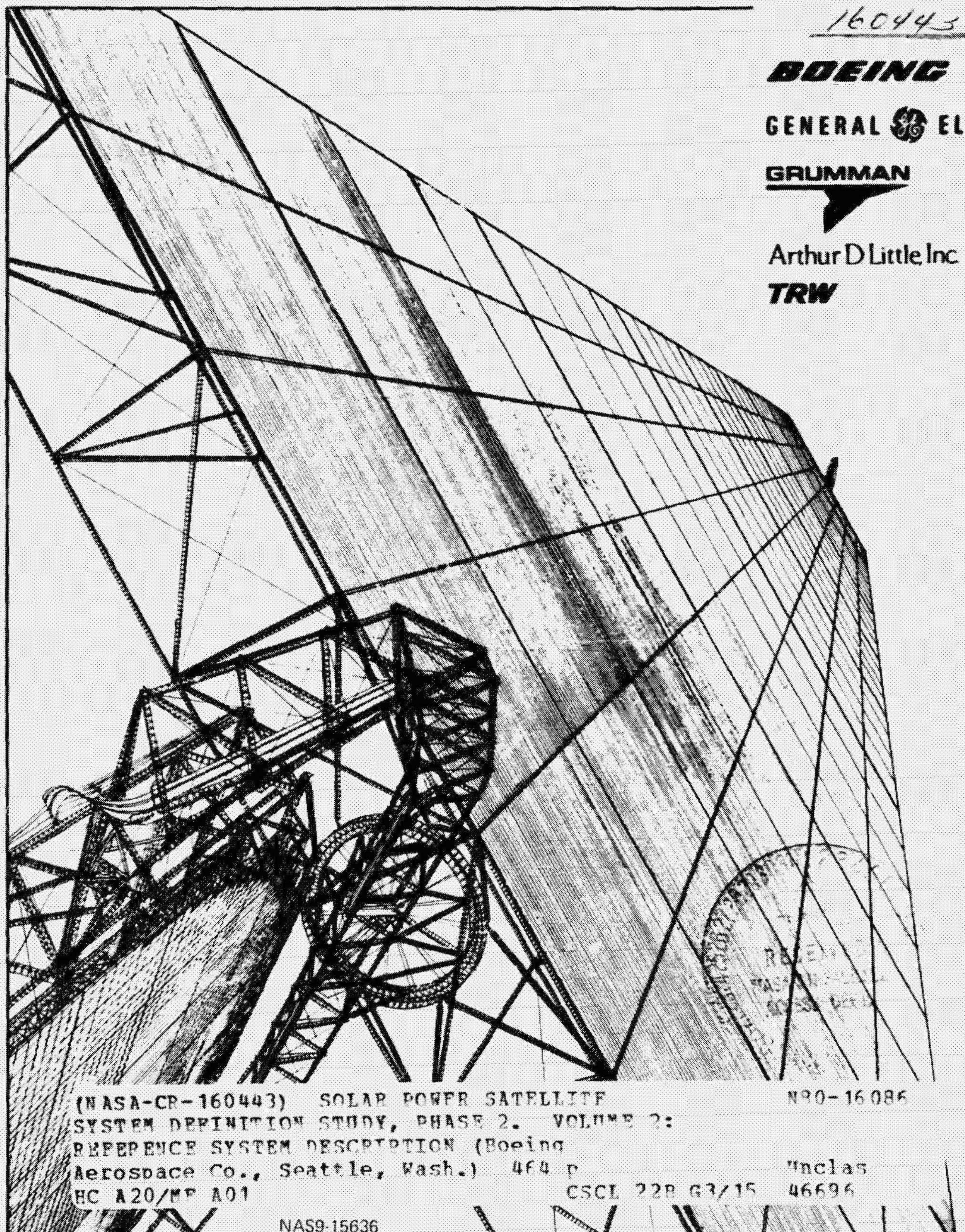
BOEING

Solar Power Satellite System Definition Study

PHASE II
VOLUME II
REFERENCE SYSTEM DESCRIPTION
D180-25461-2

NASA CR-
160443

BOEING
GENERAL ELECTRIC
GRUMMAN
Arthur D Little Inc
TRW



NAS9-15636
DRL T-1487
DRD MA-737T
LINE ITEM 4

REVISIONS

LTR	DESCRIPTION			DATE	APPROVAL
A	p.i	-	Added revision letter and date of revision		
	p.8	-	Last sentence of first paragraph is deleted.		
	p.9	-	Figure is deleted		
	p.15	-	Corrected mass for WBS 1.1.		
	p.17	-	Mass previously shows for WBS 1.1.6.4 was moved to WBS 1.1.7.		
		-	Flagnote *** added to WBS 1.1.7 cost.		
	p.87 (new)	-	Mass data for WBS 1.1.2.6 was mislocated in original. (Original p.87 to be replaced by new p.88A, see below.)		
	p.88	-	The WBS number and title on original was in error.		
	p.88A	-	Replaces original p.87.		
		-	Includes correct mass data for WBS 1.1.2.7.		
	p.88B	-	Cost data for WBS 1.1.2.7 erroneously not included in original is provided.		
	p.110	-	Photo replaced.		
	p.139	-	Deleted redundant WBS Dictionary statement.		
	p.229	-	Table 1.3.1-6 shown on this page in original was replaced with that shown on p.228.		
A	p.234	-	The LCH_4 and RP-1 propellant callouts under Stage 1 were interchanged.		

CR-160443

D180-25461-2

SOLAR POWER SATELLITE
SYSTEM DEFINITION STUDY
Conducted for the NASA Johnson Space Center
Under Contract NAS9-15636

Volume II
PHASE II, FINAL REPORT
Reference System Description
D180-25461-2

November, 1979

REVISION A
FEBRUARY, 1980

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FOREWORD

The SPS System Definition Study was initiated in June of 1978. Phase I of this effort was completed in December of 1978 and was reported in seven volumes (Boeing document number D180-25037-1 through 7). Phase II of this study was started in January 1979 and was completed in November 1979. The Phase II study results are reported herewith. This study is a follow-on effort to an earlier study of the same title completed in March of 1978. These studies are a part of an overall SPS evaluation effort sponsored by the U.S. Department of Energy (DOE) and the National Aeronautics and Space Administration.

This study is being managed by the Lyndon B. Johnson Space Center. The Contracting Officer is Thomas Mancusco. The Contracting Officer's representative and Study Technical Manager is Harold Benson. The study is being conducted by The Boeing Company with Arthur D. Little, General Electric, Grumman, TRW, and Brown and Root as subcontractors. The study manager for Boeing is Gordon Woodcock. Subcontractor managers are Dr. Philip Chapman (ADL), Roman Andryczyk (GE), Ronald McCaffrey (Grumman), Ronald Crisman (TRW), and Don Hervey (Brown and Root).

This report includes a total of five volumes:

- I - Executive Summary
- II - Reference System Description
- III - Operations and Systems Synthesis
- IV - Technical Analysis Report
- V - Phase II Final Briefing

Key team members that contributed in the various disciplines were the following:

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TABLE OF CONTENTS

INTRODUCTION

Document Purpose

One of the important functions of the SPS systems studies has been the preparation and maintenance of reference systems description documentation. This material is being used by various assessment studies for SPS evaluation.

The comparative assessment studies (comparing SPS's to other energy options) include a strong economic component. Accordingly, SPS cost estimates, their origins, and traceability, have become important. This document has been organized to emphasize cost visibility. A format has been chosen that enforces development and display of the data in a consistent and traceable manner.

Section I of this document provides a system description and cost estimate according to the work breakdown structure shown in Figure 1. Cost data are presented in terms of Design, Development, Test, and Engineering (DDT&E) and unit recurring costs. Where a theoretical first unit cost is an applicable term, this is given also. DDT&E costs are then described in terms of their apportionment to the program phases summarized in Table 1. Such apportionment is determined on the basis of an SPS program development scenario briefly summarized in the latter part of this book (Section II, Program Scenario and Non-Recurring Cost). The scenario is described in more detail in Volume IV of this report.

Cost Estimating Approach and Methodology

At the present state of SPS concept and design development it is necessary to use mainly a parametric cost estimating method. The two methods in common use are parametric and detailed or "grass roots" estimating. It is important to understand the differences in these methods and the different nature of the results.

Parametric Cost Estimating—Any parametric technique is keyed to the physical attributes of the thing being estimated.... usually mass but occasionally other attributes such as area, power, capacity, etc.

Parametric models operate at many levels. For familiar types of systems such as aircraft, high-level models exist that roughly predict cost on the basis of total aircraft weight for given aircraft type. One correlation has been published that purports to estimate the cost of any vehicular system, be it tank, truck, airplane, or ship, given only (1) mass; (2) installed power, and (3) quantity to be produced.

The Boeing Parametric Cost Model (PCM) used in this study is designed to operate at the subsystem or subsystem element level. Typical CER's represent computers, receivers, cabling, sensors, primary structure, etc. This allows the PCM to be used for unfamiliar systems such as an SPS provided that the system is made up of elements for which historical correlations exist.

The PCM is a semiautomated technique that has been used successfully on many previous studies and system definition activities. The key features of this methodology are summarized in Table 2. The PCM provides a high degree of cost visibility since it is very similar in structure to detailed cost estimating.

The PCM estimates costs beginning with the major component level (level 6 of the WBS) and builds upward to obtain the total program cost. Cost estimations are based on physical and performance parameters at the hardware level and programmatic parameters

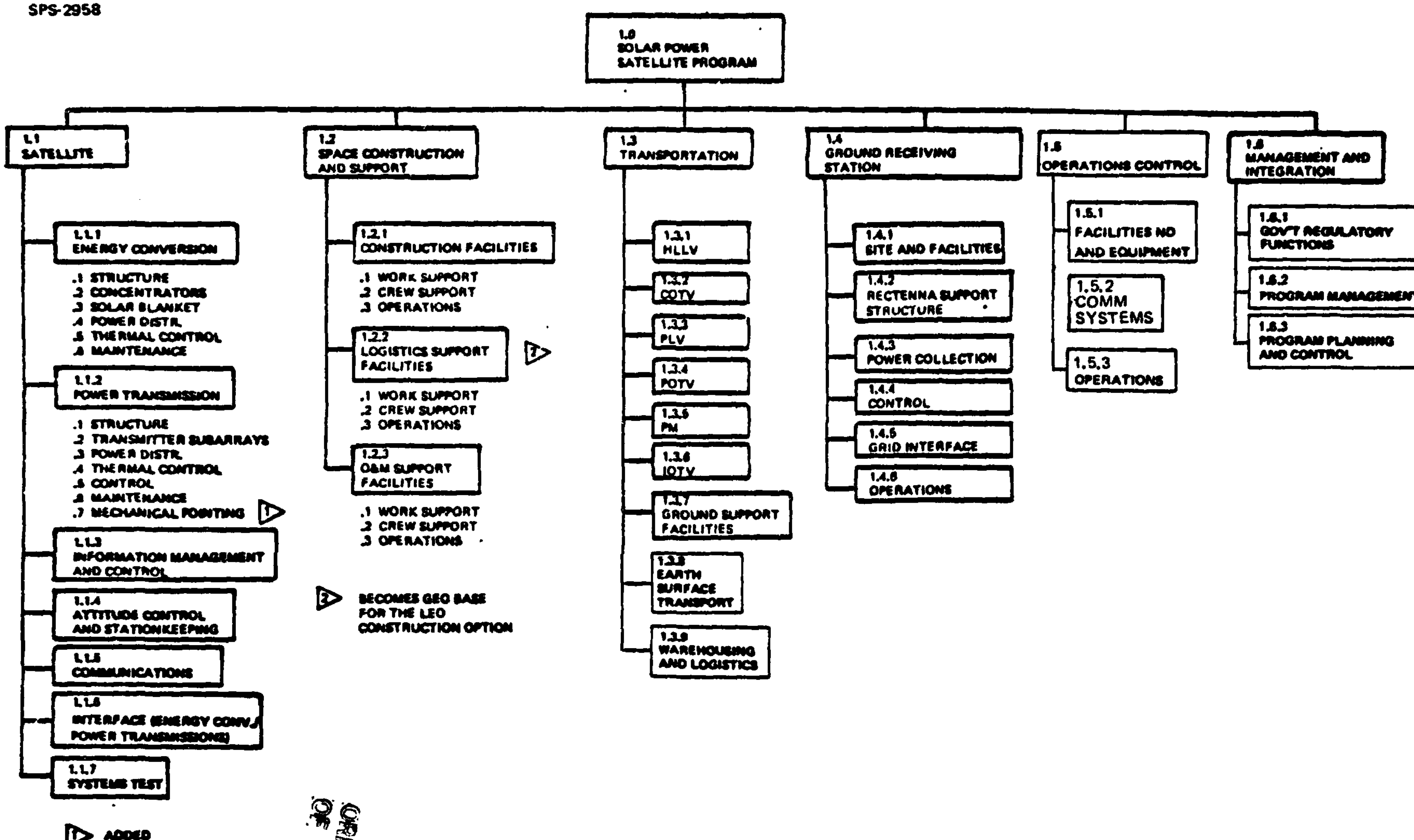

Figure 1 — Solar Power Satellite Program WBS

Table 1 – Five Phases of SPS

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

Table 2 – Key Cost Model Features

1)	Short turn around time	Investigate many alternatives in time available
2)	Minimum of descriptive inputs	Can use early program definition where big gains in cost reduction are most available
3)	Take account of "off-the-shelf" and "modified" hardware	Save development costs
4)	Hardware redundancy levels	Cost effective redundancy level
5)	Material type choices	Material selection cost impact
6)	Hardening or not	Cost effects of hardening
7)	Variable test hardware quantities	Affords cost effective design of ground and flight test program
8)	Variable level of development and production spares	Spares costs reflect needed inventory and maintenance level
9)	Tooling is function of production quantity and production rate	Tooling reflects production plan
10)	GSE is based on number of sets needed	GSE reflects facilities plan (e.g., number of launch sites)
11)	Segregates DDT&E and production costs	Identify costs by program phase for scheduling and funding purposes
12)	Cost and manhour data provided at subsystem and cost element level	Facilitates detailed trades and indicates manpower levels involved
13)	Selectable learning curves at major component level	Develops production costs based on component level learning curve analysis

(quantities, learning curves, production rates, etc.) at the project level. This methodology thus mirrors the actual approach used to develop and produce aerospace hardware. Boeing historical data collected in the Estimating Information System (EIS) data bank provide the raw information from which functional man-hour estimating relationships (MER) are formed. These MER's are based upon strong statistical correlations occurring in all Boeing space programs and relate program inputs to the PCM internal working logic. In addition, each major functional area (e.g., project engineering, developmental shop, etc.) making up Boeing's organizational mix is represented and interrelated in the model. The role of these functional areas is ultimately expressed in terms of the man-hours required for each to fulfill the objectives of the program. Using man-hours instead of dollars allows construction of more traceable estimates because it (1) eliminates the need to normalize for inflation, (2) allows construction of estimates in terms of either "constant" or "then year" dollars by simply applying the appropriately adjusted labor rates and pricing factors associated with the program's time span, and (3) allows use of large amounts of functional man-hours data accumulated by Boeing from actual programs.

Successful results of course require careful judgment about the complexity of the subsystem being designed in order to select the correct MER. Our experience in use of this model permits selection of the appropriate costing factors.

The procedure used to establish production costs is implemented in the same PCM program.

PCM uses as inputs the degree of complexity, the level of quality control, the reliability and hardness requirements, and the test requirements of the component to be costed. The data base for each type of component has been segregated along these lines to allow for this level of definition.

The validity of PCM has been demonstrated by comparing estimates to actual costs for numerous programs. In particular, its estimates have been verified by actual IUS program cost experience.

Critics of parametric costing sometimes argue that parametric models predict things that are more massive to be expensive, whereas "everyone knows it costs more to create something lighter." This is a specious argument. The general trending of cost estimating relationships is clearly correct, e.g. large structures are more expensive than small ones of the same general design. Mass reduction for a given design is handled in a parametric model through "difficulty factors," sometimes called complexity factors. Difficulty factors range from about 0.3 to about 2.0 with 1.0 being typical aerospace design. If the mass reduction is accomplished by more sophistication, e.g. fuel cells rather than batteries, the model identifies the higher cost through higher cost of the subsystem elements.

Learning Curves and Production Rate Factors

Costs of repetitive production come down with time. Estimating the average unit cost of a large production run must account for this phenomenon. There are various ways of expressing this cost reduction, commonly called "learning."

At Boeing we use an expression that relates the cost of the second unit (or unit #2N) to the cost of the first unit (or unit #N) by a fixed fraction, usually designated λ. The cost of unit N is mathematically given as

$$C_M = C_1^a \text{ where } a = \ln \lambda / \ln 2$$

The average cost of N units is closely approximated by

$$C_N = \frac{(C_1+0.5)^{(a+1)} - 1.5^{(a+1)}}{a+1} + 1$$

This methodology is based on commercial airplane experience, including over 1,500 727's.

The actual production cost of the first few units is very difficult to account, since recurring costs at this point are intimately mixed with nonrecurring costs. The cost analyst therefore uses an accounting artifice: the theoretical first unit cost. This is determined by extrapolating backwards along a historical experience learning curve, i.e., using cost records from production program, to unit #1. Thus the term "theoretical." The theoretical (learning curve) costs of the first few units are subtracted from the amalgam of nonrecurring and recurring costs and the balance is accounted as DDT&E. Cost models such as the Boeing PCM then resynthesize the cost picture for a new program by forecasting DDT&E and theoretical first unit (TFU) costs.

Learning curve slopes typically range from 0.9 for rocket engines and low-production-rate avionics, through 0.85 to 0.88 for structures and mechanical subsystems, to 0.7 for high-production-rate electronics. Figure 2 displays learning curve factors through 1000 limits.

Learning curves as experienced on airplane and missile programs reflect three phenomena:

- o Mechanical/technician job familiarization, dominant through perhaps unit #10;
- o Production plan shakedown, eliminating:
  - o excessive change activity
  - o out-of-sequence or traveled work
  - o parts and equipment logistics foul-ups

    -- dominant factors from unit #10 to perhaps unit #1000;
- o Production plan improvement, dominant beyond unit #1000

One must recognize that, to some degree, learning curves are self-fulfilling prophesies. Production managers are assigned yearly budgets based on learning curves. If they overrun, they receive much abuse from higher management. If they underrun, they get less next year.

If high production rates are expected, it is frequently appropriate to consider production rate factors. These are related to production plan improvement and reflect the influence of automation. Production rate slopes on the order of 70% have been experienced in a variety of industries (Figure 3); this largely explains why consumer electronic products cost far less than 1% of a spacecraft electronics unit of equivalent sophistication. Production rate factors and learning curve factors tend to give similar results. One suspects that learning curves in the 70% range, frequently attributed to high-production electronics, are more properly production rate factors.

