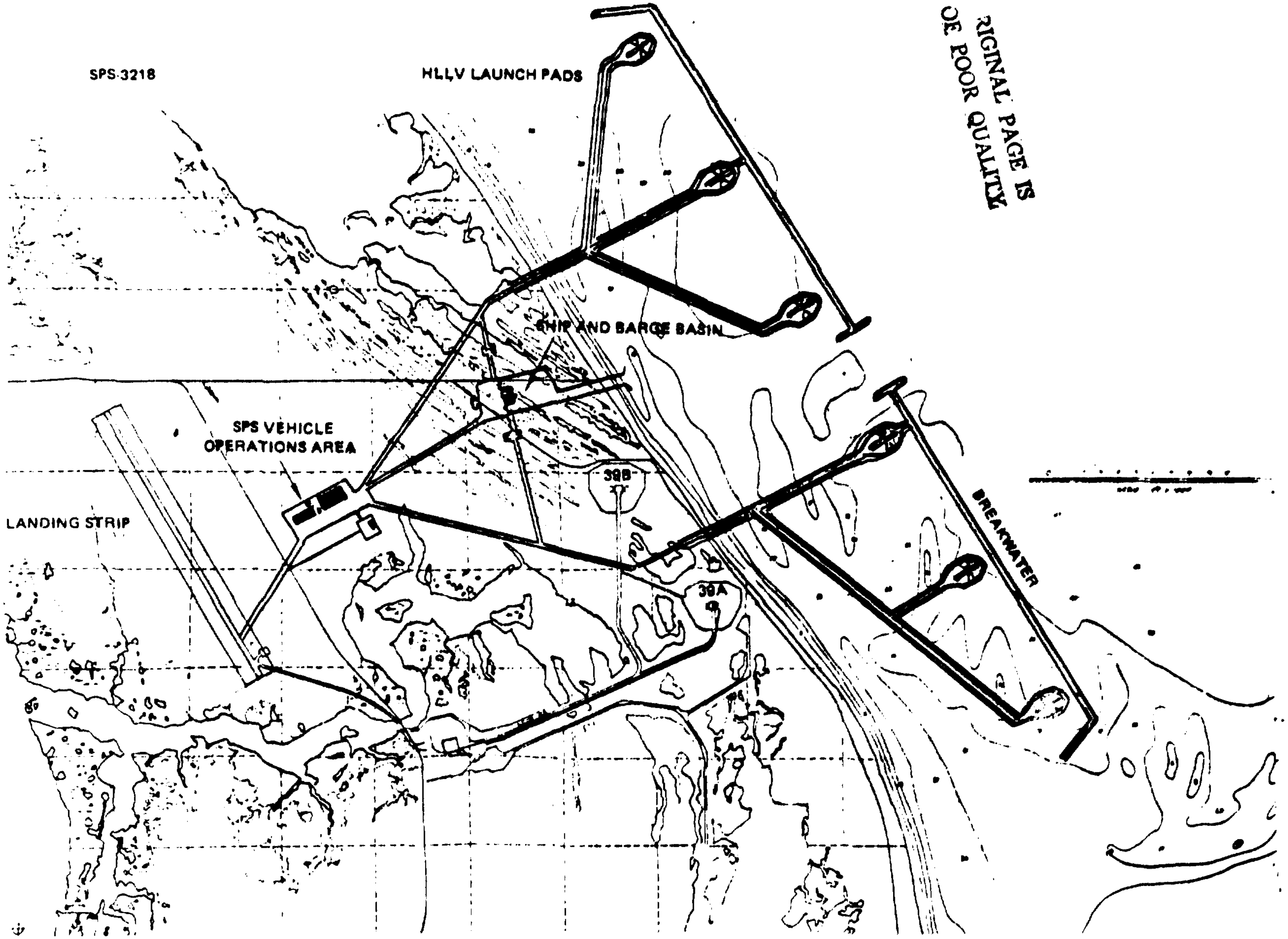
SPS LAUNCH AND RECOVERY SITE ARRANGEMENT AT KSC CONFIGURED FOR A SMALL HLLV



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COST ANALYSIS HIGHLIGHTS

The cost estimates for the alternative launch and recovery sites are summarized in this table. The 5 alternative concepts are described below:

- o Large HLLV Reference
  - o This is the reference concept for the large HLLV, described in the Reference System Description, WBS 1.3.7.
- o Large HLLV Piers
  - o This concept substitutes a 200 ft wide steel pier system in lieu of the rock causeways. Brown and Root estimates this steel pier arrangement to cost $50,000 per lineal foot.
- o Small HLLV Causeways
  - o The causeways are 100 ft wide and 50 ft high.
  - o The launch pads are scaled to be 35% as large and expensive as that required for the large HLLV,
  - o The HLLV Orbiter and Booster processing facilities were scaled down to the smaller vehicle sizes and additional bays were provided as required. Scaling down the vertical clearance height and the strength required resulted in substantial cost savings.
- o Small HLLV Piers
  - o This arrangement for this concept was identical to that described above.
  - o The only difference is that 100 ft wide steel piers are used in lieu of the rock causeways. Brown and Root estimated the cost to be $42,000 per lineal foot.
- o Small HLLV On-Shore
  - o The arrangement for this concept was shown in Figure B-2.
  - o The ship and barge basin were eliminated.
  - o The scaled-down orbiter and booster processing facilities were also used here.
  - o The cost of the new causeway was included.

It is obvious that the so-called "on-shore" pad arrangement is substantially cheaper than the "off-shore" alternatives. These cost estimates were fairly crude, so it is suggested that a task be provided in future studies to derive more detailed cost data.

The environmental effects of a 24 hour per day, 7 day per week launch schedule cannot be ignored. A more detailed study is required to define the maximum launch rate that could be tolerated at KSC.

TABLE B-1

COST COMPARISON OF ALTERNATIVE LAUNCH AND RECOVERY SITE CONCEPTS

SPS-3297

		COST, $M				
		LARGE HLLV		SMALL HLLV		
WBS	ELEMENT	REFERENCE	PIERS	CAUSEWAY	PIERS	SHORE
1.3.7.1.1	HLLV Launch Facilities	(3222)	(3345)	(3828)	[illegible]	(949)
	o Causeways & Taxiways	1727	1850	1950	[illegible]	180
	o Breakwater	673	673	1109	1109	–
	o Launch Pads	336	336	234	234	234
	o Equip/utilities/etc.	486	486	535	535	535
1.3.7.2	Recovery Facilities	(1770)	(1770)	(676.5)	(676.5)	(676.5)
1.3.7.2.1	o Landing Site	20.5	20.5	20.5	20.5	20.5
1.3.7.2.2	o HLLV Orbiter Proc. Fac.	1114	1114	265	265	265
1.3.7.2.3	o HLLV Booster Proc. Fac.	445	445	201	201	201
1.3.7.2.4	o other facilities	190	190	190	190	190
1.3.7.2.10						
1.3.7.3	Fuel Facilities	TBD	TBD	TBD	TBD	TBD
1.3.7.4	Logistics Support	(40)	(40)	(40)	[illegible]	(6)
1.3.7.5	Operations	(78.3)	(78.3)	(156.6)	(156.6)	(156.6)
	INVEST. TOTALS	$5.11B	$5.23B	$ 4.7B	$ 5.[illegible]	$1.8B

ENVIRONMENTAL EFFECTS OF THE SMALL HLLV

The objective of this task was to assess the environmental effects of the smaller and more numerous HLLV. These environmental effects include launch and reentry overpressure (sonic boom), launch facility noise, launch pad explosions, and effluent deposition in the upper atmosphere.

These environmental effects have been assessed for the baseline HLLV. The authors of these analyses were asked to make judgments as to the delta environmental effects when comparing the smaller HLLV to the baseline HLLV. This report presents the results of these assessments.

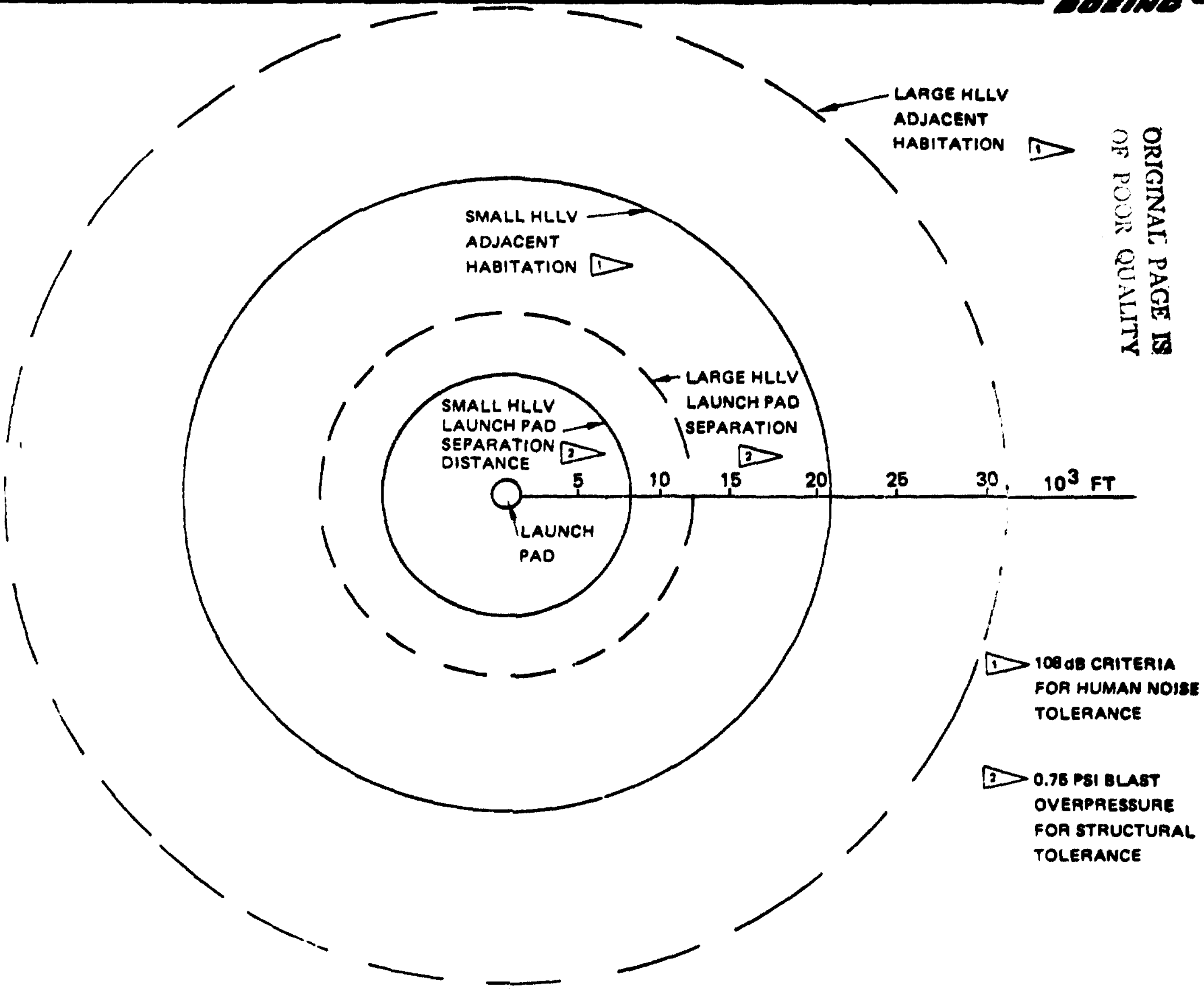
ENVIRONMENTAL EFFECTS OF THE SMALL HLLV

- o LAUNCH AND REENTRY SONIC OVERPRESSURE
- o LAUNCH NOISE
- o EXPLOSIVE HAZARD
- o EFFLUENT DEPOSITION

LAUNCH PAD SEPARATION AND ADJACENT HABITABLE AREAS

This figure shows the minimum pad separation required based on an on-pad explosion. The pads can be over 4000 ft. closer together than was required for the large HLLV. This figure also shows that the minimum distance to habitable areas can be 12000 ft closer, based on human noise exposure limitations.

Figure 6-3. Minimum Distance From Launch Pad to Adjacent Habitable Areas and to Adjacent Launch Pads



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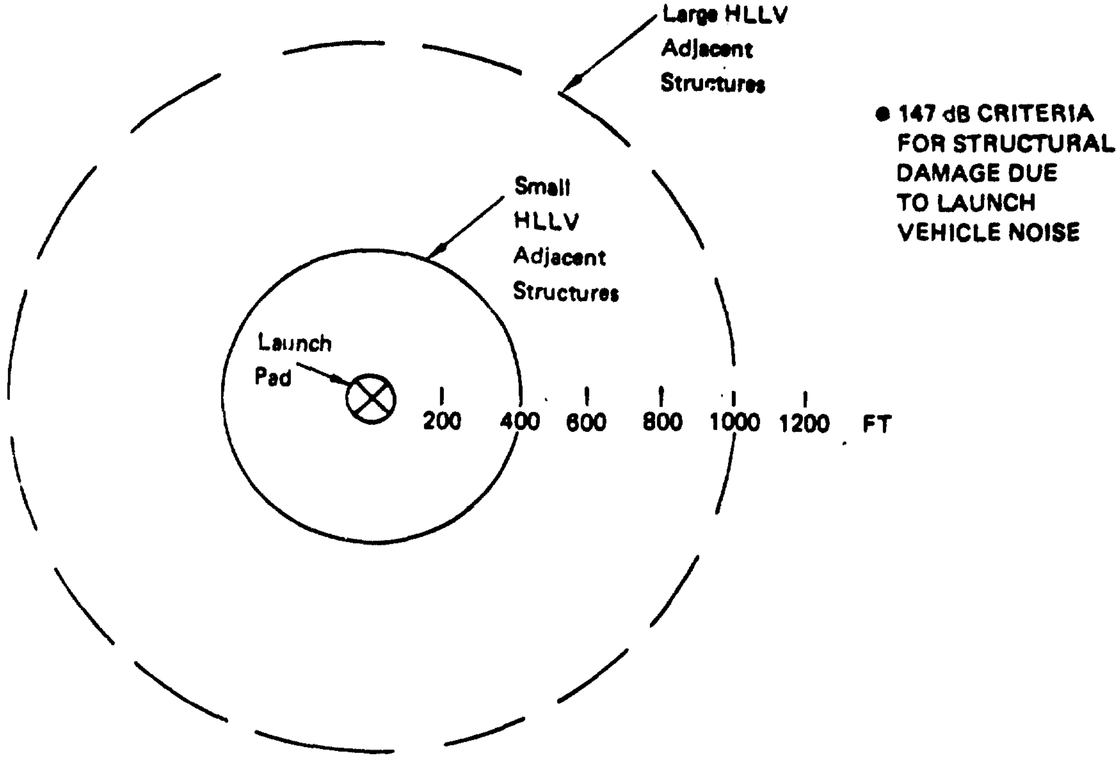
LAUNCH NOISE AND BLAST

The launch noise levels for the small HLLV will be substantially less than that for the large HLLV. The figure shows that adjacent structures can be 60% closer to the small HLLV launch pads when noise level structural damage is considered.

Figure 6-2 Minimum Distance From Launch Pad to Adjacent Structures Based on Noise Level Criteria



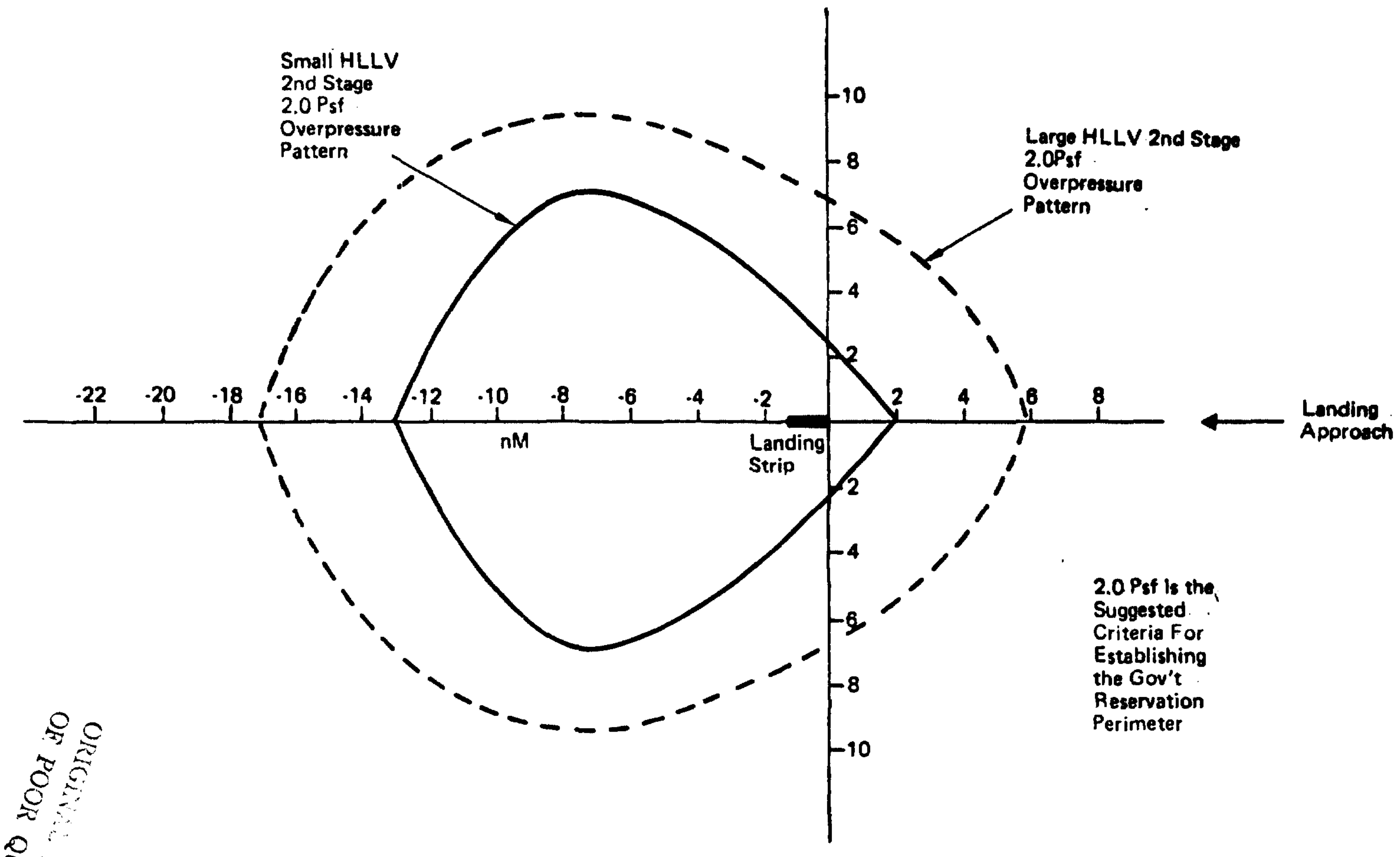
SONIC BOOM

The second stage vehicle reentry will be the source of the most severe sonic booms at the launch and recovery site. The recommended sonic boom overpressure at the boundary of the governm,ent reservation is 2.0 psf. This figure shows that this 2.0 psf boundary for the small HLLV is somewhat less than that required for the large HLLV.

UPPER ATMOSPHERE EFFLUENTS

The small HLLV will deposit 1.71 times as much effluent into the atmosphere per week as the large HLLV. However, this increase may be substantially offset by a slower rate of diffusion that will allow the effluents to be chemically decomposed into non-harmful constituents.

Figure 6-1. Minimum Distance From an Launch Pad to Adjacent Structures Based on Noise Level Criteria



DELTA COST SUMMARY SMALL HLLV

The delta costs between the small HLLV and the large reference system are summarized on the facing page. Satellite design changes resulted in increased costs for the space construction systems that were reflected as nonrecurring investment costs in hardware. The necessity to use smaller crew modules results in a DDT&E savings, but an investment increase from the need to buy more of the smaller modules. Transportation includes direct DDT&E savings on the smaller launch vehicle, savings resulting from less complex facilities and increase in the fleet investment and in the HLLV factory and savings resulting from less development activity on shuttle derivatives as a result of having the small heavy lift launch vehicle. It may be noted that the large increase in HLLV factory and tooling costs probably, in part, reflects an underestimate in tooling for the large HLLV. The cost model has been updated since the original figures were developed and now reflect higher tooling costs. In the recurring column, results include the cost of SPS hardware under SPS, the cost of transporting the additional SPS mass under Transportation, and the cost of construction operation in the third column. Recurring cost for the small HLLV is higher than for the large one, but the small HLLV also accomplishes crew rotation from Earth to low Earth orbit, resulting in a savings. The net recurring result is 887 millions per year, about 440 millions per SPS, or roughly 3% increase per SPS.

DELTA COST SUMMARY - SMALL HLLV

	NONRECURRING	RECURRING SPS	RECURRING TRANSPORTATION	RECURRING CONSTRUCTION
SATELLITE DESIGN CHANGES	230 (BASE CHANGES)	16.3	90.4	4.12
CARGO LOGISTICS	250.1	—	—	5.2
SMALLER CREW MODULES		—	—	132.1
DDT&E	-2521 [1]			
INVESTMENT	3925 + 34.4			
TRANSPORTATION		—	1040 (HLLV) -400 (PLV)	—
DDT&E	-3075			
FACILITIES INVESTMENT	-3049			
FLEET INVESTMENT	790 [2]			
HLLV FACTORY	1619			
LESS SHUTTLE MODS	-3204			
TOTAL	-5000.6	16.3	730.4	141.42
		TOTAL = 887		

[1] INCLUDES CREDIT FROM DEMONSTRATION PHASE

[2] TOOLING UNDERESTIMATED FOR LARGE HLLV?

SMALL HLLV NET EFFECTS

In summary, the small HLLV has positive features and some negative features. In general, the positive features outweigh the negative features and it is recommended that the small HLLV be adopted as an SPS reference system.

SMALL HLLV NET EFFECTS

POSITIVE

- o LESS NONRECURRING COST: MORE COMMONALITY WITH SHUTTLE
- o REDUCED NOISE & SONIC OVERPRESSURE
- o LESS FACILITIES COST: OFFSHORE PADS NOT NEEDED
- o SIZE APPROPRIATE FOR ALTERNATIVE MISSIONS
- o CREW AS WELL AS CARGO DELIVERY

NEGATIVE

- o SLIGHTLY HIGHER RECURRING COST
  - . GREATER NUMBER OF CONSTRUCTION CREW
  - . MORE PROPELLANT CONSUMED
- o MORE FREQUENT FLIGHTS
- o MORE EFFLUENT DEPOSITED IN UPPER ATMOSPHERE

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SOLID STATE SPS BACKGROUND

The present solid state report builds on analysis and experimental work conducted in earlier phases. A synopsis of the background is presented on the facing page.

SOLID-STATE SPS BACKGROUND

SPS-3368

- INTEREST IN SOLID-STATE STEMS FROM ORDER-OF-MAGNITUDE RELIABILITY ADVANTAGE.
- SOLID-STATE DEVICES ARE LOW-VOLTAGE AND LOW-POWER.
- TWO CONFIGURATION OPTIONS IDENTIFIED: SEPARATE (CONVENTIONAL) ANTENNA AND SANDWICH.
- SANDWICH IS THERMALLY-CONSTRAINED: SEPARATE-ANTENNA REQUIRES INNOVATIVE POWER DISTRIBUTION IN VIEW OF LOW VOLTAGE.
- SOLID-STATE POWER COMBINER ANTENNA ELEMENT EXPERIMENTALLY DEMONSTRATED UNDER TECHNOLOGY CONTRACT.
- DIRECT DC AT 4 KV WITH SERIES-PARALLEL POWER SUPPLY TO POWER AMPS SELECTED IN PHASE II.
- PHASE III EFFORT ADDED DETAIL TO AMPLIFIER DESIGN AND IMPROVED POWER DISTRIBUTION.

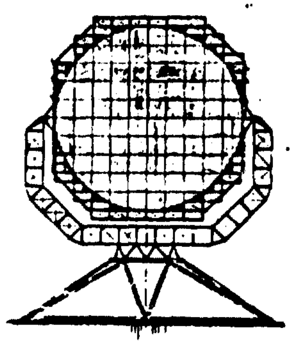
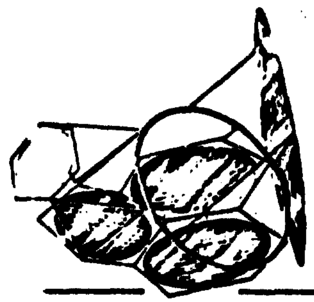
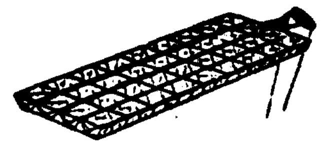
SPS RF DESIGN OPTIONS

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 bus 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

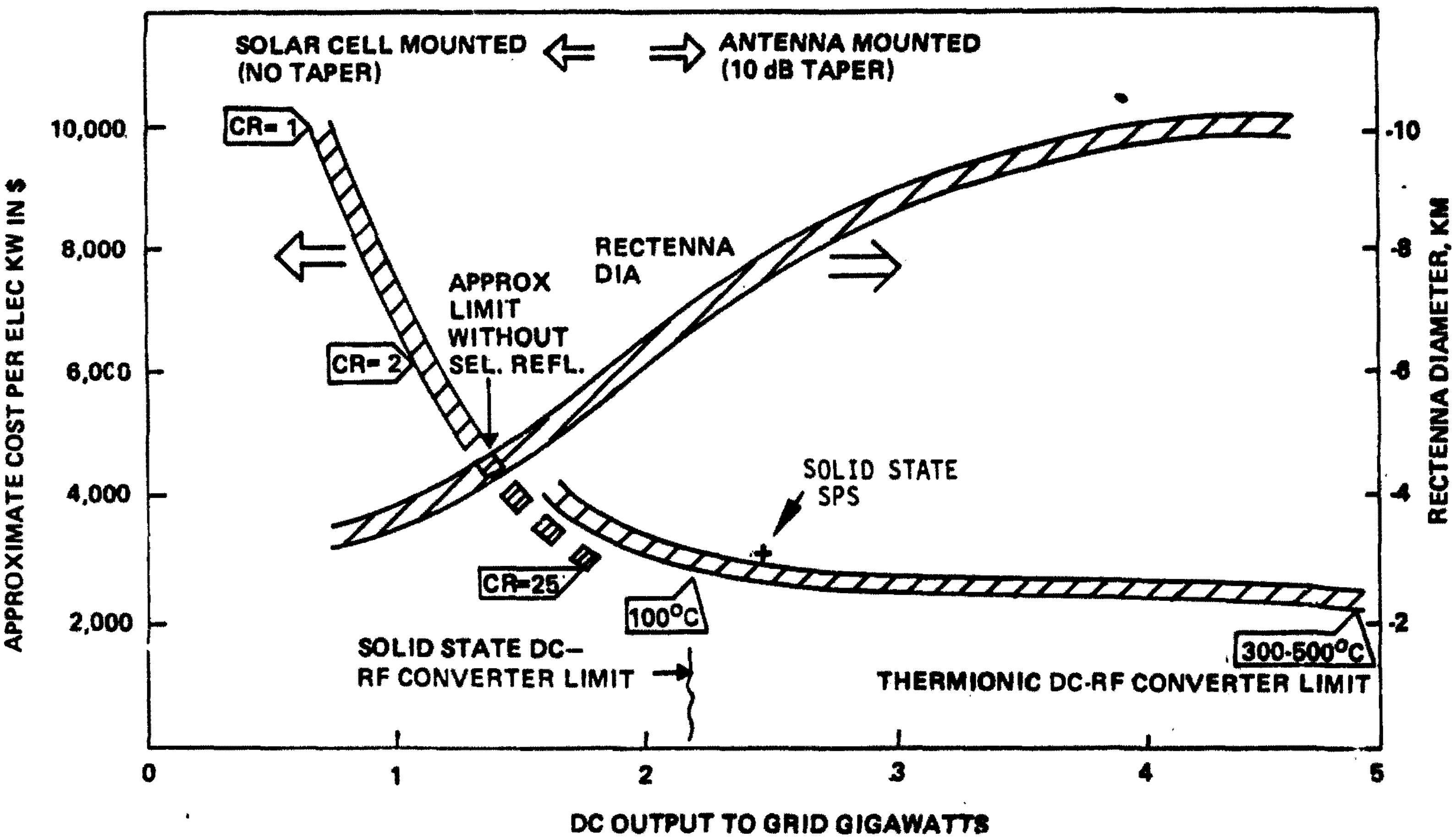
RF CONVERTER →	ANTENNA MOUNTED		SOLAR CELL MOUNTED (CONCENTRATION RATIO = 3)	
SPS DESIGN ↓			OPTICAL REFLECTOR 	RF REFLECTOR 
	KLYSTRON OR CFA	SOLID STATE	SOLID STATE	SOLID STATE
POWER OUTPUT TO GRID	5 GW	2 GW	0.7 GW	0.2 GW per km^2 SOLAR CELLS
SPACE ANTENNA DIAMETER	1 km	1.5 km	2.7 km	HIGH POWER WAVEGUIDE
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