Platform Factors—Experienced production costs for equivalent products are observed to vary by end use. As an example, a given product for a launch vehicle or military aircraft may cost 30% what the same type of unit would cost for a spacecraft. Platform factors are less significant for developmental costs and were not considered in SPS development costing.

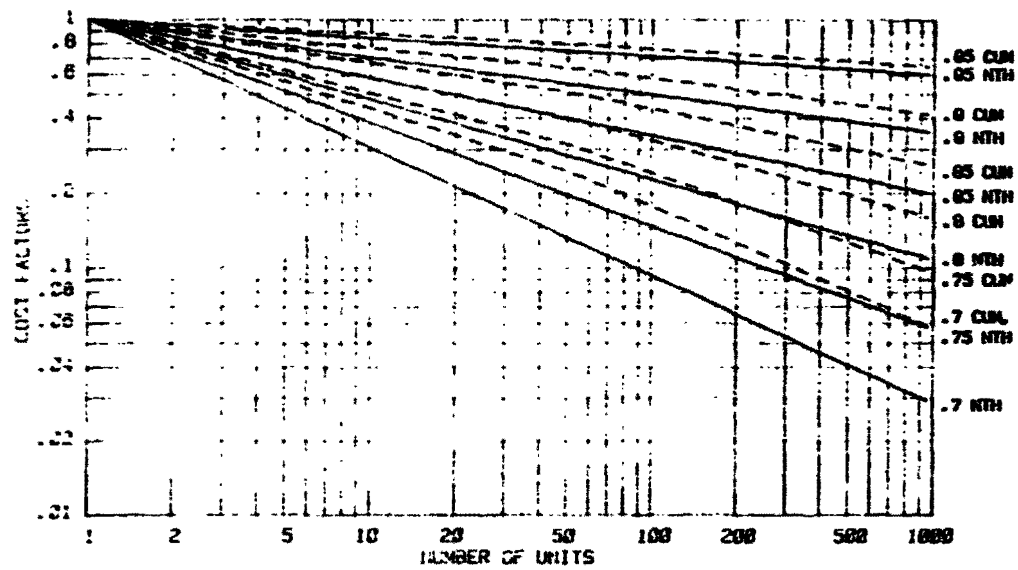

Figure 2 – Learning Curve Factors

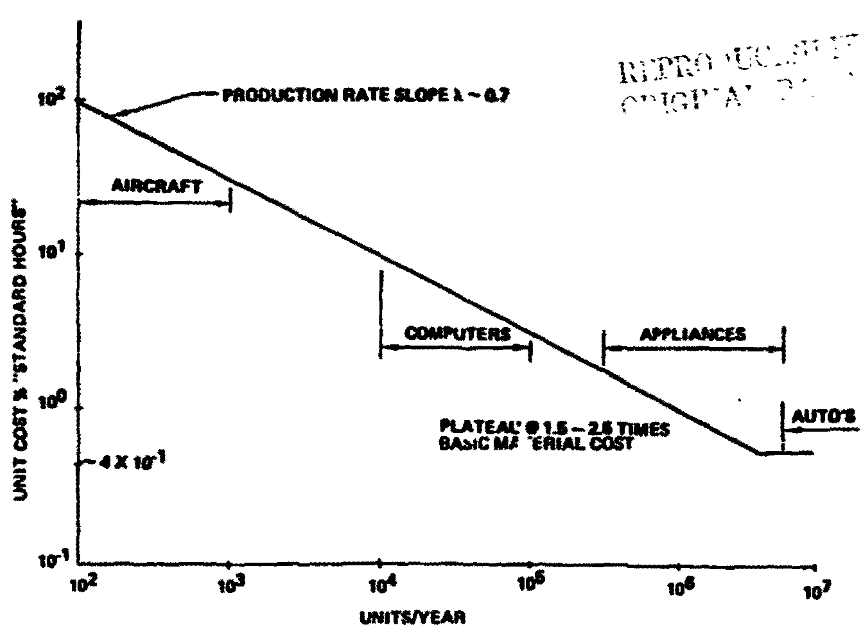

Figure 3 – Mature Industry – Production Rate Curve

Limits—Unfettered use of factors can occasionally predict costs below materials and energy costs. This is particularly larger if exotic materials or very high production rates are involved. Accordingly, the cost analyst must apply a "reasonableness" test to cost estimates to ensure that a realistic value-added factor on basic materials and energy cost is preserved. A minimum value-added factor is roughly 2. Very large industries such as the U.S. auto industry achieve about this performance.

"Mature-Industry" Costs—This term was coined by Dr. Joe Gauger, who investigated the remarkable correlations between the size or "maturity" of basic manufacturing industries and the costs of their products. These correlations were used, in certain instances, as guides to application of particular attention in developing SPS cost projections. The "mature industry" correlation would, for example, predict solar cell costs less than 5¢ per watt at SPS rates. These "mature industry" correlations were not used directly. They did, however, point to solar arrays, graphite structure, klystron amplifiers, and the ground receiver (rectenna) as items for which detailed estimates, rather than parametric estimates, should be used for production costs.

Detailed Estimating—This procedure requires estimating costs from the basic components of costs: labor, materials, and capital. To do this, one must prepare a detailed plan, apply labor estimates to each element of the plan, develop materials estimates, determine the facilities and equipment capital costs, and amortize these. This method was used to develop cost estimates for the SPS research plan presented in the SPS Research Planning Report, Boeing Document D180-25381-1. Parametric models do not lend themselves to estimates of research or study costs.

Detailed estimating is ordinarily applied when the nucleus of a design, development, and production team is in place, i.e., during or following a Phase B study and prior to a full-scale development bid submittal. During a concept study, the skills and resources to support a responsible detailed estimate are not available.

Cost Predictability; Comparison of Parametric and Detailed Estimating

It is clearly much easier to observe that computers, for example, follow a certain historical trend of DDT&E and unit cost versus means (i.e., a parametric estimate) than it is to lay out all of the tasks, materials, and facilities required to design, develop, and produce a computer (i.e. a detailed estimate). This is especially true if the trend data are incorporated in an automated estimating model, as is the case.

It is sometimes stated that a parametric estimate is a "will-cost" result, whereas a detailed estimate is a "should-cost" result. This is an excellent summary of the difference:

1) The parametric estimate reflects a historical average of experienced costs including technical problems and other overrun factors. Given an adequate design definition, a parametric model properly used will predict an expected actual cost, i.e. a "will-cost". One cannot, of course, expect a cost model to compensate for deficiencies in design definition.

2) The detailed estimate reflects a cost forecast for an orderly, well-executed program with no serious technical or management problems. It is ordinarily produced in a competitive environment in which it is recognized by those involved that only the lowest rationalizable estimate can win.

A parametric estimate and a detailed estimate for the same development program will tend to differ by a factor on the order of 2.

Production cost estimates by the two methods differ by much less. This is because the kinds of problems that result in developmental overruns are generally eliminated early in a production program.

Illustrative Examples

We will exhibit three illustrative examples from the SPS cost estimates: solar array, phase control receiver, and a launch vehicle stage.

Solar Array:

This example was chosen to illustrate a situation where PCM could not be used. The experience base is not applicable to SPS production since scale-ups of production rate on the order of thousands together with development of new processes is necessary. A learning curve approach yields ~ $120/M^2 at 80% and ~ $5/M^2 at 70%. The mature industry analysis suggested attention to materials and energy costs. The development of array and process technology was roughly estimated as $65 million for research, covering three photovoltaic technologies and associated process research. Other nonrecurring estimates were:

$ 68 million for engineering verification: process work and a 1-megawatt flight test array

$925 million for a demonstration program including pilot production facilities, process development, and a demonstration array of roughly 600 megawatts.

$ 5 billion for the SPS array production plant with 18,000 megawatts/yr capacity.

These are clearly rough guesses.

These led to the following table for unit area production cost:

Production cost was estimated based on materials, cost, amortization, and labor.

Materials	
Silicon @ 115g/m^2, $60/kg, and 40% yield	$17.25/m^2
Glass @ 280 g/m^2, $3/kg, 80% yield	$ 1.05/m^2
Other @ 30 g/m^2, $10/kg, 80% yield	$ 0.375/m^2
Amortization	
Plant @ $500M, 15 years, 100 km^2/yr	$ 0.33/m^2
Equipment @ $4.5B, 8 years, 100 km^2/hr	$ 5.625/m^2
Levelized - ROI	4.895
Labor @ $60,000/yr, 17,500 people	$10.475/m^2
	$40.00/m^2

In view of the extrapolation involved, substantial uncertainty must be accorded this estimate.

Phase Control Receivers

In this example, we will neglect DDT&E cost which was derived directly from PCM and consider only production cost.

The phase control receiver will be about the size of a pack of cigarettes and will weigh about 1 kg, including the aluminum box with 1-cm walls for heat sink and radiation shielding. Internally, it will consist of RF filters, RF/SF amp IC's, and one or two small processing chips. There are no electromechanical components; the device is fixed-tuned and gain control is automatic.

The PCM model predicted a prototype cost for 6 units of $220K. This corresponds to a TFU of $62K where support such as spares and management has been factored in. A platform factor of 0.3 was applied since the phase control receiver will be more akin to a high-quality industrial instrument than a one-of-a-kind spacecraft device. This yields a production TFU of $18.5K.

The learning factor applied was the 1000th unit at 70%. Alternatively, this could be viewed as a production rate factor wherein at 200/year the receivers would exhibit an $18K cost, but at the required 200,000/year, the 1000th @ 70% should be applied. In either case, the factor is 0.03 (actually a 73% curve) and the unit cost result is $560. This figure, compared to existing products of comparable size and complexity and at comparable production rates, is reasonable. Note that the annual sales represent $100 million per year, a desirable piece of business.

This represents an estimate of intermediate certainty; the definition is soft but probably representative; the production mean is state-of-the-art; the principal uncertainty is in extrapolation to high production rate.

Launch Systems

A detailed discussion of launch vehicle costing is not warranted. The PCM model was used directly for DDT&E and TFU costs. Learning applied was normal aerospace experience. The number of units to be produced is dozens, well within the experience base.

Launch vehicle cost per flight is dominated by hardware (production and spares) costs. Launch vehicles were ascribed a 300-flight life ... this is within expected shuttle orbiter accomplishment. Engines were assumed to meet the life and service specifications applied to the Space Shuttle Main Engine.

Principal risks are:

- o Will the engines be as serviceable as assumed?
- o Will the thermal protection system be serviceable enough to avoid turnaround delays for TPS repair?
- o Can the complete reusability of the vehicle design be maintained in detail design, e.g. are there lower-level elements such as stage separation aids that will be expendable?

Given the expected several years' Shuttle operations experience that will precede SPS launch system design, these are viewed as low risks. Accordingly, the launch system costs for SPS are believed high-confidence estimates.

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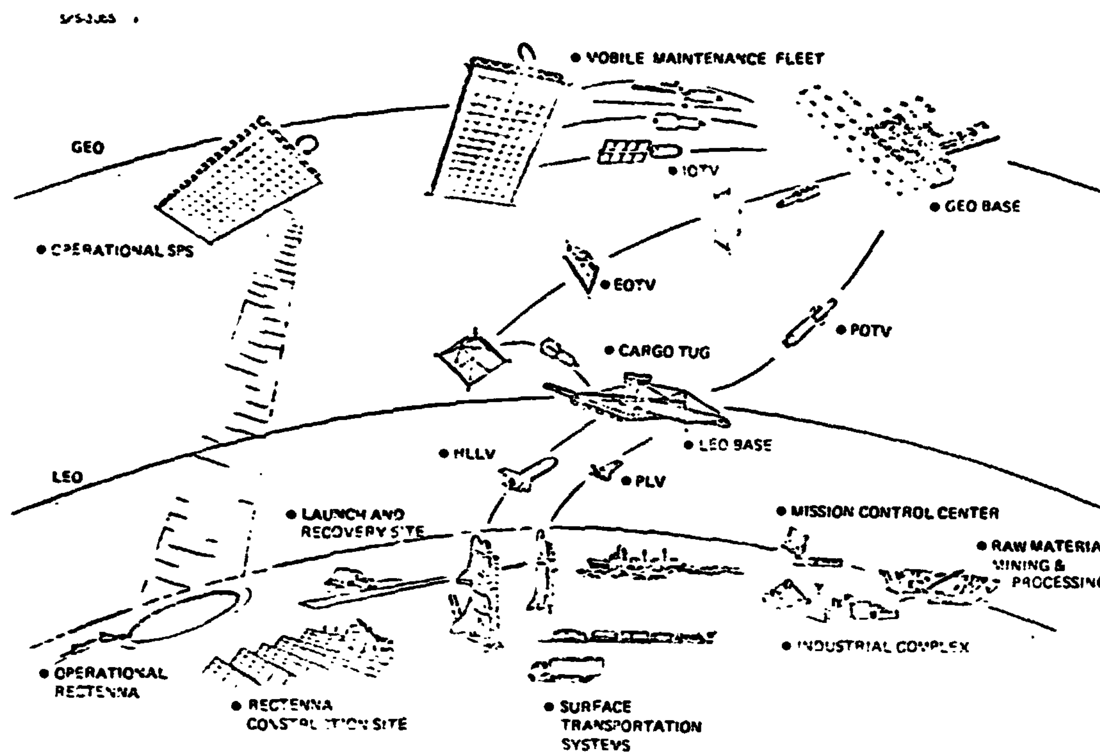

Figure A — SPS Program Elements

Table A —SPS Recurring Cost Summary(1979 Dollars)

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

1.0 WBS DICTIONARY

The SPS program includes all elements necessary to provide baseload electric power generation from a satellite solar power plant. The principal elements are:

1.1 Solar Power Satellites
1.2 Space Construction and Support
1.3 Space and Ground Transportation
1.4 Ground Receiving Stations
1.5 Operations Control
1.6 Program Management and Integration

The program is conceived as occurring in five phases beyond the present study phase, as described in the introduction.

2.0 DESCRIPTION

The reference solar power satellite system consists of 60 SPS's each rated at 5000 megawatts usable output power at earth for a total of 300,000 megawatts. This is equal to the total U.S. baseload generating capacity today and represents roughly ½ the expected baseload generating capacity in the time period 2000-2020. The SPS's are to be serially produced (according to the reference scenario) at a rate of two per year beginning in the year 2000; the entire constellation would be in place by 2030.

The complete SPS system includes all support systems required as well as the satellites and ground systems. Figure A symbolizes the major system elements.

3.0 DESIGN BASIS

The reference system design has evolved through a series of studies. The satellite size of 5000 megawatts is based on optimization for minimum recurring cost per kilowatt. This is discussed under WBS 1.1.2.

The silicon solar array is one of two reference options, the other being gallium arsenide. The rationale for silicon is discussed under WBS 1.1.1.

The design bases for the other system elements are discussed under the respective element descriptions.

4.0 MASS AND MASS BASIS

This is discussed under the respective WBS element descriptions.

5.0 COST AND COST BASIS

The estimated costs of these phases are: (1979 dollars)

Research	\$ 430 million
Engineering Verification	\$9,145 million
Demonstration	\$26,349 million
Investment	\$66,363 million
Commercial Production - See Table A	

The first (prototype) full-sized commercial SPS was estimated as \$15,040 million.

These nonrecurring cost estimates are presented in more detail in Section II, Program Scenario Summary.

The recurring cost for SPS's is summarized under Table A. The recurring cost for SPS hardware as computed by the cost model includes an implied amortization of factories and equipment. Since this item is expressly accounted as an investment cost, it is deleted here.

Estimating the cost of an SPS to a utility company requires the establishment of a specific financial and management scenario. That was not done in this study. A rough estimate may be provided by adding back the deleted factory amortization and adding about 15% for capital-related costs such as interest during construction.

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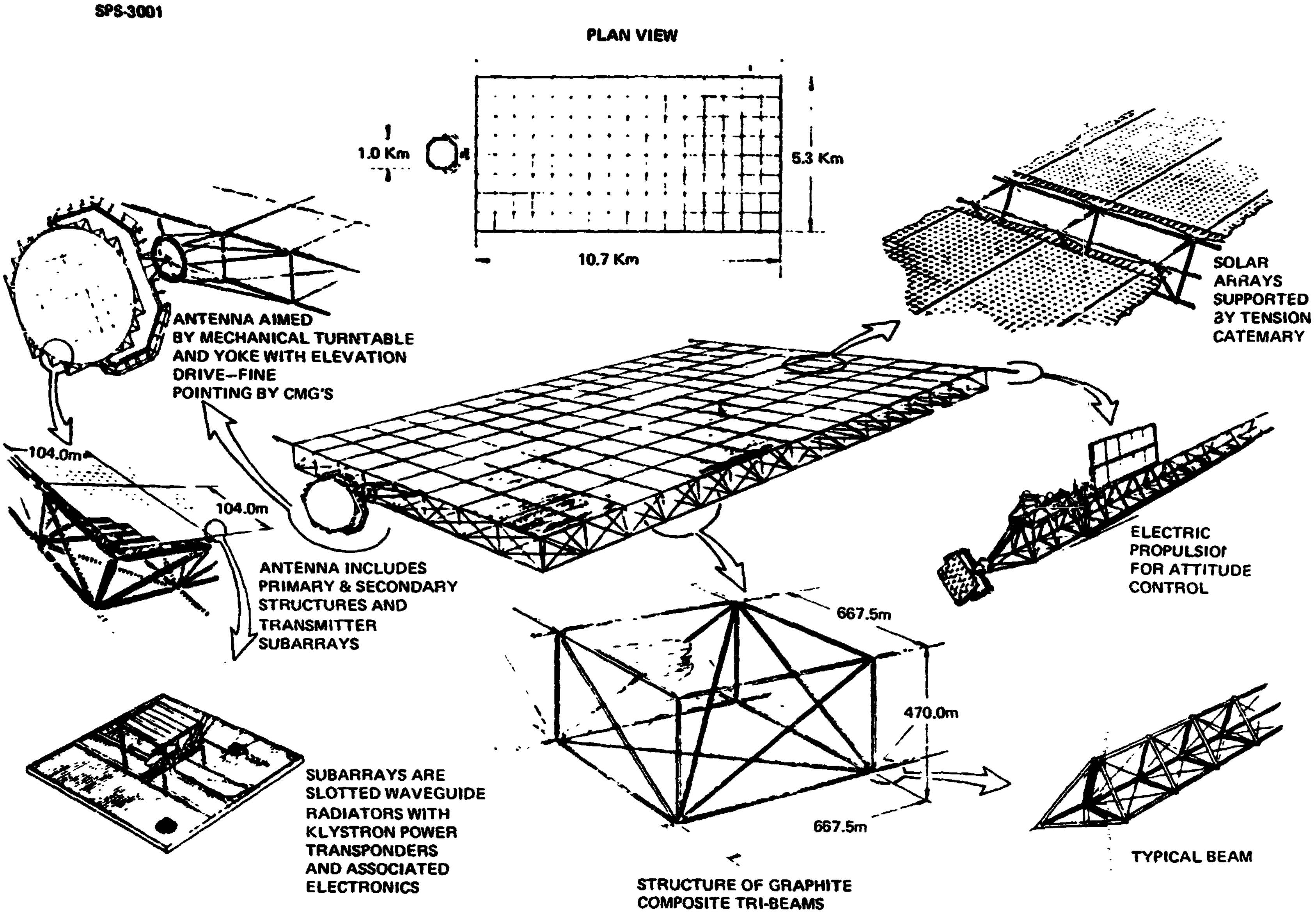


1.0 WBS DICTIONARY

This element includes the complete solar power satellite itself including all permanently installed maintenance equipment.

The subelements are

- 1.1.1 Energy Conversion System
- 1.1.2 Power Tranmission System
- 1.1.3 Information Management and Control
- 1.1.4 Attitude Control and Stationkeeping
- 1.1.5 Communications
- 1.1.6 Interface (between 1.1.1 and 1.1.2)

2.0 DESCRIPTION

In a geostationary orbit 36,000 km above the Earth's equator, each SPS is illuminated by sunlight over 99% of the time and is in continuous line-of-sight contact with its ground receiving station. Electrical power produced on the satellite by photovoltaic conversion of sunlight is reconverted to single-frequency electromagnetic energy at high efficiency, and formed into a narrow beam precisely aimed at the ground station. The ground station receiver reconverts the energy into electricity for distribution. The reference system provides 5,000 megawatts of useful output to the power grid.

The reference silicon (solar cell) configuration is illustrated. The silicon cells are encapsulated in glass to form array elements that are in turn supported by a lightweight open trusswork structure. Electric power from the array is carried to the transmitter through aluminum conductors, through a slip ring, and fed to a phased array of klystron power transponders operating at 2450 megahertz. Beam formation is controlled by a pilot signal from the ground station; the power transponders amplify the pilot signal millions of times (using the electric power from the solar array), and return it to the ground station as a power beam.

3.0 DESIGN BASIS

The silicon reference system is one of two reference systems included in the NASA reference system set and is the subject of the present study, (The other reference system employs gallium arsenide solar cells).

The sizing of the SPS is mainly dictated by microwave power transmissions considerations; these are discussed under WBS 1.1.2. Flight controls analyses showed that no penalty in attitude control and stationkeeping propellants is incurred by the straight forward end-mounted antenna approach. This is true because stationkeeping requirements dominate propellant consumption and all attitude control requirements can be accommodated by suitable modulation of stationkeeping thrust.

Principal design considerations for the other subelements are discussed under the respective subelements.

4.0 MASS AND MASS BASIS

The SPS mass is the sum of subelement masses. A comprehensive satellite mass and cost statement is presented in Table A. A margin of 22% above identified mass is allocated to cover potential risks in solar array and microwave power transmission system performance estimates.

5.0 COST

Cost data are also presented in the comprehensive mass and cost Table A. The costs given are the identified recurring costs for the satellite. Cost margins are presented at the program level, WBS 1.0. Costs in the table following include amortization of factories and production equipment where applicable.

Non-recurring costs were distributed among the program phases as summarized in Section II.

TABLE A
WBS 1.1 Solar Power Satellite
Mass and Production Cost

No.	Item	Mass Metric Tons	Production Cost $Millions	
1.1	SPS	50984.0	4945.9	A
1.1.1	Energy Conversion	27665.7	2859.6	
1.1.1.1	Structure	4654.6	448.2	
1.1.1.1.1	Primary Structure	4137.2	273	
1.1.1.1.2	Catenary System	462.9	167	
1.1.1.1.3	Power Distribution Support	54.5	8.2	
1.1.1.2	Concentrators	(0)		
1.1.1.3	Solar Blankets	21144.9	1987.8	
1.1.1.3.1	Solar Cell Panels	21,069.1	1984	
1.1.1.3.2	Interbay Jumpers	75.8	3.8	
1.1.1.4	Power Distribution	1246.0	149.9	
1.1.1.4.1	Main Busses	1090.0	88.8	
1.1.1.4.2	Acquisition Busses	39.7	3.2	
1.1.1.4.3	Switchgear	116.3	57.9	
1.1.1.5	Thermal Control- Allocated to Subsystems	(0)		
1.1.1.6	Maintenance	621.0	273.7	
1.1.1.6.1	Laser Annealers	178.0	233.76	
1.1.1.6.2	Docking Ports	4.0	6.528	
1.1.1.6.3	Tracks	439.0	33.4	
1.1.2	Power Transmission	13,628.9	1768.7	
1.1.2.1	Structure	324.3	25.6	
1.1.2.1.1	Primary Structure	153.7	12.6	
1.1.2.1.2	Secondary Structure	170.6	13.0	
1.1.2.2	Transmitter Subarrays	10,389.1	889	
1.1.2.2.1	Klystrons & Thermal Cont.	7007.1	477	
1.1.2.2.2	Distrib. Waveguide	434.0	33	
1.1.2.2.3	Radiating Waveguide	1903.0	145	
1.1.2.2.4	Thermal Control - Allocated to Subsystems	(0)		
1.1.2.2.5	Wiring Harness	91.0	1	
1.1.2.2.6	Control Circuits	380.0	108	

TABLE A (Con't)
WBS 1.1 Solar Power Satellite
Mass and Production Cost

No.	Item	Mass Metric Tons	Production Cost $Millions
1.1.2.2.7	Structure	574.0	44
1.1.2.3	Power Distr & Cond.	2538.7	81
			324.1
1.1.2.3.1	Conductors	356.0	17.8
1.1.2.3.2	Switchgear	222.1	70.9
1.1.2.3.3	DC/DC Converters	1111.5	178.5
1.1.2.3.4	Processor Thermal Cont.	535.9	52
1.1.2.3.5	Energy Storage	313.2	4.9
1.1.2.4	Thermal Control - Allocated To Subsystems	(0)	
1.1.2.5	Phase Distr.	12.3	12.5
1.1.2.5.1	Master Ref Revrs	.072	1.3
1.1.2.5.2	Slave Repeaters	1.2	10.0
1.1.2.5.3	Cabling	11.0	1.2
1.1.2.6	Maintenance Systems	230.2	503.9
1.1.2.6.1	Gantries & MRWS's	91.3	291.6
1.1.2.6.2	Docking Ports	16.5	26.9
1.1.2.6.3	Cargo Handling	5.0	4.22
1.1.2.6.4	Crew Busses	30.0	71.4
1.1.2.6.5	Component Transp.	4.0	4.95
1.1.2.6.6	Unidentified Equip (20% of above)	29.4	63.8
1.1.2.6.7	Tracks	54.0	41
1.1.2.7	Antenna Mech Pointing	134.3	13.6
1.1.2.7.1	CMG's	127.9	11.4
1.1.2.7.2	Star Scanners	.015	1.2
1.1.2.7.3	Installation Prov.	6.4	1.0
1.1.3	Info Mgmt & Control	95.6	48.0
1.1.3.1	Ant. Computers	2.8	18.2
1.1.3.1.1	Main Computers	0.15	
1.1.3.1.2	Sector Control	0.9	
1.1.3.1.3	Area Control	0.8	

TABLE A (Con't)
WBS 1.1 Solar Power Satellite
Mass and Production Cost

No.	Item	Mass Metric Tons	Production Cost $Millions	
1.1.3.1.4	RTU's & Instrumentation	1.0		
1.1.3.2	Ant. Cabling	60.4	4.4	
1.1.3.3	Array Computers	1.7	12.5	
1.1.3.4	Array Cabling	30.7	12.9	
1.1.4	Attitude Control & Stakp	212.1		
1.1.4.1	Sensor Systems	1.0	160**	
1.1.4.2	Electric Propulsion	178.8		
1.1.4.2.1	Thrusters	5.6		
1.1.4.2.2	Propellant	50.0		
1.1.4.2.3	Propellant Tanks	3.8		
1.1.4.2.4	Propellant Feed	1.0		
1.1.4.2.5	Power Processors	112.3		
1.1.4.2.6	Installation Provisions	6.1		
1.1.4.3	Chemical Propulsion	26.1		
1.1.4.4	Structure & Inst'l.	6.2		
1.1.4.5	Maintenance Systems			
1.1.5	Communications	0.18	8	
1.1.6	Interface	235.6	101.6	
1.1.6.1	Structures	175.4	26.6	
1.1.6.2	Turntable & Drive	38.4	46	A
1.1.6.3	Elec Rotary Joint & Feeders	21.8	20	
1.1.6.4	Maint Systems	-		
1.1.7	Growth & Contingency (22%)	9146	***	

** Estimate was not broken out lower

***Cost growth contingency carried at program level, see Table A in WBS 1.0

1.0 WBS DICTIONARY

This element includes:

1.1.1.1	Structure (the solar array support structure)
1.1.1.2	Concentrators—The silicon reference configuration does not employ concentrators
1.1.1.3	Solar Blankets
1.1.1.4	Power Distribution
1.1.1.5	is reserved for thermal control—no specific thermal control subsystem is identified for this reference design
1.1.1.6	Maintenance Provisions

2.0 DESCRIPTION

The energy conversion system consists of a silicon solar array suspended trampoline-fashion in a hexahedral truss structure, and the power collection and distribution system required to conduct the generated power to the energy conversion-power transmitter interface.

3.0 DESIGN BASIS

The energy conversion system is designed around the solar array (blanket) described under WBS 1.1.1.3. Silicon was selected for the solar array because of its relatively advanced state of the art and apparent adequate performance. More advanced systems might yield some attractive SPS's provided that array cost can be low enough.

4.0 MASS

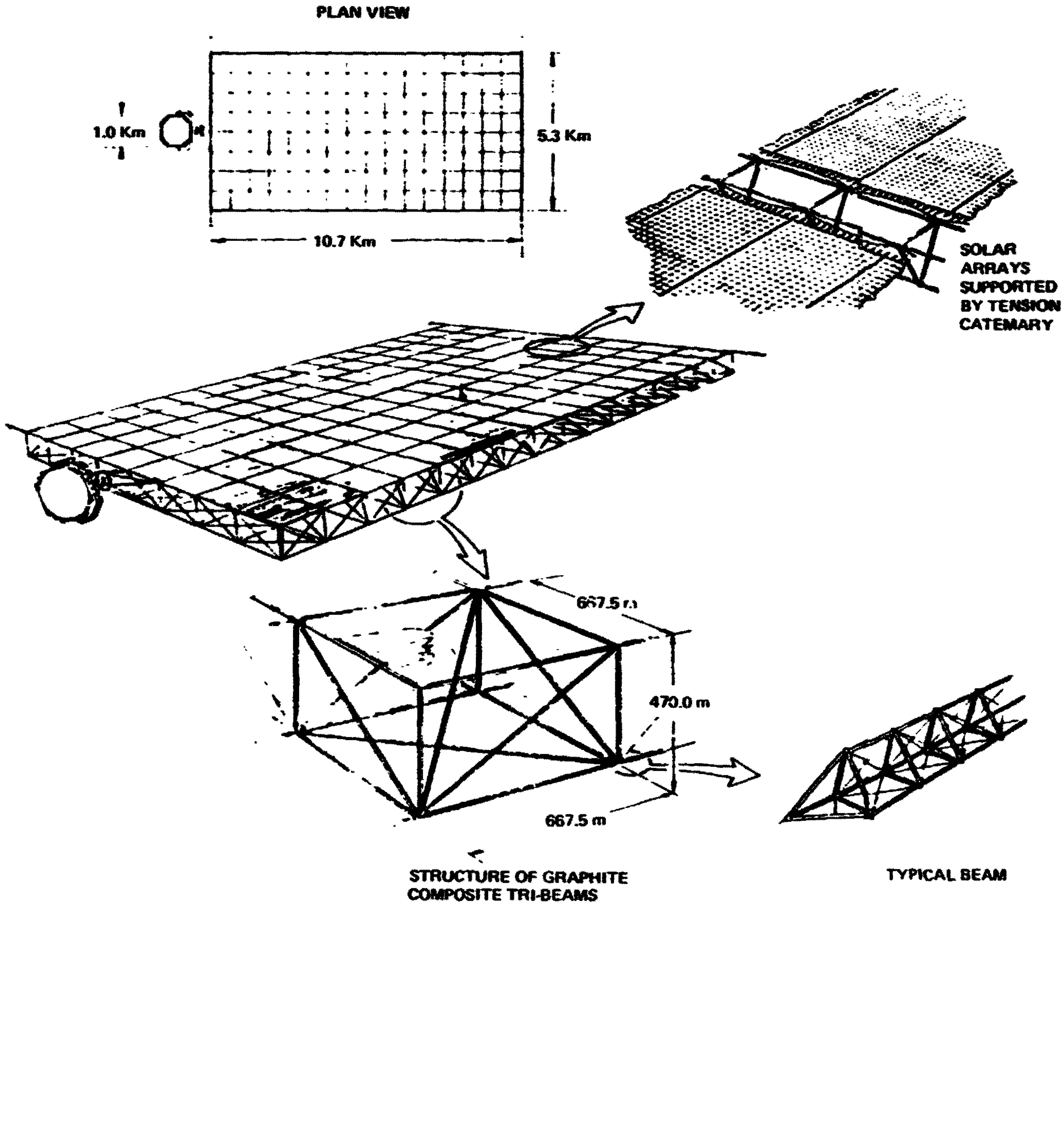
This element mass is the sum of subelement masses. A comprehensive mass summary is provided under WBS 1.1.

5.0 COST

This element cost is the sum of subelement costs. A comprehensive recurring costs summary is provided under WBS 1.1. Now recurring costs are summarized under the program scenario in Section II of this report.

FOLDOUT FRAME

SPS-3001



WBS 1.1.1.1 STRUCTURE

FOLDOUT FRAME

1.0 WBS DICTIONARY

This element includes all necessary members to support the solar blankets and other energy conversion subsystem hardware. It includes structural beams, beam couplers, cables, tensioning devices, and secondary structures which are required as an interface between the primary structure and the mounting attach points of components, assemblies, and subsystems.

2.0 DESCRIPTION

The energy conversion portion of the satellite is comprised of 128 bays each 667.5 meters square by 470 meters in depth. The bays are arranged 8 wide by 16 long (aspect ratio = 2). The mainframe structure is a repeating hexahedral truss arrangement made up of two sizes of graphite composite tri-beams. The solar arrays are supported uni-axially using a catenary cable and uniform tensioning by the use of constant-force blanket tensioning springs at each blanket support tape. The support for power distribution main busses provide for thermal expansion capability at each vertical beam by using tension support ties from the busses to the main structure. Support provisions are included for non-energy conversion subsystems mounted on the energy conversion structure.

3.0 DESIGN BASIS

Derivation of structural design requirements for the satellite structure has required investigation of many areas. Outstanding requirements include accommodation of gravity gradient torques which impose primary loads on the structure; long life in the rigorous geosynchronous orbit radiation environment, and prevention of continuous wave motion in solar array blankets suspended from a huge, lightly damped structure subject to periodic excitations. Selection of an approach to the satellite structural design has required both parametric study of structural configurations and consideration of the fabrication and assembly techniques available. Trade studies in the areas of construction base sizing and fabrication in geosynchronous orbit led to selection of a planar hexahedral truss structure configuration.

With the baseline structural arrangement selected, parametric studies were used to minimize the mass of the individual structural elements. The final structure meets all design requirements at a structural mass fraction of 10%.

4.0 MASS AND MASS BASIS

ITEM	MASS ESTIMATE	REFERENCE
Primary Structure	4,137.2 MT	See WBS 1.1.1.1.1
Catenary System	462.9 MT	See WBS 1.1.1.1.2
Pwr. Dist. Support	54.5 MT	See WBS 1.1.1.1.3
TOTAL	4,654.6 MT	

5.0 COST

5.1 COST SUMMARY

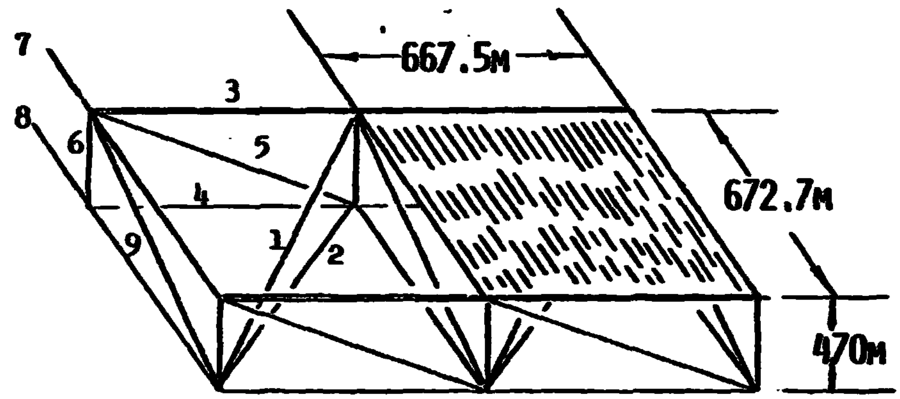
	COST, $ MILLIONS
o Research	16.7
o Engineering Verification	30.0
o Demonstration	88.7
o Investment	599.0
o Production	273

5.2 COST DETAILS

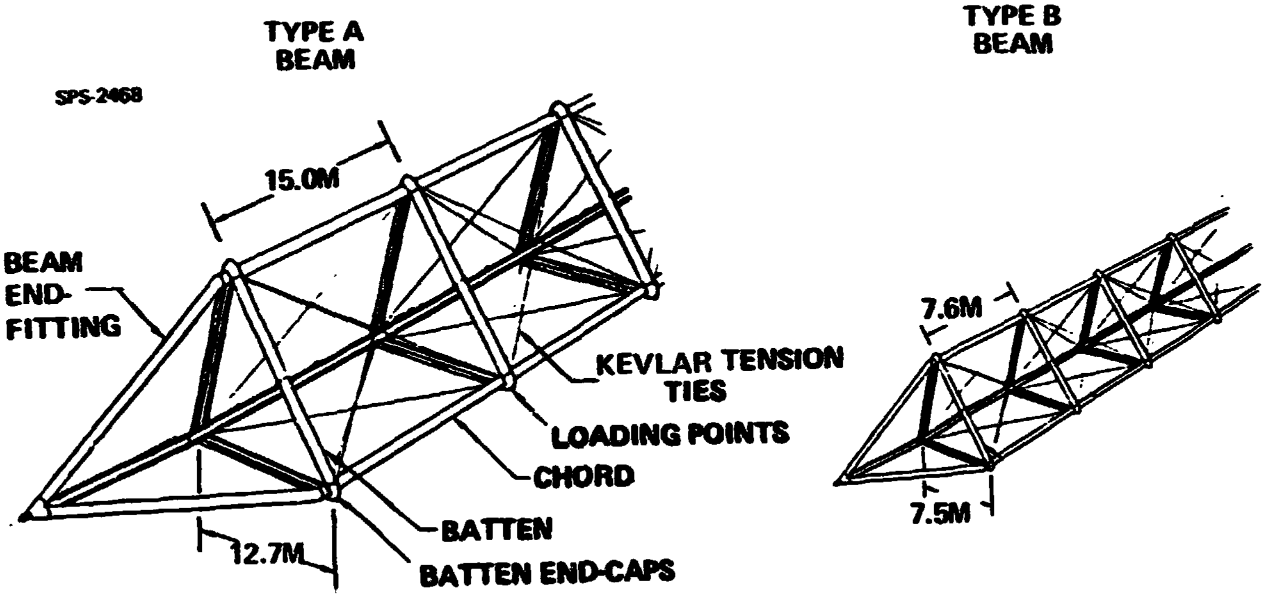
- <u>RESEARCH</u> (16.7)
  - All structures and materials except low-CTG waveguides
  - Decured in Research Planning Doc. D180-25381-1
- <u>ENGINEERING VERIFICATION</u> (30.0)
  - $20M DDT$\Delta$E (based on 20 MT ROM mass)
  - $10M to build test unit
- <u>DEMONSTRATION</u> (88.7)
  - Structure is the same as the EOTV structure: basic development cost is carried under EOTV (WBS 1.3.2)
  - Assume delta DDTΔE is 20% of all-up structure value = $443.6/5
- <u>INVESTMENT</u> (599)
  - $200M for production plant - this comes from cost matrix from NAS9-15196, Vol. VI Evaluation Data Book (D180-22876-6)
  - DDTΔE - $399M
    - 10% credit taken for demonstration phase
- <u>PRODUCTION</u> (273)
  - $66/kg x 4137.2 MT

The figure of $66/kg includes 20% inflation added to the value $55/kg estimated in 1977 dollars as reported in D180-22876-6 pp. 166-171.