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

SPS-2695



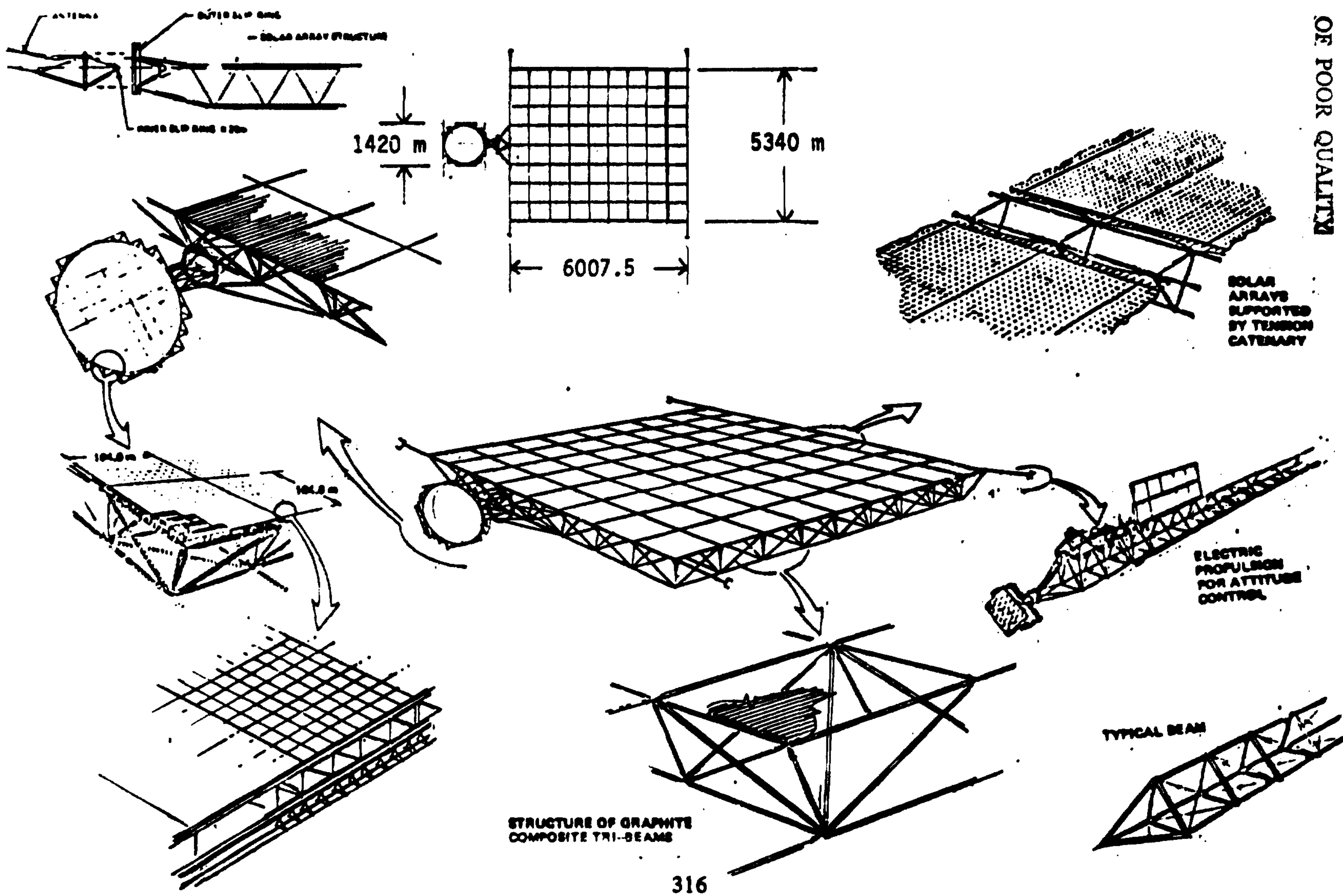
2.5 GW SOLID STATE SPS CONFIGURATION

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

SPS-3342

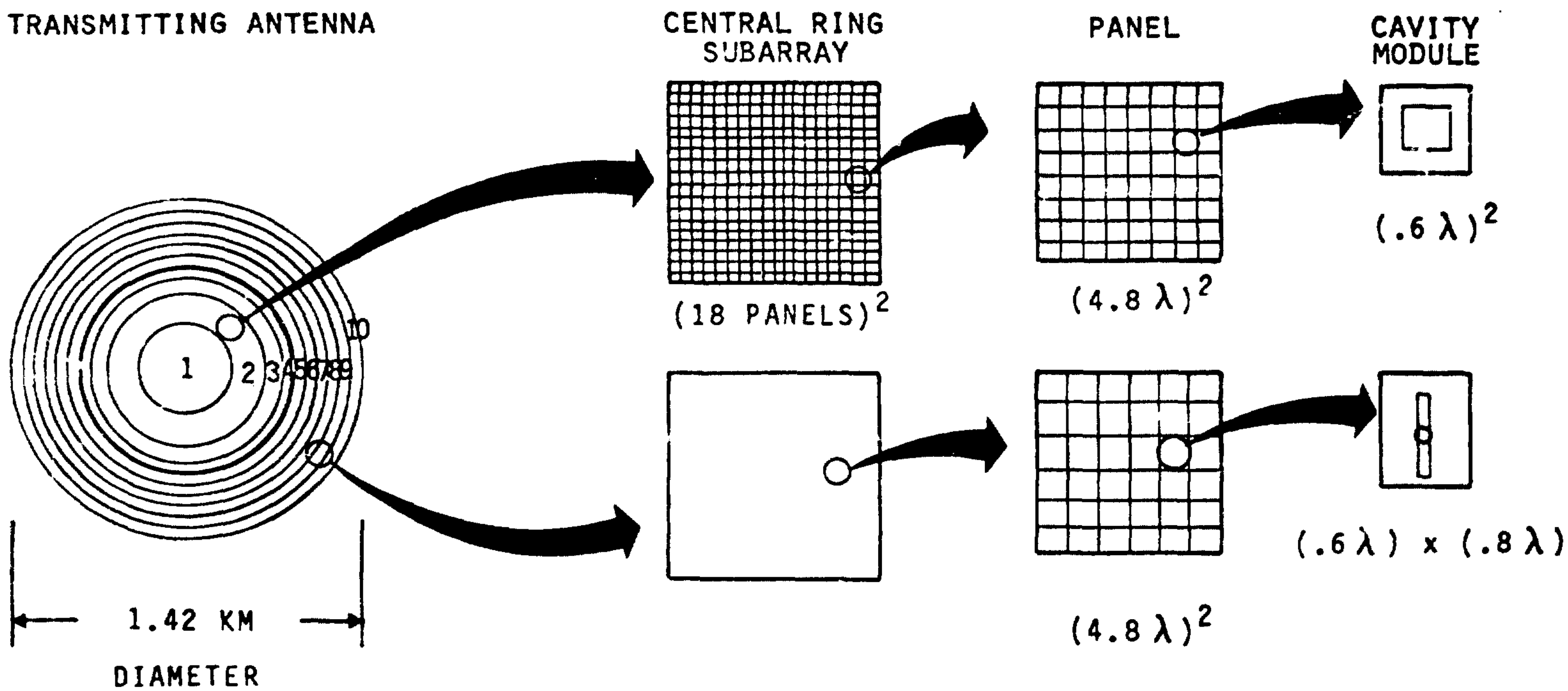
BOEING



SOLID STATE TRANSMITTING ANTENNA QUANTIZATION HIERARCHY

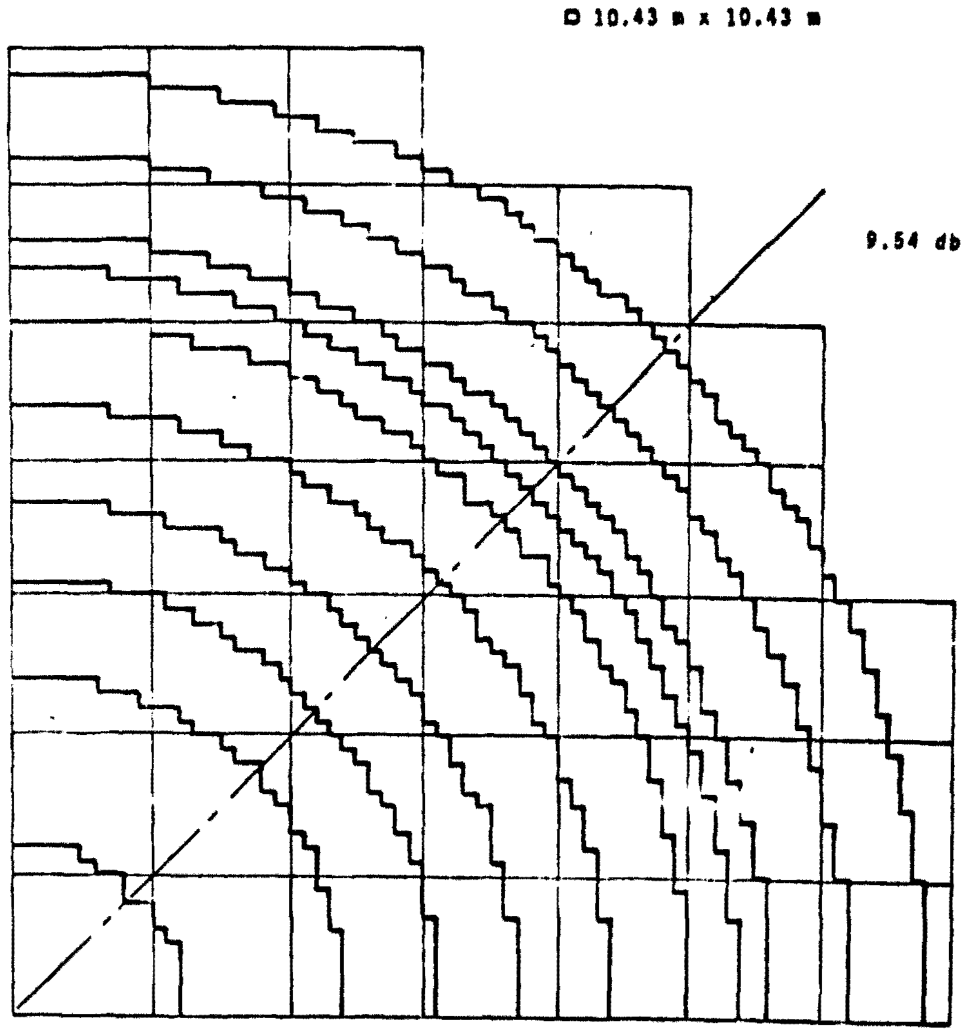
The hierarchical organization of the transmitter from the entire array down to the solid-state radiator unit is illustrated in this figure. Subarrays are somewhat arbitrarily sized at 10 X 10 metres. Panels are sized at slightly less than 5 wavelengths in order to facillitate phase distribution. The panel size is selected on the basis of judgment as to the degree to which open loop phase distribution can be used. Finally, the individual radiator modules are sized to be .6 of a wavelength square. The high power regions on the transmitter use a cavity module which has excellent heat rejection capability. The low power elements of the transmitter use a dipole type radiator which has a much lower mass per unit area.

SOLID STATE TRANSMITTING ANTENNA QUANTIZATION HIEARCHY



2.5 GW SOLID STATE SPS TRANSMITTING ANTENNA

The quantization of the 9.54 db gaussian taper is shown here.


D 10.43 m x 10.43 m
9.54 db GAUSSIAN STEP QUANTIZATION

SOLID STATE TRANSMITTING ANTENNA QUANTIZATION

The solid state transmitter is quantized into a 10 step approximation of a 10 dB Gaussian taper much like the reference system. The table on the facing page summarizes the quantization and summarizes the mass estimate for the transmitter.

TABLE III. SOLID STATE TRANSMITTING ANTENNA QUANTIZATION

SPS-3292

STEP	NUMBER OF SUBARRAYS	MODULE TYPE	MODULE POWER (W)	$(P/A)_{RF}$ (kWm^{-2})	RADIATED STEP POWER (MW)	STEP MASS (T)
1	472	High Power 4-FET, Cavity Radiator (6.73 kgm^{-2})	28.7	5.50	282.4	345.6
2	1392	"	24.0	4.45	673.9	1019.1
3	1208	Reduced Power 4-FET Cavity Radiator (6.46 kgm^{-2})	19.2	3.56	467.8	848.9
4	1296	"	16.0	2.97	418.7	910.8
5	1764	2-FET Cavity Radiator (5.50 kgm^{-2})	12.8	2.37	455	1055.4
6	1860	2-FET Dipole (2.69 kgm^{-2})	12.8	1.78	360.2	544.3
7	1136	"	9.6	1.33	164.4	332.4
8	840	"	8.5	1.18	107.8	245.8
9	2208	1-FET Dipole (2.06 kgm^{-2})	6.4	.89	213.8	646.1
10	2476	"	4.3	.59	158.9	724.6
TOTALS	14652					6673.0

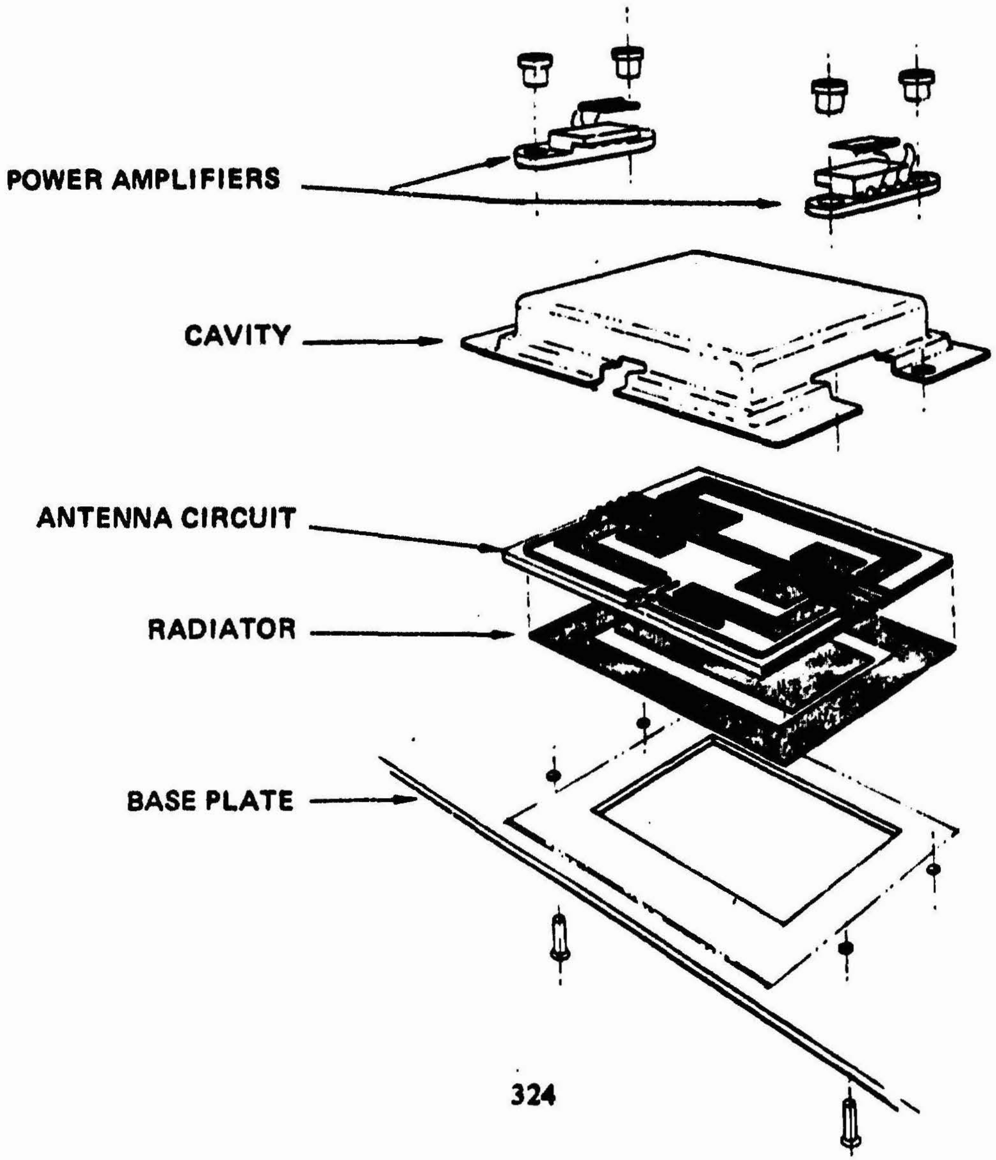
SOLID STATE COMBINER RADIATOR MODULE

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 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



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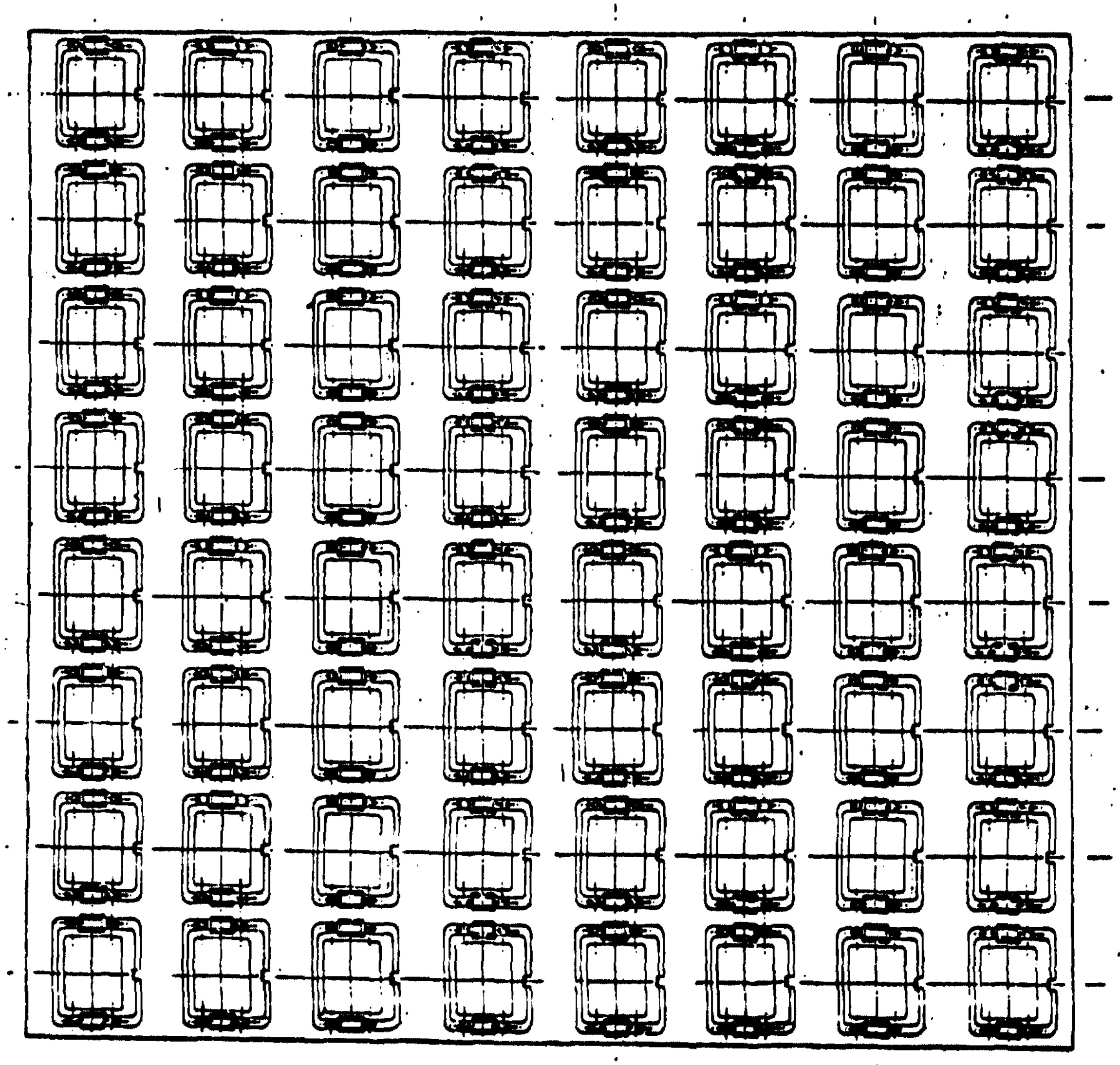
64 MODULE PANEL LAYOUT

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

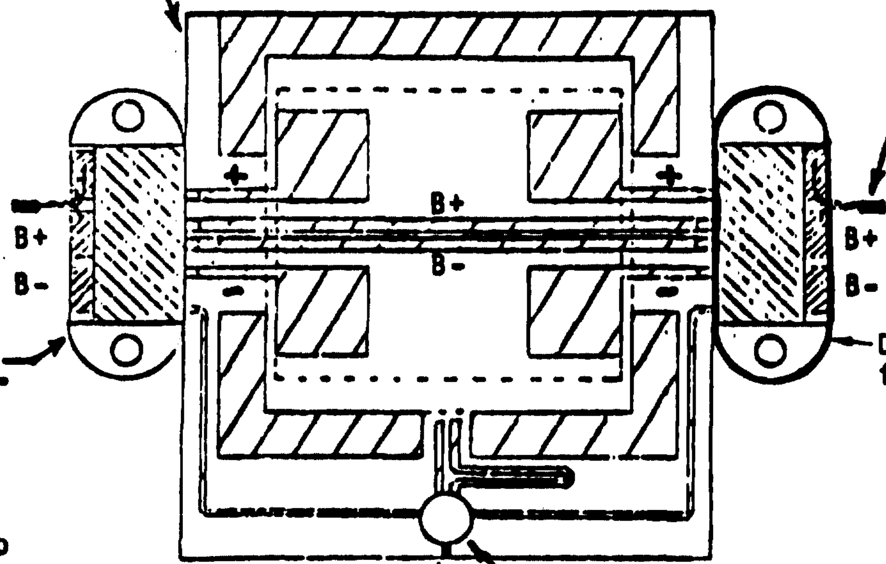


SOLID STATE POWER MODULE CONCEPT

The high power solid state cavity radiator power module is illustrated. Push/pull gallium arsenide FET power modules drive the radiator module through four coupling patches in the cavity. These couple to a radiating element which in turn drives the cavity slots.

SOLID-STATE POWER MODULE CONCEPT

RADIATING ELEMENT POWER COMBINING
- Antenna exciters (4)
- Low loss combining
- Ceramic substrate
- Metallized both sides (thick film)



FAIL SAFE FEATURES
- Open circuit protection
- Heat radiated to space

DC float allows standoff for series-parallel chain

GaAs FET POWER MODULE
- 30 dB gain
- 10 watts output
- Hybrid technology
- Sapphire, microstrip

INPUT (2450 MHz @ 1 mw)

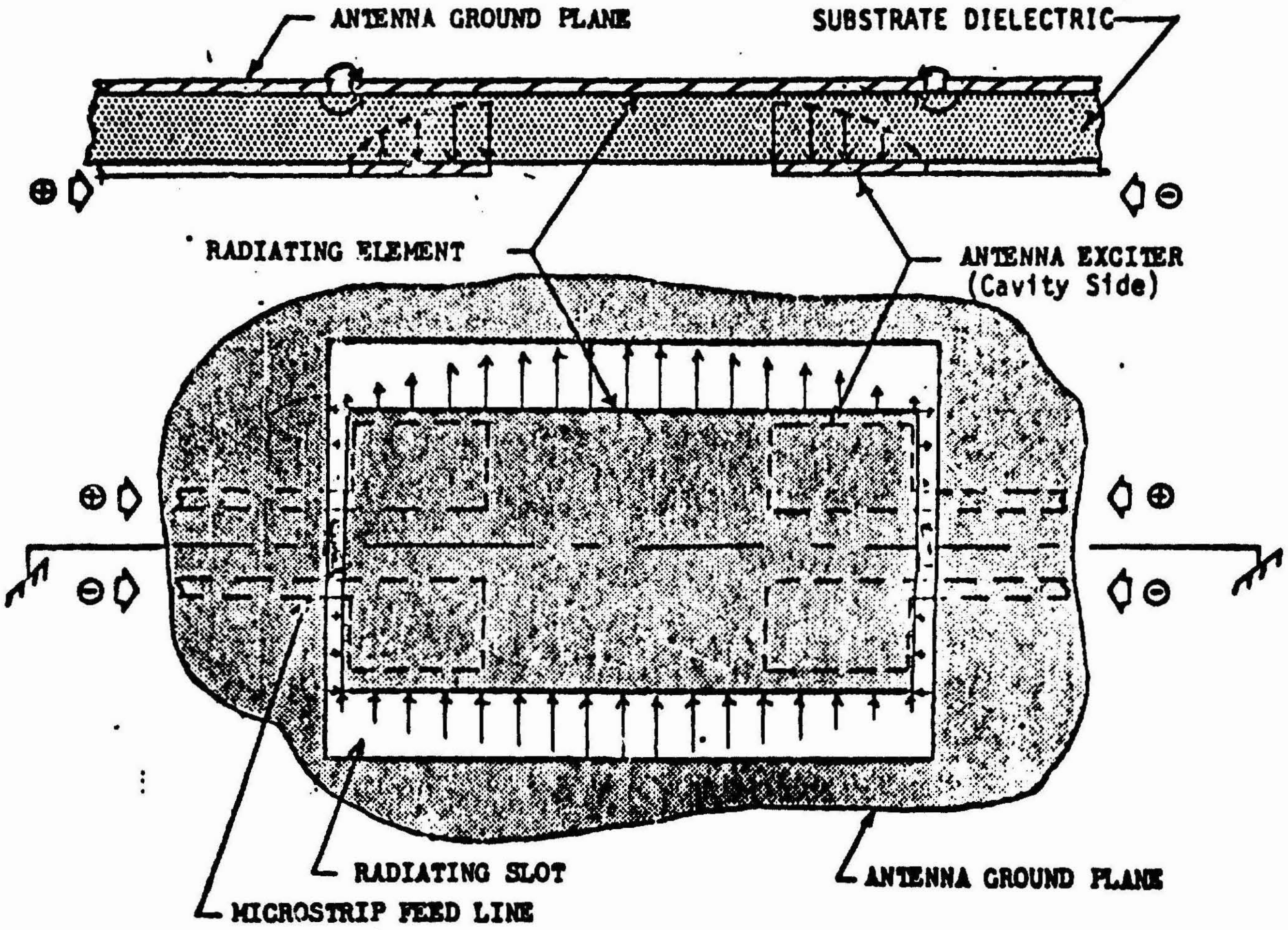
PHASE ERROR CORRECTION
- Printed cavity coupling probes
- Single GaAs chip integrated circuit
  - Phase detector
  - Low pass filter
  - Phase shifter
  - 2450 MHz amplifier

FOUR FEED POWER COMBINING MICROSTRIP ANTENNA

The electric field patterns inside the cavity radiator module are shown.

FOUR FEED POWER COMBINING MICROSTRIP ANTENNA

SPS-3390



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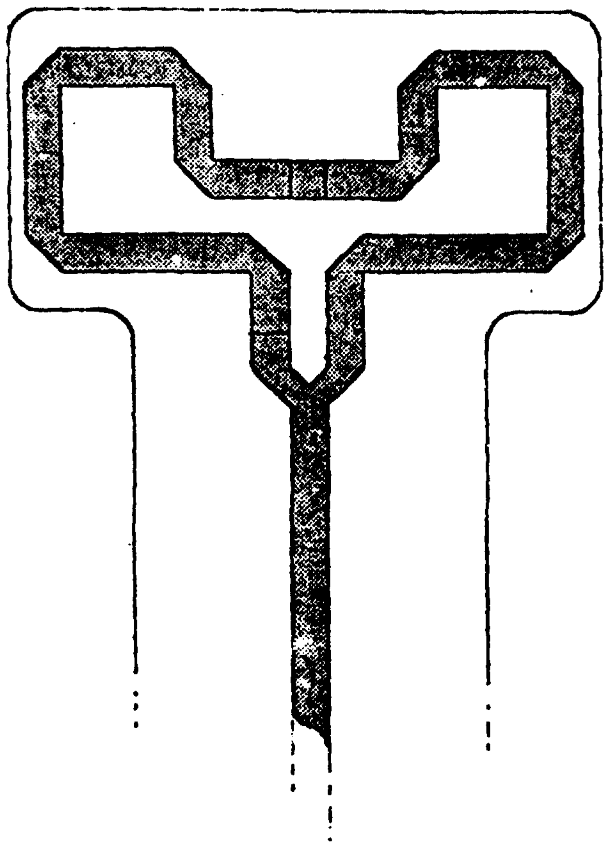
BOTTOM VIEW OF PHASE DISTRIBUTION NETWORK COUPLING LOOPS

A key aspect of the Phase III cavity radiator module design is the coupling of the microwave signals across the approximately ± 4 kilovolt supply potentials. This is to be done with stripline coupling loops such as those shown here.