FOLDOUT FRAME



Solar Power Satellite Structural Bay Configuration



SPS Beam Configurations

2

FOLDOUT FRAME

WBS 1.1.1.1.1 MAIN STRUCTURE

1.0 WBS DICTIONARY

This element includes all of the necessary members required to support the solar blankets. It includes the structural beams and beam couplers and required interfaces between the primary structure and the attach points required for other energy conversion subsystems.

2.0 DESCRIPTION

The mainframe structure is a repeating hexahedral (box) truss arrangement made up of two sizes of graphite composite tri-beams. The heavier 12.5-meter beams support the uni-axial solar array stretching levels. The lighter 7.5-meter beams are used in all other locations. Characteristics of the beams are shown below:

ITEM	TYPE A UPPER SURFACE LONGITUDINAL BEAM	TYPE B BEAM USED IN ALL OTHER LOCATIONS
SECTION	CLOSED	OPEN
Ref. Side Length	38 CM	38 CM
Mat'l Thickness	0.86 MM	0.71 MM
EI_X	3.39 E8 N/CM^2	1.80 E8 N/CM^2
BEAM WIDTH	12.7 M	7.5 M
BATTEN SPACING	15.0 M	12.7 M
CRITICAL LOAD	17480 N (Crip, Chord)	7090 N (Buck Beam)
MASS/LENGTH	7.48 KG/M	4.11 KG/M

The satellite is comprised of 128 bays, each 667.5 meters square by 470 meters in depth. The bays are arranged eight wide by sixteen long to provide an aspect ratio of two.

3.0 DESIGN BASIS

The energy conversion structure provides the strength required to tension the solar array blankets and decouples array blanket vibrational modes from control system induced excitation. It also provides the overall stiffness required to ensure control system stability. A hexahedral planar truss was chosen over tetahedral and pentahedral options as the basic structural configuration offering the best compromise for strength, stiffness and manufacturing ease. Space fabricated beam elements of triangular cross section were selected for the basic structural elements of the truss for structural efficiency and to take advantage of existing designs for space based beam fabrication machinery.

Graphite composite materials were selected for the beams to provide thermal stability and a high stiffness-to-mass ratio.

4.0 MASS AND MASS BASIS

Detailed mass estimates were used to derive mass per unit length for the two types of major structural beams shown in 2.0 above. Total structural mass was estimated as shown below:

MEMBER	BEAM SIZE	BEAM LENGTH	BEAMS PER SPS	TOTAL LENGTH
1 - Body Diagonal	7.5M	1,057.8M	128	135,400M
2 - Cross-Bay Diagonal	7.5M	947.7M	128	121,300M
3 - Upper (Solar Array) Lateral	12.7M	667.5M	136	90,780M
4 - Lower Lateral	7.5M	667.5M	136	90,780M
5 - Lateral Diagonal	7.5M	816.4M	136	111,000M
6 - Corner Post	7.5M	470M	153	71,900M
7 - Upper Longitudinal	7.5M	10,775.9M*	9	96,870M
8 - Lower Longitudinal	7.5M	10,775.9M*	9	96,870M
9 - Longitudinal Diagonal	7.5M	820.6M	144	118,200M

* Continuous Longitudinal Beam Length = 672.7M/Bay x 16 Bays + 7.5M = 10,775.9M

SUMMARY:

12.7M (TYPE "A" BEAM) = 90,780M

7.5M (TYPE "C" BEAM) = 842,320M

GEO STRUCTURE MASS

12.7M TYPE "A" BEAM - 90,780M @ 7.476 Kg/M = 678,671.3 Kg

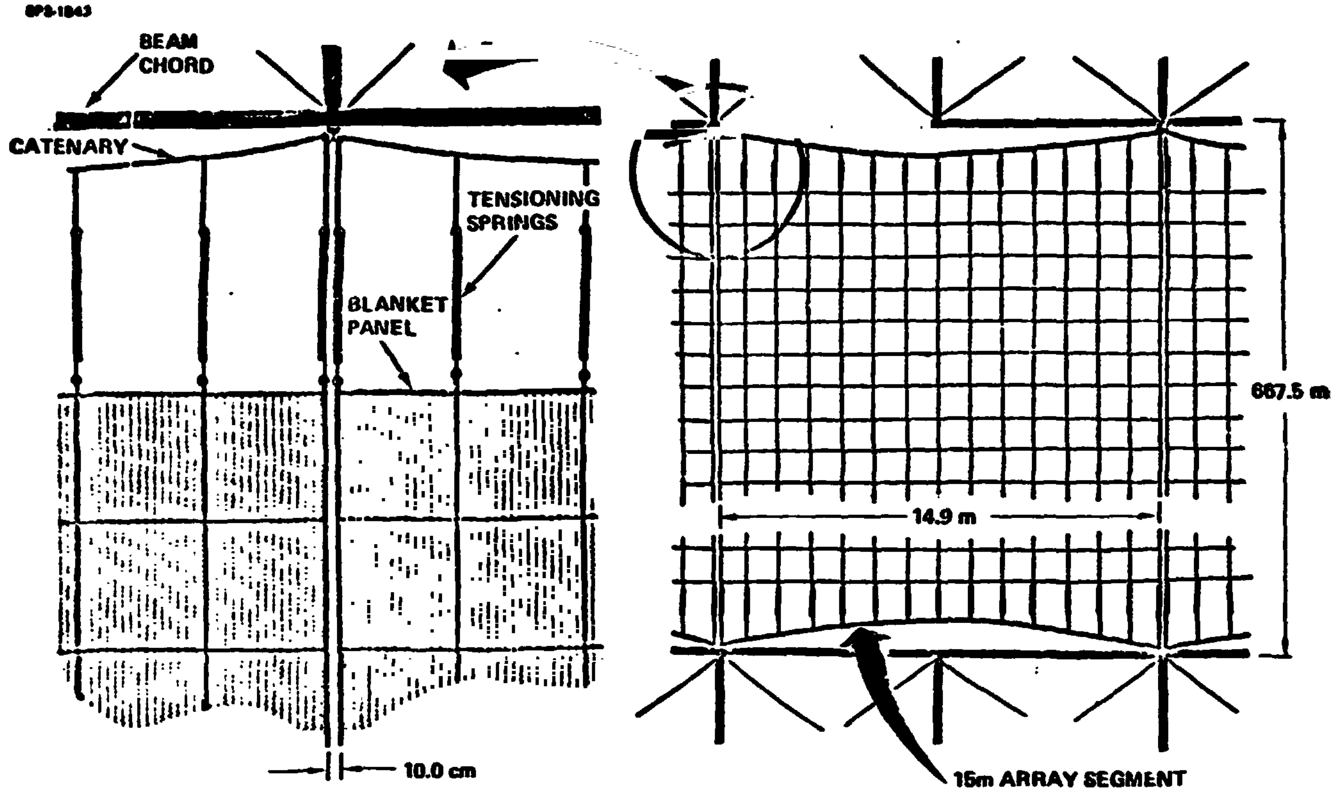
7.5M TYPE "C" BEAM - 842,320M @ 4.106 Kg/M = 3,458,565.9 Kg

TOTAL STRUCTURAL MASS = 4,137,237.2 Kg = 4,137.2 MT

5.0 COST

The cost estimating factor used for primary structural members is \$55 per kilogram (mature industry projection in 1977 dollars - Ref NAS9-15196 Part II, Volume VI, D180-22876-6 Par. 3.0) times 1.15 (1977 to 1979 inflation adjustment) or \$63.25 per kilogram. Total recurring cost is 261.7 million dollars (4,137,237.2 Kg X \$63.25/Kg = \$261.7 X 10^6).

FOLDOUT FRAME



1.0 WBS DICTIONARY

This element includes all the hardware necessary to support the solar array, trampoline fashion, within the structural bay. It includes cabling and tensioning devices attached between major structural beams and the solar array blanket segments.

2.0 DESCRIPTION

The method of supporting the solar blanket within the primary structural bays provides a uniform tension to the end of each solar array segment by the use of constant-force blanket tensioning springs at each blanket support tape. These springs are also attached to a catenary cable that is then attached to the primary structure, upper surface, beams at 15 meter intervals. The springs are in compression, for better reliability, and exert a uniaxial force of approximately 4.1 N to each blanket support tape.

3.0 DESIGN BASIS

The solar array blankets, attached to the sunfacing side of the structural bays, will undergo significant temperature changes in going from the unocculted to occulted condition and vice versa (Reference NAS9-15196 Part I, Vol. II, D180-20689-2, pp 113, 114). In order to accommodate any length changes which occur in the solar array blanket during these temperature excursions the blanket support system selected was a catenary system which is compatible both with the major structural beams and the array blanket segments.

WBS 1.1.1.1.2 CATENARY SYSTEM

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

4.0 MASS AND MASS BASIS

The catenary cable mass was estimated in NAS9-15196 Part II and was derived as a mass value which could be added to the solar array mass per unit area since the support required is proportional to the area. This mass factor was 2.52 grams per square meter of array. Using this value the total catenary mass is .00252 Kg/meter^2 times the array area of 49,600,000 meters square for a total mass of 125.0 MT. Tensioning devices are estimated to have a mass of 2 Kg, with a total of 168,960 devices per satellite. The total mass of the tensioning devices is 337.9 metric tons. The total catenary system mass which is the sum of the cable mass (125.0 MT) and tensioning devices mass (337.9 MT) is 462.9 MT.

5.0 COST

5.1 COST SUMMARY

	COST, $ MILLIONS
o Research	Included in Space Construction
o Engineering Verification	23.5
o Demonstration	25
o Investment	23.5
o Production	167

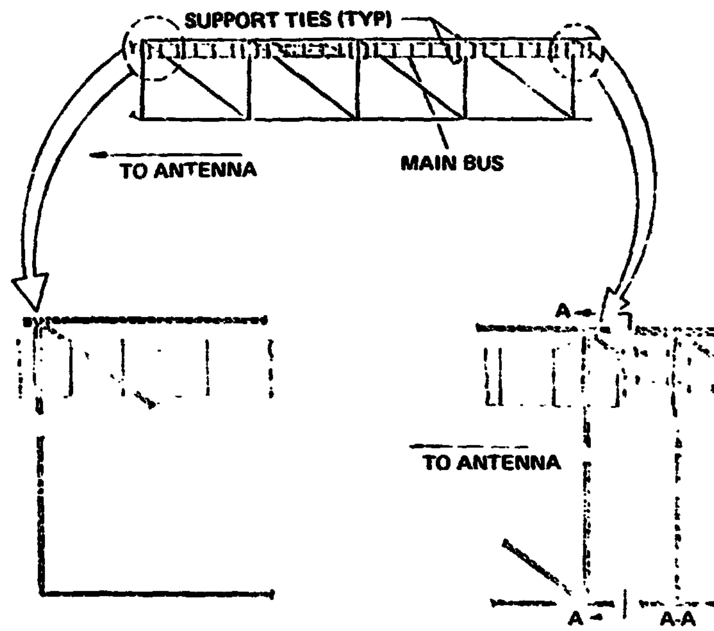
5.2 COST DETAILS

- ENGINEERING VERIFICATION — 23.5
  - DDT&E factored from NAS9-15196, Vol. VI, Evaluation Data Book (D180-22876-6).
  - Old value of $3.6M for D&D was proportioned a share of SE&I, etc. and added 15% for 1977-79.
- DEMONSTRATION — 25
  - ROM estimated as 15% of production unit:
- INVESTMENT — 23.5
- PRODUCTION — 167
  - Unit cost ($145.5M) from reference cited above was inflated 15%.

FOLDOUT FRAME

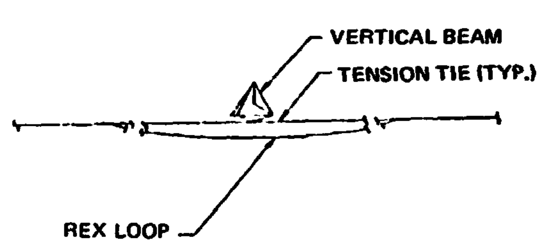
POWER DISTRIBUTION SYSTEM

BUS SUPPORT CONCEPT



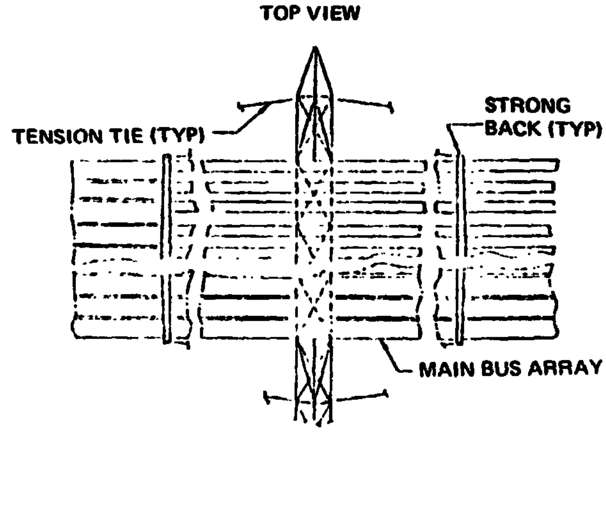
POWER DISTRIBUTION SYSTEM

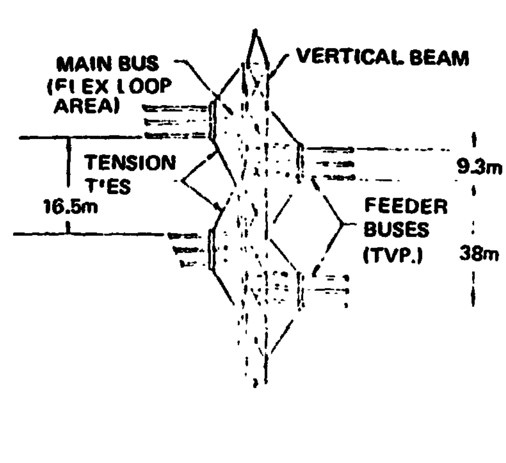
MAIN & FEEDER BUS SUPPORT



MAIN POWER BUS AT A VERTICAL BEAM

TOP VIEW





1.0 WBS DICTIONARY

This element includes all of the hardware necessary to support the main power busses and the power acquisition busses.

2.0 DESCRIPTION

The support structure for the power distribution power busses includes flex loops in the bus material at each vertical beam to allow for thermally induced length changes to occur in bay length increments. The tension support ties from the busses to the main structure are preloaded to maintain the natural frequency of the power bus system higher than that of the satellite. The tension/cable system selected, in addition to providing tension to compensate for thermal expansion, also tries to react the magnetic forces (caused by both interconductor and intraconductor current induced magnetic fields and the Earth's magnetic field) acting on the conductors. Additional strongbacks are used to maintain conductor positions between tension ties. Pallets are also provided to support switchgear.

3.0 ELEMENT DESIGN BASIS

The basic requirements for the bus support subsystem are as follows:

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

Trades conducted to satisfy these requirements led to the final selection of the main bus configuration shown above. This view shows several bays near the slipring end of the satellite, where there are 20 parallel busses. The three point spring/cable ties to the main structure are shown, and the tension ties to react the bus magnetic repulsion forces can be seen.

4.0 MASS AND MASS BASIS

The mass of the power distribution support structure was estimated to be 5% of the power distribution system mass, 54.5 MT.

5.0 COST

5.1 COST SUMMARY

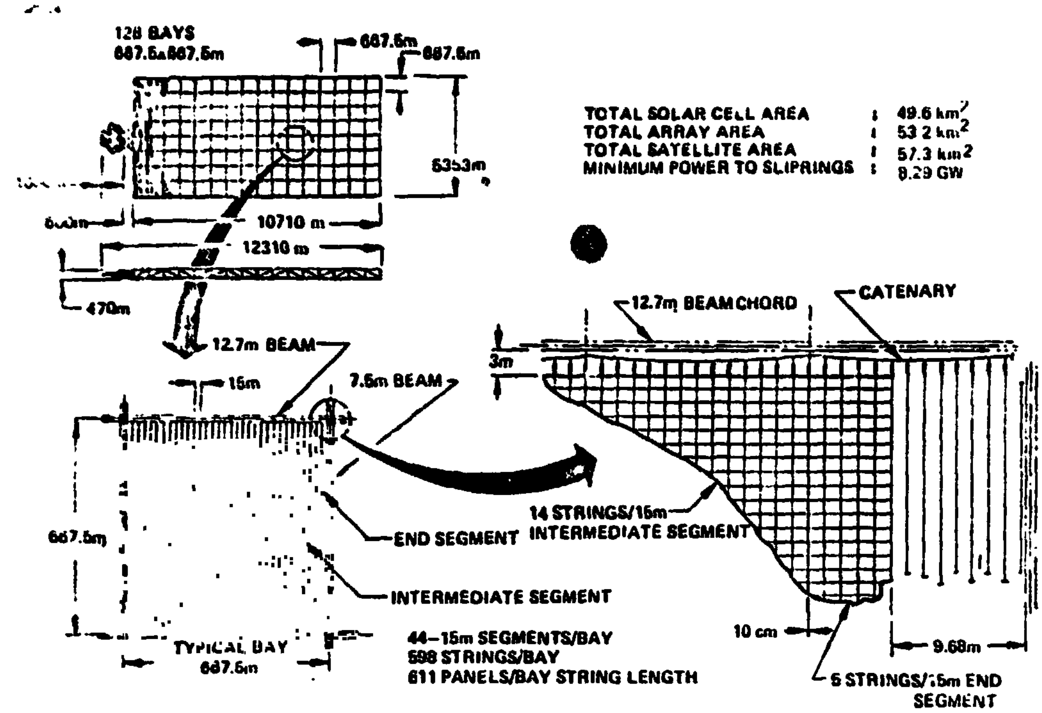
	COST, $ MILLIONS
o Research	--
o Engineering Verification	26.3
o Demonstration	15.8
o Investment	26.3
o Production	8.2

5.2 COST DETAILS

- RESEARCH – Not Identified --
- ENGINEERING VERIFICATION 26.3
  - D&D from structural CER curve = $8M.
  - Factor from D&D to total is 3.3
  - Yields 26.3
- DEMONSTRATION 15.8
  - 60% of EVTA
- INVESTMENT 26.3
  - 100% of EVTA
- PRODUCTION 8.2
  - $150/kg x 54.5 MT

WBS 1.1.1.2 CONCENTRATORS

(There are no concentrators on the baseline satellite.)



1.0 WBS DICTIONARY

This element converts solar energy to electrical energy and provides power to the power distribution and conditioning busses. It includes the photovoltaic conversion cells, coverplates, substrate, electrical interconnects, and any integral attach points required for mounting. Excluded are tools and support equipment required for deployment and tensioning.

2.0 DESCRIPTION

The solar array blanket provides for the conversion of solar energy into electrical energy and delivers the electrical power to the power distribution system in the voltage range of 42 to 44 kilovolts. In order to generate this voltage, cell strings are connected in series. Jumper cabling is used to connect cell strings between satellite bays. Jumper cables are #12 insulated aluminum conductors. Two millimeter thick silicon solar cells were selected as the basic energy conversion devices.

3.0 DESIGN BASIS

The overall solar blanket design concept was developed to satisfy the following criteria:

- o Solar blanket width compatible with the main structural beam batten spacing.
- o Compatible with the construction operation selected.
- o Solar blanket segment lengths compatible with the main structural bay length.
- o Solar array sized to provide the performance shown below:

	EFFICIENCY	MEGAWATTS PER LINK	
Main Bus I^2R	0.934	8,876	SOLAR ARRAY OUTPUT
Rotary Joint	1.0	8,290	
Antenna Power Distribution and Processing	0.97	8,290	TOTAL INPUT TO ANTENNA
DC-RF Conversion	0.85	8,041	
Waveguide I^2R	0.985	6,836	TOTAL RF POWER
Ideal Beam	0.965	6,733	TOTAL RADIATED POWER
Inter-Subarray Losses	0.976	6,497	
Intra-Subarray Losses	0.981	6,341	
Atmosphere Losses	0.98	6,221	
Intercept Efficiency	0.95	6,097	
Rectenna RF-DC	0.89	5,792	INCIDENT ON RECTENNA
Grid Interfacing	0.97	5,155	
	0.563	5,000	NET TO GRID

SOLAR INPUT:	1,353 W/m^2
Solar-Cell Conversion Efficiency (0.173)	234.1
Blanket Factors (0.9453)	221.3
Thermal Degradation (0.954)	211.1
Orientation Loss (0.919)	194.0
Aphelion Intensity (0.9675)	187.7
Nonannealable Radiation Degradation (0.97)	182.1
Regulation, Auxiliary Power, and Annealing (0.983)	179
EOL BLANKET OUTPUT:	179 W/m^2
TOTAL SOLAR-CELL AREA:	49.6 km^2
SOLAR ARRAY OUTPUT:	8,876 MW

4.0 MASS AND MASS BASIS

ITEM	MASS ESTIMATE	RATIONALE	REFERENCE
Solar Cell Panels	21,069.1 MT	See WBS 1.1.3.1	See WBS 1.1.3.1
Interbay Jumpers	75.8 MT	See WBS 1.1.1.3.2	See WBS 1.1.1.3.2
TOTAL	21,144.9 MT	SUM	---

5.0 COST

5.1 COST SUMMARY

	COST, $ MILLIONS
o Research	65.1
o Engineering Verification	41
o Demonstration	680
o Investment	5000
o Production	1984

5.2 COST DETAILS

o RESEARCH — 65.1

Research Phase is $65.1M per research planning book (D180-25381-1). This includes silicon, gallium arsenide, and other p/v research.

o ENGINEERING VERIFICATION — 41

Current cost is $5 for one 50- m cell (2x2) in experimental lots.

EVTA Array is 1 megawatt, assume at 12% effective.

Area is $10^3/1.353x.12 = 6159m^2$, @ 2500 cells/m^2 = 15.4×10^6 cells.

If we use $37,500 based on $15/cell for first square meter, and 80% learning curve, we get $$20.49 \times 10^6$.

o DEMONSTRATION — 680

Pilot production line -

Rate is 600 MW/yr, all-up SPS rate is 176W/yr (3½% of SPS rate).

Assume Pilot Line = 10% of SPS line.

Production rate slope is 70% - 75%.

Exponents are -.515 to -.415.

Rate ratio is 28.57.

Cost ratio 18% to 25% or 4 to 6 x SPS array.

SPS array is $\$35/m^2$, inflated to $40 (15%).

So. Demo array is $\$160-\$240/m^2$ and area is $3.4\ km^2$.

Cost is $544M - $816.

Take average = $680M.

o	INVESTMENT	5000

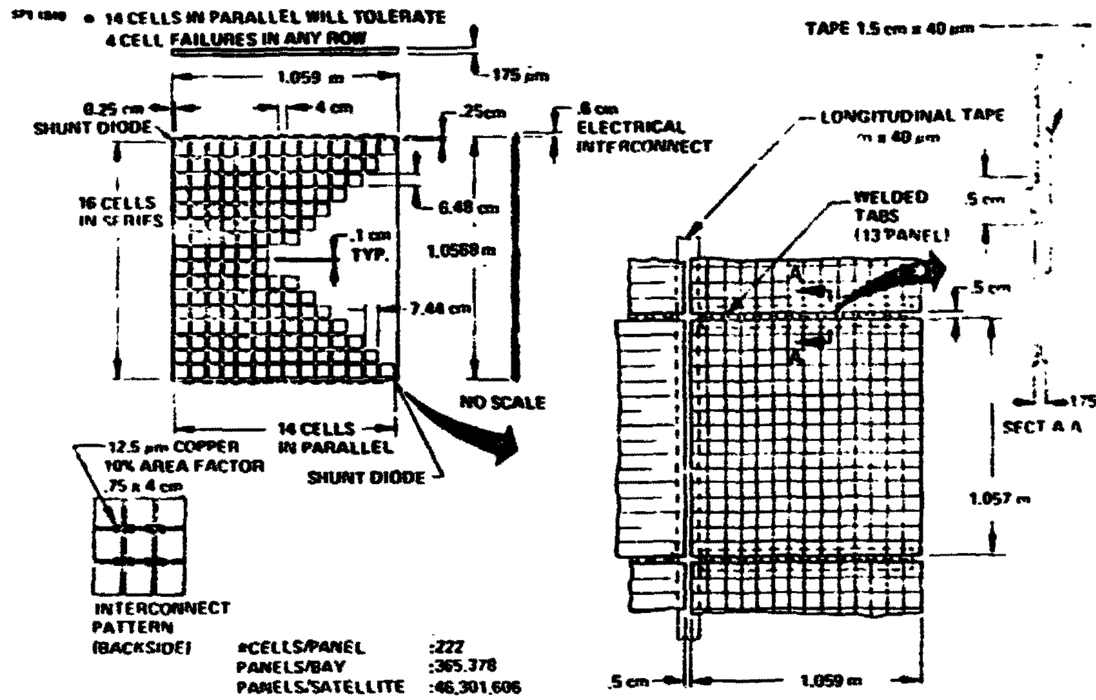
The solar array production plant and equipment was roughly estimated as $5 billion. This estimate is little more than a guess since the production process has not been identified.

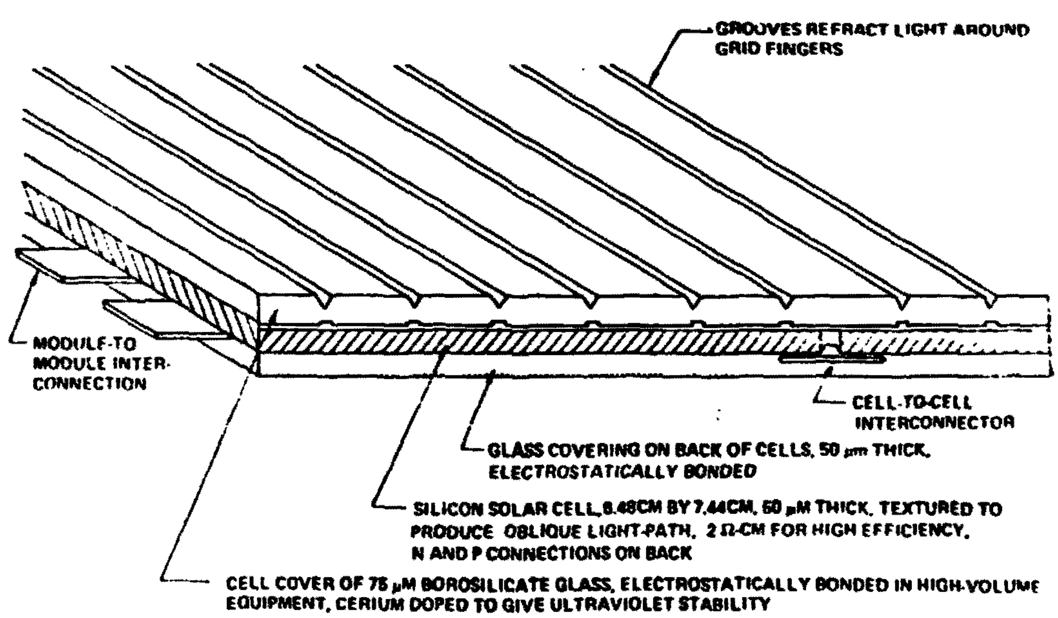
o	PRODUCTION	1984

Production cost was estimated based on materials, cost, amortization, and labor.

Materials	
Silicon @ $115 g/m^2$, $60/kg, and 40%	$\$\ 17.25/m^2$
Glass @ $280 g/m^2$, $3/kg, 80% yield	$\$\ 1.05/m^2$
Other @ $30\ g/m^2$, $10/kg, 80% yield	$\$\ 0.375/m^2$
Amortization	
Plant @ $500M, 15 years, $100\ km^2/yr$	$\$\ 0.33/m^2$
Equipment @ $4.5B, 8 years, $100\ km^2/yr$	$\$\ 5.625/m^2$
Levelized —POI	$\$\ 4.895/m^2$
Labor @ $60,000/yr, 17,500 people	$\$\ 10.475/m^2$
	$\$\ 40.00/m^2$
	$\$\ 49.6/km^2$
	$ 1984M

FOLDOUT FRAME





INTERCONNECTORS: 12.5-μM COPPER, WITH IN-PLANE STRESS RELIEF, WELDED TO CELL CONTACTS

1.0 WBS DICTIONARY

This element includes the hardware necessary to convert solar energy to electrical energy. It includes the photovoltaic conversion cells, coverplates, substrates, electrical interconnects and attachment provisions for the catenary blanket suspension system.

2.0 DESCRIPTION

The basic energy conversion device is a 50 μm thick, 6.48 cm by 7.44 cm silicon solar cell with a textured surface reduce reflectance. The cover glass is 75 μm thick cerium doped borosilicate glass which is electrostatically bonded to the solar cell. The substrate is 50 μ m thick glass which is electrostatically bonded to the back of the cell. The cell is designed with both p and n junctions brought to the back of the cell. The interconnects are 12.5 μm thick, silver-plated copper. Complete panels are assembled by welding together the module-to-module interconnections.

The basic panel adopted for design studies has a matrix of 222 solar cells, each 6.48 by 7.44 cm in size, connected in groups of 14 cells in parallel by 16 cells in a series. Spacing between cell and edge spacings are as shown. Tabs are brought out at two edges of the panel for electrically connecting panels in series. Cells within the panel are interconnected by conducting elements printed on the glass substrate. Shadowing protection is provided by redundant shunting diodes at the panel level.

Panels are assembled to form larger elements of the solar array. The interconnecting tabs of one panel are welded to the tabs of the next panel in the string and then the interconnections are covered with a tape that also carries structural tension between panels. The 0.5 cm spacing between panels provides room for the welding electrodes, and also permits reasonable tolerances in the large sheet of 75 μ m glass that covers the cells and 50 μ m sheets of substrate glass.

The panels are joined in a matrix that is 14.9 meters wide by 656 meters long to form blanket segments. After assembly, the segment is accordion folded, at panel intersections, into a compact package for transport to the low-Earth-orbit assembly station.

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

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

Important panel requirements were these:

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

3.0 ELEMENT DESIGN BASIS

The selection of the silicon solar cell as the energy conversion device was based on system trades performed in Parts I and II of NAS9-15196 (Ref. Volume III, Part II, D180-22876-3, "SPS Satellite Systems".) The important results of those trades are as follows:

- Silicon Costs Not "Too High"
- Silicon System Not Sensitive to Cell Performance
- CR-1 Preferable to CR-2
- Annealing Critical to Silicon System
- Gallium Supply and $$ in Question
- GaAs Thin Film Critical Technology
- If Gallium Supply and Thin Film Ok--GaAs Attractive and not as sensitive to annealing or LEO/GEO trade
- Other thin films look competitive but poor data base

With respect to the cost of silicon solar cells, we found that the large number (2×10^{10}) of 5 by 10 cm cells required for each solar power satellite could be manufactured in automated factories which would be entirely different from today's solar cell production facilities, and that the cell cost would be as proportionately low as today's high-volume semiconductor products. The "mature industry" approach to pricing indicated that the cost of the satellite would indeed be reasonable. The weight and cost of the satellite was not too sensitive to solar cell performance. Practical satellites could be designed around solar cells having efficiencies even as low as 15.0 percent; this is achievable today.

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

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

Glass was chosen for the substrate to enable annealing of radiation damage by heating. With all glass-to-silicon bonds made by the electro-static process there are no elements in the blanket which cannot withstand the 773^{o}K (931^{o}F) annealing temperature, which at present seems to be required.

4.0 MASS AND MASS BASIS

The mass of the solar cell blanket is the result of a detailed estimate and is summarized below in grams per square meter.

AVAILABLE BLANKET	DENSITY			Area Factor	Mass Per Sq. Meter (g/m^2)
Covers--Fused Silica	2.20	55.88	3.0	1.0	167.64
Cells--Silicon	2.36	59.94	2.0	0.9607	115.17
Interconnects--Copper	8.94	227.08	.5	0.100	11.35
Substrate--Fused Silica	2.20	55.88	2.0	1.0	111.76

7 mils:
- 3 mils cover
- 2 mils cell
- 2 mils substrate and interconnects

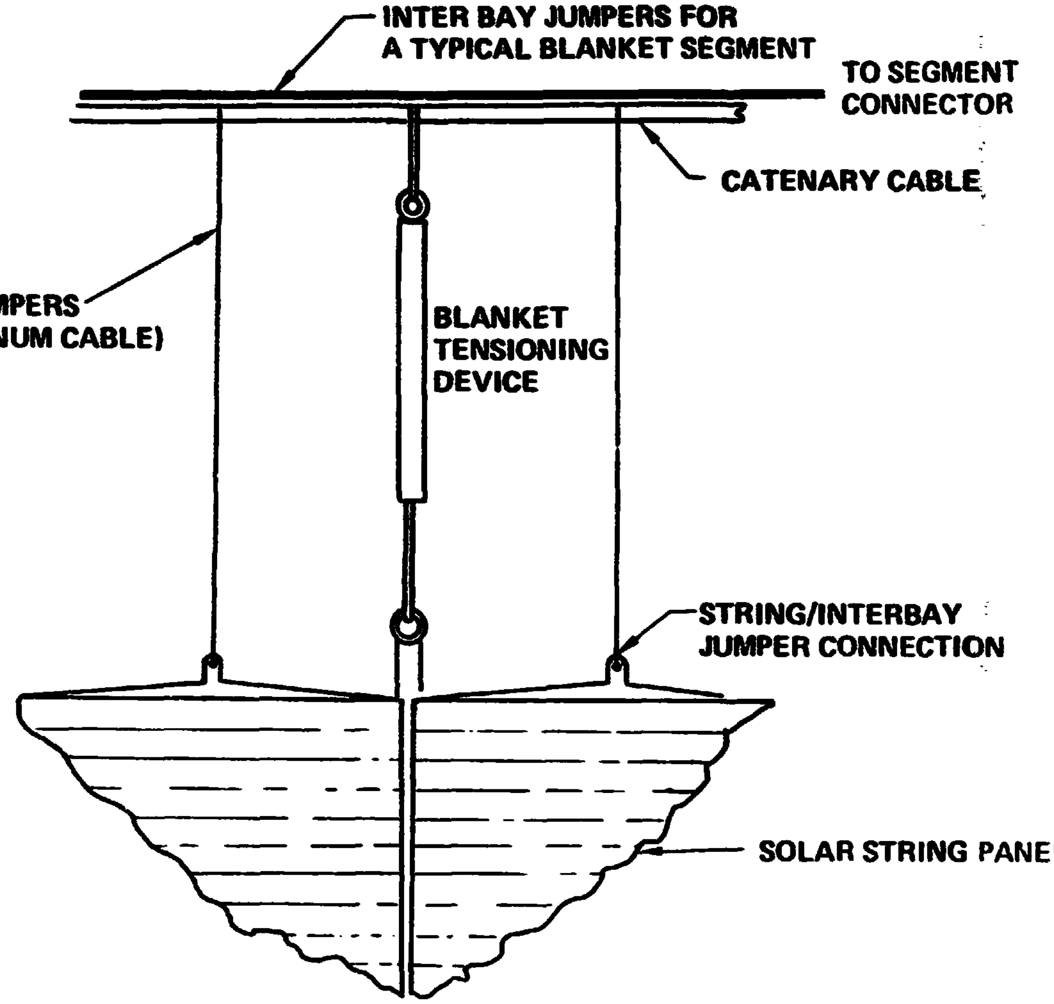
Theoretical Panel Weight	405.92
Tolerances Allowance (5%)	20.30
Estimated Panel Weight	426.22
Panel Area Factor (.9913)	422.51
Segments Area Factor (.9972)	421.33
Joint/Support Tapes	2.93
Estimated Array Weight	424.78

The total mass is estimated as the product of array area (49,600,000 square meters) times the per unit mass (0.42478 kilograms per square meter) = 21,069.1 metric tons.