BOTTOM VIEW OF PHASE DISTRIBUTION NETWORK COUPLING LOOPS



SOLID STATE CAVITY RADIATOR MODULE-EXPLODED VIEW

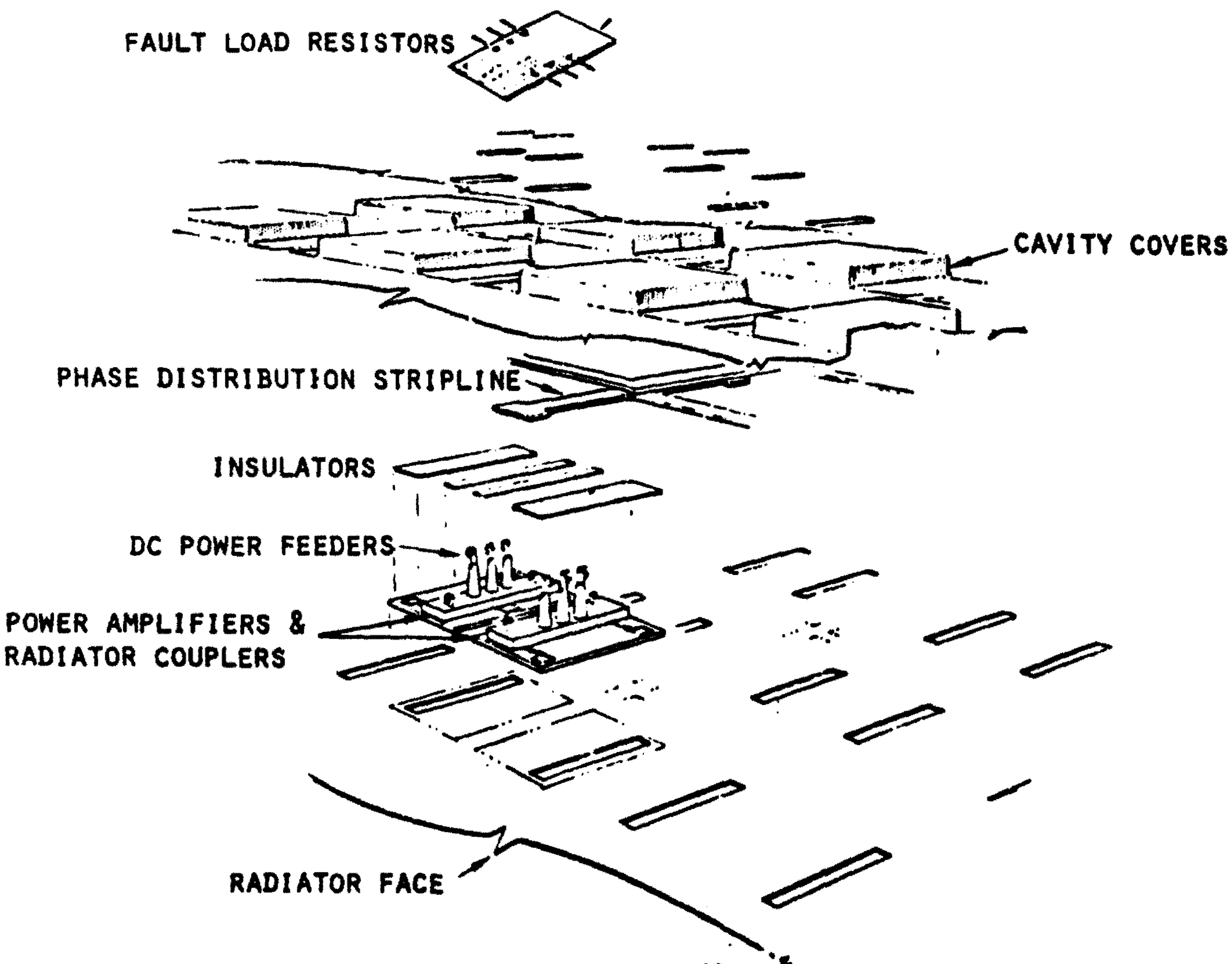
This exploded view of a cavity radiator antenna panel illustrates the sequence to the word for automated construction. Starting with the radiator face sheet at the bottom, the interior components are added layer by layer and covered with the cavity cover sheet. The last step is the adding of fault load resistor panels which are crimped to the dc power feeders that stand off through the cavity covers.

SPS

SPS-3287

SOLID STATE CAVITY RADIATOR MODULE - EXPLODED VIEW

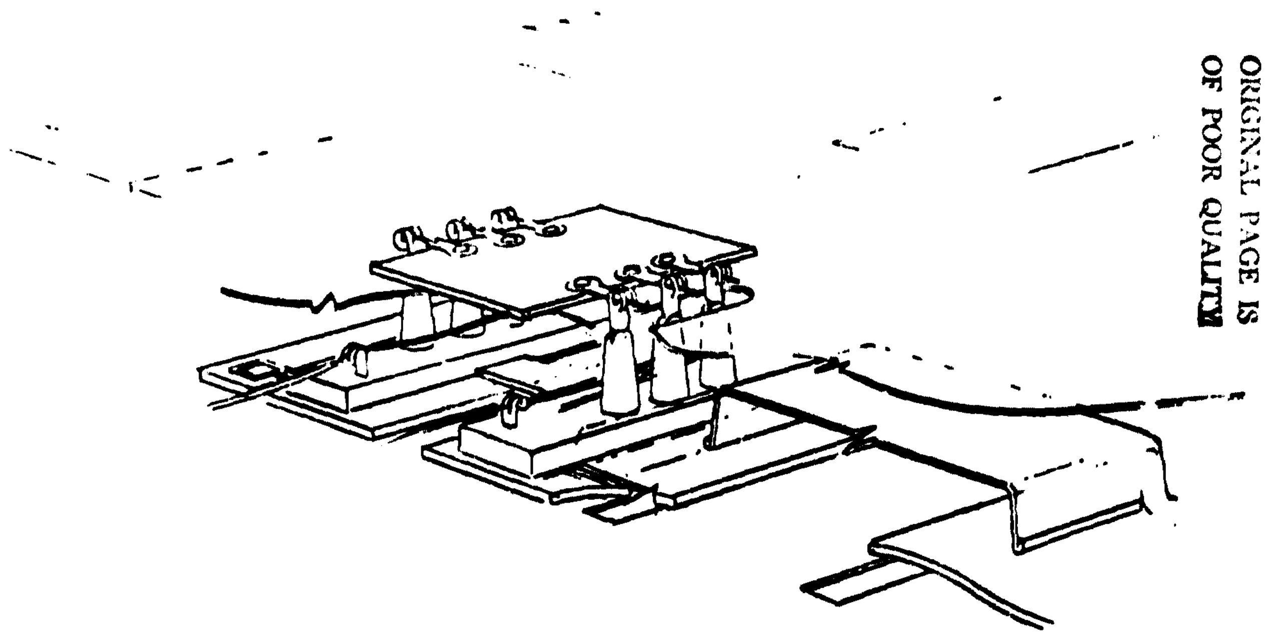
BOEING



FAULT LOAD RESISTOR CONFIGURATION

The fault load resistors are to dissipate a module's nominal power in case of module open circuiting. The resistors are fabricated by printed circuit methods on a ceramic substrate that it held behind the panel back surface by standoffs that protrude through the cavity covers.

FAULT LOAD RESISTOR CONFIGURATION

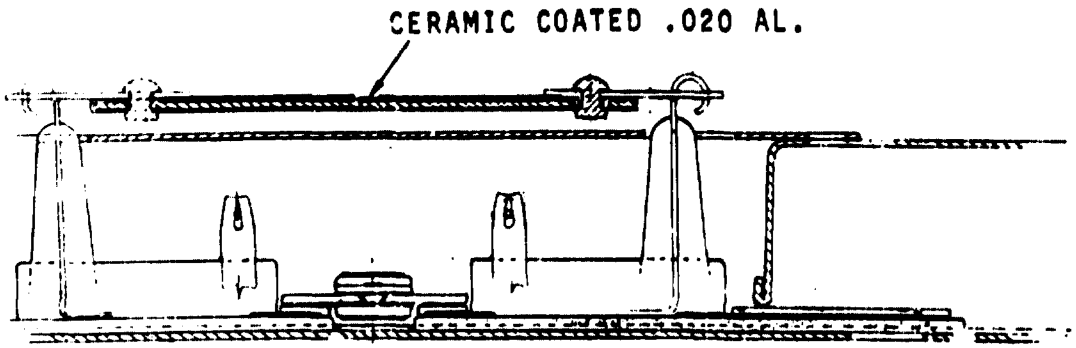


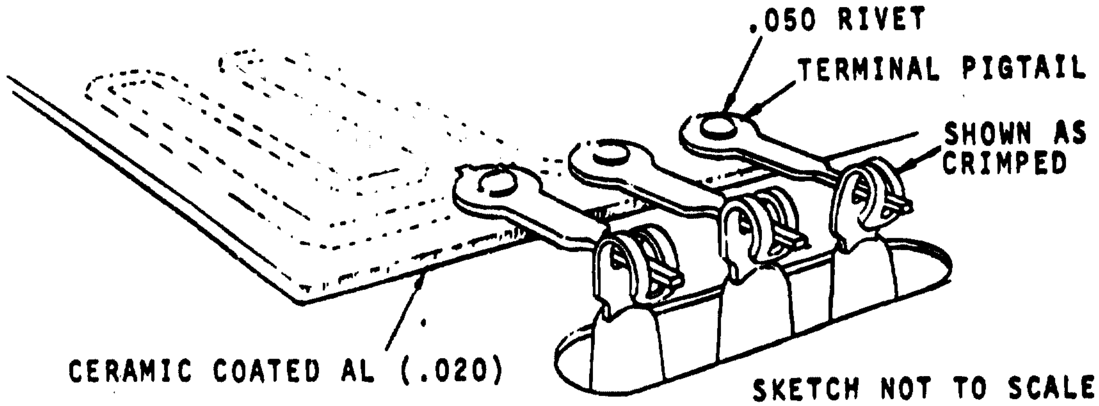
POWER HOOKUP DETAILS

The configuration and crimping scheme for the fault load resistors is shown.

POWER HOOKUP DETAILS

SPS-3348





MASS STATEMENT - HIGH POWER DENSITY FOUR-FET SOLID STATE CAVITY RADIATOR

The facing page presents a mass estimating rationale for arriving at the mass density for the high power section of the solid state transmitter.

MASS STATEMENT: HIGH POWER DENSITY 4-FET SOLID STATE CAVITY RADIATOR COMBINING MODULE DESIGN

ITEM	COMMENTS		MASS (g)
FACE SHEET	$.6\lambda \times .6\lambda \times .010'' \times \rho_{Al}$	=	3.70
BeO SUBSTRATE	$.5\lambda \times .5\lambda \times .040'' \times \rho_{BeO}$	=	7.61
POLYSULFONE INSULATION	$2 \times .5\lambda \times .1\lambda \times .015'' \times \rho_{PS}$	=	1.14
AMPLIFIER MODULE (W. FAULT LOAD TOWERS)	$2 \times .003\ m \times .1\lambda \times .2 \times (3000\ kgm^{-3})$	=	5.39
SHIELD CAN	$.6\lambda \times .6\lambda \times .020'' \times \rho_{Al}$	=	7.40
TOP SHEET AND FAULT LOAD RESISTOR	$.6\lambda \times .3\lambda \times .01'' \times \rho_{Al}$	=	1.85
PHASE DISTRIBUTION STRIPLINE	$.1\lambda \times .6\lambda \times .020'' \times \rho_{Al}$	=	1.23
MODULE TOTAL			28.32 g = 5.25 kg/m^2
X 64			1.81 kg
PANEL STRUCTURE			.20 kg
PANEL TOTAL			2.01 kg
X 324			651.2 kg
SUBARRAY STRUCTURE			68.3 kg
SUBARRAY ELECTRONICS			12.0 kg
SUBARRAY TOTAL			731.5 kg = 6.73 kg/m^2

MASS STATEMENT - REDUCED POWER DENSITY FOR FET CAVITY RADIATOR MODULE DESIGN

The facing page presents the mass estimating rationale for a reduced power density cavity radiator where some mass reduction can be accommodated in view of reduced thermal loading.

MASS STATEMENT: REDUCED POWER DENSITY 4-FET CAVITY RADIATOR MODULE DESIGN

ITEM	COMMENTS		MASS (g)
FACE SHEET	$.6\lambda \times .6\lambda \times .0075" \times \rho_{Al}$	=	2.78
BeO SUBSTRATE	$.5\lambda \times .5\lambda \times .040" \times \rho_{BeO}$	=	7.61
POLYSULFONE INSULATION	$2 \times .5\lambda \times .1\lambda \times .015" \times \rho_{PS}$	=	1.14
AMPLIFIER MODULES (W. FAULT LOAD TOWERS)	$2 \times .003\ m \times .1\lambda \times .2\lambda \times (3000\ kgm^{-3})$	=	5.39
SHIELD CAN	$.6\lambda \times .6\lambda \times .020" \times \rho_{Al}$	=	7.40
TOP SHEET AND FAULT LOAD RESISTOR	$.6\lambda \times .3\lambda \times .0075" \times \rho_{Al}$	=	1.39
PHASE DISTRIBUTION STRIPLINE	$.1\lambda \times .6\lambda \times .020" \times \rho_{Al}$	=	1.23
MODULE TOTAL			26.94 g = 5.00 kg/m^2
X 64			1.72 kg
PANEL STRUCTURE			.20 kg
PANEL TOTAL			1.92 kg
X 324			622.1 kg
SUBARRAY STRUCTURE			68.3 kg
SUBARRAY ELECTRONICS			12.0 kg
SUBARRAY TOTAL			702.4 kg = 6.46 kg/m^2

MASS STATEMENT - TWO FET SOLID STATE CAVITY RADIATOR MODULE DESIGN

Further mass reduction is possible as one moves outward from the center of the transmitter and is able to employ a cavity radiator using only two FET's. The rationale is presented on the facing page.

[illegible]

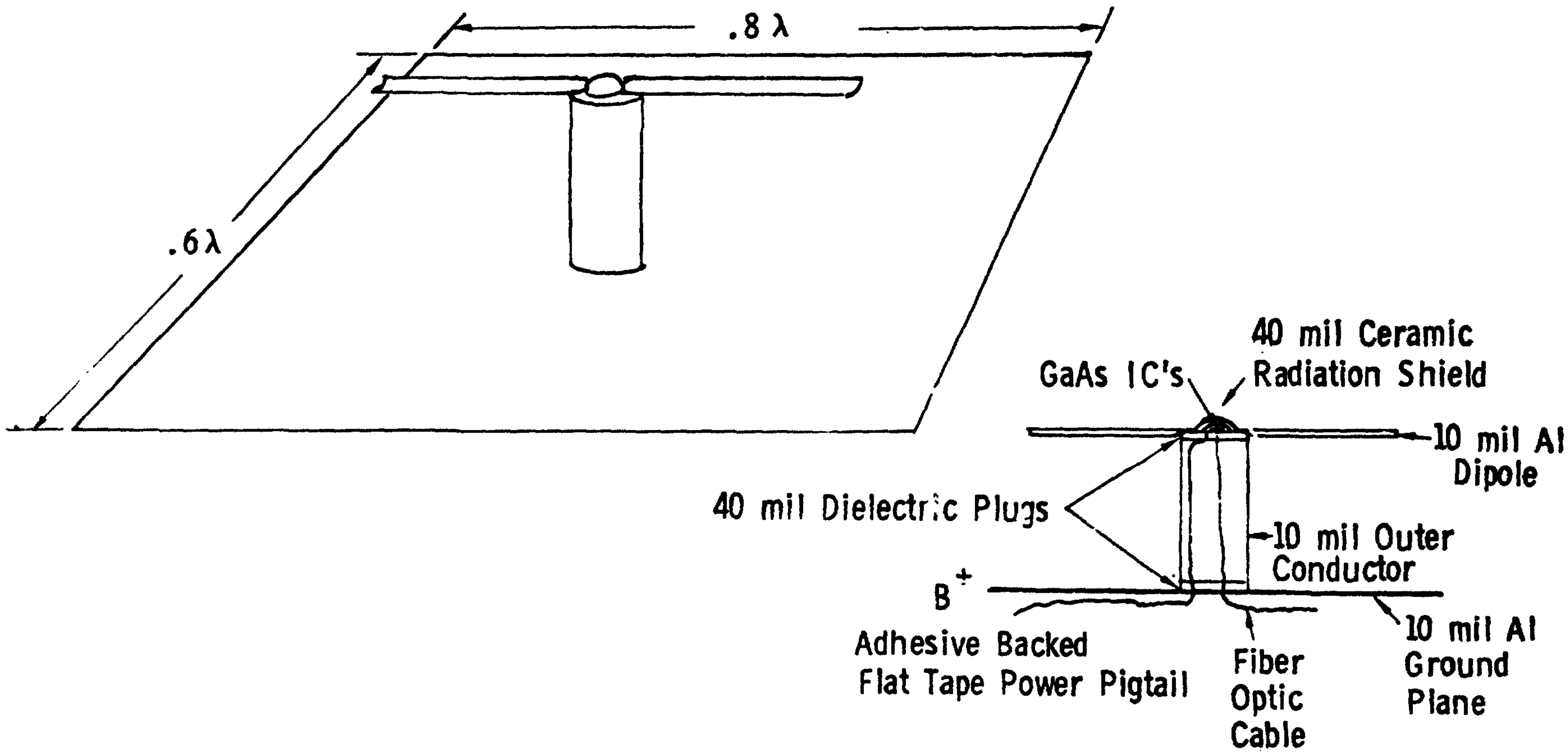
MASS STATEMENT: [illegible]-FET SOLID STATE CAVITY RADIATOR MODULE DESIGN

ITEM	COMMENTS	MASS (g)
FACE SHEET	[illegible] x [illegible] x [illegible]" x ρ_{Al}	= [illegible]
BeO SUBSTRATE	[illegible] x [illegible] x [illegible]" x ρ_{BeO}	= [illegible]
POLYSULFONE INSULATION	[illegible] x [illegible] x [illegible] x [illegible]" x ρ_{PS}	= [illegible]
AMPLIFIER MODULES (W. FAULT LOAD TOWERS)	[illegible] x [illegible] x [illegible] x [illegible] ([illegible] kg m^{-3})	= [illegible]
SHIELD CAN	[illegible] x [illegible] x [illegible]" x ρ_{Al}	= [illegible]
TOP SHEET AND FAULT LOAD RESISTOR	[illegible] x [illegible] x [illegible]" x ρ_{Al}	= [illegible]
PHASE DISTRIBUTION STRIPLINE	[illegible] x [illegible] x [illegible]" x ρ_{Al}	= [illegible]
MODULE TOTAL		[illegible] g = [illegible] kg/m^2
x 64		[illegible] kg
PANEL STRUCTURE		[illegible] kg
PANEL TOTAL		[illegible] kg
x 324		[illegible] kg
SUBARRAY STRUCTURE		[illegible] kg
SUBARRAY ELECTRONICS		[illegible] kg
SUBARRAY TOTAL		[illegible] kg = [illegible] kg/m^2

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 (.6λ x .8λ instead of .6λ x .6λ).

SOLID STATE DIPOLE RADIATOR MODULE



DIPOLE RADIATOR MODULE MASS STATEMENT

Dipole radiator modules have a mass per unit area of 2.7 Kgm^{-2}. Over two thirds of this mass is aluminum and much of the rest is dielectric.

DIPOLE RADIATOR MODULE MASS STATEMENT

$.6\lambda \times .8\lambda$ MODULE SIZE

ITEM	MASS	
10 MIL Al GROUND PLANE	4.93 g	
CERAMIC SHIELD	.7 g	
DIPOLE AND SUPPORT, 10 MIL Al	3.75 g	
DIELECTRIC PLUG(S)	2.8 g	
CHIPS, METALLIZATIONS, BONDING, ETC.	.5 g	
TOTAL MODULE	12.68 g	= 1.76 kgm^{-2}
X 48	608.6 g	
PANEL STRUCTURE	150.0 g	
TOTAL PANEL	758.6 g	
X 324	245.8 kg	
SUBARRAY STRUCTURE	35.0 kg	
SUBARRAY ELECTRONICS	12.0 kg	
SUBARRAY TOTAL	292.8 kg	= 2.69 kgm^{-2}

DRIVING RESISTANCE IN AN INFINITE ARRAY

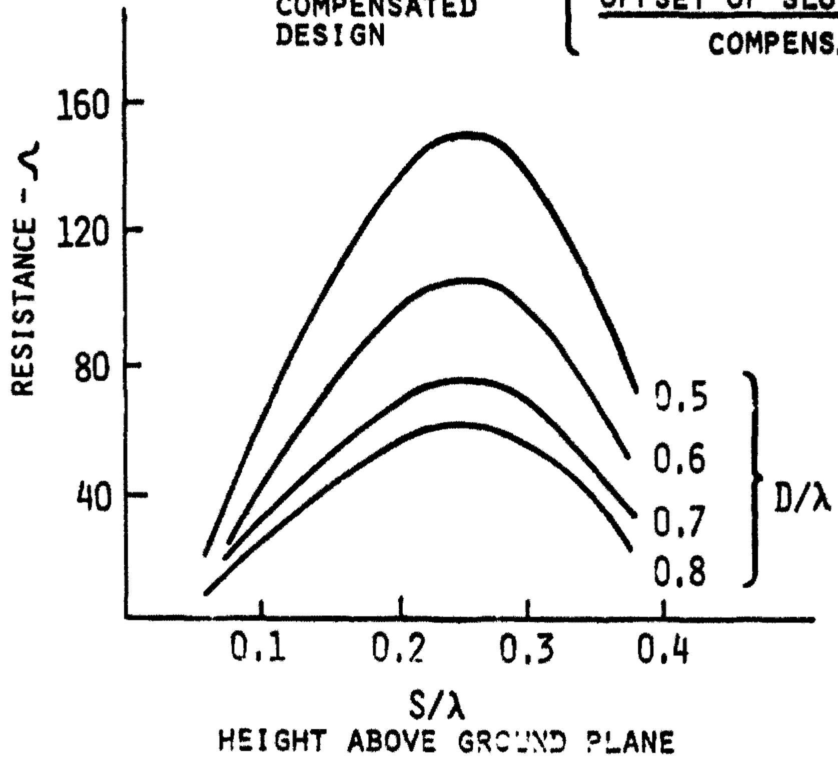
Dipole radiator antenna arrays of the type desired for the solid state SPS are well understood. The effective resistance that the dipole presents to the power amplifier may be varied to match the amplifier by changing the dipole standoff distance and spacing.

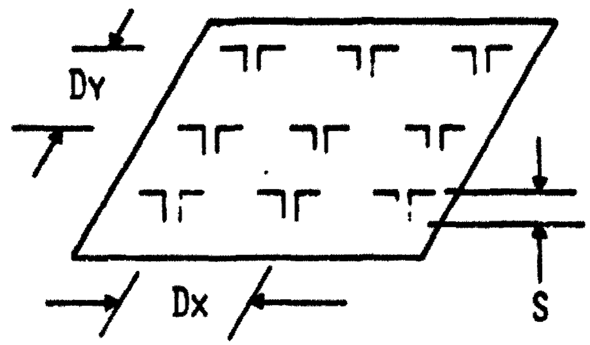
DRIVING RESISTANCE IN INFINITE ARRAY

SPS-3394

IN A VARIABLE SPACING DESIGN OR EDGE EFFECT COMPENSATED DESIGN

- LENGTH OF SLOT
  COMPENSATES FOR VARIABLE REACTANCE
- OFFSET OF SLOT
  COMPENSATES FOR VARIABLE RESISTANCE





$$R = \frac{120}{\pi} \frac{\sin^2(2\pi\ 2/\lambda)}{D_X D_Y}$$

Ref.

L. Stark
Hughes Tech. Doc. FL60-230
May '60

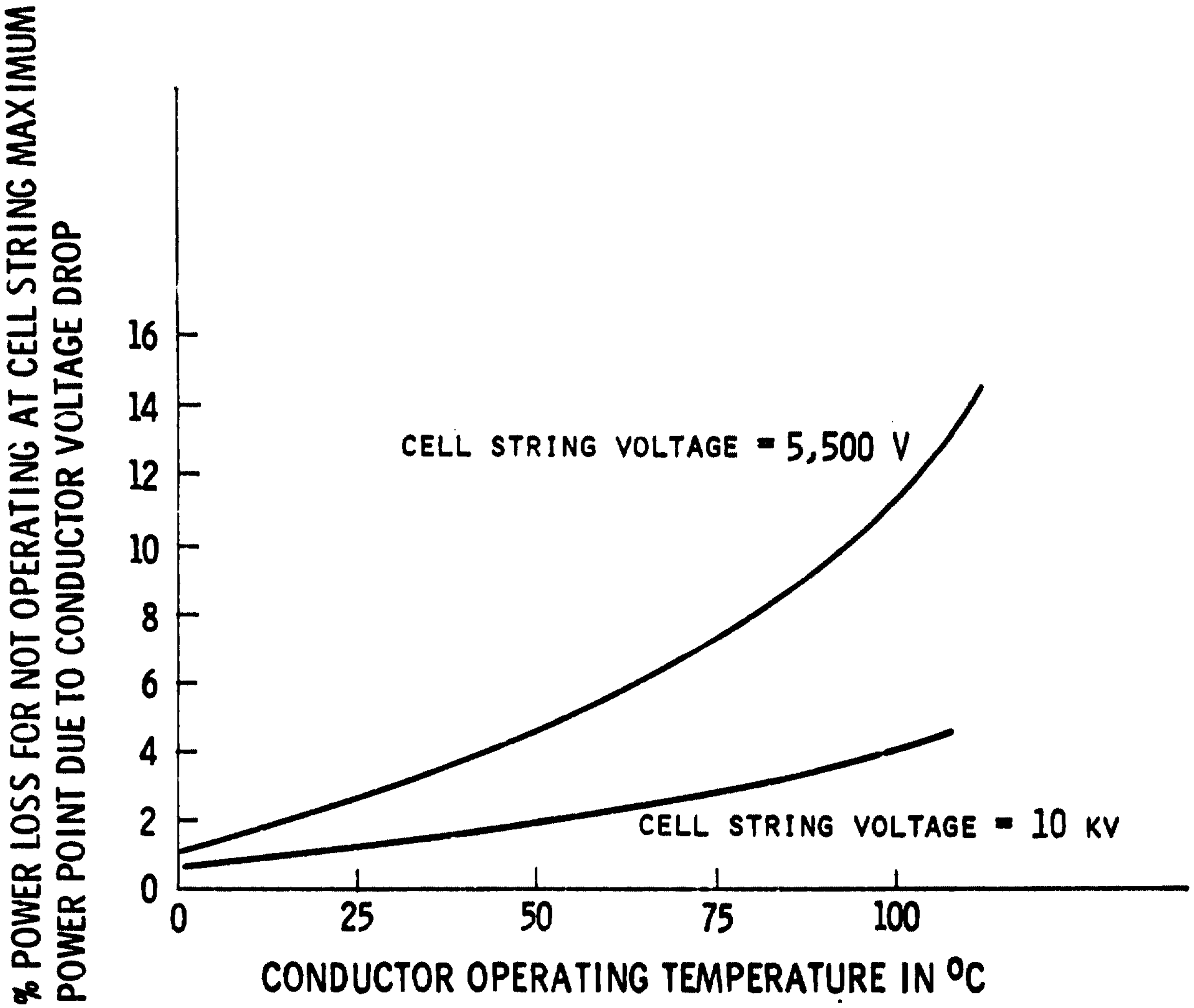
ARRAY MISMATCH LOSSES

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.

SPS-3137

ARRAY MISMATCH LOSSES AS A FUNCTION OF TEMPERATURE

2.5 GW SOLID STATE SPS CONFIGURATION

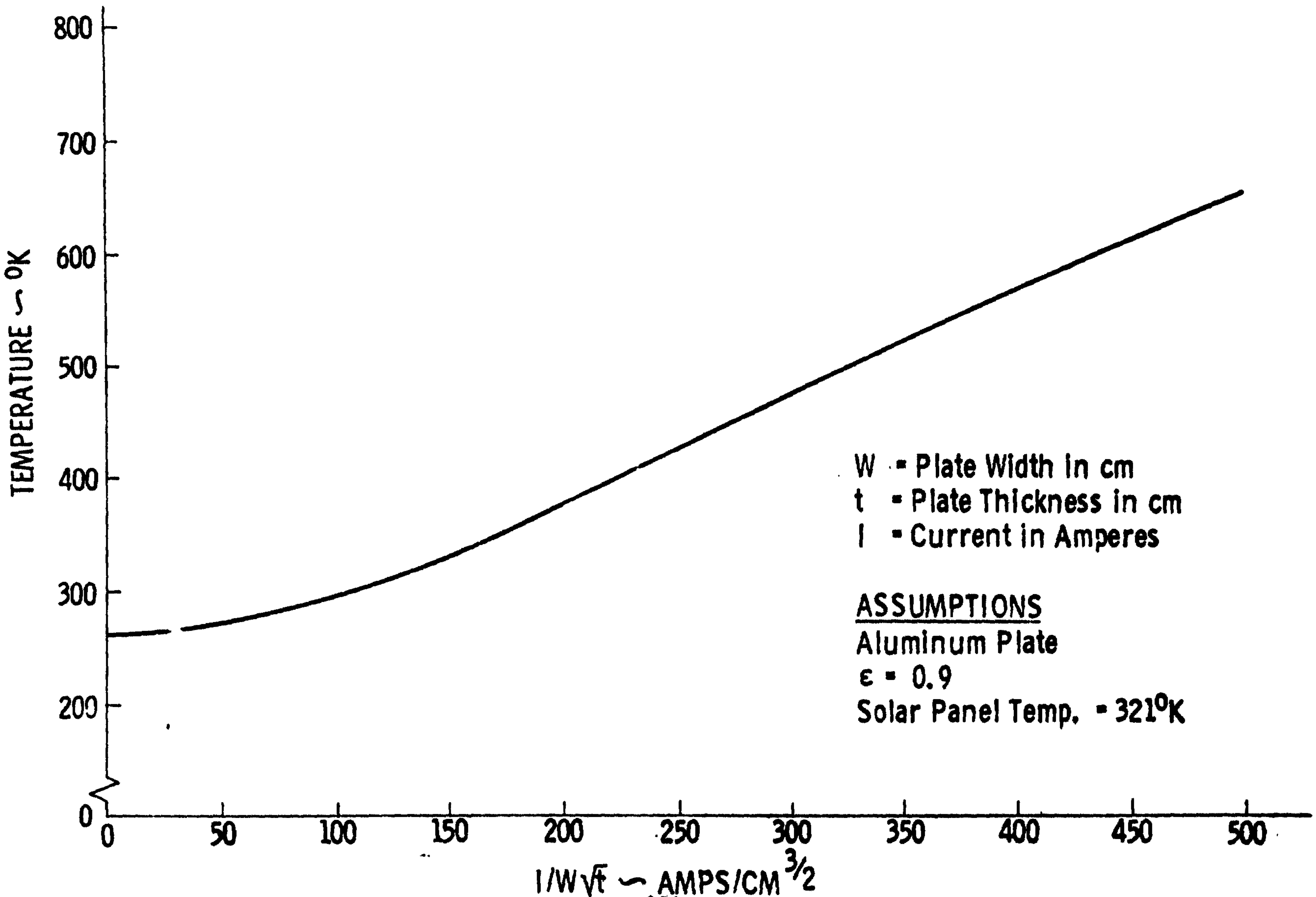


POWER BUS SIZING

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

SPS-3140

POWER BUS SIZING



PHASE III SOLID STATE SPS POWER DISTRIBUTION SYSTEM PARAMETERS

The data on the facing page summarize a tradeoff of power distrubtion parameters as a function of power distribution conductor temperatures. Unlike earlier tradeoffs of this nature, the tradeoff illustrated here emphasizes minimizing cost rather than minimizing mass.

TABLE I. REVISED SOLID STATE SPS POWER DISTRIBUTION SYSTEM PARAMETERS AS A FUNCTION OF TEMPERATURE

. Subarray Voltage = 8640 V
. Subarray Power = 4200 MW

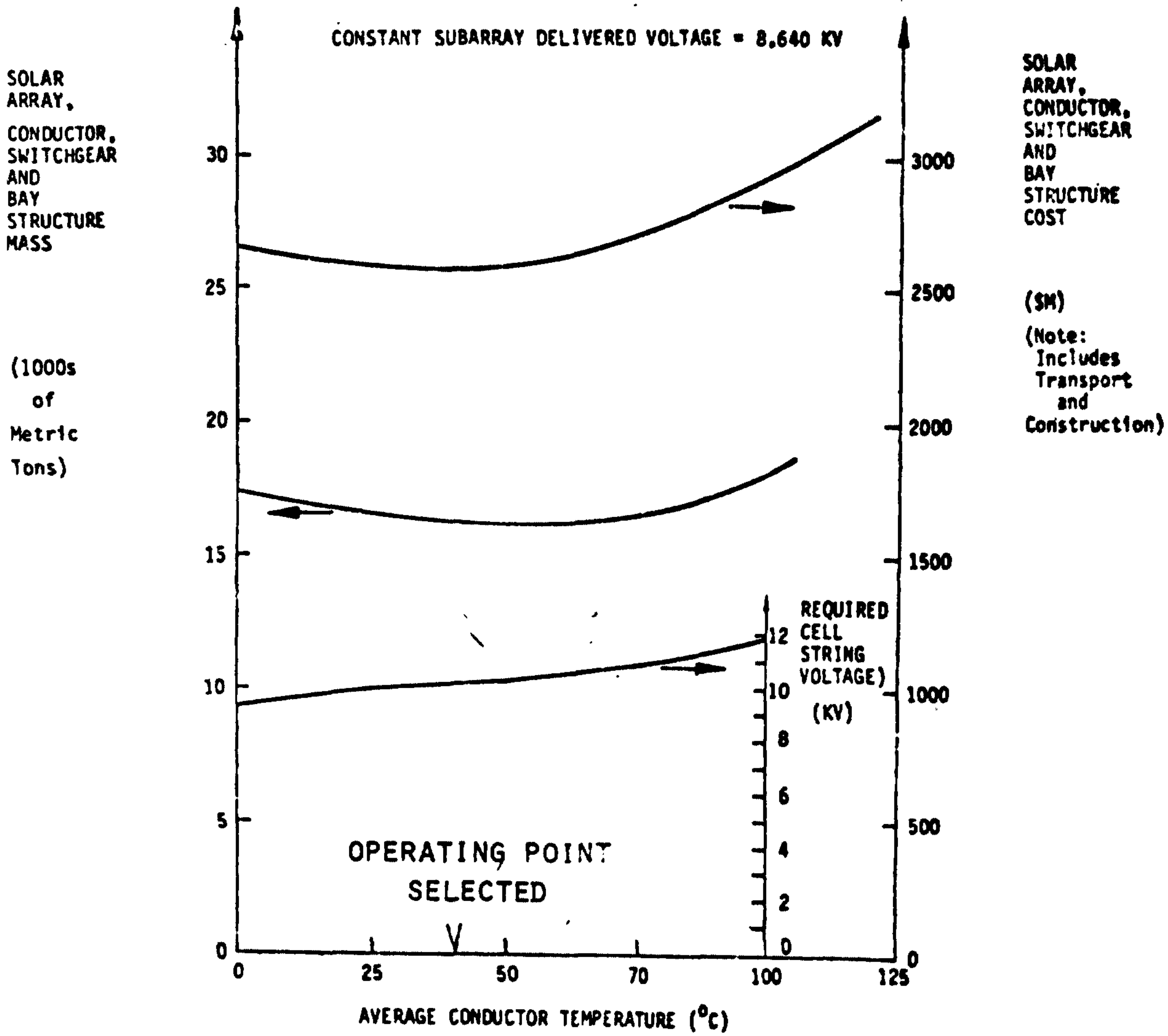
	MASS/COST (Metric Tons/$M)				POWER LOSS (Megawatts)			
Conductor Temperature (^{o}C)	0	25	50	100	0	25	50	100
Non-P_{max} Power Loss	-	-	-	-	56.1	84.1	112.6	302.0
Power Busses ($37 kg^{-1})	4517.4/167.2	2630.6/97.3	1997.5/73.9	1585.2/59.3	251.6	522.4	642.5	1245.1
Array Power (Megawatts)	4507.9	4806.5	4955.1	5747.1	307.7	606.5	755.1	1547.1
Array Area (km^2 @ 179 w m^{-2}	25.00	26.85	27.68	32.11				
Array Mass/Cost .425 kg m^{-2}, $40 m^{-2}	10683.3/1005.5	11412.0/1074.1	11764.9/1107.2	13645.3/1284.3				
Switchgear (.0273 kg mw^{-1}; 6.53 $ kw^{-1})	123.1/29.4	126.8/31.4	125.2/32.4	133.3/37.5				
Number of Bays (Smeared @ 69.34 MW/Bay)	65.0	69.3	71.5	82.9				
Bay Structural Mass/Cost (Smeared @ 32.3 T/Bay, 66$ kg^{-1})	2097.2/138.5	2240.5/147.9	2309.2/152.4	2678.6/176.8				
Total Mass/Component Cost	17421.0/1340.6	16409.9/1350.7	16196.8/1365.9	18042.4/1557.9				
Transportation & Constr. Cost ($75 kg^{-1})	1306.6	1230.7	1214.8	1353.1				
Total Cost Involved in Tradeoff	2647.2	2980.4	2580.7	2911.0				
Cell String Voltage (V)	9273	9888	10193	11823				

COST AND MASS VERSUS CONDUCTOR TEMPERATURE TRADE FOR SOLID STATE SPS

Results of the conductor temperature tradeoff are shown on the facing page. The cost tends to minimize the slightly lower temperatures than the mass as solid state conductors are less expensive than solar arrays. The selected operating point was 35°C.

COST AND MASS vs. CONDUCTOR TEMPERATURE TRADE FOR SOLID STATE SPS

SPS-3285

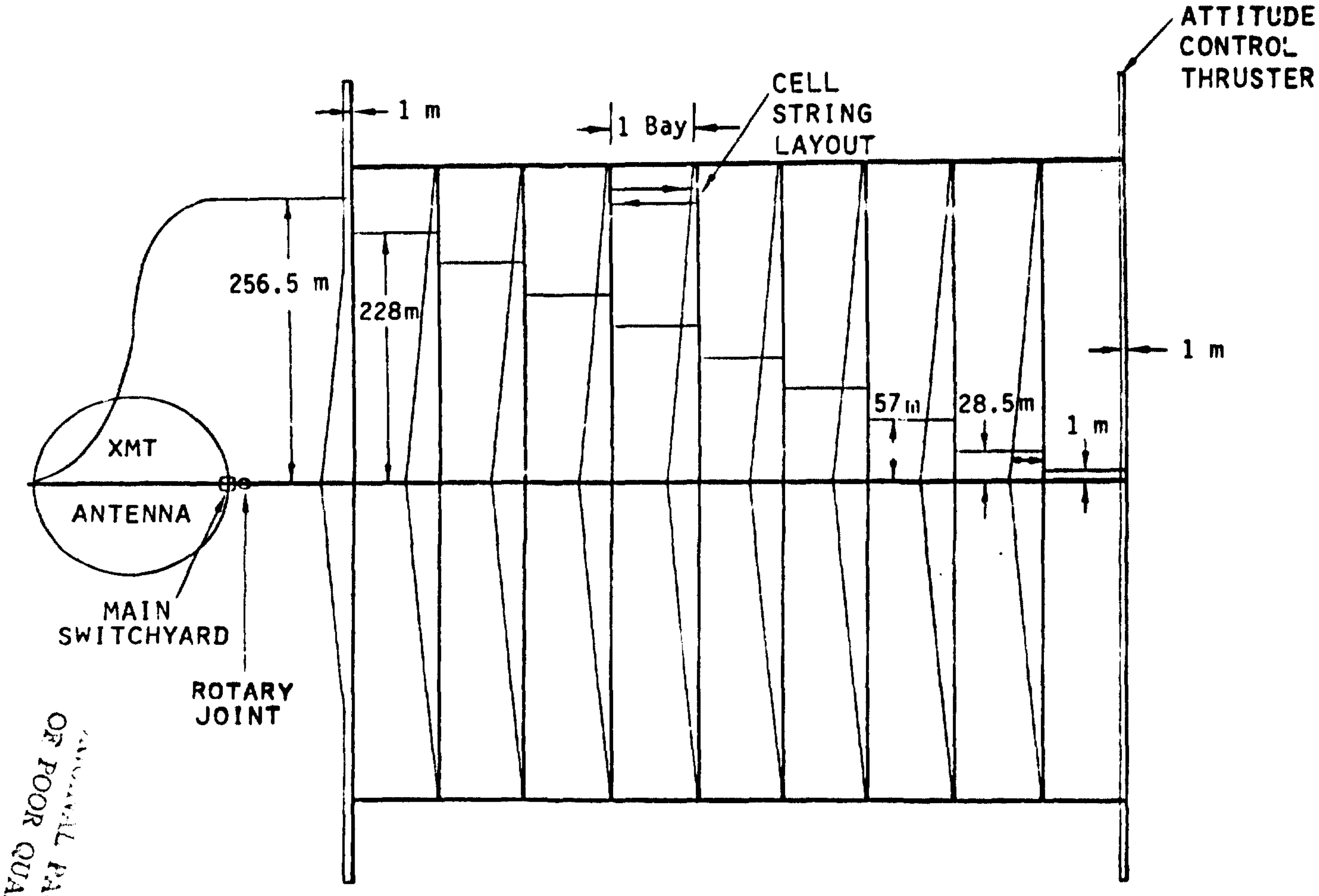


2.5 GIGAWATT SOLID STATE SPS MAIN BUSING ARRANGEMENT

The busing arrangement is illustrated on the facing page. Because the string voltage is only about 10 kV as compared to 40 kV for the reference system, buses are required to collect string currents and route these currents to the central main buses down the centerline of the SPS. Bus widths and arrangements are illustrated.

2.5 GW SOLID STATE SPS MAIN BUSSING ARRANGEMENT

$V_{SUBARRAY} = 8640\ V,\ T_{CONDUCTOR} = 40^{o}C$



SOLID STATE SPS EFFICIENCY AND SIZING

A summary efficiency chain for the solid state SPS is presented on the facing page. This efficiency chain does not include the solar cell efficiency itself. Principal improvements over the solid state configuration are reductions in array, mismatch losses, and reductions in main bus I^2R losses. This efficiency chain represents slightly more than 10% greater loss than is the case for the reference system.

TABLE II. SOLID STATE SPS EFFICIENCY & SIZING

ITEM	EFFICIENCY	MEGAWATTS	
Array Mismatch			
Array Mismatch	.975	5033	Ideal Array Output
Main Bus I^2R	.954	4907	
Antenna Distr	.985	4191	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	.97	2577	
	.497	2500 Net to Grid	

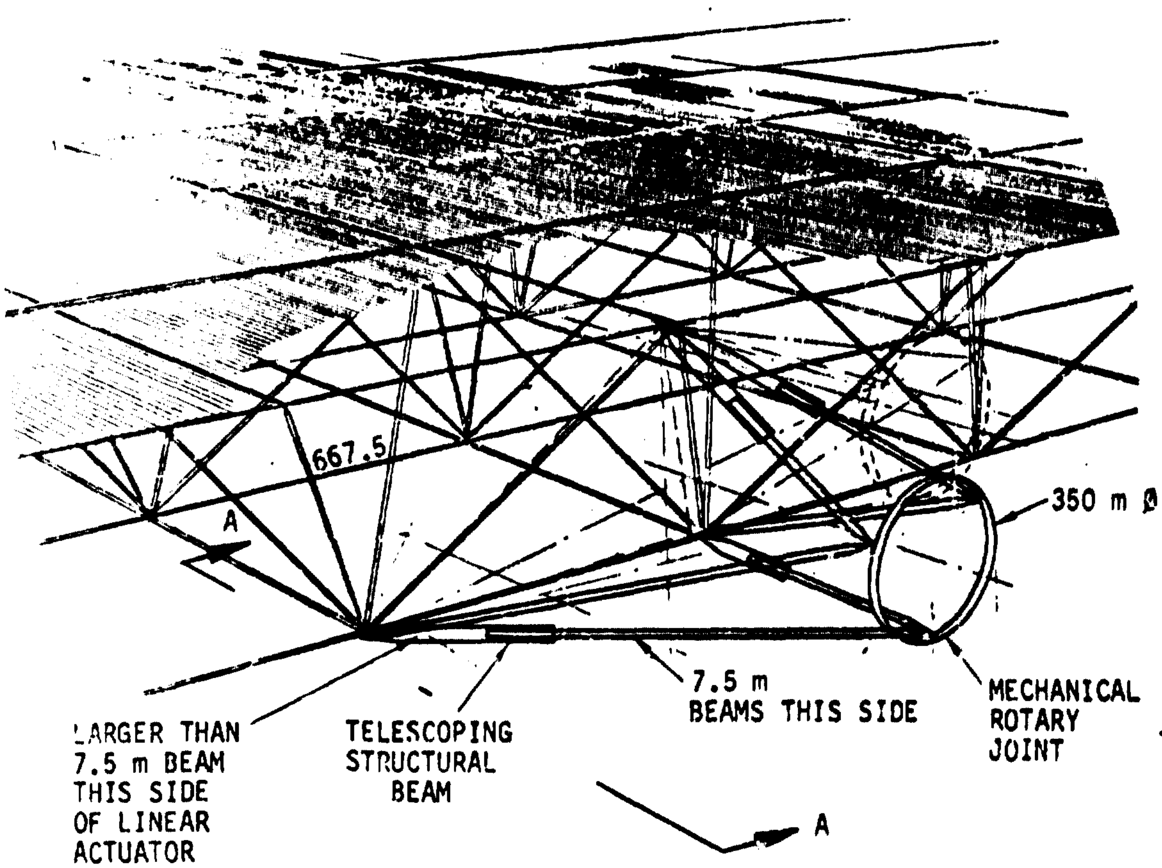
TOTAL ARRAY OUTPUT 5033 MW

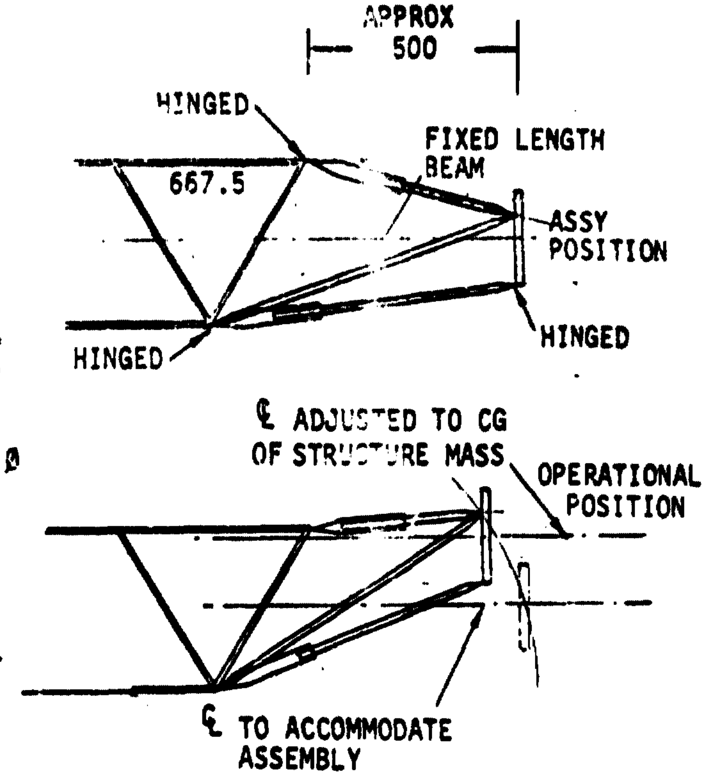
TOTAL SOLAR ARRAY AREA = 28.1 km^2

SOLID STATE TRANSMITTER INTERFACE SYSTEM STRUCTURE

Because of the relatively large diameter of the solid state transmitting antenna, an end-mounted interface configuration was selected instead of a yoke. The end-mount employs telescoping structure to reposition the interface from the most convenient assembly position to the most practical operating position with the centerlines adjusted to the center of gravity of the structure. This interface adjustment mechanism serves only to reposition the antenna from the assembly position to the operating position.

INTERFACE SYSTEM STRUCTURE



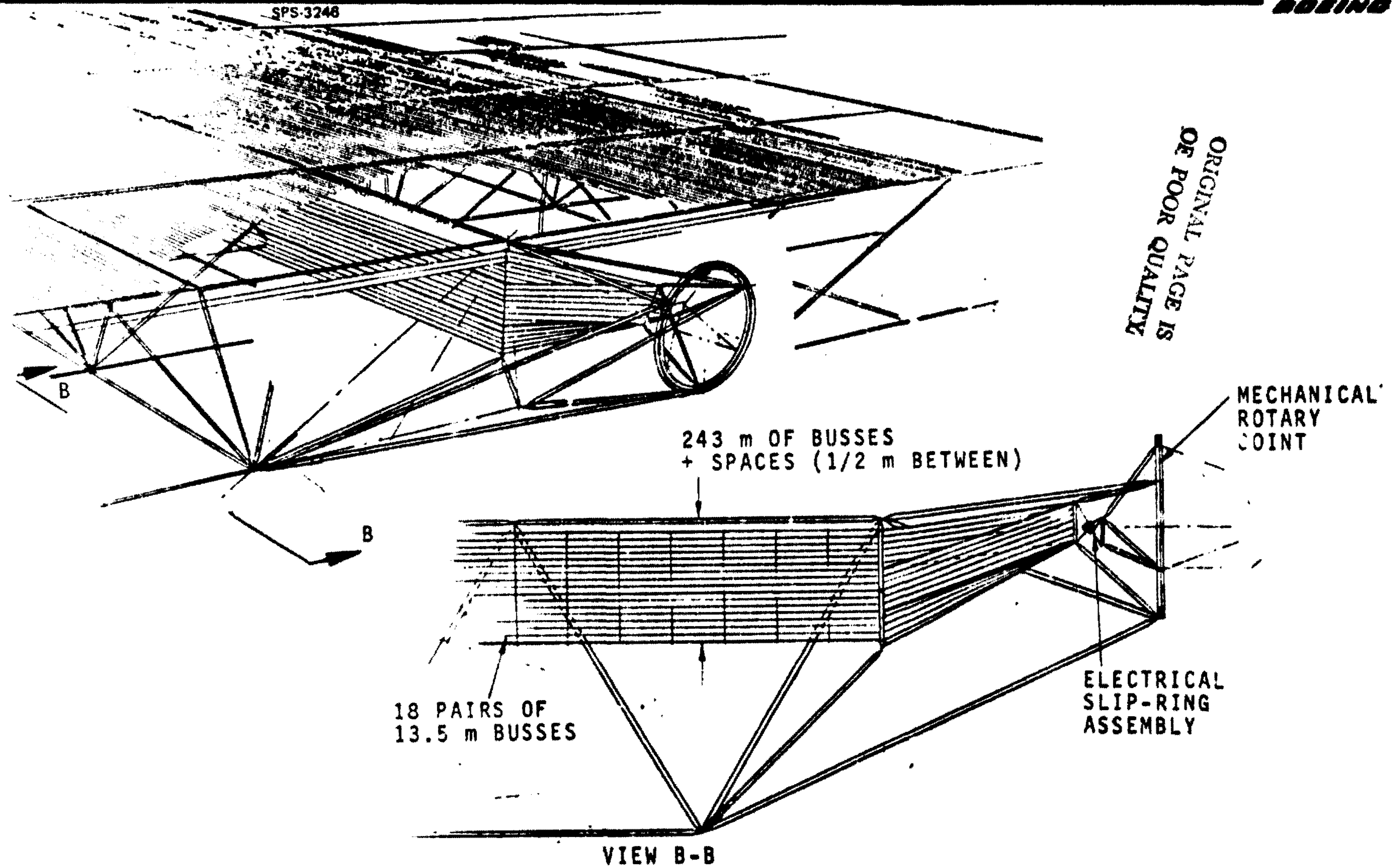


SECTION A-A

INTERFACE SYSTEM BUSES

The solid state transmitter uses a very wide set of buses as prepared to the reference system to minimize losses. These buses are brought into a staging area prior to final routing to the electrical slip ring assembly. The convergence of the buses into the staging area is illustrated on the facing page.

INTERFACE SYSTEM BUSSES

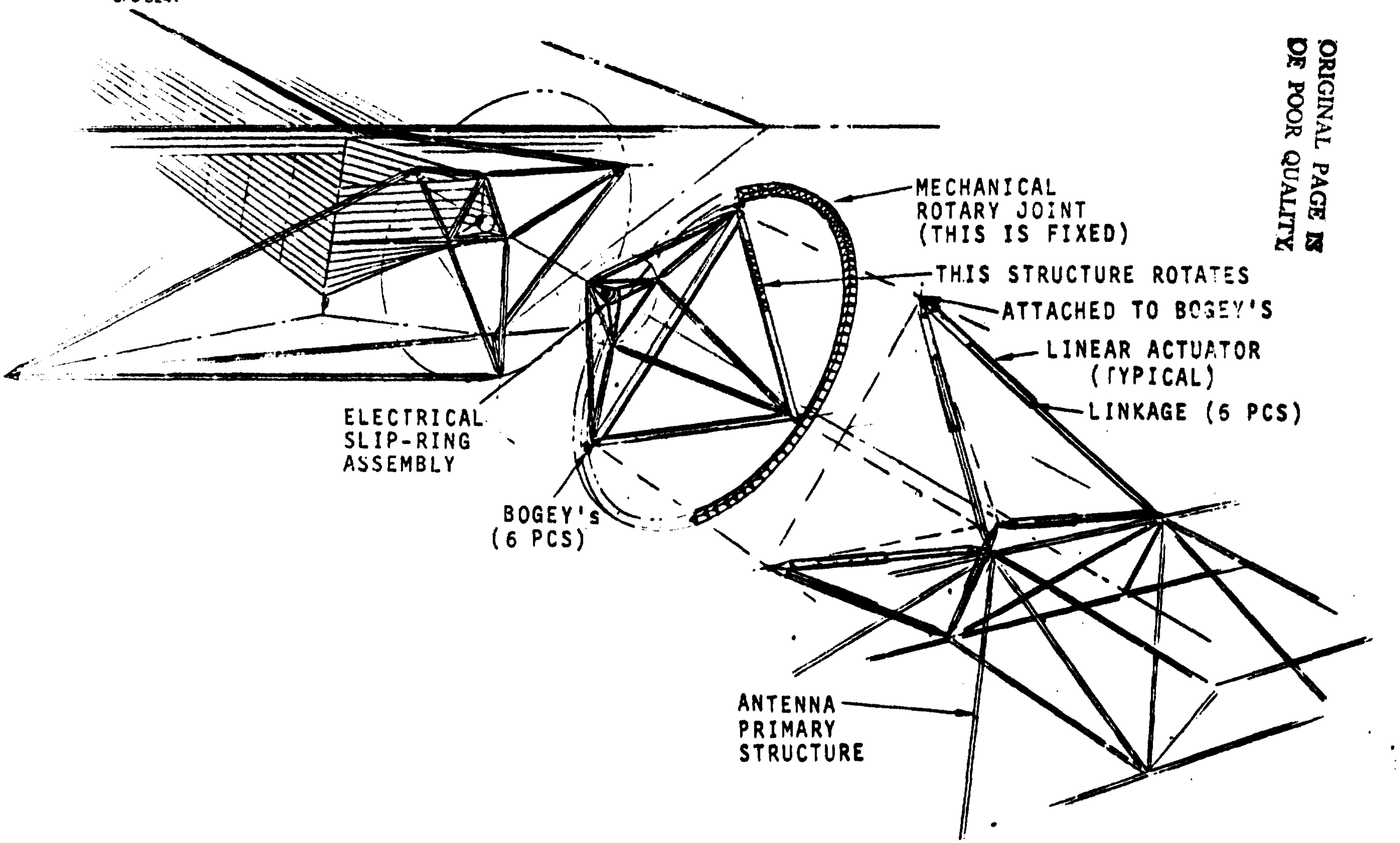


INTERFACE SYSTEM - MECHANICAL ROTARY JOINT AND ACTUATOR

The mechanical rotary joint and actuator system employs a mechanical turntable drive for the diurnal rotation and a linear actuator system to accomplish elevation drive.

INTERFACE SYSTEM MECHANICAL ROTARY JOINT AND ACTUATORS

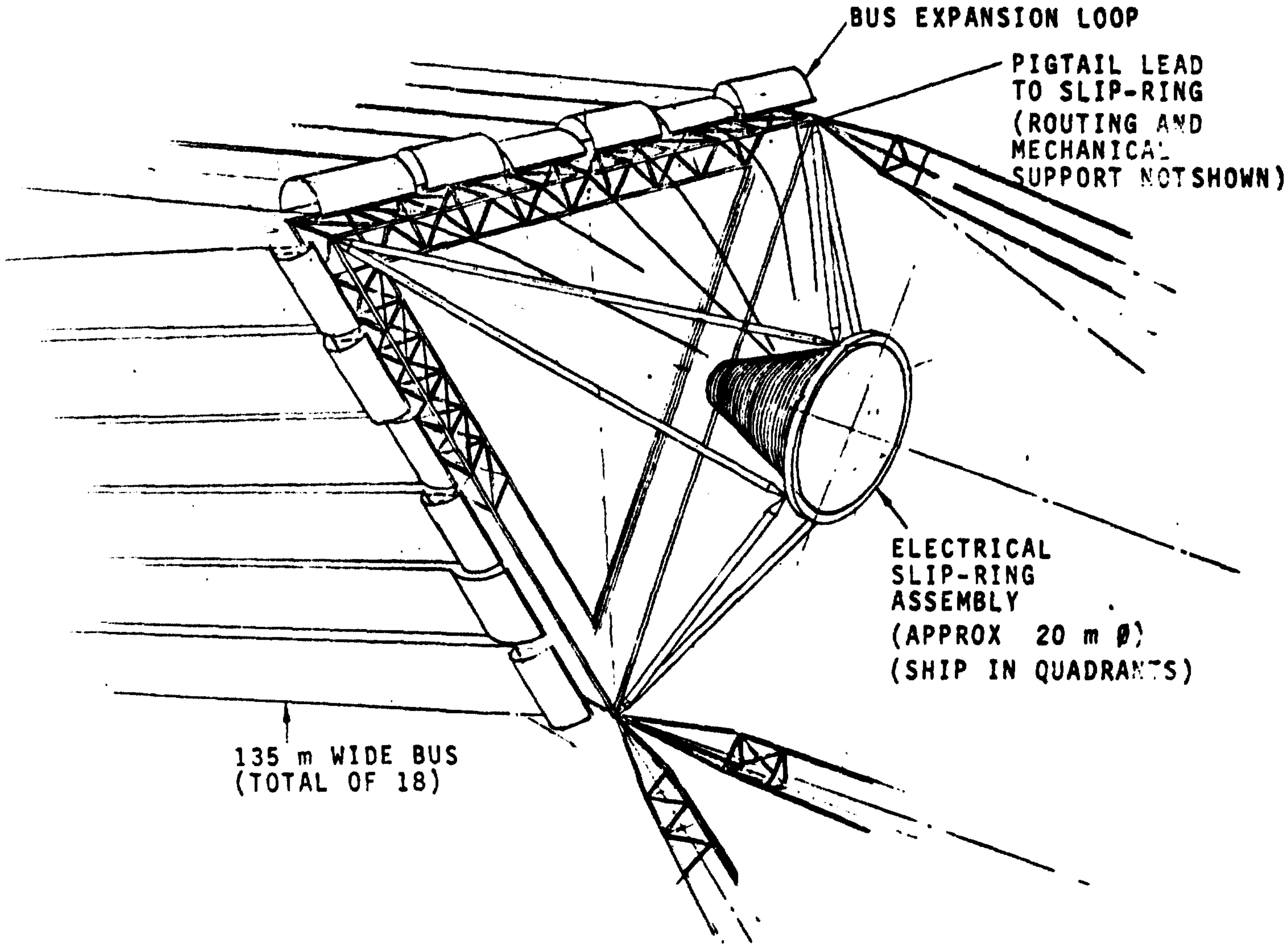
SPS-3247



INTERFACE SYSTEM - ELECTRICAL ROTARY JOINT

Illustrated on the facing page is the feed-in of pigtails from the flat sheet conductors to the rotary joint itself. Because of the higher current, the electrical rotary joint for this configuration is larger than that for the reference system even though the power is less.