5.0 COST AND COST BASIS

This element's cost is included in WBS 1.1.1.3.

SPS-1752



Inter Bay Jumpers

2

1.0 WBS DICTIONARY

This element includes the hardware necessary to provide for interbay power distribution within a power sector for the solar blanket and for connection to the acquisition busses of the power distribution system.

2.0 DESCRIPTION

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

3.0 DESIGN BASIS

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

4.0 MASS AND MASS BASIS

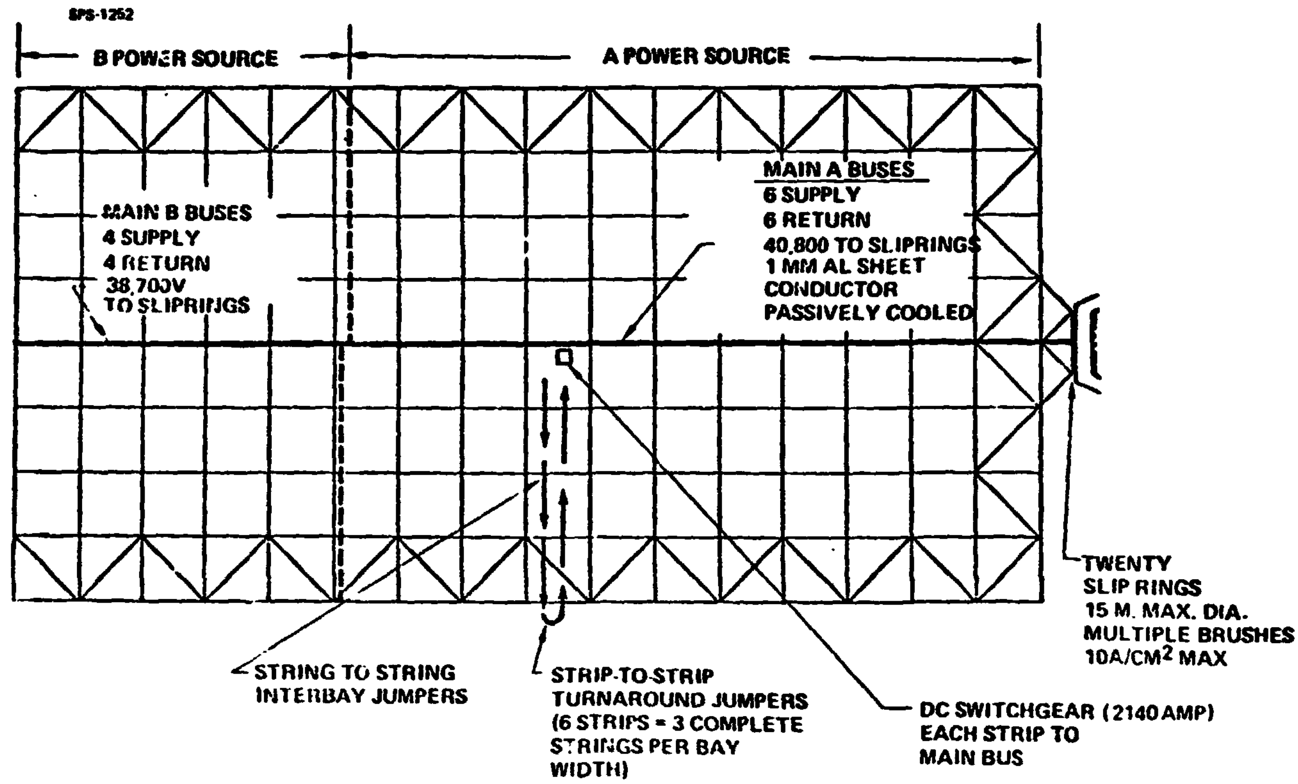
There are a total of 95,680 interbay jumpers required on a 5 GW SPS. The average length of each jumper cable is 20.4 meters. The per unit mass of the cable is estimated to be 0.0293 Kg/meter. The connector mass is estimated to be 0.2 Kg.

Mass per jumper = (20.2)(0.0293) + 0.2 = 0.792 kilograms
Total mass = (95,680)(0.792) = 75,765 kilograms

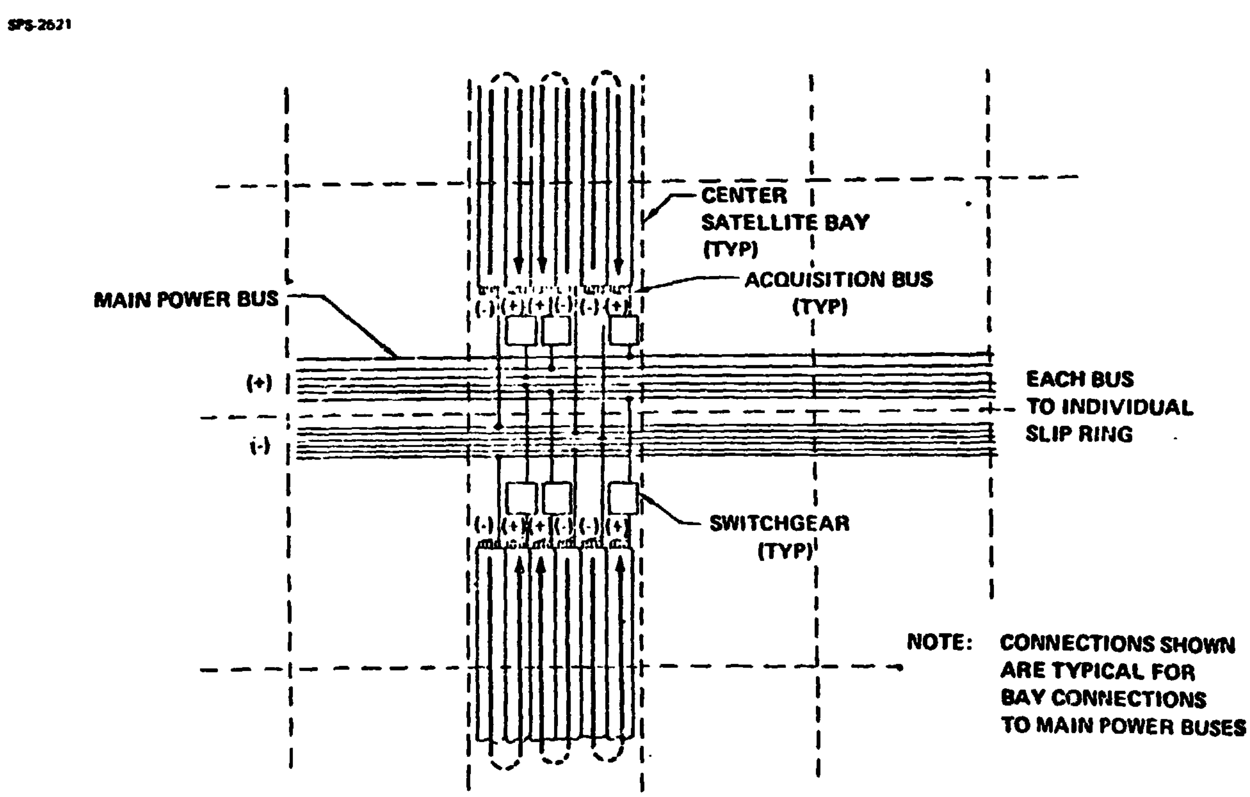
5.0 COST AND COST BASIS

Production cost of interbay jumpers was estimated as $50/kg for a total of $3.8 million. Other costs are included in solar blanket figures.

FOLDOUT FRAME



Power Distribution Concept



Multiple Bus/Array Connection

WBS 1.1.1.4 POWER DISTRIBUTION

1.0 WBS DICTIONARY

This element includes the power conductors, switch gear and conditioning equipment required to transfer power from the solar blanket to the interface subsystem power distribution elements. Also included are electrical cables and harnesses required to distribute power to equipment located on the energy conversion structure. Excluded are data busses which are included in the information management and control subsystem (WBS No. 1.1.3).

2.0 DESCRIPTION

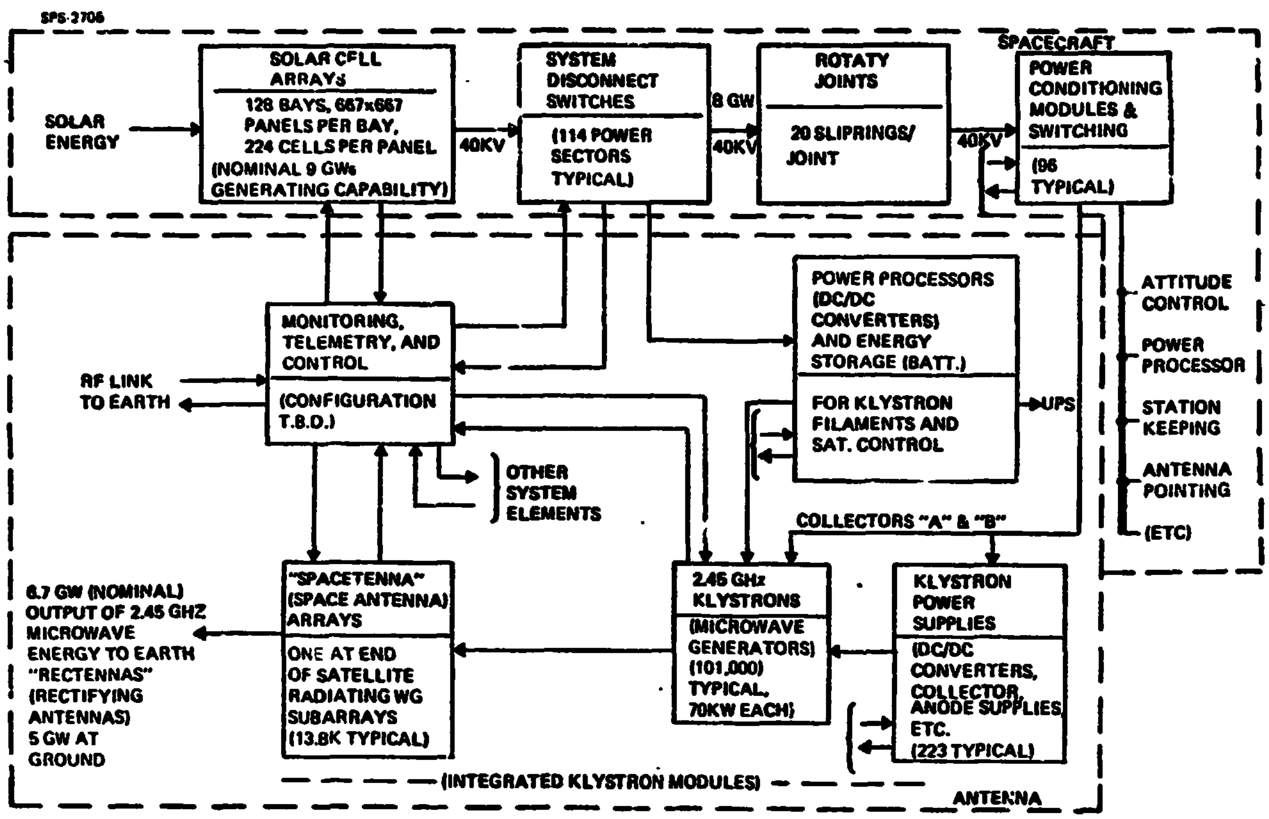
An overall SPS functional diagram is shown above. The power distribution system for the energy conversion portion of the SPS is divided into two power areas (power sources A and B). Six main power busses (Positive and Returns) are used to route power from the power source A portion of the array and 4 main power busses (Positive and Return) are used from power source B. The B power source is located farthest from the MPTS antenna. The main power busses are aluminum sheet, one millimeter thick, whose width is proportional to the current flowing through them. The solar array is divided into 96 power sectors. At each power sector feed to the main power distribution busses switchgear is installed for power system control and operation. The switchgear includes both DC circuit breakers and disconnect switches. Acquisition busses are used to collect power from the solar cell strings and to route the current flow to the switchgear. Acquisition busses are triangular shaped, one millimeter thick, sheet conductors whose width increases as each additional solar cell string is connected. Maximum width occurs at the point where the power feeder to the switchgear is attached.

Four power processors are installed on the energy conversion portion of the SPS to provide power to housekeeping systems installed thereon. Some energy storage is also provided.

3.0 ELEMENT DESIGN BASIS

The design of the energy conversion power distribution system was driven by the power requirements of the klystrons used as DC-to-RF power converters on the MPTS. Two of the depressed collectors on the antenna require about 85% of the total supplied power. The power system concept selected provided power to these elements directly from the solar array to avoid the mass penalty of power processors for processing all power supplied to the antenna. The resulting design incurs this penalty for only 15% of the required power. This 15% increment of power is required at several different levels of much lower voltages. A minimum mass system is realized by using antenna mounted DC/DC converters to develop the required voltages. (REF NAS9-15196, Part II, Vol. III, D180-22576-3 pp 42-65.)

The satellite was divided into two power sources to provide these two primary voltage levels. Each power source is further divided into power sectors to provide the required power control and to provide for isolation for maintenance and repair. Multiple main power busses are provided to reduce potential fault currents on any main bus.



Simplified SPS Functional System Block Diagram

4.0 MASS AND MASS BASIS

ITEM	MASS ESTIMATE		RATIONALE	REFERENCE
Main Busses	1,090	MT	See WBS 1.1.1.4.1	See WBS 1.1.1.4.1
Acquisition Busses	39.7	MT	See WBS 1.1.1.4.2	See WBS 1.1.1.4.2
Switchgear	116.4	MT	See WBS 1.1.1.4.3	See WBS 1.1.1.4.3
Power Processing and Energy Storage		MT		

5.0 COST AND COST BASIS

5.1 COST SUMMARY

	COST, $ MILLIONS
o Research	--
o Engineering Evaluation	40
o Demonstration	352.6
o Investment	352.6
o Production	149.9

5.2 COST DETAILS

- o RESEARCH --
  - o Switchgear research carried under MPTS
- o ENGINEERING EVALUATION 40
  - o Allocate $20M for EVTA bus and breaker design. The EVTA bus will be approx. 600V and 1000 amps.
  - o Allocate $20M for hardware.
- o DEMONSTRATION 352.6
  - o Use 60% of computed DDT&E cost of $587.6.
- o INVESTMENT 352.6
  - o Use 60% of computed DDT&E cost of $587.6.
- o PRODUCTION 149.9

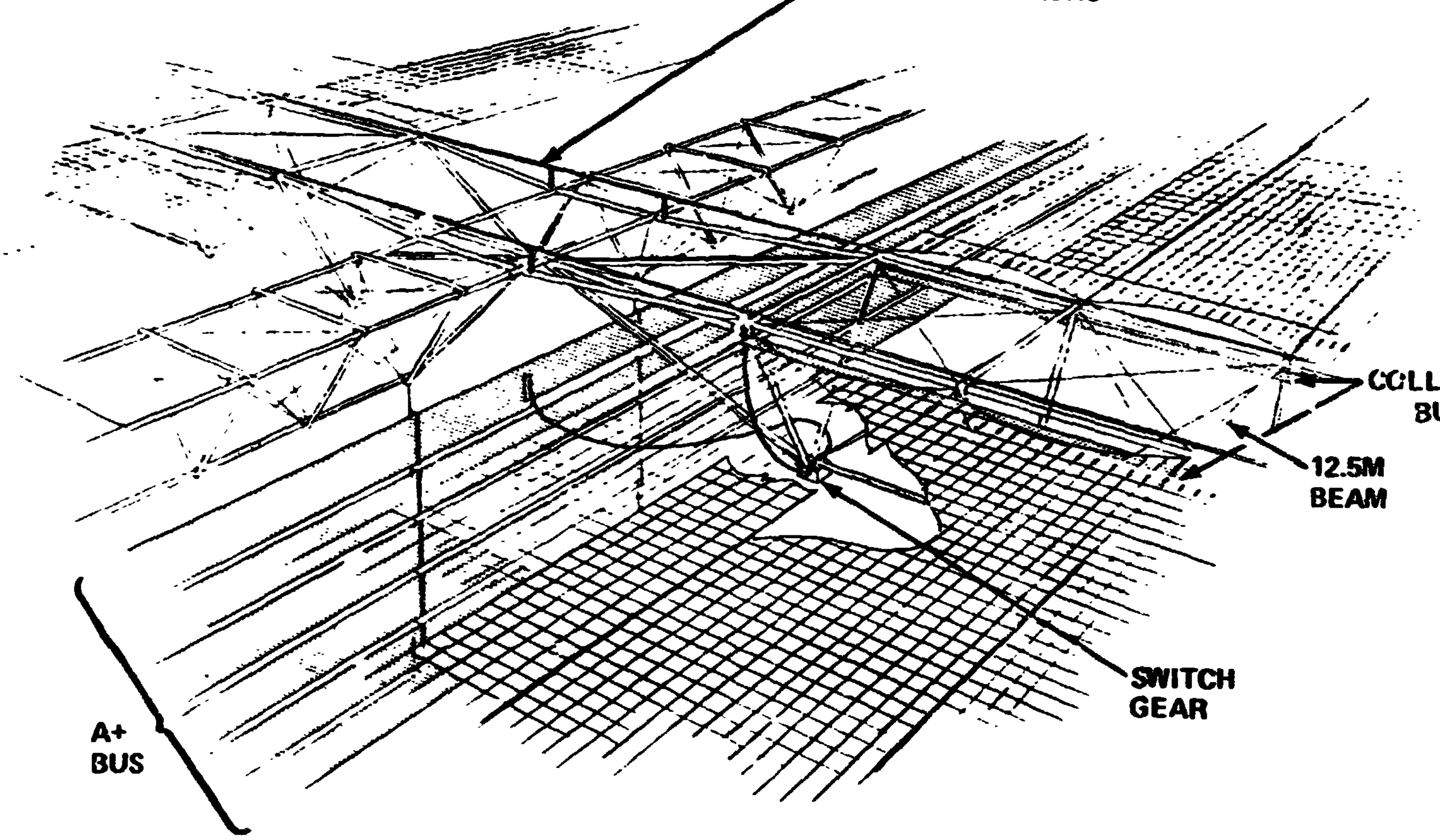
Number of Units

Main Bus	1	$37/kg (update Vol 6, D180-22876-6)
Acquis Busses	384	$37/kg
Ckt Brkr #1	96	96th @ .8 .3 platform
Dis Sw #1	192	96th @ .8, .3 platform
Ckt Brkr #2	4	4th @ .8, .3 platform
Discon Sw #2	4	4th @ .8, .3 platform

	TFU	Factors	Prod Unit	Per SPS
Ckt Brkr #1	7.29	.23x.3	0.505	$ 48.3M
Dis Sw #1	0.64	.23x.3	$44K	$ 8.5
Ckt Brkr #2	0.55	.3	$165K	$ 0.65M
Dis Sw #2	.35	.3	$106K	$ 0.43
Main Bus				88.8
Acquis Busses				3.2
			TOTAL	$149.9M

FOLDOUT FRAME

SPS-2703



Power Bus Concept

1.0 WBS DICTIONARY

This element includes the power conductors required to transfer power from the power sector switchgear connections to the interface system power distribution elements.