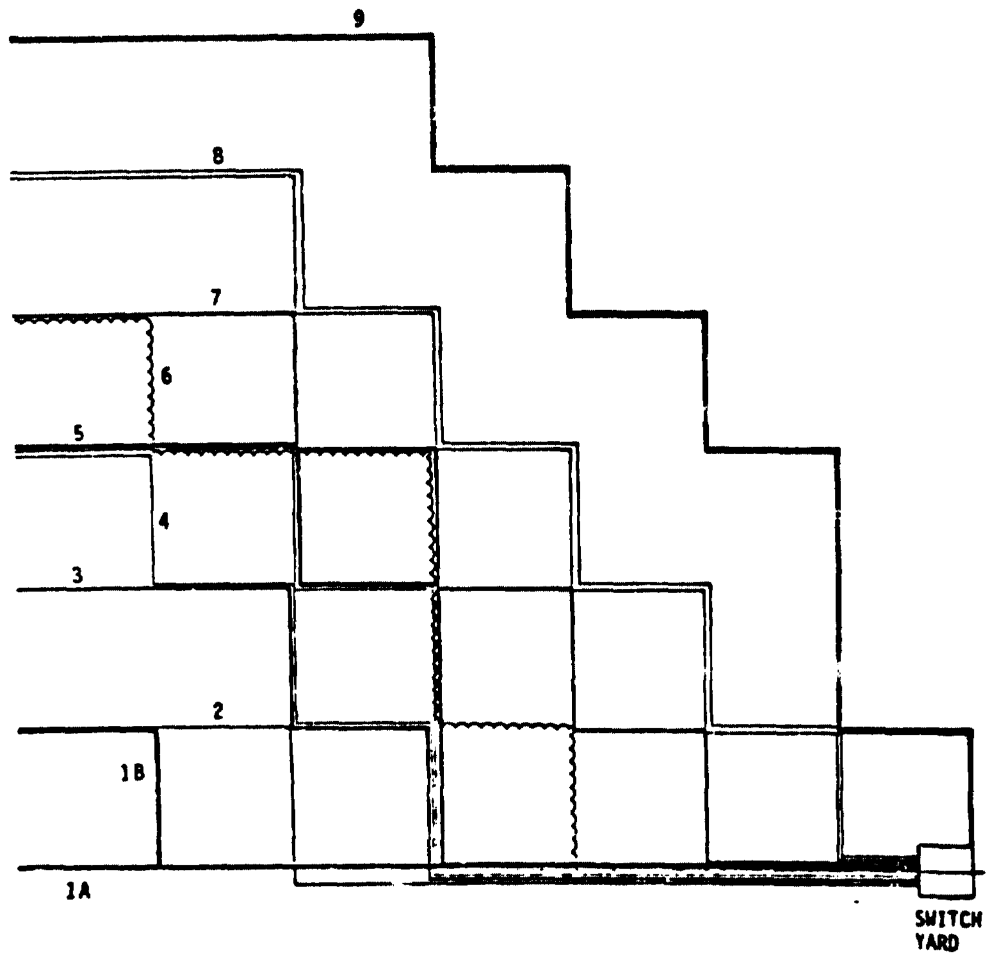
INTERFACE SYSTEM ELECTRICAL ROTARY JOINT



2.5 GIGAWATT SOLID STATE SPS TRANSMITTING ANTENNA - MAIN BUS CONFIGURATION

Main buses are routed on the back of the SPS solid state transmitter through a main switch yard that distributes the DC power to the subarray sections.

2.5 GIGAWATT SOLID STATE SPS TRANSMITTING ANTENNA - MAIN BUS CONFIGURATION



SOLID STATE SPS CONSTRUCTION REQUIREMENTS & ISSUES

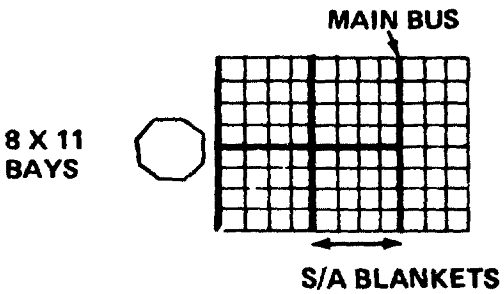
The 2500 MW Solid State Solar Power Satellite (SPS) is to be constructed entirely in GEO and is to be assembled similar to the 5000 MW reference satellite. To facilitate comparison with the reference SPS program scenario, the smaller capacity solid-state SPS will have to be produced at a faster rate. That is, to meet the reference program goal of 10 GW annual capacity growth, one 2500 MW solid state SPS will have to be fully assembled and checked out every 90 days.

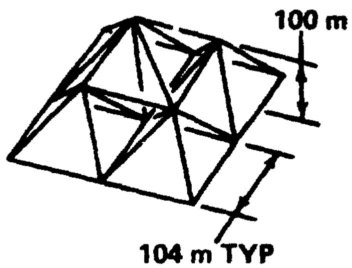
The solid state satellite has a single antenna located at one end of the 8 x 11 bay photovoltaic energy conversion system, as shown on the facing page. The microwave antenna is designed with the reference pentahedral primary structure, whereas the energy conversion system uses the reference hexahedral structure. The interface system retains the reference rotary joint design with its solar array support structure. However, the reference antenna support yoke is replaced by an end-mounted linear actuator.

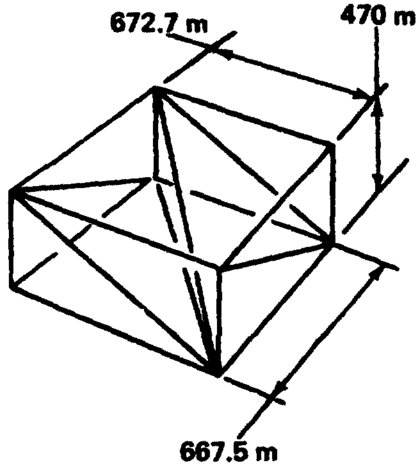
To achieve SPS microwave power transmission performance requirements, both solid state and reference klystron antenna concepts must be constructed to meet similar flatness design goals (i.e., 2 arc minutes rms with a maximum of 3 arc minutes). Hence, to cover all aspects of the Solid State SPS construction process, a broad range of technology issues (which are beyond the scope of this study) must be addressed. For example, as the Solid State SPS 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.

SOLID-STATE SPS CONSTRUCTION REQUIREMENTS & ISSUES

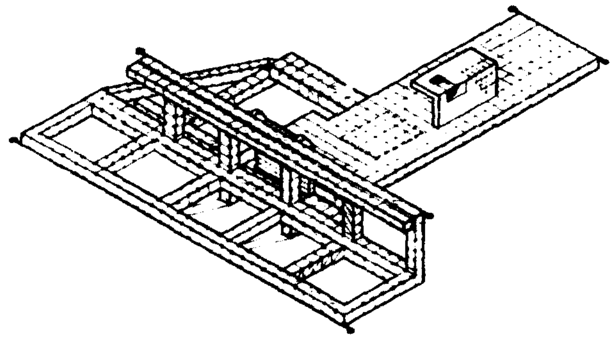
- KEY PRODUCTION RATE TO BASELINE 10 GW ANNUAL GOAL







- PH-2 REF STRUCTURAL SYSTEMS (D180-25461-2)
- 4 BAY END BUILDER REF GEO BASE
  - 2 PASS LONG ENERGY CONV ASSY
  - 11 ROW LATERAL ANTENNA ASSY
- MPTS FLATNESS – 2 $\widehat{\text{MIN}}$ GOAL : 3 $\widehat{\text{MIN}}$ MAXIMUM
- 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

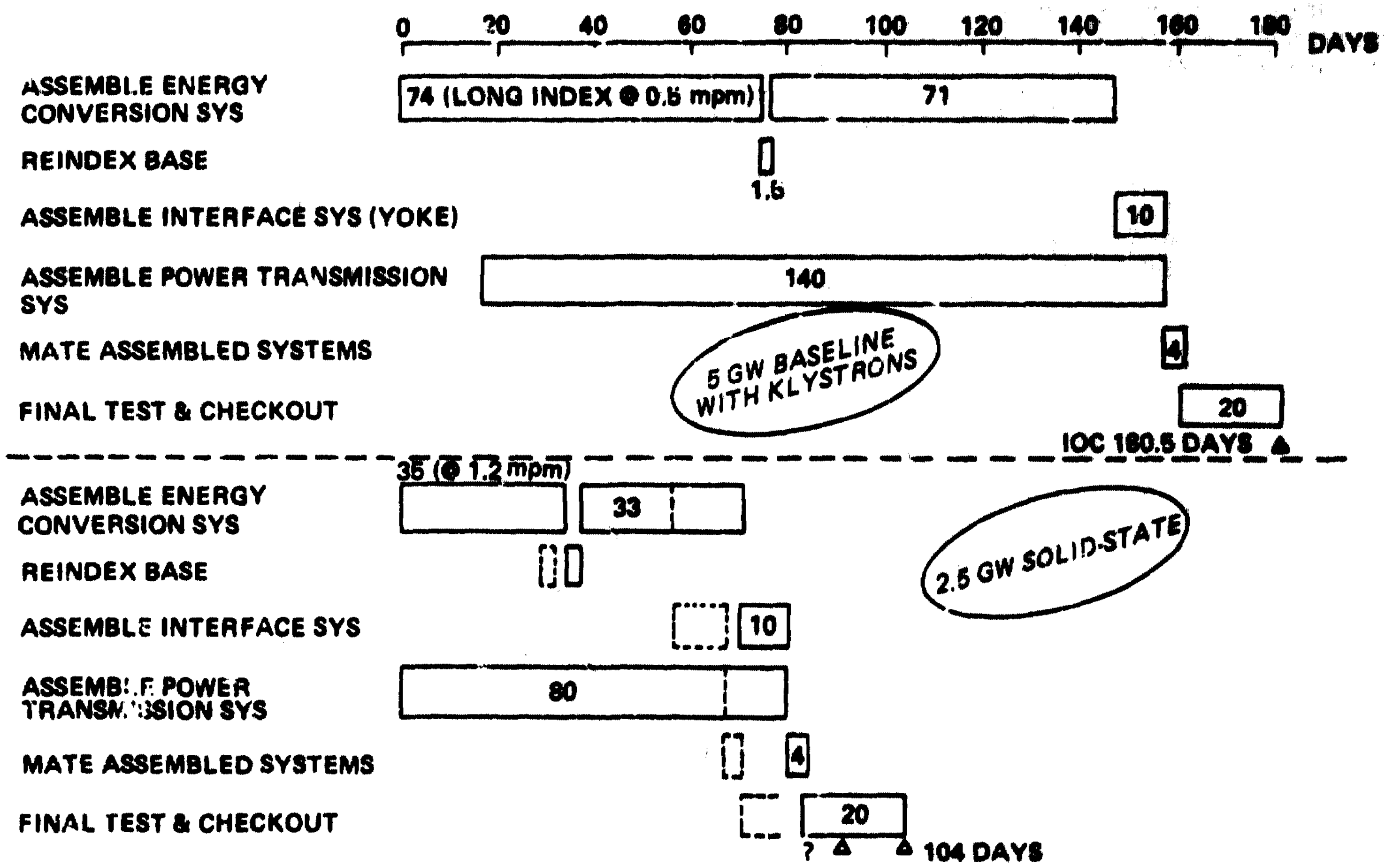


0580-025W

SPS GEO CONSTRUCTION TIMELINES – 5 GW BASELINE & 2.5 GW SOLID-STATE

Comparative timelines for constructing the 5 GW reference SPS and the 2.5 GW solid-state SPS concept are shown on the facing page. Both timelines follow the same construction approach. That is, where the energy system conversion assembly is timed for simultaneous completion and mating with the satellite's power transmission and interface systems. The 4 Bay End Builder also assembles the solid-state 8 x 11 bay energy conversion system during two successive passes, as previously defined. However, the production rate to complete final test and checkout of the 2.5 GW solid-state SPS is slower than the baseline 5 GW SPS with klystrons. The 5 GW klystron satellite is fully constructed and checked in GEO in six months. The production rate for the reference system is 27.7 MW/day. In order to match this production rate, the 2.5 GW solid-state SPS would have to be completed in one-half the time (i.e., 90 days). At this juncture, the solid-state SPS construction operation appears to fall short of the 10 GW annual production goal. The present design and construction approach used for the solid-state SPS has slowed the production rate to 24.03 MW/day or 104 days to IOC.

SPS GEO CONSTRUCTION TIMELINES – 5 GW BASELINE & 2.5 GW SOLID-STATE

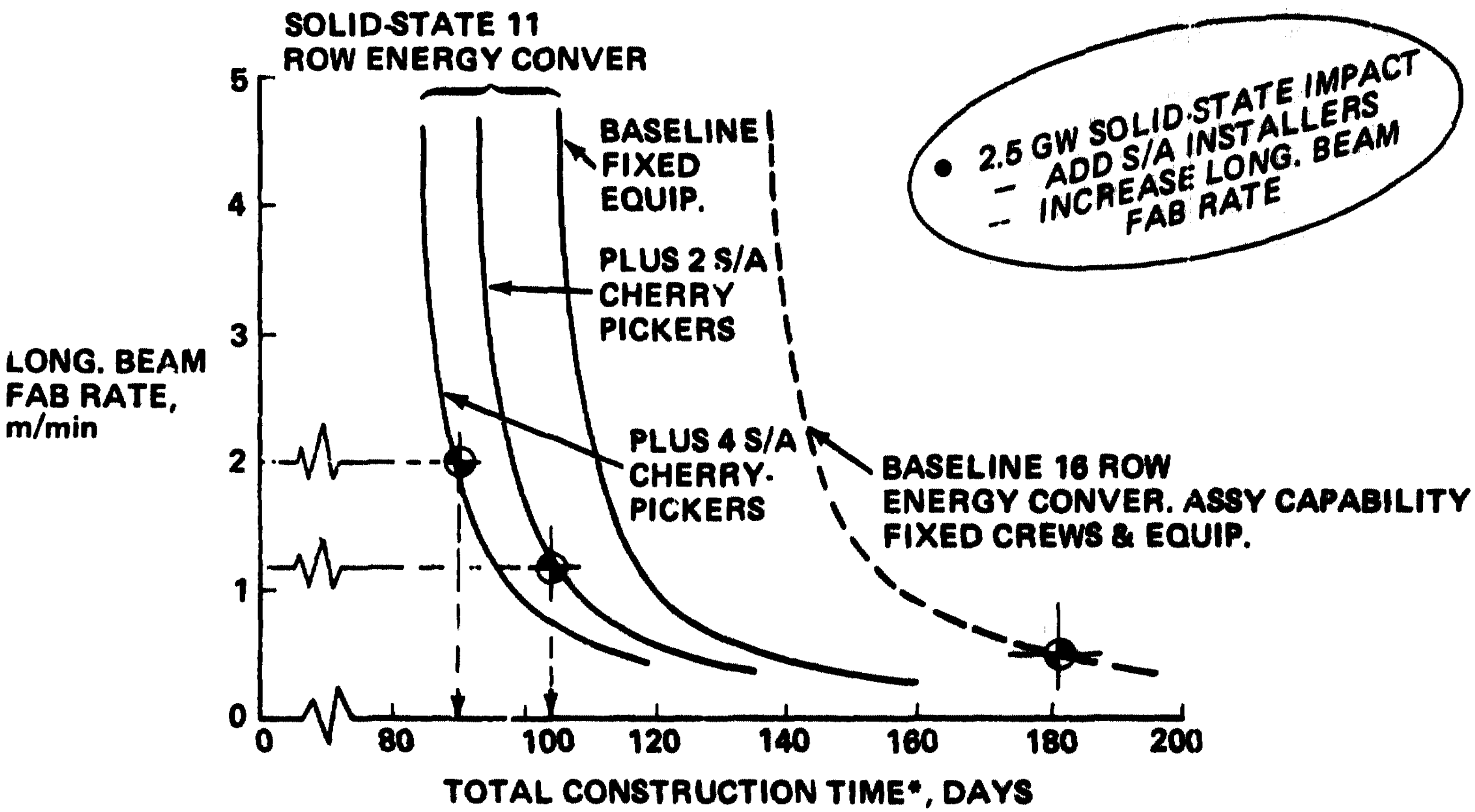


0580-003W

GEO BASE ENERGY CONVERSION PRODUCTION CAPABILITY

The inherent production capability of the 4 Bay End Builder Construction Base is illustrated on the facing page. This figure shows how the total satellite construction time can be altered by either changing the fabrication rate for continuous longitudinal beams, reducing the length (i.e., number of rows) of the energy conversion system, or both. For example, the baseline SPS, which has a 16 row energy conversion system, is constructed in 180 days by limiting synchronized longitudinal beam fabrication to 0.5 m/min. By increasing the beam fabrication rate to 3 m/min the entire SPS (including yoke assy, systems mating, test and checks) would be constructed in 140 days. A similar production advantage can be achieved with the shorter solid-state energy conversion system which is only 11 rows long. However, increasing the operating rate of the longitudinal beam builders is not sufficient to achieve the solid-state SPS construction goal either 90 or 104 days. To achieve these goals, additional cherry pickers must be provided to speed up the installation of solar array blankets. Hence the solar collector assembly facility on the reference GEO base can be revised as required to meet either construction goal for the solid-state SPS concept. The time critical construction operation, therefore, lies with the assembly of the solid-state SPS antenna.

GEO BASE — ENERGY CONVERSION PRODUCTION CAPABILITY



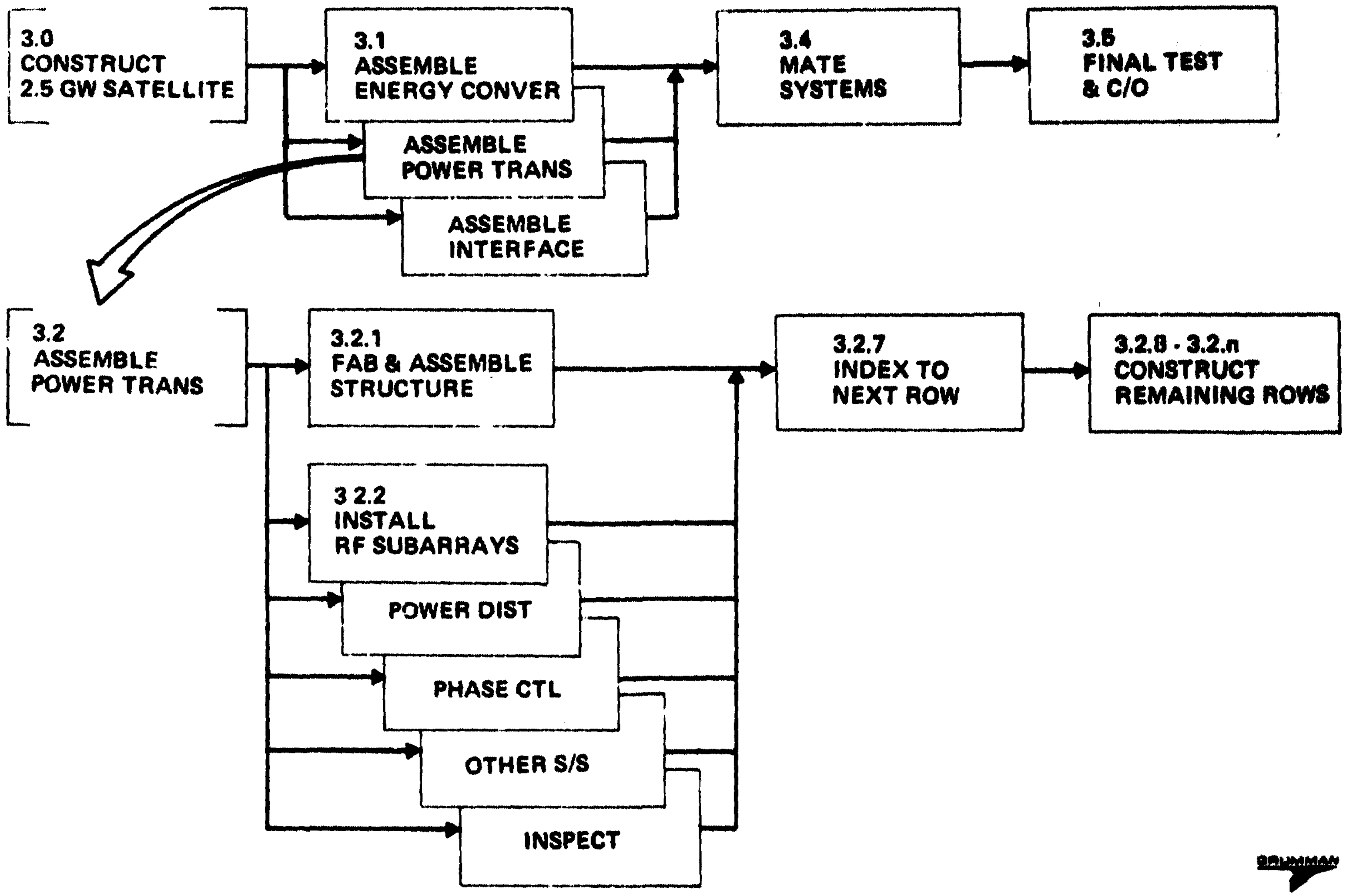
*INCLUDES 34 DAYS – YOKE ASSY, SYS MATE, TEST & C/O

SATELLITE POWER TRANSMISSION CONSTRUCTION OPERATIONS ANALYSIS

During Phase 3, the major construction operations of the Solid State SPS antenna were analyzed from the top down, as previously done for the reference system. As shown on the facing page, construction of the 2.5 GW solid-state SPS follows the same sequence as the reference 5 GW Klystron SPS.

A breakdown of the assembly operations for the SPS power transmission system is shown by the abbreviated flow illustrated on the lower half of the page. This assembly activity includes the fabrication and assembly for the first row of primary and secondary structure (3.2.1). It also includes the parallel installation and inspection of other subsystems during first row construction. These subsystems include the installation of RF subarrays (3.2.2), power distribution, phase control, and so forth. When first row construction is complete, the antenna is indexed (3.2.7) away to allow the second row to be added. The remaining rows of the antenna are constructed in a like manner.

SATELLITE POWER TRANSMISSION CONSTRUCTION OPERATIONS ANALYSIS



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SPS BASELINE AND SOLID STATE ANTENNA CONCEPTS

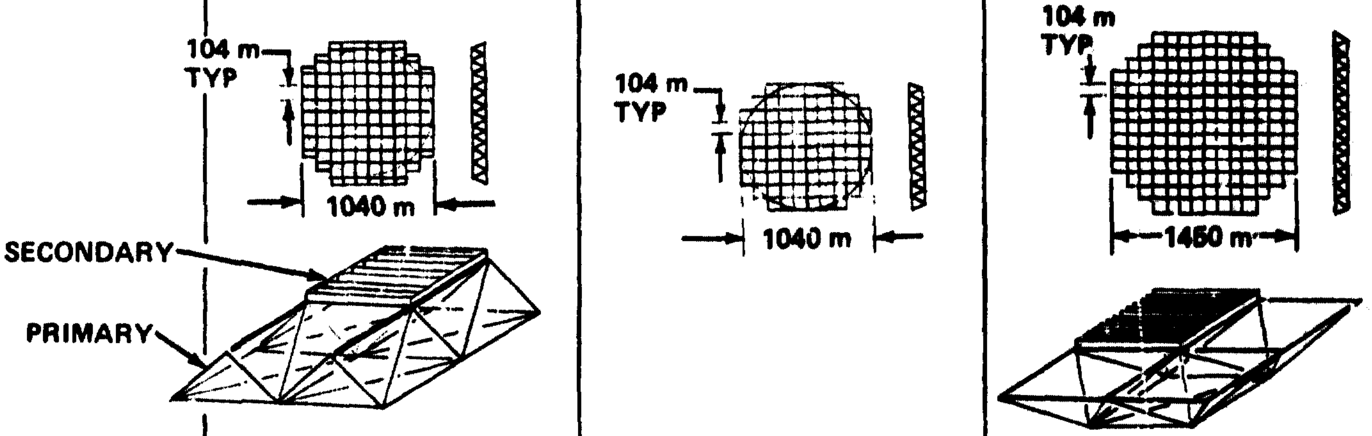
In Phase I of the study the antenna provided a transmitting area, 1 km in diameter, made from 98 bays of A-frame primary structure. Each bay has ten triangular beams, 7.5 m deep, produced in space by beam machines operating at 5 m/min. Secondary structure, mounted to the primary structure, supported energy transmitting equipment. There was eighty-eight, 104 m square, bays of this structure.

At the end of Phase II, the 1 km diameter reference antenna was changed to a more efficient pentahedral structure having 88 bays of primary structure. Each bay had 9 or 11 members, dependent upon whether it required closing beams or not, which were 1.5 m deep beams. Construction of this structure was never analyzed, therefore no beam production rate was assumed. Again, secondary structure supported RF subarray equipment on 88 bays.

The solid-state SPS system in Phase III requires an antenna whose area increases to 1420 m diameter, effectively twice that of Phases I & II. Primary structure uses the same pentahedron bays, as defined in the Phase II reference system description (D180-25461-2). Fabrication of the 1.5 m deep triangular beams is limited to a beam production rate of about 1 m/min. Being larger in area, 172 bays of 104 m^2 secondary structure are required to support transmitting equipment.

SPS BASELINE & SOLID-STATE ANTENNA CONCEPTS

	PHASE I 5 GW BASELINE	PHASE II 5 GW BASELINE	PHASE III 2.5 GW/SOLID-STATE



	PHASE I	PHASE II	PHASE III
• PRIMARY STRUCTURE	A-FRAME	PENTAHEDRAL	PENTAHEDRAL
– TOTAL BAYS	98	88	172
– BEAMS/BAY	10/BAY	9-11/BAY	9-11/BAY
– BEAM SIZE (FAB RATE)	7.5 m (5 mpm)	1.5 m	1.5 m (1 mpm)
• SECONDARY STRUCTURE BAYS	88	88	172

GRUMMAN

0580-035W

ANTENNA CONSTRUCTION OPTIONS

The 1.0 km diameter reference 5 GW klystron antenna is constructed at the GEO base by progressive build-up of its 11 row plan form. The antenna is assembled, one row at a time, as it is indexed back and forth through the antenna construction facility. As a result, the antenna must be supported during this process on a platform at least twice as large as the antenna is wide.

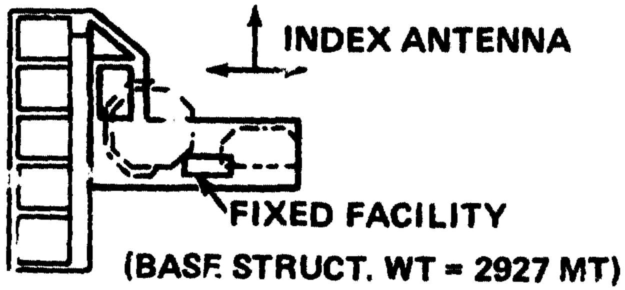
The area of the SPS, 1.4 km diameter, 2.5 GW, solid-state antenna is nearly twice that of the 1.0 km diameter reference antenna. Hence if the reference antenna construction approach was simply adapted to the solid-state antenna requirement, the large antenna support platform would simply grow in proportion. As a consequence, other assembly approaches were considered to reduce the overall size of the antenna construction facility. Three GEO base antenna assembly options are shown here for the solid-state concept. The 4 Bay End Builder solar collector assembly facility is common to all concepts. The first option uses the 5 GW baseline method to build the new antenna in an area approximately 65% greater than the 5 GW antenna area, also shown. This method caters for parallel construction of a yoke support for the antenna, as well as for the current cantilever support baselined for these options.

The second construction method is an edge builder in which the antenna indexes in one direction only. The construction facility is now much longer since it must cover the width of the antenna to provide many machines for building all longitudinal beams simultaneously. Area for antenna construction is about 25% less than that for the first option but needs the longer facility for the increased number of beam machines. An antenna yoke support could be built on this facility but it would be a sequence operation which extends the timeline.

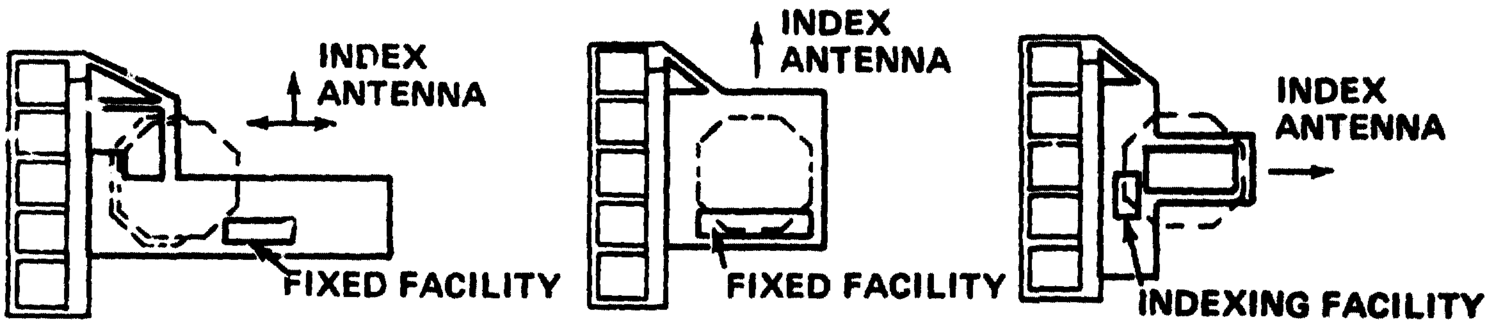
The third option retains the unidirection indexing of the antenna (Option 2) but relocates the small construction facility of Option 1 and allows it to move laterally to cover the width of the antenna. Construction area is minimum for this method and is, in fact, less than 5 GW baseline area even though the antenna is larger. This is reflected in the reduced weight for the base. To accommodate construction of a yoke support for the antenna would require added platform area and facilities and would extend the timeline. This third option was selected for preliminary design work to derive weights and costs.

ANTENNA CONSTRUCTION OPTIONS

5 GW BASELINE



2.5 GW SOLID-STATE



- 5 GW BASELINE METHOD
- EDGE BUILDER METHOD
- INDEXING FACILITY METHOD (Δ WT = -142 MT)

0580-024W

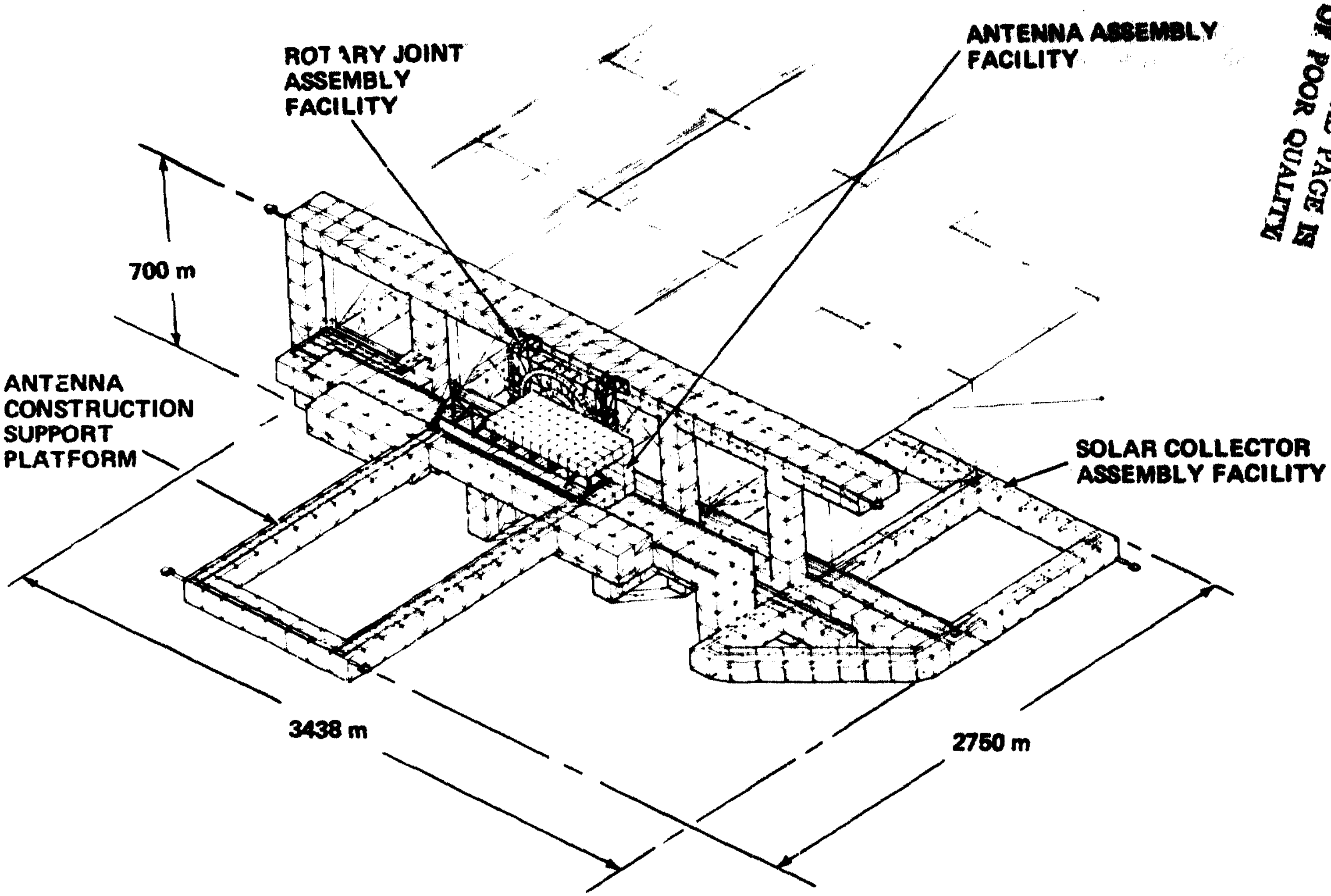
SOLID-STATE SPS CONSTRUCTION BASE

The configuration of this Solid State SPS Construction Base closely follows the reference GEO base described in the Phase II Study. The energy conversion system is built in the same solar collector assembly facility, while the rotary joint is assembled on a facility very similar to that of the previous base.

The main differences are in the antenna construction facility. It is smaller in area than that on the reference base, since the construction method can now be simplified due to the change in support of the antenna from the rotary joint. Instead of a fixed antenna assembly facility and bilateral indexing of the growing antenna, the antenna assembly facility now indexes laterally across the antenna platform as it builds the antenna in rows. The platform is a frame of open truss members which provides tracks along which the antenna indexes as it is built.

Facilities for mating the antenna to the rotary joint are similar to those in the Phase II Study.

SOLID-STATE SPS CONSTRUCTION BASE



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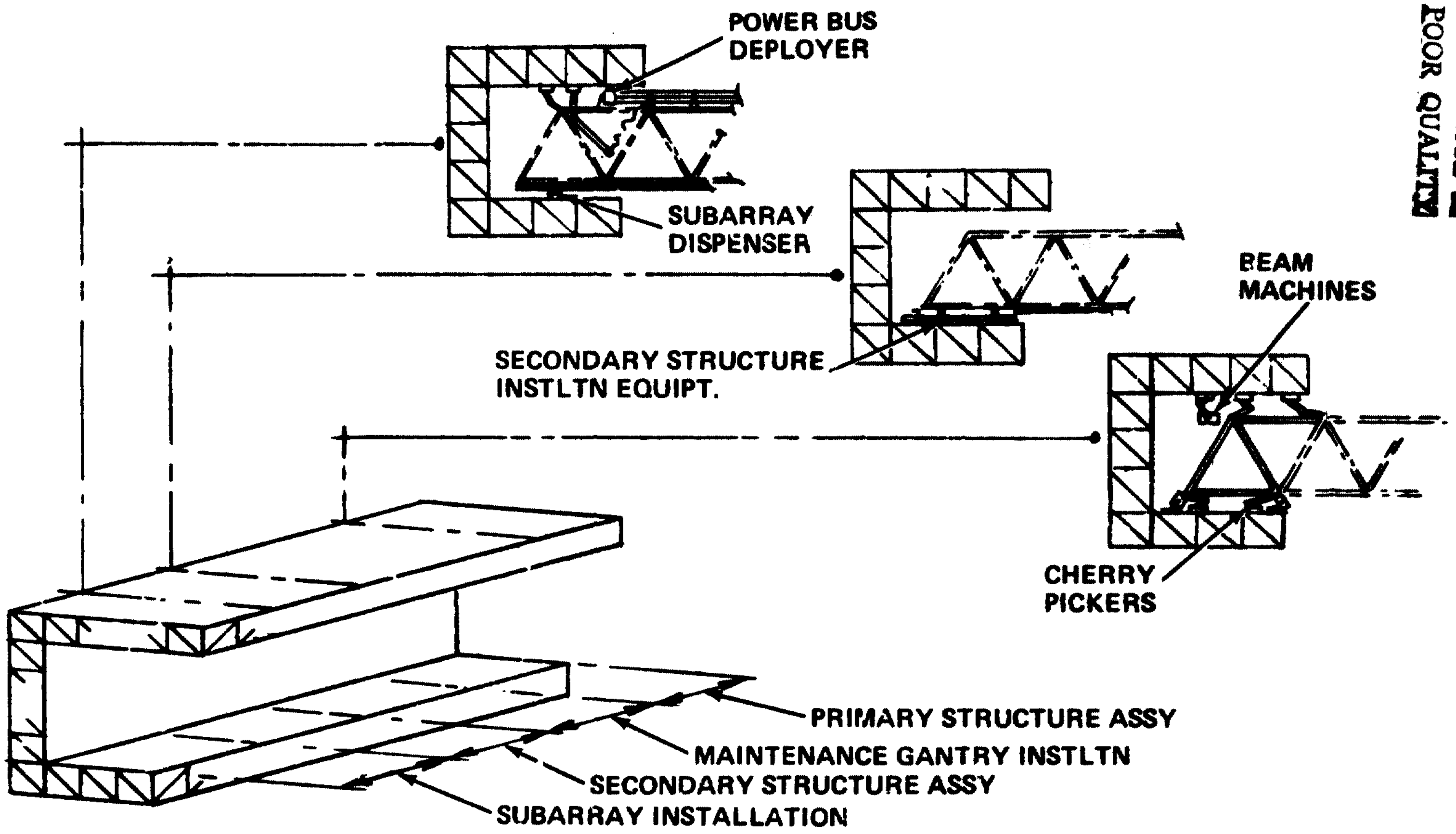
SOLID STATE ANTENNA ASSEMBLY FACILITY

The assembly facility shown here covers four bays of the antenna structure and builds in one direction only. At one end, the facility builds primary structure on the lower and upper levels. Maintenance gantries are installed in the next lower facility, followed by fabrication and installation of the secondary structure to the primary structure. In the last lower level facility, subarrays are installed on the secondary structure. At the upper level, following primary structure fabrication, power distribution busses and switch gear are installed.

Following charts discuss in some detail primary and secondary structure fabrication and assembly, as well as installation of subarrays.

SOLID-STATE ANTENNA ASSEMBLY FACILITY



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SOLID STATE ANTENNA CONSTRUCTION SEQUENCE

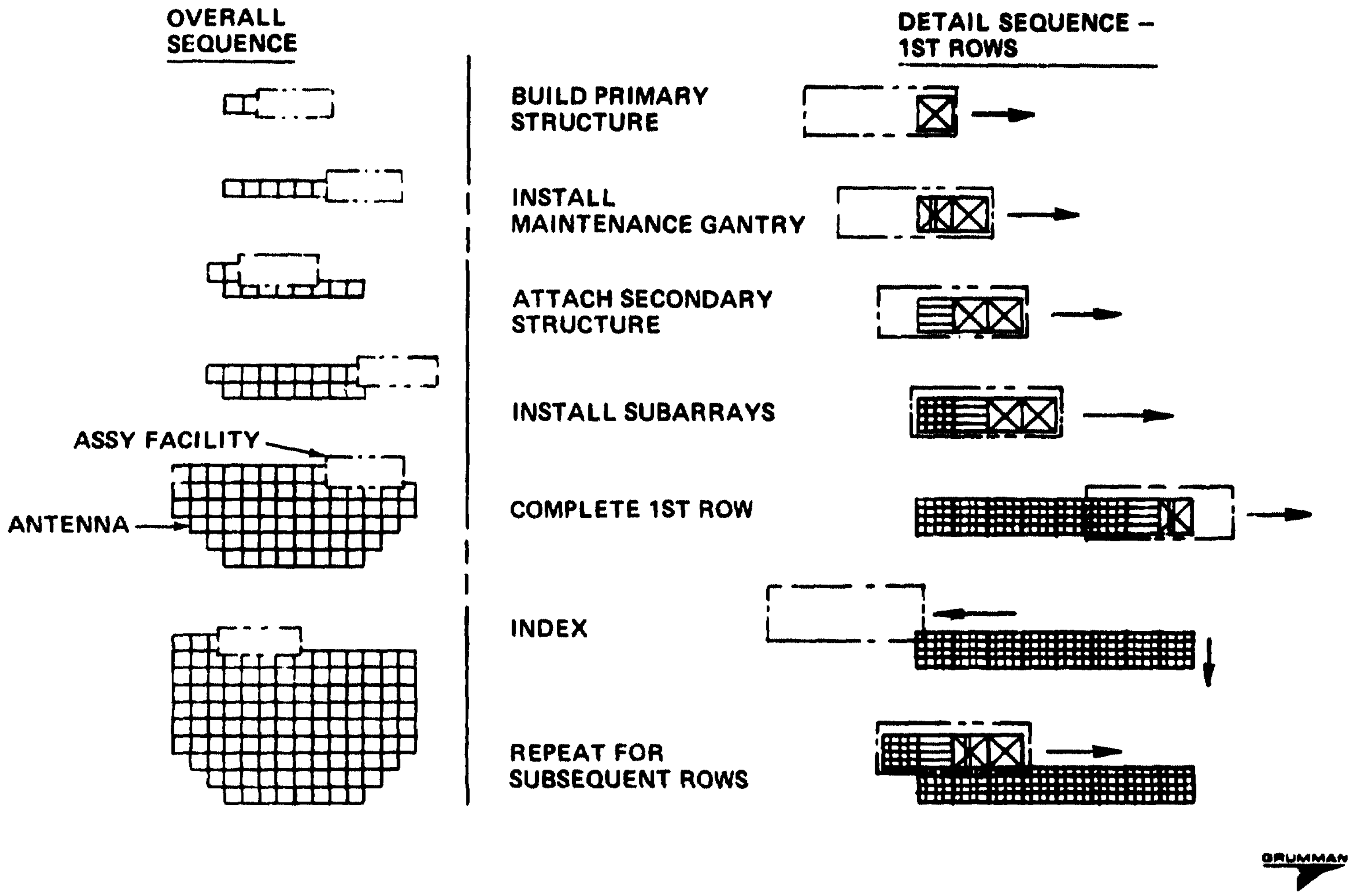
Preceding charts have discussed the antenna construction concept and its assembly facility. This chart shows the overall assembly sequence, which is to build the antenna in rows of repeatable bays. The facility indexes across the construction base to fabricate and assemble the first row as it goes. It then indexes back along the track while, at the same time, the completed row indexes forward for one row width. The second row is now built onto the first row by the indexing facility on its second construction pass. This process is repeated until the antenna is completed.

Taking a more detailed look at the sequence as it builds the first rows, the facility starts construction by building primary structure for the first bay of the first row. The facility then indexes for one bay length, then builds primary structure for the second bay while, at the same time, installing maintenance equipment in the first bay. Following another one bay index of the facility, the third bay primary structure is built while secondary structure is assembled to the first bay primary structure in parallel. Another one bay index of the facility is followed by construction of the fourth bay primary structure while, at the same time, secondary structure is added to the second bay and subarrays installed on the first bay secondary structure. This process continues to complete the first row. It should be noted that maintenance gantries are installed only on the first and last bays of this and all subsequent rows. Thus, two parallel maintenance operations can be performed along each row.

At completion of the first row, the facility indexes back along its track while, at the same time, the completed row is indexed forward for one bay width. The sequence is now repeated for the second and subsequent rows to completion of the antenna build.

C-5

SOLID-STATE ANTENNA CONSTRUCTION SEQUENCE



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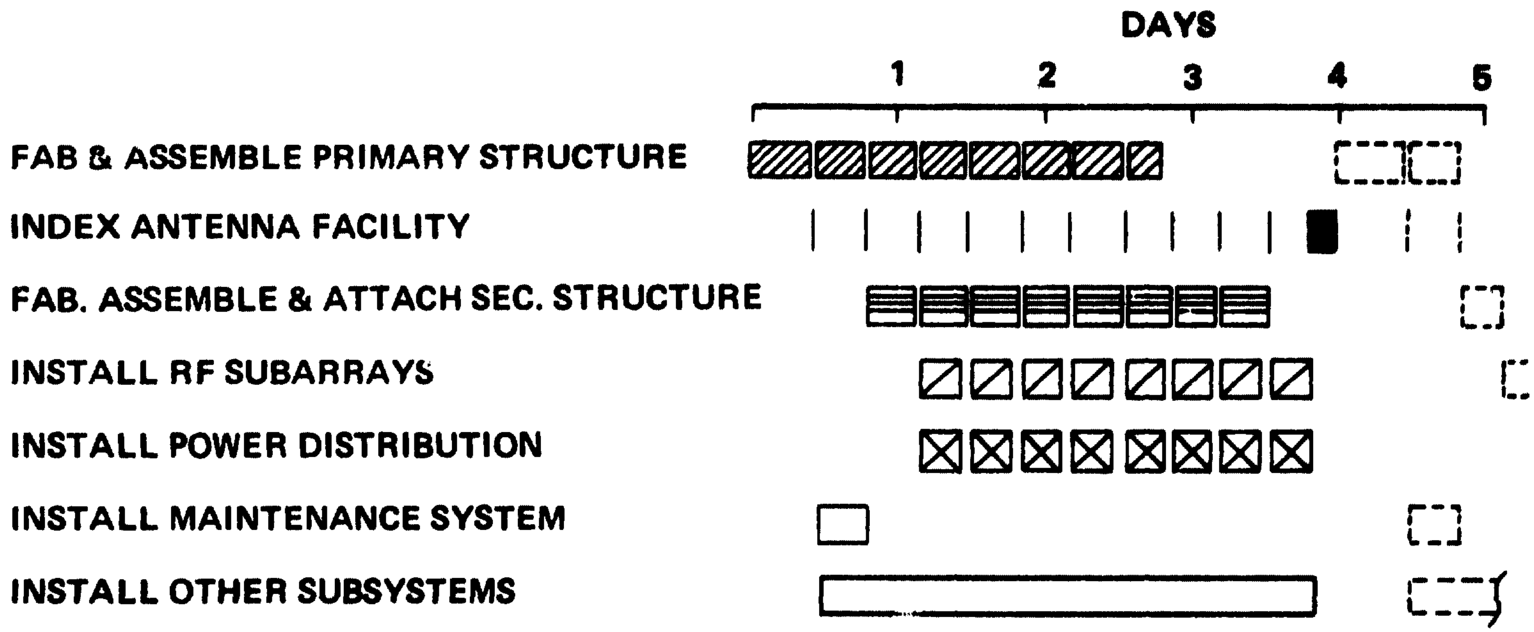
0560-022W

2.5 GW SOLID STATE POWER TRANSMISSION SYSTEM ASSEMBLY - 1st ROW TIMELINE

The timeline for assembling the 1st row of the solid-state power transmission antenna is shown on the opposite page. As previously described, the antenna facility builds the structure in progressive steps and sequentially installs the required subsystems. There are 8 primary pentahedral structural bays in the 1st row of construction. As each primary pentahedral bay is built, the antenna facility moves sideward to allow the next pentahedral bay to be added. Maintenance equipment is installed in the first structural bay before the secondary structure is attached. Hence the sequential installation of RF subarrays and power distribution subsystems parallels the assembly of the 4th structural bay at the start of Day 2. This one day lag in subsystem installation is common to each row of antenna construction operations.

2.5 GW SOLID-STATE POWER TRANSMISSION SYSTEM ASSEMBLY – 1ST ROW TIMELINE



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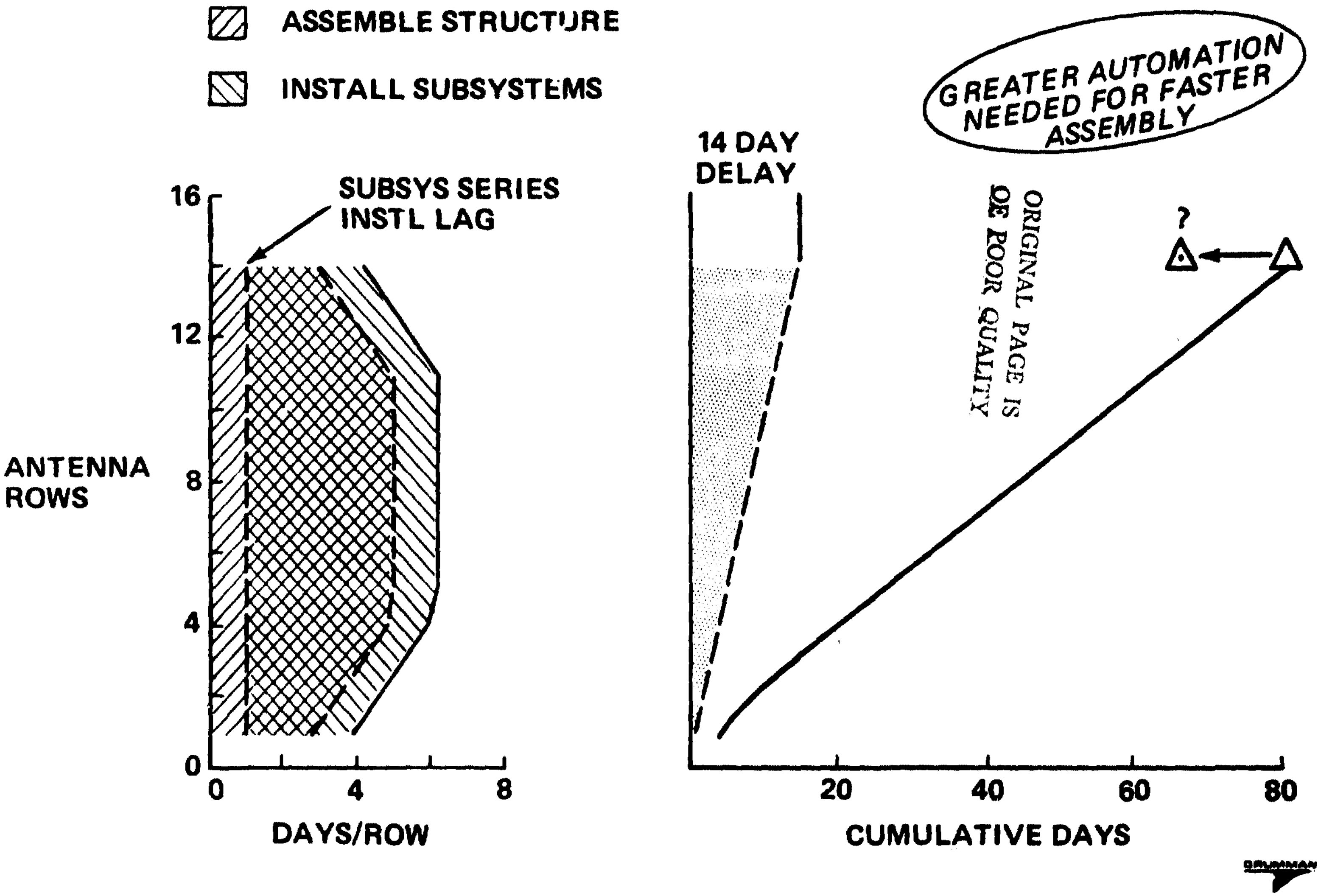
SOLID STATE ANTENNA CONSTRUCTION TIME

The 2.5 GW solid-state antenna configuration contains 172 pentahedral bays which are arranged in rows of 8, 10, 12 and 14 bays per row. The time allowed to fully assemble the 14 rows of structure (primary and secondary) and install the required subsystems (RF subarrays, power distribution, etc) is shown. As each row is constructed, there is a one day lag in the sequential installation of subsystem hardware. The cumulative effect of this sequential process results in a 14 day delay in the total antenna construction time that may be used for either structural assembly or subsystem assembly. Therefore, only 66 days are available for dedicated assembly operations from the total construction time scheduled (80 days). In light of the 14 day constraint, it is questionable that any further reduction can be made in construction time without impacting the assembly facility, construction equipment and related work crews. If faster antenna construction times are needed, it is recommended that the assembly sequence be re-examined with an eye toward implementing a greater degree of automation.

SOLID-STATE ANTENNA CONSTRUCTION TIME



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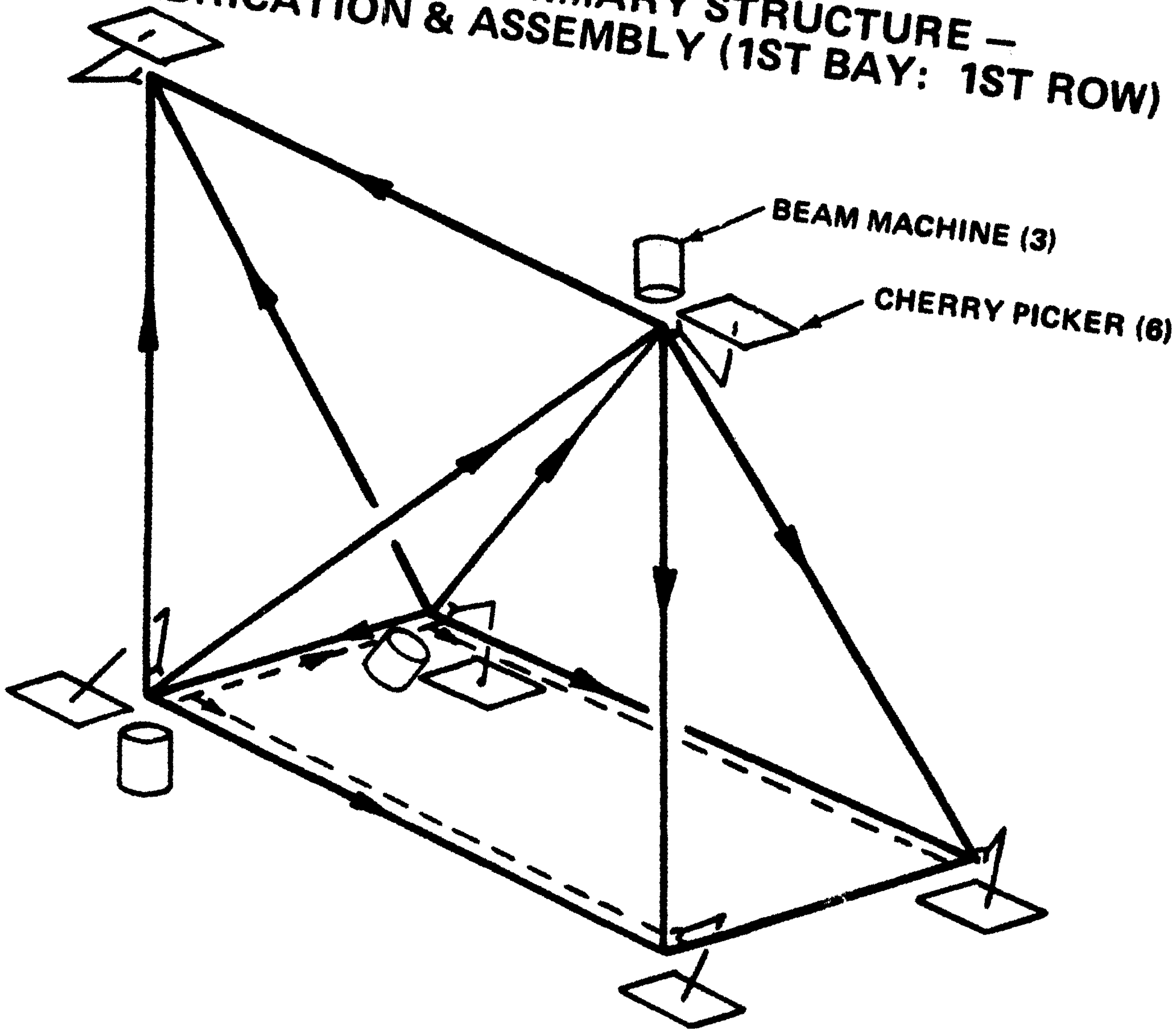
0580-020W

ANTENNA PRIMARY STRUCTURE – FABRICATION & ASSEMBLY

(1ST BAY: 1ST ROW)

Equipment types and quantities for building the antenna within the prescribed timeline are dicated by baseline construction scenarios. Considering the first row of the primary structure, three beam machines and six cherry pickers will build all structural elements. Except for the 1st structural bay, each beam builder substation fabricates 3 beams in the required orientation and location. During the assembly of the first bay in each row, 4 or 5 beams may be fabricated from these fixed beam builder substations. As shown in the illustration, the outboard edge member is transferred to its assembly location by cherry pickers, after it is produced by a beam machine located on the same level. The other beams in this structure are produced and located by pointing the pivot mounted beam machines in the required direction. Cherry pickers, located at node points, then align the beams and join them. An arrow on each beam member shows its direction of fabrication and indicates the beam machine which produced it.