2.0 DESCRIPTION

The main power busses are one millimeter thick, conductor grade, aluminum sheets. The width of the sheets are proportional to the bus current. There are a total of 20 main power busses--A power source: 6 positive and 6 return; B power source: 4 positive and 4 return. The maximum width of the A power busses is 3.58 meters. The maximum width of the B power busses is 2.54 meters.

3.0 DESIGN BASIS

Conductors - The conductors for the satellite were selected to be one millimeter thick electrical conductor (EC grade aluminum sheet). Aluminum was selected as the conductor material based on the product of resistivity and density. Sheet conductors were selected over other shapes because they maximize the ratio of surface area (for radiation of waste heat) to enclosed area (for current conduction). The thickness of one millimeter was selected to minimize handling damage.

Conductor Operating Temperature - Conductor operating temperature was selected to minimize the total satellite mass. The sum of conductor mass and power generation system mass required to generate the conductor I^2R losses was minimized. The optimum conductor operating temperature was determined to be 373K (212°F).

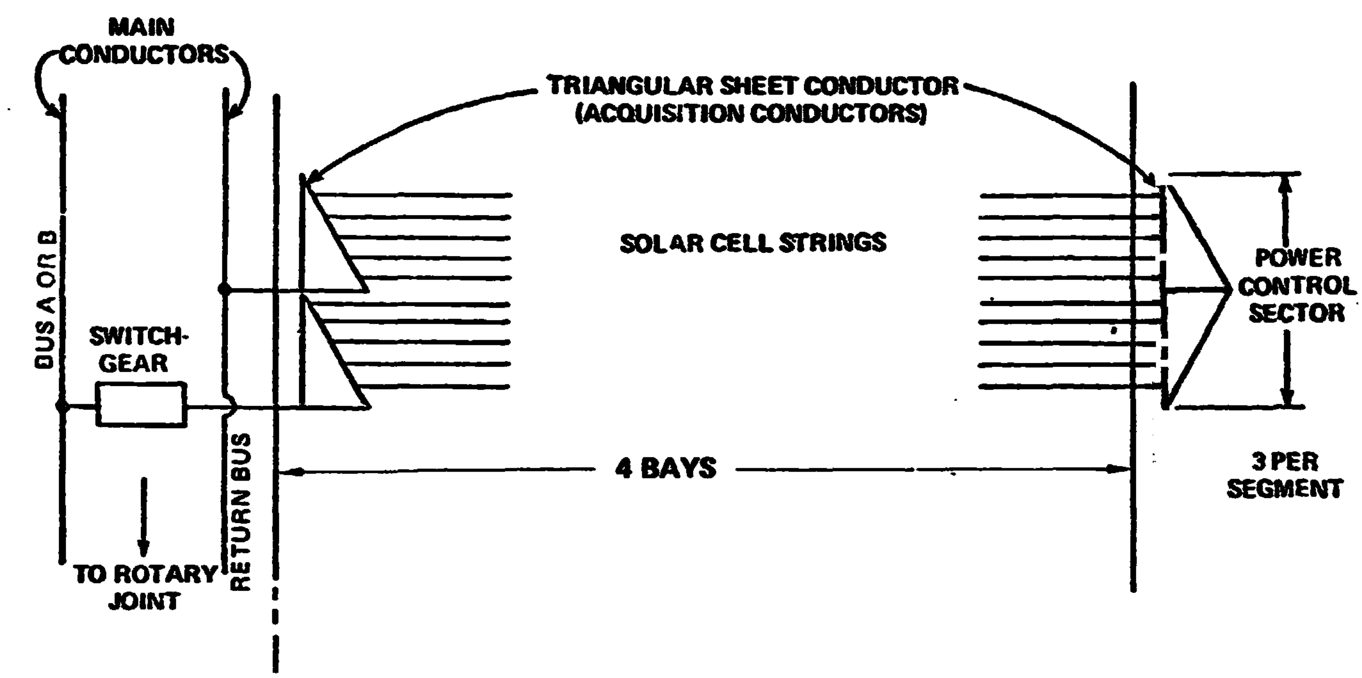
4.0 MASS AND MASS BASIS

The mass of the main power busses was estimated to be 1,090 metric tons. The estimate was similar to that shown in NAS9-15196, Part II, Vol. 3, D180-22876-3, Pages 61-65.

5.0 COST AND COST BASIS

This system cost is presented under 1.1.1.4 at the higher level.

FOLDOUT FRAME



Satellite Acquisition Bus Configuration

1.0 WBS DICTIONARY

This element includes the conductors required to collect power from the solar cell string and route it to the power sector switchgear installation.

2.0 DESCRIPTION

An acquisition bus is a one millimeter thick, triangular shaped, aluminum conductor. Its length is approximately 110 meters and its maximum width is 41.5 centimeters. Provisions are included for attaching the cell strings to the bus.

3.0 DESIGN BASIS

The formulation of high voltage in the solar array is accomplished by connecting approximately 78,000 sets of solar cells in series. The strings must traverse across 4 bays and then return across the same 4 bays. The purpose of the acquisition busses is to provide a current path between cell strings at the end of the 4th bay farthest from the switchgear and to collect the current from the cell strings at the bay end nearest the switchgear for subsequent connection to the switchgear on the positive end and to the return bus on the negative end of the power sector. The selections of conductor material and operating temperature are discussed in WBS 1.1.1.4.1 (Main Busses).

4.0 MASS AND MASS BASIS

The conductor mass for each acquisition bus is estimated to be 51.7 kilograms. Attachment provisions are estimated (guess) to be the same. There are 384 acquisition busses required per SPS.

Total mass = 384 (51.7 + 51.7) = 39,706 kilograms

5.0 COST AND COST BASIS

This system cost is presented under 1.1.1.4 at the higher level.

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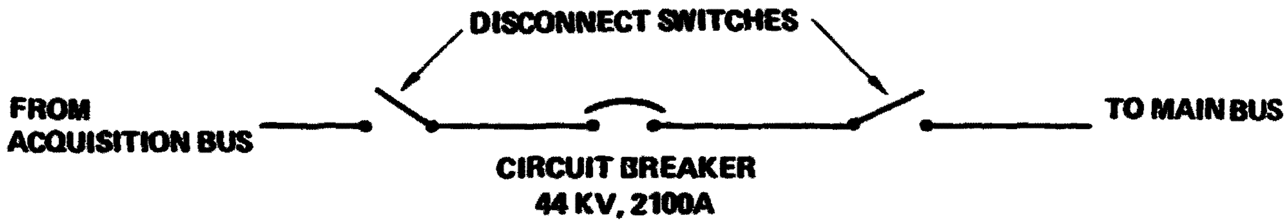
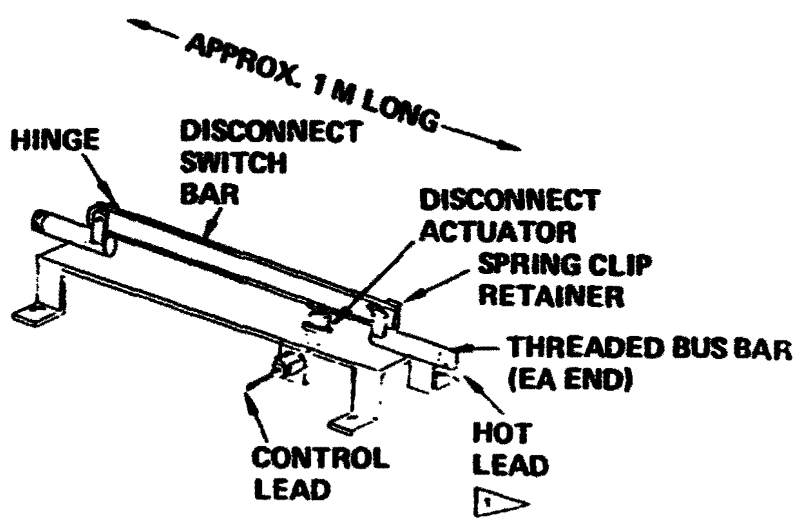
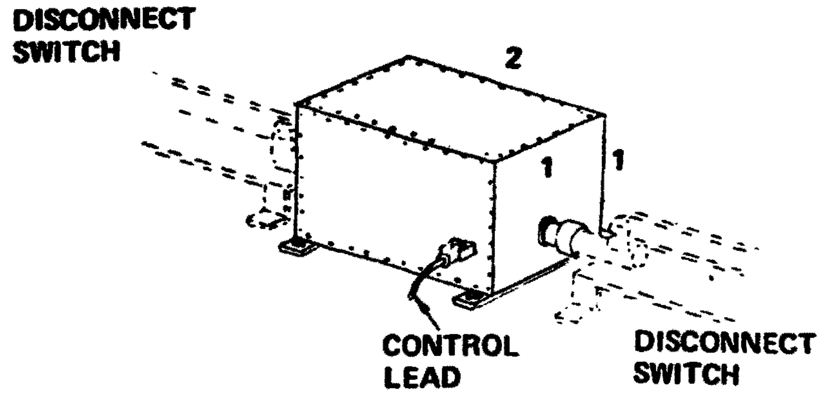


Simplified Switchgear Schematic
(Typical 96 Places)



Disconnect Switch



Circuit Breaker

FOLDOUT FRAME

1.0 WBS DICTIONARY

This element includes the circuit breakers, required for power system operation and control, and disconnect switches, required for isolation for maintenance or repair, of the energy conversion portion of the main power distribution and control system.

2.0 DESCRIPTION

The circuit breakers are of the vacuum type with nominal ratings of 44,000 volts and 2,200 amperes. They include circuits for under voltage, overvoltage, overcurrent, and reverse current detection and operation. Transducers for sensing sector current and voltage are also included. The disconnect switches contain provisions for remote operation as well as local. They are to be operated only when no current flow is present.

3.0 DESIGN BASIS

The size of the switchgear is based on the application and is judged by General Electric to be achievable.

4.0 MASS AND MASS BASIS

(See WBS 1.1.2.3.2)

The mass of each circuit breaker is estimated to be:

(44,000 V) (2,200 A) (.010Kg/1000 watts) = 968 Kg

The mass of a disconnect switch is estimated (guess) to be 120 Kg.

Item	Unit Mass	Quantity	Total Mass
Circuit Breaker 44 KV, 2.2 KA	968 Kg	96	92,928 Kg
Disconnect Switches 44 KV, 2.2 KA	120 Kg	192	23,040 Kg
Circuit Breaker 44 KV, 100 A	44 Kg	4	176 Kg
Disconnect Switches	60 Kg	4	240 Kg
Total			116,384 Kg

5.0 COST

This system cost is presented under 1.1.1.4 at the higher level.

WBS 1.1.1.5 THERMAL CONTROL

(This element has been included within the descriptions of the subelements.)

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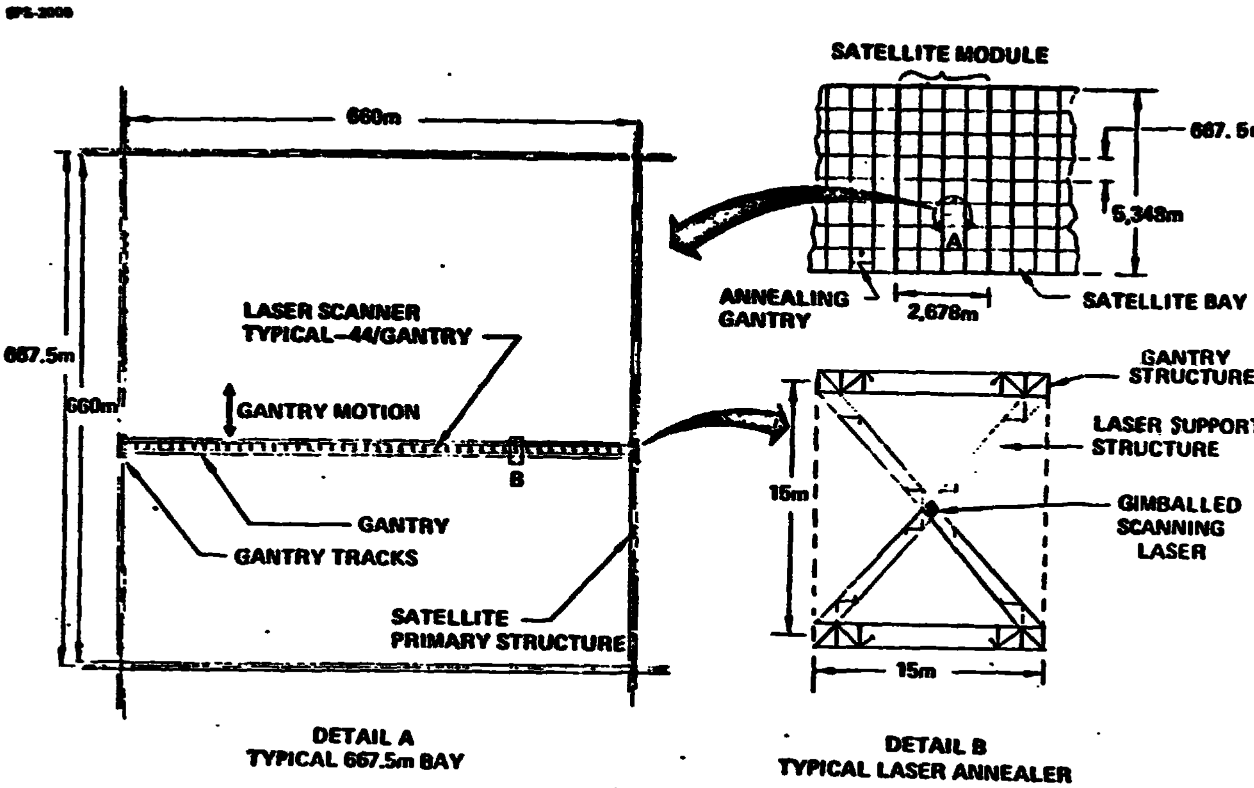


Figure A. Laser Annealing Concept

1.0 WBS DICTIONARY

This element includes maintenance access provisions and solar array annealing hardware.

2.0 DESCRIPTION

This section describes the built-in energy conversion system maintenance equipment. The maintenance operations are described in WBS 1.2.3.3.

WBS 1.1.1.6.1 Main Power Bus Access System

The main power busses are suspended on a cable-support system below the upper surface of the solar collector. These busses are not accessible by a cherrypicker mounted on the annealing machine gantry for two reasons: (1) a cherrypicker could not find a clear path through the structural beams (there are cable stays in the beams) and there is no room between the ends of the solar arrays and the beams, and (2) the main bus stack could be as much as 60 meters tall. Subsequently, the main busses and the switch gear assemblies must be accessed from below the solar array surface.

Figure A illustrates the main bus access concept. A track beam is required that would parallel the main busses (see Figure B for the general pattern of these track beams). The track beam is tied into the parallel SPS structural beam to provide torsional rigidity. Each of the legs of this track system would have a flying cherrypicker carriage attached to which a flying cherrypicker would dock.

WBS 1.1.1.6 MAINTENANCE SYSTEMS

The basis for the maintenance access provisions are given in Section 13 of the Operations and Systems Synthesis document (D180-25461-3).

WBS 1.1.1.6.2 Solar Array Annealing Equipment

The annealing gantry with its equipment, shown in Figure C, D, and E, includes the following:

- Gantry structure that spans one bay, 667.5 meters.
- Wheel and drive system for moving about the array on the track network.
- Laser unit. This includes a set of CO_2 electric discharge lasers, scanning optics, power processors, thermal control equipment, motive equipment for moving along the gantry, and a docking port for a flying cherrypicker.
- Solar array atop the gantry to power the lasers. This avoids the need to have the laser gantry obtain power from the SPS array.
- Power bussing to deliver array power to the annealer system.

3.0 DESIGN BASIS

The following assumptions were used:

1. Laser heat input 50% efficient in heating array.
2. Asymptotic temperature 500° C requiring 6.4 w/cm^2 laser intensity.
3. Heating time 5 sec, resulting in 32 w-sec/cm^2.
4. Area of one bay is 387,500 m^2 of active solar array area, requiring total input of 1.24 x 10" watt/sec input.
5. Electric power input to laser set = 1 megawatt laser system 15% efficient; 150 kw output by 44 lasers (3.4 kw per laser). Time to anneal one bay is 1.24 x 10"/150,000 = 8.27 x 105 sec = 9.56 days. Time to anneal SPS = 128 days x 9.56 days/4 gantries = 306 days.

Laser annealing will be carried out whenever the SPS solar array accumulated enough radiation damage to degrade output by a noticeable amount (say, more than 2%). It is likely that this will require about three anneals per solar cycle (array-degrading comes mainly from solar flare protons). These anneals are expected to be concentrated in the few years around solar maximum, with no activity during solar minimum.

The worst case power outage due to annealing is approximately one-half of four bays disconnected due to being shadowed by the annealers. Normally, the array output available exceeds the Transmitter rating by more than this. Only if annealing takes place at summer solstice (minimum array output), and the Transmitter has been recently refurbished, will annealing operations result in a reduction of ground output. In that case, annealing could reduce ground output by as much as 1½%.