ANTENNA PRIMARY STRUCTURE – FABRICATION & ASSEMBLY (1ST BAY: 1ST ROW)



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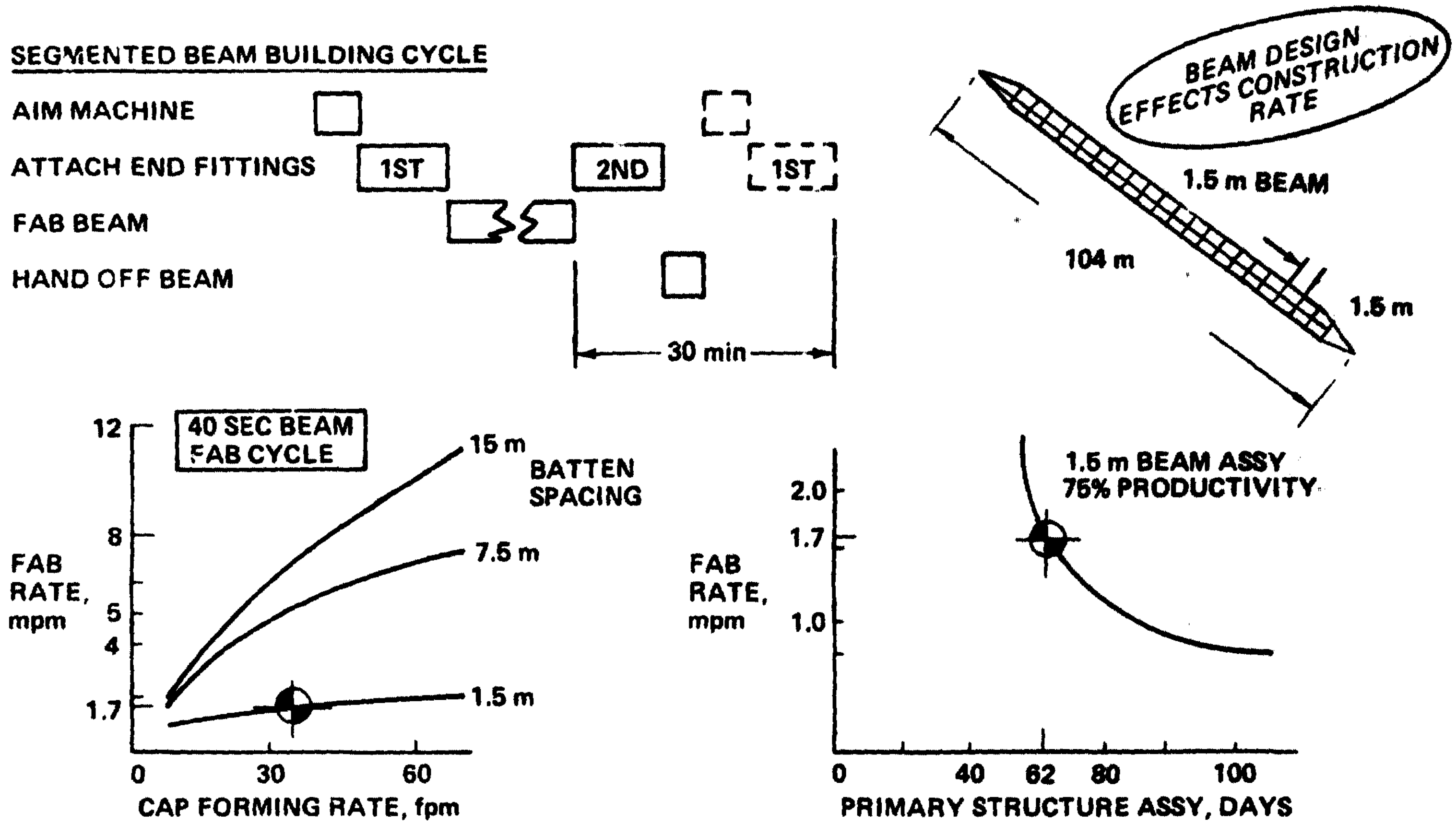
ANTENNA PRIMARY STRUCTURE FABRICATION REQUIREMENTS

Requirements on segmented beam design and automated beam building operations affect the assembly rates achievable for the antenna primary structure. For example, automated fabrication of the segmented beams for the pentahedral structure requires that four basic operations must be performed as shown on the facing page. A typical beam building cycle includes about 30 minutes for handling each 104-m long beam. This time is over and above beam fabrication time and allows for alignment of the beam builder and attaching end fittings. The actual fabrication time is a function of beam length and beam batten spacing design. Achievable composite beam fabrication rates are shown in the lower left corner of the chart for different beam batten spacings and beam cap forming rates. (These data were developed by Grumman in support of its Phase 1 SPS studies for Boeing-D180-25037-2). For the required beam batten spacing of 1.5 m, a fabrication rate of 1.7 m/minute was selected since the curve quickly becomes asymptotic above this rate. Using the foregoing data and a productivity rate of 75%, primary structure requires at least 62 days to be assembled.

ANTENNA PRIMARY STRUCTURE FABRICATION REQUIREMENTS



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0580-018W

ANTENNA FLATNESS & SUPPORT CONSIDERATIONS

To achieve the required SPS microwave power transmission performance, the solid-state antenna must be constructed to meet similar flatness requirements to those defined for the reference klystson antenna. The basic alignment requirement for the subarray surface is ±3 arc minutes in the operating environment. This includes all manufacturing errors, all static and dynamic movement due to construction flight attitude loads, and all related thermal distortions. A recent study on achievable flatness in Large Microwave Power Antenna (NAS9-15423) recommended a design goal of 2.00 arc minutes rms for the subarray slope error. This 2.00 design slope error was budgeted between manufacturing tolerance (1.50), maneuvering tolerance (1.10), thermal allowance (0.70) and attitude control system (0.00). Attitude control errors only become important for the completed SPS when line-of-sight pointing accuracy must be maintained. At that point any built in manufacturing bias should be detectable and correctable by electronic beam offset techniques.

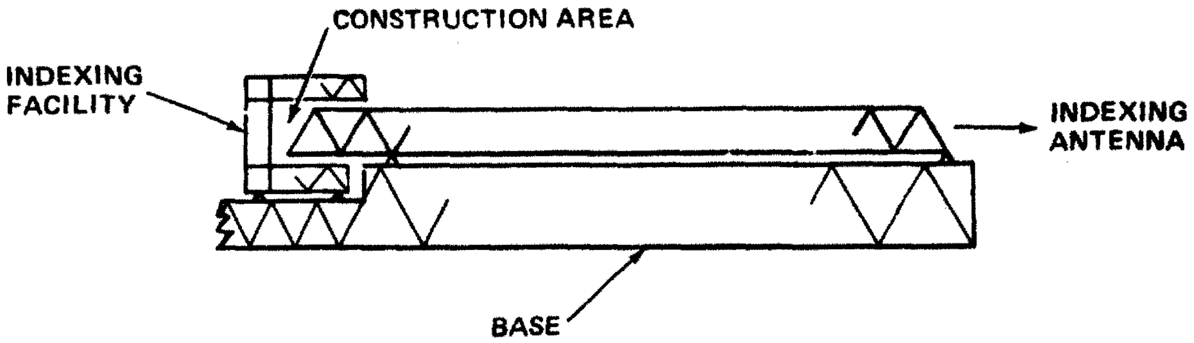
During space assembly, the antenna is supported by indexers which run on a flatbed outrigger structure. Deviations from flatness of the bed will be reflected in the flatness of antenna structure. Other sources of misalignment during fabrication are tolerances of the structural beam lengths and of assembly jigs. A proposed solution for this problem is to locate Electro Optical Distance Measuring Equipment on the base and optical reflectors at suitable points on the emerging antenna. The equipment will sense misalignments and call for adjustments of structure beam lengths to compensate.

The firing of attitude control thrusters will impose inertia forces on the antenna, resulting in distortion of its structure. These distortions can be minimized by the number of indexers tying the antenna to the stiffer base.

Thermal distortion effects, due to differing thermal coefficients for dissimilar materials and to thermal expansion variation with sun/shade changes, require careful materials selection and a constant attitude to the sun.

While plausible techniques have been identified to meet the antenna flatness requirement, a great deal of additional analysis and technology development work remains to be accomplished before we can be confident in the achievable flatness. For example, future dynamic analysis of the satellite construction process should investigate the effect of base interactions on the surface flatness of the emerging antenna.

ANTENNA FLATNESS & SUPPORT CONSIDERATIONS



<u>*MISALIGNMENT SOURCES*</u>

- FABRICATION
  - STRUCTURE ELEMENT TOLERANCES
  - ASSY JIGS TOLERANCES
  - INDEXING BED FLATNESS
- CONTROL FORCES
  - INERTIAS RESULTING FROM BASE ATTITUDE CONTROL IMPULSES
- THERMAL EFFECTS
  - DISSIMILAR MATERIALS
  - BASE SHADOWING
  - LIGHT/DARK CYCLING

<u>CANDIDATE SOLUTIONS</u>

- ELECTRO OPTICAL ALIGNMENT SENSING
- LENGTH ADJUSTMENT ON STRUCTURE ELEMENTS
- SUFFICIENT INDEXING TIEDOWNS
- MAINTAIN CONSTANT ATTITUDE TO SUN

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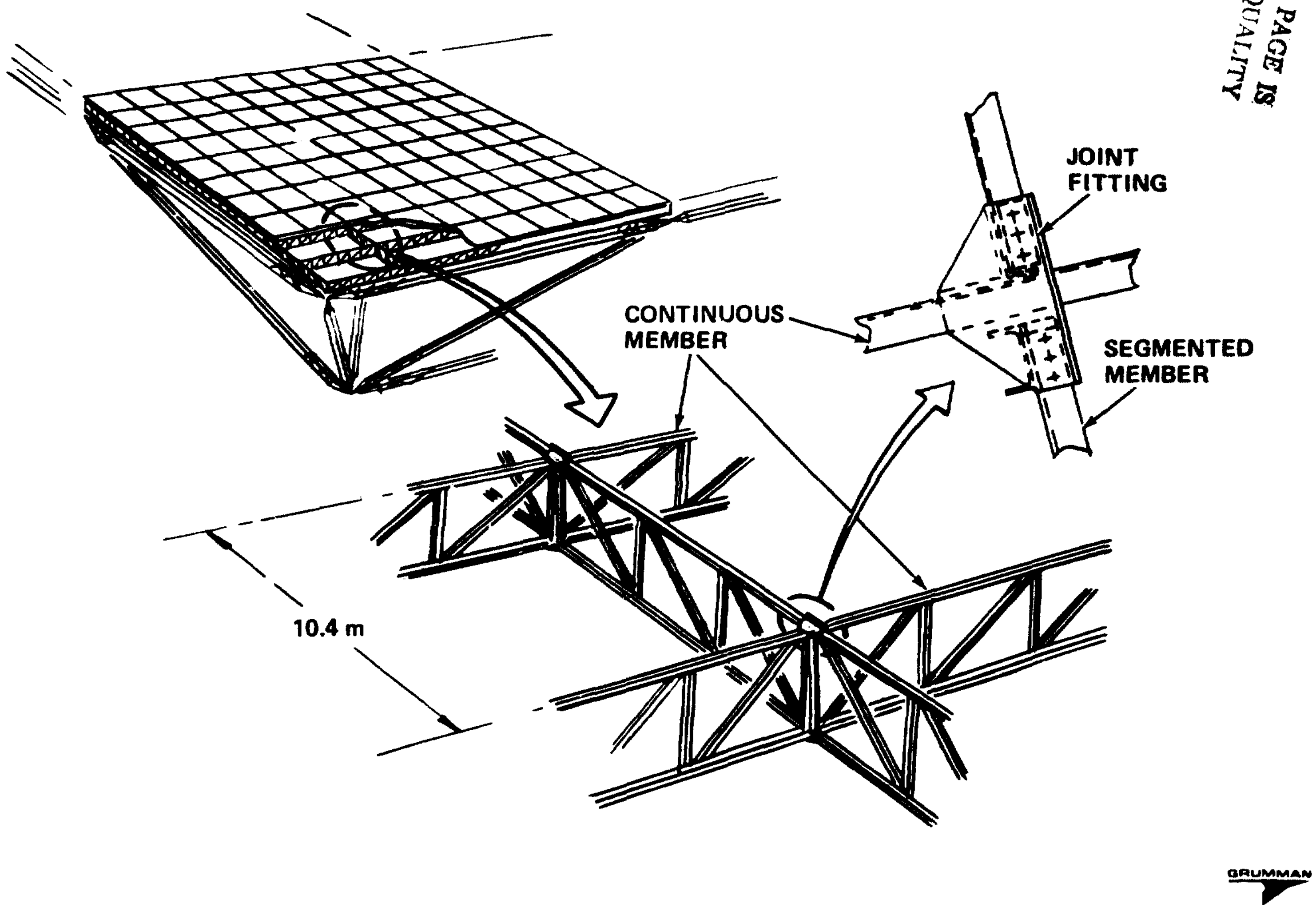
0580-017W

SECONDARY STRUCTURE ASSEMBLY REQUIREMENTS

A secondary structure is necessary to provide mounts for the 100 subarrays located within each pentahedral bay. This eggcrate structure is assembled with 2.5 m deep beams which are spaced to support the 10.4 m-wide subarrays and provide lateral stability at 20.8 m intervals. The longitudinal and lateral beams are joined to form a grid work having 50 cells (10.4 m x 20.8 m). The following charts consider the options for assembling and installing this structure.

SECONDARY STRUCTURE ASSEMBLY REQUIREMENTS



0580-015W

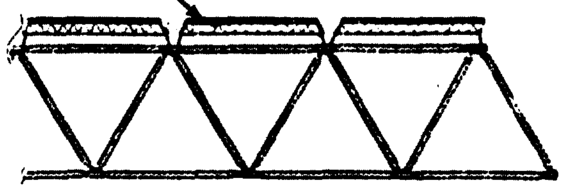
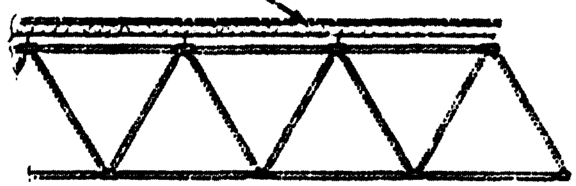
SECONDARY STRUCTURE INSTALLATION CONCEPTS

The secondary structure can be built as segments to cover one bay of the primary structure, or it can be built as a continuous structure covering the whole antenna. Segmented structure is easier to assemble, handle and install since it can be built in the 104 m square units then individually mounted at three points to the primary structure, thus minimizing effects of primary structure operational distortions. A disadvantage is that, being separate squares, closing members are necessary and these add to the total beam length and antenna mass.

Continuous secondary structure adds to antenna overall stiffness, which helps to minimize subarray flatness distortions during operation. Installation to the primary structure is more complex since it would be built in sections, which are then attached to the primary structure and to each other by moment carrying joints.

The segmented secondary structure approach is the preferred option since it simplifies construction.

SECONDARY STRUCTURE INSTALLATION CONCEPTS

	SEGMENTED SECONDARY STRUCTURE 	CONTINUOUS SECONDARY STRUCTURE 
ADVANTAGE	• SIMPLER ASSY & INSTALLATION • MINIMIZES EFFECTS OF PRIMARY STRUCTURE DISTORTIONS	• ADDS TO ANTENNA STIFFNESS
DISADVANTAGE	• ADDITIONAL BEAM LENGTH	• MORE DIFFICULT ASSY & INSTALLATION • SHARES PRIMARY STRUCTURE DISTORTIONS

0580-014W

SECONDARY STRUCTURE ASSEMBLY OPTIONS

Options for building the 104 m^2 secondary unit are presented on this chart. The basic building element is a 2.5 m deep beam which may be prefabricated on the ground for high density nestable space transport or produced in space by automated beam machines. The beams form an eggcrate pattern, made up from 10.4 m x 20.8 m rectangles.

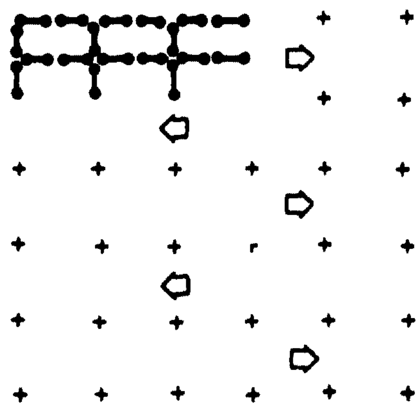
One option is to assemble the unit completely from 10.4 m long beams. This would be done by a facility weaving across a support bed, assembling in series as it goes. Many joints must be made to assemble two, three and four beams at a time.

Second option is to build from 20.8 m long beams. This involves a similar operation to the 10.4 m beams assembly but reduces the number and complexity of the assembly joints.

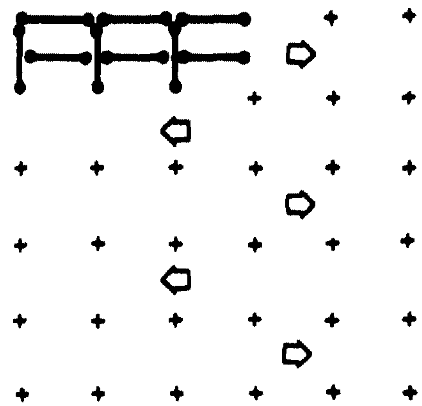
Third and fourth options use the end builder principle by producing synchronized continuous beams in one direction, joined by segmented beams to form the eggcrate structure. In one case, 11 beam machines fabricate continuous beams which are interjoined by sixty 10.4 m beams. The other case uses six beam machines to produce continuous beams interjoined by fifty-five 20.8 m beams.

Selection of a preferred option requires consideration of equipments and timelines, which are reported on the next chart.

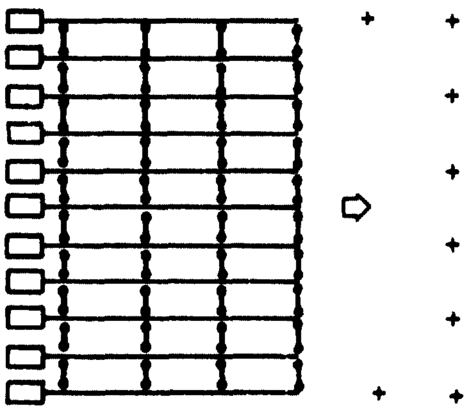
SECONDARY STRUCTURE ASSEMBLY OPTIONS



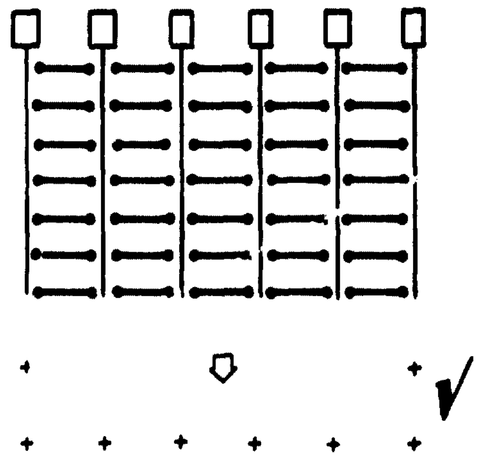
10.4 m BEAM BUILDUP



20.8 m BEAM BUILDUP



11 BEAM AUTOFAB



6 BEAM AUTOFAB

0580-013W

SECONDARY STRUCTURE ASSEMBLY OPTIONS COMPARISON

The two preceding charts discussed concepts for building the secondary structure and optional ways of assembling the selected concept. The four assembly options (10.4 m or 20.8 m beam buildup and 6 or 11 beam autofab) are compared on the facing page in terms of their structural assembly method, total assembly time, required construction equipment, construction base impact, and number of crew operators per shift.

As previously noted, the secondary structure must be completed and installed in parallel with the assembly of preceding primary structure. Due to the primary structure assembly time limit (308 minutes), only the two autofab methods can meet this requirement. Both methods require four crew operators and have the same impact on the base. The discriminator is, therefore, the number of beam machines and dispensers. This leads to the six beam autofab method as the preferred option.

SECONDARY STRUCTURE ASSEMBLY OPTIONS COMPARISON

	10.4 m BEAM BUILDUP	20.8 m BEAM BUILDUP	11 BEAM AUTOFAB	6 BEAM AUTOFAB
ASSEMBLY METHOD	SERIES BAY-TO-BAY	SERIES BAY-TO-BAY	SYNCHRONIZED FRAME-TO-FRAME	SYNCHRONIZED FRAME-TO-FRAME
ASSEMBLY TIME, MIN	930	720	225	305
CONSTRUCTION EQUIPMENT	100 m GANTRY 2 BEAM DISPENS (10 m LAT & LONG) JOINERS	100 m GANTRY 2 BEAM DISPENS (20 m LAT & LONG) JOINERS	11 BEAM BUILDERS 10 LAT DISPENS (10 m) JOINERS	6 BEAM BUILDERS 5 LAT DISPENS (20 m) JOINERS
BASE IMPACT	MOBILE SUBSTA SUPPORT	MOBILE SUBSTA SUPPORT	FIXED SUBSTA UTILITIES	FIXED SUBSTA UTILITIES
CREW OPERATORS	8	6	4	4
PRIMARY STRUCTURE ASSEMBLY LIMITATION = 308 MIN				PREFERRED

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0580-012W

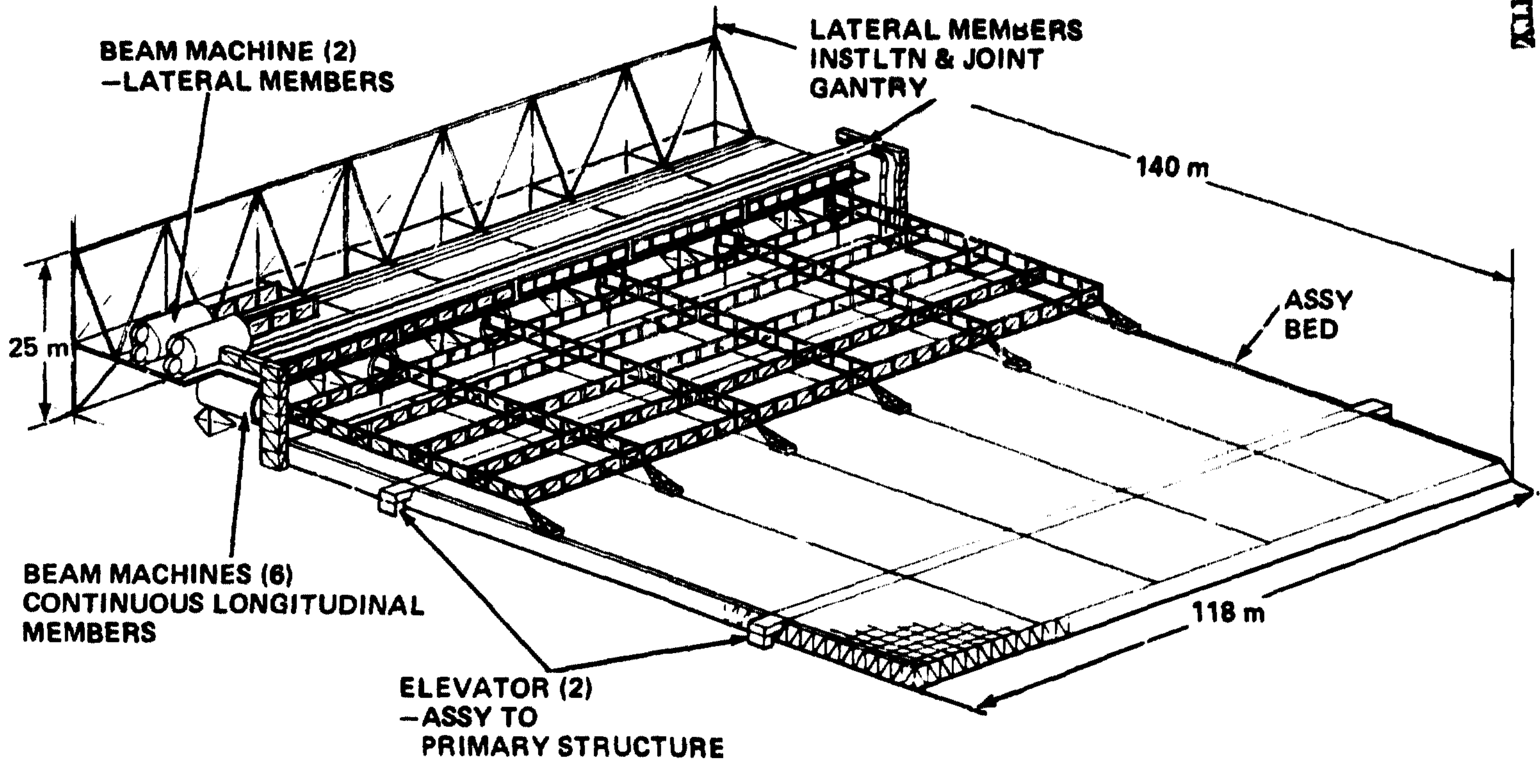
SECONDARY STRUCTURE ASSEMBLY STATION

This station is located in the antenna assembly facility which indexes across the construction base to build the antenna in successive rows. Here, secondary structure is fabricated, assembled and installed.

The secondary structure assembly station is 140 m x 118 m x 25 m in size. A large bed, sized for the 104 m per side structure unit, provides a flat surface for its assembly. This assembly station operates like a mini end builder which operates six beam machines to fabricate continuous longitudinal, two-dimensional, 2.5 m beams in unison. At the same time, two similar beam machines located at an upper level produce 20.8 m beams. These segmented beams are collected by the Lateral Member Installation gantry for assembly to the continuous beams. Continuous beam fabrication proceeds in 10.4 m steps to accommodate synchronized lateral member attachment operations. The gantry, with five 20.8 m beams mounted on it, positions and joins these beams to the continuous longitudinal beams. The gantry then returns to its original position to collect five more short beams. As this process is repeated, the assembled structure is indexed outboard across the bed. Indexers guide the leading edge of the structure to maintain the required geometry and provide structural support.

On completion of this 104 m^2 unit structure, two elevating cross beams lift and support the secondary structure for its attachment to the primary structure positioned overhead.

SECONDARY STRUCTURE ASSEMBLY STATION



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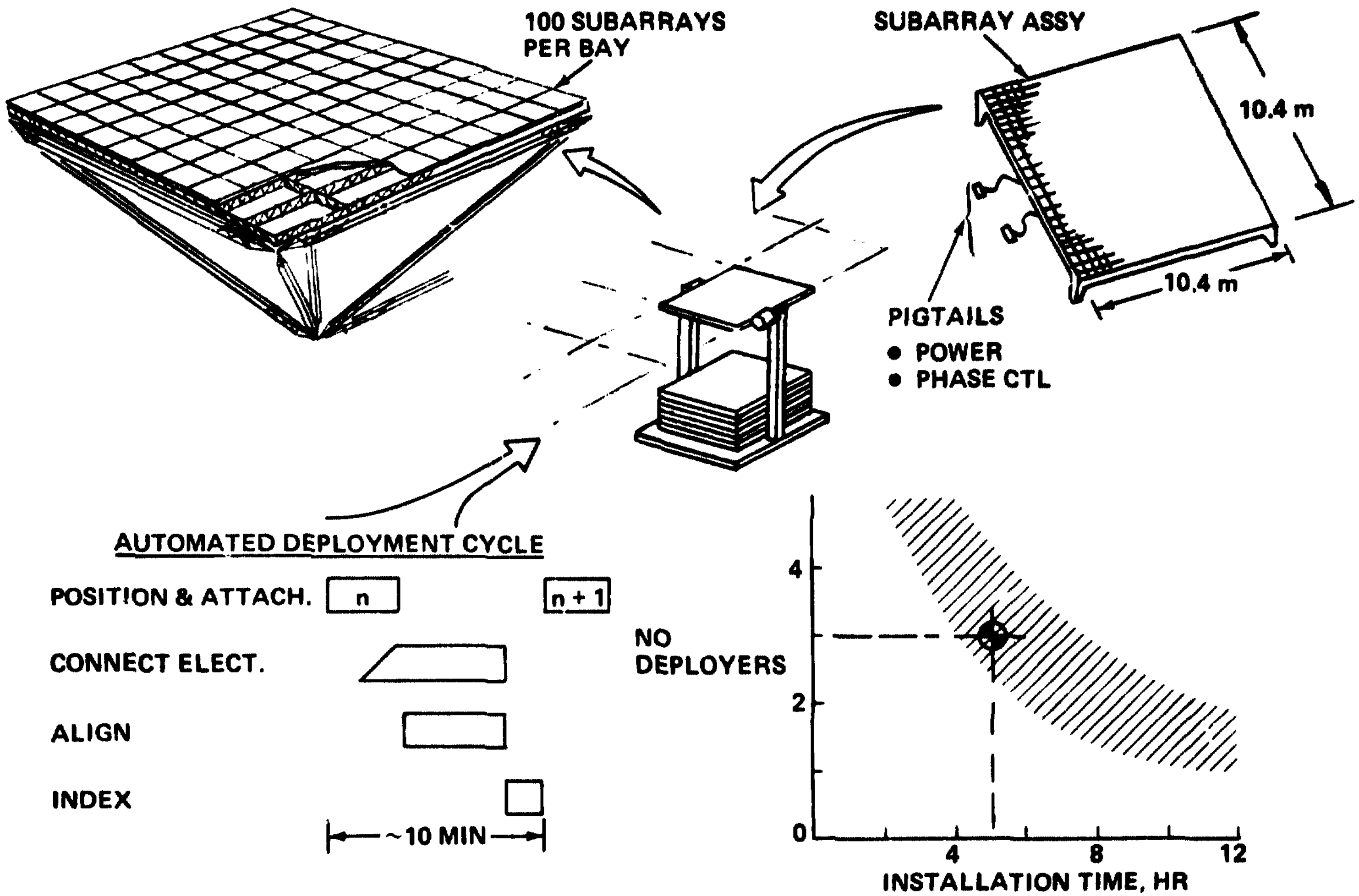
0580-054W

SOLID-STATE SUBARRAY INSTALLATION REQUIREMENTS

Once the secondary structure is attached to each bay of primary structure, 100 preassembled solid state subarrays must be installed as shown on the facing page. Each 10.4 m^2 subarray has mechanical and electrical connections to be made. The method for automatically dispensing and installing each subarray is based on the equipment concepts defined in Boeing's earlier System Definition Study (document D 180-24071-1). Subarray deployment was estimated to be about 10 minutes. Therefore, the number of deployers needed for the subarrays is a function of the installation time, which must match the time allotted to the building of primary structure. At least three deployers are needed to meet this requirement.

SOLID-STATE SUBARRAY INSTALLATION REQUIREMENTS

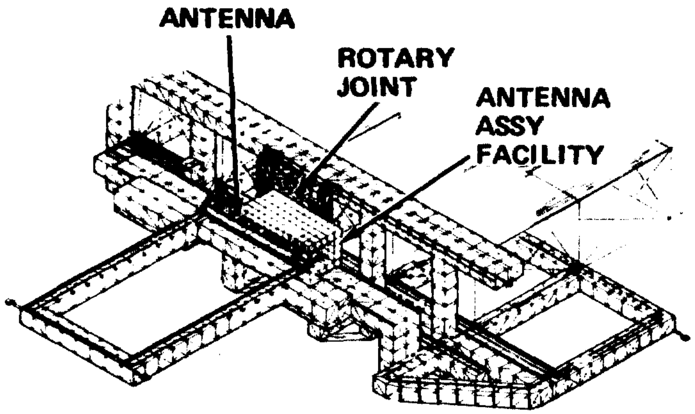


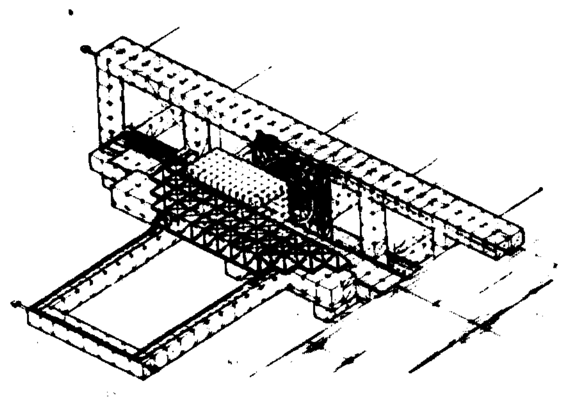
0580-016W

ANTENNA CONSTRUCTION OPERATIONS

These figures show the construction base and illustrate antenna construction operations as described in some detail in earlier charts. The antenna is built in one direction, bay by bay, with an assembly facility which indexes across the base. As the antenna is progressively built, the completed rows are indexed outboard and the assembly facility tracks back to start building the next row. The antenna assembly facility and the rotary joint assembly facility are able to operate independently and index across the base as needed. The rotary joint, which provides electrical and mechanical interface between energy conversion and power transmission systems, is built in parallel.

ANTENNA CONSTRUCTION OPERATIONS





- BUILD FIRST ROW OF ANTENNA BY INDEXING ASSEMBLY FACILITY
- START ROTARY JOINT CONSTRUCTION IN PARALLEL

- CONTINUE ANTENNA BUILD, ROW-BY-ROW, TO COMPLETION
  - INDEX ASSY FACILITY FOR EACH ROW
  - INDEX ANTENNA OUTB'D AS EACH ROW IS COMPLETED
- CONTINUE ROTARY JOINT CONSTRUCTION TO COMPLETION

OF POOR QUALITY

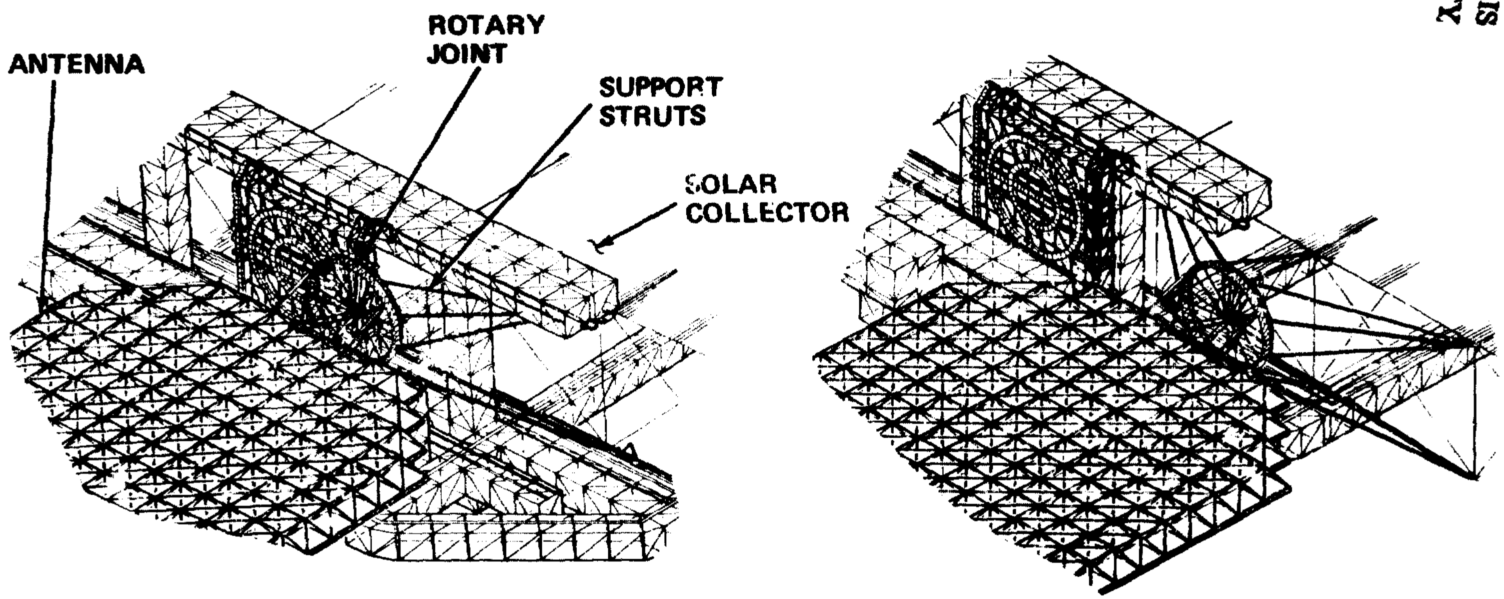
0580-056W

FINAL SYSTEMS MATING

When the power transmission system is fully constructed, the antenna assembly facility is moved away and the rotary joint facility is positioned to build and attach the interface end-mounted linear actuator support structure. The electrical bus is fed across this structure to connect the rotary joint slip ring with the antenna systems.

Final mating of antenna and solar collector assemblies is accomplished, similar to the reference approach, as shown on the facing page. First the base is indexed to the solar collector antenna support strut pickups, then the antenna assembly is indexed to align with the collector and the rotary joint facility is positioned. Two mobile 7.5 m beam builder substations, mounted on the joint facility, initiate fabrication of the outboard support struts. These stations align the beam fabrication with the collector-pickup point areas where cherry pickers mounted on the collector facility wait to capture and attach the fabricated struts to the collector attach fittings. The joint facility mobile cherry picker perform this same operation in attaching the strut end to the rotary joint pickup fitting. This procedure is repeated until all five outboard struts are installed. Next the base is re-indexed and the joint facility is repositioned to fabricate and install the four center 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 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 OPERATION



- INSTALL ANTENNA/ROTARY JOINT INTERFACES
- INDEX BASE TO SOLAR COLLECTOR PICKUP
- INDEX ANTENNA TO ALIGN WITH COLLECTOR
- POSITION ROTARY JOINT FACILITY TO FAB & INSTALL ONE SET OF SUPPORT STRUTS
- RE-INDEX BASE & REPOSITION ROTARY JOINT FACILITY TO FABRICATE & INSTALL REMAINING SUPPORT STRUTS
- INSTALL POWER BUS.
- FINAL CHECKOUT

0580-057W

SOLID-STATE SPS CONSTRUCTION EQUIPMENT COMPARISON

This chart identifies changes in baseline equipment when going to a solid-state SPS. Redesigned primary structure affects numbers and sizes of beam builders. The heavy increase in the number of cherry pickers is due to the shorter time available to build each SPS when striving for production goal of 10 GW per year. In addition, due to the lower operating voltage of the solid state system, the power bus in the energy conversion system is much wider (250 m vs 75 m) and requires more bus deployers. As a result, the total equipment used for constructing the Solid State SPS is heavier than the reference equipment listing (481.1 MT vs 460 MT). It also requires a higher investment cost to begin construction operations ($2251M vs $1800M).

SOLID-STATE SPS CONSTRUCTION EQUIPMENT COMPARISON

EQUIPMENT	5 GW BASELINE	2.5 GW SOLID-STATE	RATIONALE
• BEAM BUILDERS			
1.5 m MOBILE MANNED	–	3	PH-2 VS PH-1 DEFN
7.5 m MOBILE MANNED	2	–	
• CHERRY PICKERS			
30 m	–	17	MPTS ASSY & SOLAR ARRAY
90 m	2	–	
120 m	2	–	
150 m	–	1	
250 m	1	–	
• INDEXERS			
45 m SINGLE SUPPORT	–	5	
130 m SINGLE SUPPORT	6	–	
230 m SINGLE SUPPORT	2	–	
20 m MULTI SUPPORT	–	2	ASSY FACILITY INDEX REQ
70 m MULTI SUPPORT	–	2	ASSY FACILITY INDEX REQ
BUS DEPLOYERS			
– ENERGY CONV BUS	1	3	LOWER VOLTAGE REQ
– ANTENNA BUS	1	1	
ANTENNA DEPLOYMENT PLATFORM	1	–	
SECONDARY STRUC ASSY SUBSTA		1	
SUBARRAY DEPLOYERS		3	

Δ MASS = +21.1 MT
Δ COST = $+451M

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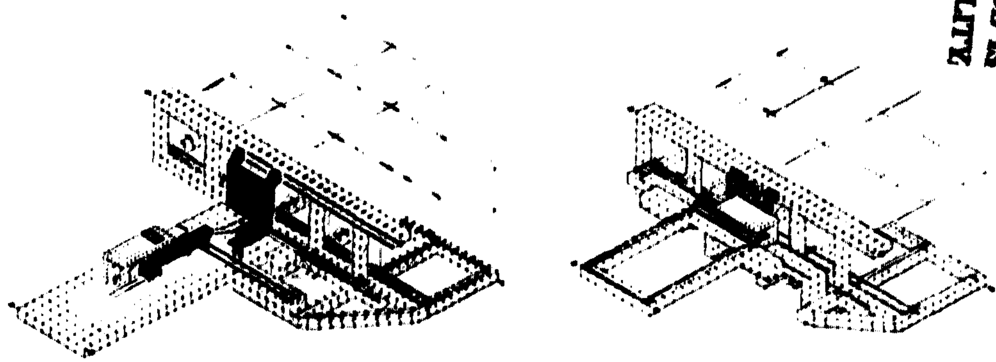
0580-011-V

SOLID STATE SPS GEO BASE STRUCTURE COMPARISON

A comparison of the estimates on GEO base structure mass and cost are shown on the facing page for the reference SPS and for the solid state option. The major difference between these 4 Bay End Builder construction bases lies in the geometry, arrangement and support of their respective antenna construction platforms. While these platforms are located at different levels on each base, they are both attached to the support structure shared by the rotary joint assembly facility.

At this stage of concept development, the solid state SPS construction base is somewhat lighter than the reference GEO base. The alternate solid state antenna construction platform could also be modified to build the smaller reference antenna (1.0 km vs 1.4 km diameter). If that were done, the modified reference would then be lighter than the solid state construction base shown.

SOLID STATE SPS GEO BASE STRUCTURE COMPARISON



	5 GW REF END BUILDER	2.5 GW SOLID STATE END BUILDER
ANTENNA ASSY CAPABILITY	1.0 km dia	1.4 km dia
BASE STRUCTURE		
• MASS	2927 MT	Δ = -142 MT
• UNIT COST (1979$)	$337M	Δ = -$17 M

MODIFY REF BASE
FOR ALT ANTENNA
CONSTRUCT. APPROACH

SOLID STATE SPS CONSTRUCTION BASE IMPACTS

The impact of Solid State SPS construction is summarized on the facing page in terms of penalty (or gain) to the reference GEO base mass, cost and productivity.

The reference base work facilities must be revised primarily for the solid state antenna construction operation. Due to the alternate antenna construction approach, less structure is needed for the base. However, to strive for the 10 GW annual production goal, additional construction equipment and operating crews are needed. It is estimated that reference construction crew (444) must be increased by 47 people which necessitates that another 17 m diameter habitat be added. The net effect increases the initial mass of the reference base by 122 MT. The investment cost and annual operations costs also increase as shown. For the Solid State SPS construction base defined, it was not practical to accelerate the antenna assembly operation further to complete construction in less than 104 days. Consequently, productivity of the Solid State SPS construction base is 86.5% of the reference. It is possible, however, that another more highly automated antenna facility could have built the entire solid state satellite in the desired time. This remains as an area for future study.

SOLID-STATE SPS CONSTRUCTION BASE IMPACTS

BASE PRODUCTIVITY
- SOLID STATE SPS = 8.65 GW/YR
- REFERENCE SPS = 10 GW/YR

GEO BASE ELEMENT	Δ MASS, MT	Δ UNIT COST, $M79
WORK FACILITIES		
– STRUCTURE	- 142	- 16
– CONSTRUCTION EQUIPMENT	21.1	451
CREW SUPPORT FACILITIES		
ADDED HABITAT (17 m DIA)	243	385
WRAPAROUND FACTOR (47%)		385
TOTAL	122 MT	$1205M

ANNUAL OPERATIONS (+ 47 CREW)		
SALARIES & TRAINING		70
RESUPPLY	119 MT/YR	67
		$ 137M/YR

0580-009W

SOLID STATE SPS OPERATIONAL FACTORS

This chart compares some of the solid state SPS operational factors to those of the reference SPS.

Industrial Complex - More solar array, graphite fiber, and aluminum power bus sheet will be required over 2.5 billion FETS/satellite will be required. Berylium oxide will be consumed at 19000MT/yc.

Rectenna Construction - Will require four of the 2.5 gw ground receiving stations to be brought on-line each year. Two times as many sites will be required as for the reference but the sites will be half the size.

Launch and Recovery Site - The additional mass-to-orbit per year will require an additional HLLV orbiter and booster. This will require larger vehicle processing facilities. No additional launch pads will be required.

LEO Base - No impact.

Space Transportation - Four additional EOTV's will be required in the fleet.

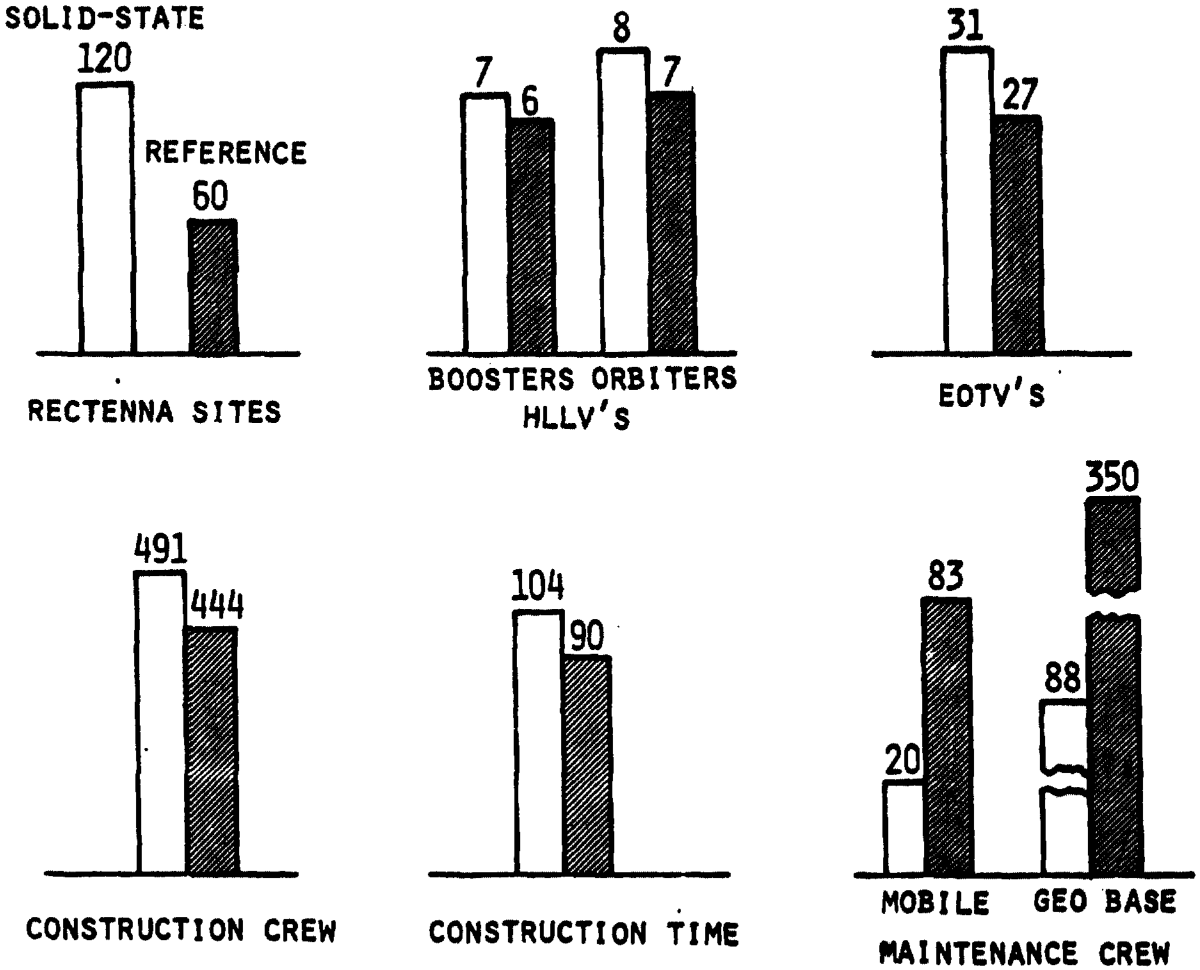
GEO Base - The impact on the GEO base is discussed in detail on other charts.

Maintenance - Several hundred phase control system component failures per year per satellite will be the primary maintenance requirement. The solid state transmitter can tolerate substantial numbers of failures.

Utility Grid - No significant impacts.

Mission Control - No significant impacts.

SOLID STATE SPS OPERATIONAL FACTORS



SOLID STATE SPS MASS AND COST SUMMARY

The mass estimate for the realized solid state configuration and the cost estimate for the satellite only are summarized on the facing page. The cost figures shown do not include space transportation, space construction, or the ground antenna.

SOLID STATE SPS MASS & COST SUMMARY

		MASS (MT)	ESTIMATING BASIS	COST ($M)
1.1	SPS	30,201		3,890
1.1.1	ENERGY CONVERSION	17,037		1,662
1.1.1.1	STRUCTURE	2,333	Detailed Estimate	225
1.1.1.2	CONCENTRATORS	(0)	Not Required	(0)
1.1.1.3	SOLAR BLANKETS	12,027	Scaled from Reference	1,131
1.1.1.4	POWER DISTRIB.	2,250	Detailed Estimate	116
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	7,296		1,289
1.1.2.1	STRUCTURE	460	Scaled from Reference	38
1.1.2.2	TRANSMITTER SUBARRAYS	6,673.0	Detailed Estimate	1,097
1.1.2.3	POWER DISTR. & COND.	631.0	Scaled from 1.1.1.4	70
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.	5,464	Same % as Reference	701

SPS MASS COMPARISONS

Mass estimates for the referenced SPS and the solid state options are summarized on the facing page. The improvement between the Phase II and Phase III systems came from the increase in distribution voltage and consequent reduction in power losses, principally reflected as a reduction in the solar array size.

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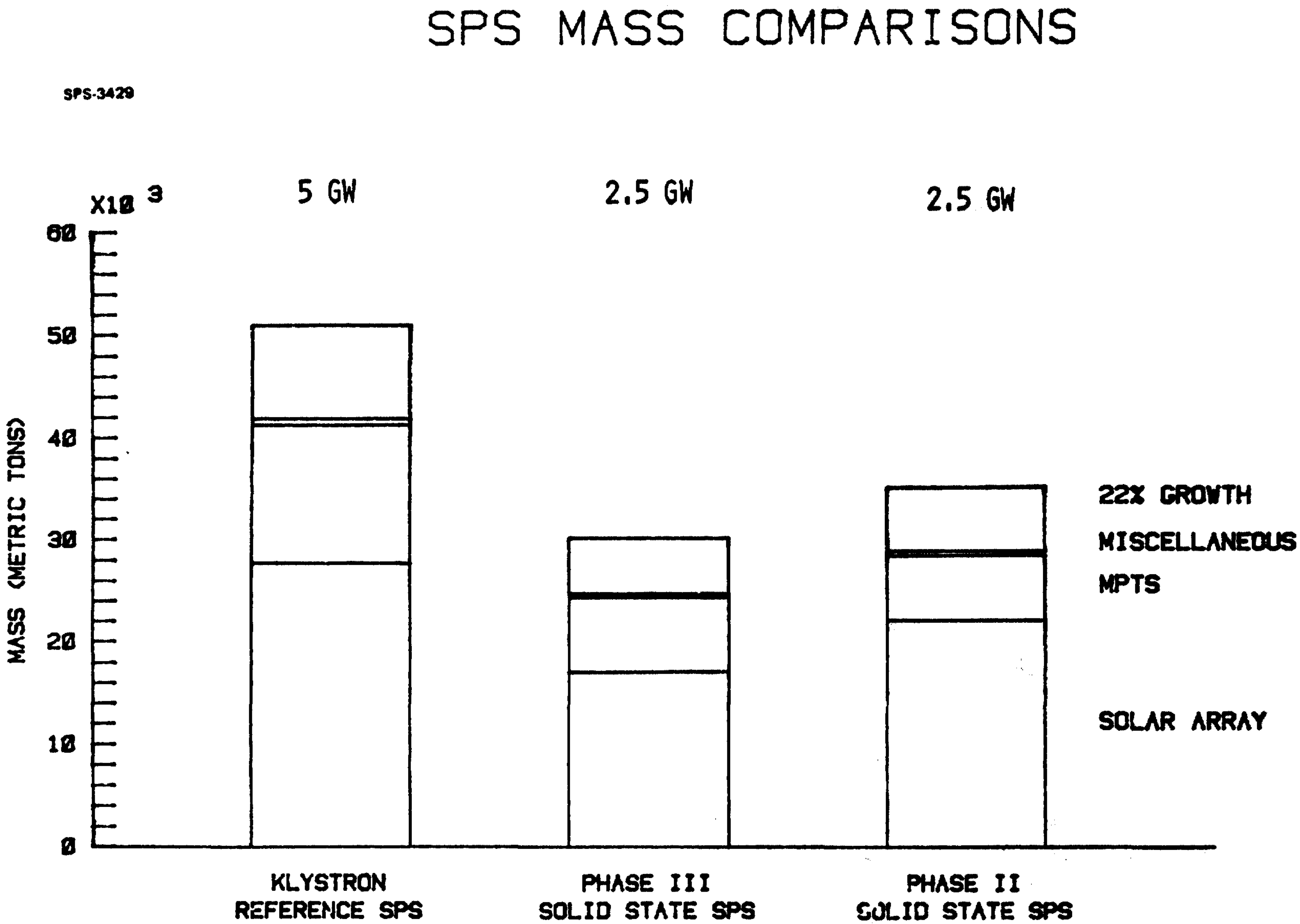
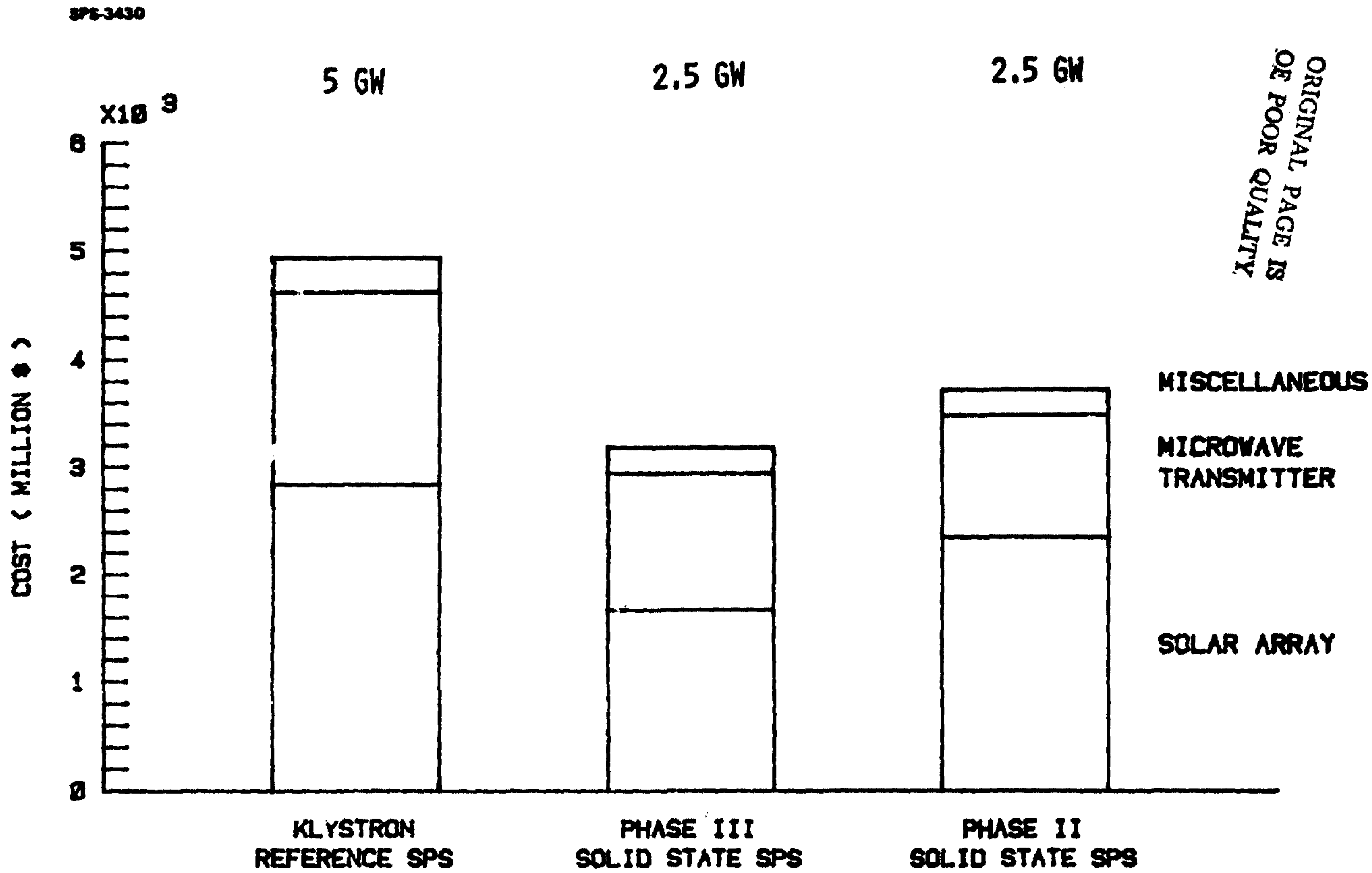

SPS MASS COMPARISONS
SPS-3429
X10 3
MASS (METRIC TONS)
60
50
40
30
20
10
0
5 GW
2.5 GW
2.5 GW
22% GROWTH
MISCELLANEOUS
MPTS
SOLAR ARRAY
KLYSTRON
REFERENCE SPS
PHASE III
SOLID STATE SPS
PHASE II
SOLID STATE SPS

SPS COST COMPARISONS

Not surprisingly, satellite cost deltas track the mass deltas. The main difference between the Phase II and Phase III solid state SPS costs is a substantial solar array cost reduction. The slight cost increase in the microwave transmitter is due to the fact that the Phase III solid state cavity combiner modules are somewhat more expensive (as they are also more massive).

SPS COST COMPARISONS

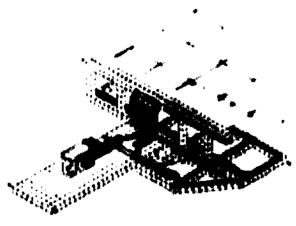
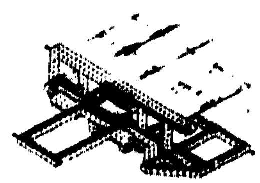


ALTERNATE SPS CONSTRUCTION BASES

Two construction bases were developed during Phase 3 for comparison with the Phase 2 reference GEO construction base. As shown on the facing page, one alternate base is defined to build a 2500 MW photovoltaic SPS with solid state transmitting antenna; a second alternate base is defined to build a 100 MW indirect optically pumped laser SPS. This chart compares the annual production rate, unit cost, mass, and crew required to operate these bases with the Phase 2 baseline, as updated on the preceding chart.

Further discussion on construction requirements for the solid state and laser systems is contained in the appropriate sections of this report.

ALTERNATE SPS CONSTRUCTION BASES

	BASELINE	SOLID-STATE	LASER
			
• SPS PRODUCTION RATE/YR	10 GW	8.65 GW	0.2 GW
• UNIT COST, 1979$	9.01B	10.21B	12.09B
• MASS, MT	6656	6778	4950
• CONSTRUCTION CREW	444	491	587

0980-066W

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SPS GEO CONSTRUCTION BASE – PHASE 3 CONCLUSIONS

- GEO BASE FOR SOLID STATE SPS CONSTRUCTION IS COMPARABLE TO PH-2 REF. BASE, EXCEPT
  - PROVIDES 15% LESS ANNUAL PRODUCTIVITY
  - NEEDS 10% LARGER CREW
  - ADDS 10% TO UNIT COST & OPERATIONS COST
- GEO BASE FOR IOP LASER SPS CONSTRUCTION IS SMALLER (25% LIGHTER) THAN PH-2 REF BASE, BUT
  - HAS 98% LOWER ANNUAL PRODUCTIVITY
  - USES 30% LARGER CREW
  - INCREASES UNIT COST & OPERATIONS COST 30%
- SMALLER CREW MODULES ADD 14% TO GEO BASE MASS
  - INCREASES INVESTMENT PHASE COSTS 50% (INITIALLY)
  - PROVIDES OPTION FOR EARLY DEVMT UNDER DEMONSTRATION PHASE

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SPS CONSTRUCTION TECHNOLOGY – RECOMMENDED NEXT STEPS

- BROADEN SATELLITE CONSTRUCTION TECHNOLOGY
  - ALTERNATIVE STRUCTURES & ASSEMBLY METHODS
  - SUBSYSTEM INSTALLATION TECHNIQUES
  - FINAL ASSEMBLY TEST & CHECKOUT CONCEPTS
- EXPAND CONSTRUCTION SYSTEM TECHNOLOGY
  - WORK FACILITY REQUIREMENTS & EQUIPMENT
  - CREW OPERATIONS SUPPORT & SAFETY
  - BASE/SATELLITE DYNAMICS & CONTROL
  - BASE BUILDUP REQUIREMENTS
- CONDUCT LABORATORY SCALE DEMONSTRATIONS
  - STRUCTURAL CONCEPTS & MATERIALS
  - STRUCTURAL FABRICATION & ASSEMBLY
  - CONSTRUCTION SUPPORT OPERATIONS
  - SUBSYSTEM ASSEMBLY METHODS
- ESTABLISH EARLY CONSTRUCTION EXPERIMENTS FOR SHUTTLE FLIGHT DEMO

GRUMMAN