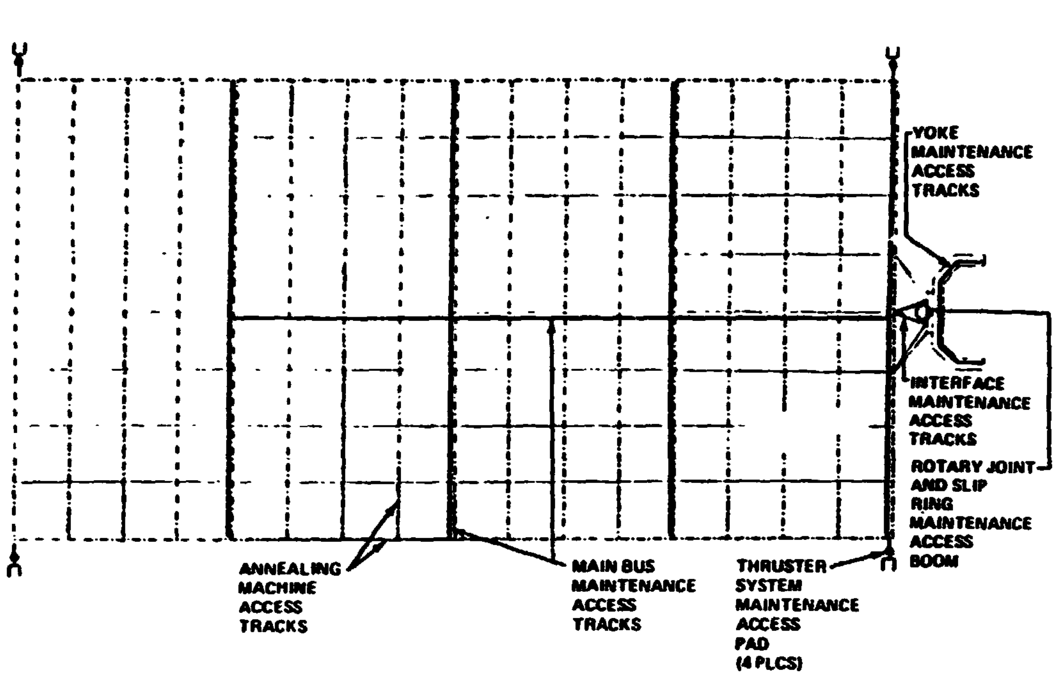
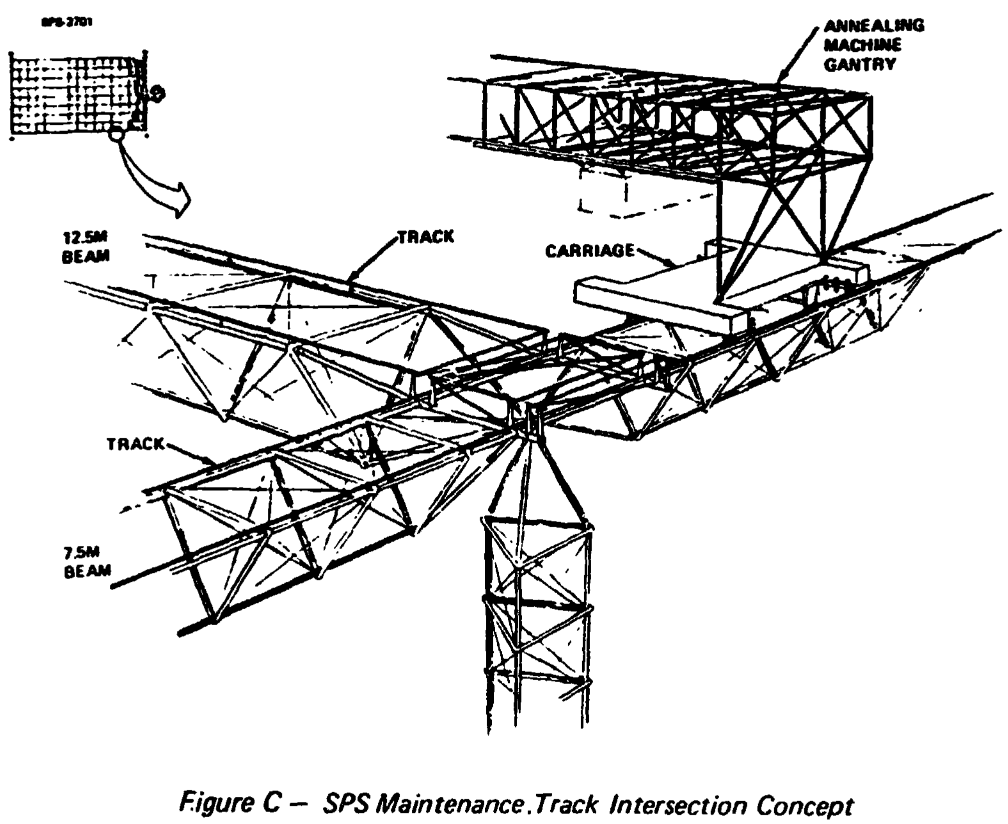


Figure B — SPS Maintenance Access Systems



FOLDOUT FRAME

Figure C — SPS Maintenance Track Intersection Concept

4.0 MASS AND MASS BASIS

The mass estimate is tabulated below. A contingency allowance is provided (in addition to that at the satellite level) to cover maintenance needs and equipment not yet identified.

SOLAR ARRAY MAINTENANCE MASS ESTIMATE

ITEM	MASS (MT)	RATIONALE
Gantries	50	15 kg/m x 667.5m x 4 gantries, 25% added for transport mechanisms
Self-contained Solar Array	28	7000 m^2/gantri/x 1 kg/m^2 x 4 gantries
Power Bussing	1	Guess
Power Processors	10	12 kw x 4 gantries x 2 kg/kw.
Thermal Radiators (Laser & PPU coolers)	60	2500 m^2 x 6 kg/m^2 x 4 gantries
Lasers	9	1100 kw x 4 gantries x 2 kg/kw_e
Docking Ports	4	16 positions x 250 kg each; includes main bus access requirements
Growth & Cont.	30	20%
Moving Equip Total	182	
Tracks	439	Length of track x mass/length This track mass includes annealing gantry tracks and bus access tracks
Total	621	

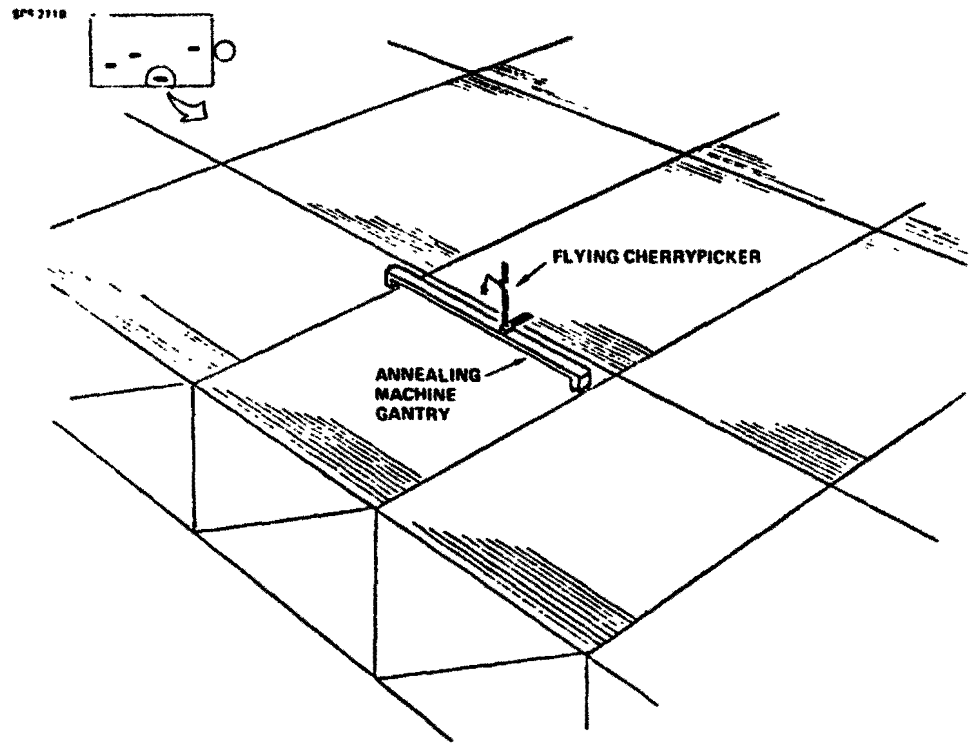


Figure D – Solar Array Top Surface Maintenance Access System

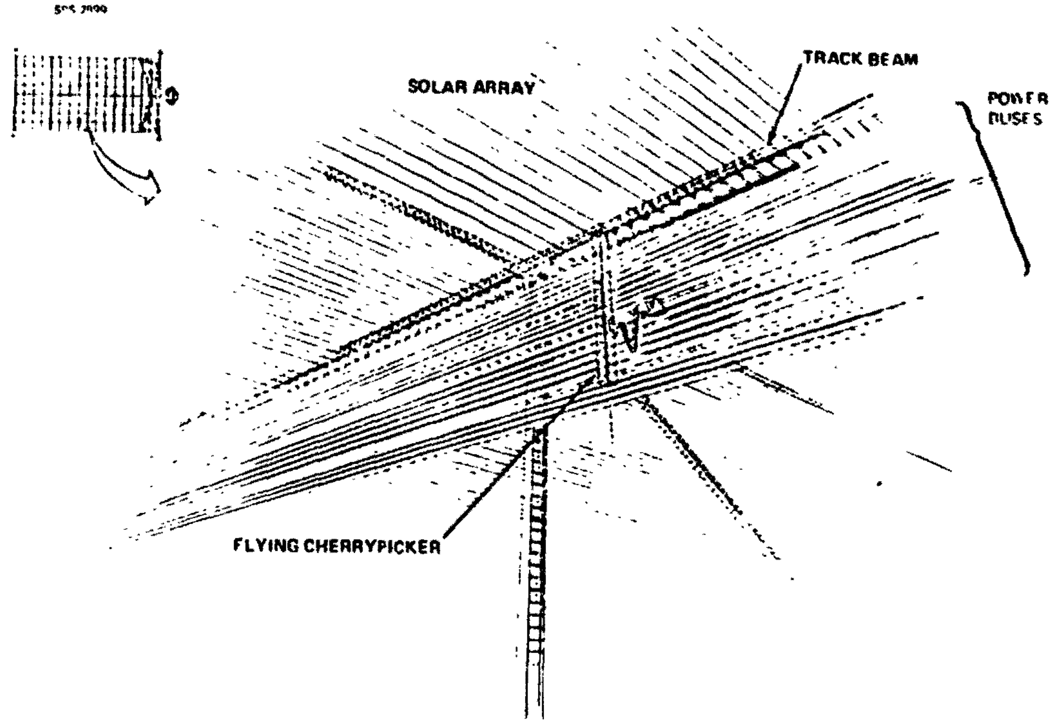


Figure E – Main Bus Maintenance Access System

5.0 COST

5.1 COST SUMMARY

Research - Included in solar blanket research

Engineering Verification	- $ 76.2M
Demonstration	- $367.6M
Investment	- $175.1M
Production	- $267.12M

5.2 COST DETAILS

Engineering Verification

This program will develop the laser and its PPU and test at the LEO development lab. Costs to transport the equipment to the LEO development lab and conduct the in-space tests are included in the LDL costs

Develop Laser Prototype	$ 3.5M
Develop PPU	$12.7M
Integrate and ground test	$60.0M
	$76.2M

Demonstration

DDT&E per PCM	$291.85M
Hardware on Demo Unit	$ 75.75M

Investment

Delta DDT&E	$175.1M
No Special Facilities	

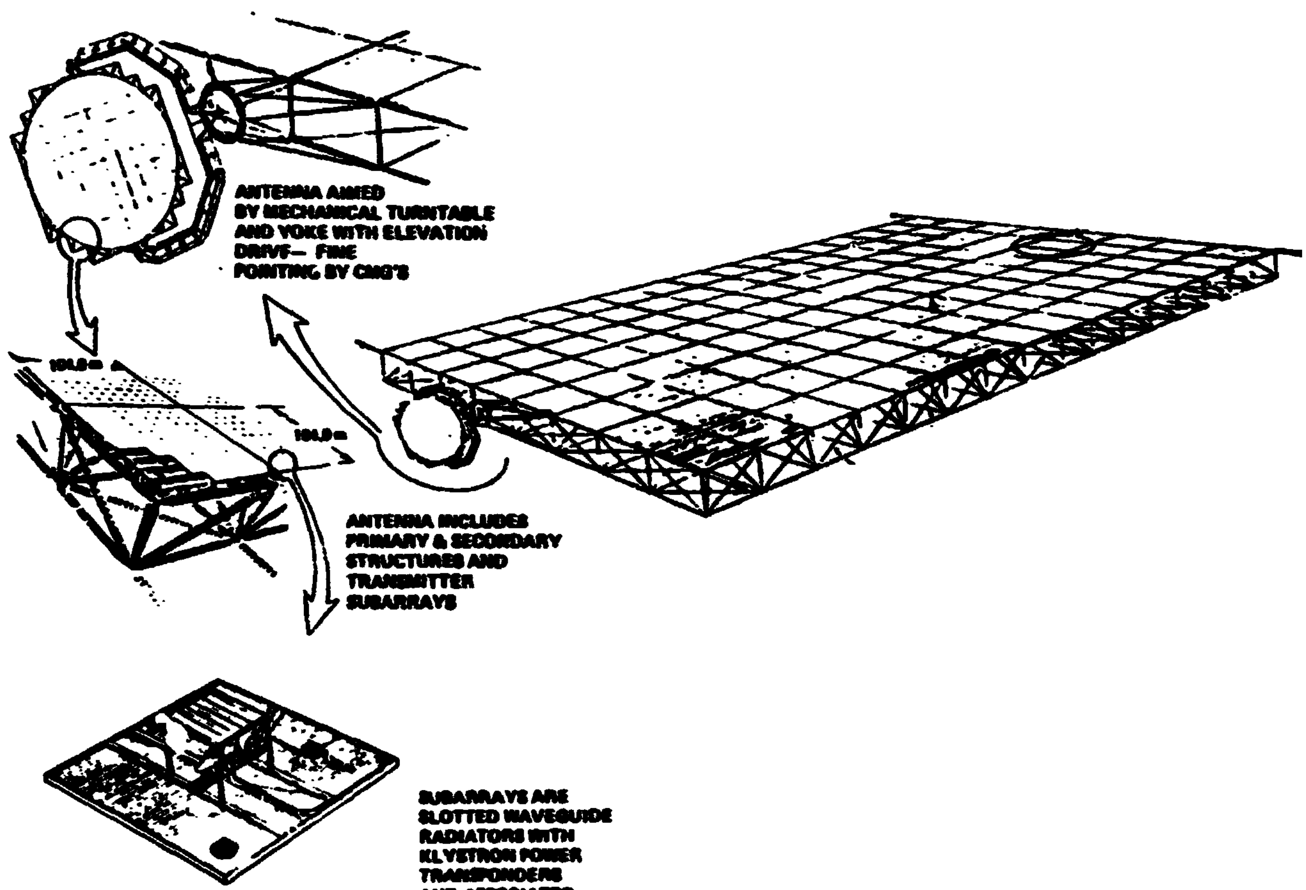
<u>Production</u>

Item	TFU	Factors	#RQD	Prod Unit	Per SPS
Gantry	$3.8M	4th @85% =.7225	4	2.75	11.0
Array	—	$100/m^2	4	0.7	2.8
Bussing	431 K	4th @85%	4	311	1.245
PPU's	9.6755	4th @85%	4	6.99	27.96
Thermal Cont	3.132	40th @85% =.42	40	1.316	52.6
Lasers	1.193	176th @90% =.45	176	.537	94.5
Growth & Cont	—	23% of above	—	—	4[illegible]
Tracks	—	$76/kg	439 tons		33.36
					267.12

FOLDOUT ...

SPS-3081

FOLDOUT FRAME



1.0 WBS DICTIONARY

This system includes all elements needed to convert DC electric power to microwave power at 2450 megahertz and to direct this power in the form of a coherent beam, to the receiving antenna on Earth. The major subelements are:

1.1.2.1 Structure

1.1.2.2 Subarrays

1.1.2.3 Power Conditioning and Distr.

1.1.2.4 Reference Phase Distribution

1.1.2.5 Thermal Control (allocated to the other subsystem elements; no mass or cost is attributed to this element)

1.1.2.6 Maintenance Equipment

1.1.2.7 Antenna Mechanical Pointing

Also mounted physically on the antenna, but not included in this WBS element are portions of:

1.1.3 Information Management and Control

1.1.5 Communications

2.0 DESCRIPTION

The power transmitter is a large planar phased array made up of subarrays mounted on a two-tier (primary and secondary) structure. Each of the 7220 subarrays includes from four to thirty-six klystron power amplifiers and associated control electronics. The quantized variation in the number of klystrons per subarray, and hence power density, provides an approximation to a 9.54 db, truncated Gausian power illumination taper. This taper reduces sidelobe intensity about 7 db (factor of 5) below the levels projected for a constant illumination, and improves aperture-to-aperture beam efficiency.

The subarrays are supported by the secondary structure, in turn supported by the primary structure. DC power from the solar array is fed to the subarrays through power processing and protective switch gear. About 15% of the power is processed to alternate voltages and regulated as necessary. The remainder is provided directly to the klystrons. All power is connected through interrupters and disconnect switches for fault isolation.

The reference phase distribution system distributes a coherent reference clock signal to all subarrays. This signal and the uplink (pilot) signal are phase conjugated at each klystron power amplifier to provide low-level RF drive signals of the correct phase. These signals are amplified to about 5 watts by solid-state preamplifiers and fed to each klystron; the klystron RF power output is approximately 70 kw each.

The antenna mechanical pointing includes star sensors and control moment gyros that aim the antenna toward its ground station to an accuracy of about one minute of arc. Computation is provided by the information management and control system; ground commands to correct residual aiming errors can be input through the communications system if necessary. Continuous desaturation of the CMG's is provided by a feedback loop that commands the antenna turntable drive. Low-pass filters and a compliant antenna mechanical suspension permit the CMG's to retain fine pointing control authority.

The antenna maintenance equipment includes crew provisions and mobility systems to support periodic removal and replacement of failed equipment.

3.0 DESIGN BASIS

A power transmission link is most economic in cost per kilowatt of transmission capacity when it is designed to the maximum capability permitted by constraints. The microwave power transmitter is bounded by these constraints.

1. Maximum allowable beam energy intensity at Earth in the center of the beam. This limit is presently estimated as 23 milliwatts per square centimeter (mw/cm^2) based on analytical projections of ionosphere disturbance thresholds. The uncertainty in this limit is substantial.

2. Maximum allowable beam energy intensity at the transmitter beam center. This limit is presently estimated as about 25 kw_{RF} per square meter. The limit is established by the heat rejection capability of the transmitter and is less uncertain than item 1.

3. Maximum allowable sidelobe intensity, i.e., maximum RF power intensity outside the fenced receiver area. A value of 0.1 mw/cm^2 is presently being employed as a nominal design value. This figure is considerably below the microwave safety standards presently in use in the U.S., but these standards were not set with SPS in mind. Substantial uncertainty should be accorded this limit. The degree of sidelobe suppression is controlled mainly by the illumination taper. The reference taper of 9.5db places the maximum sidelobe level 24 db below the beam center. A 17 db taper offers an additional 10 lb of sidelobe suppression. There is little or no economic incentive to raise the sidelobe limit appreciably above 0.1 mw/cm^2. Analyses have indicated that values as low as 0.01/mw/cm^2 could be met with modest cost penalty; additional study and tests would be needed to confirm this estimate.

These constraints have the following principal influences:

1. If an excessive amount of power is transmitted by a large aperture, the intensity-at-Earth limit is exceeded. Reducing aperture relieves this problem but exceeds the intensity-at-transmitter limit. There is therefore a combination of aperture and transmitted power where both constraints are just met; this will be the most economic system in terms of cost per megawatt of capacity. If the sidelobe intensity is reduced, the limit power is reduced slightly and the aperture increased. For example:

Sidelobe limit = 0.1 mw/cm^2 (baseline)
Aperture = 1000 m
Power = 5000 mw

Sidelobe limit = 0.01 mw/cm^2
Aperture = 1200 m
Power = 4000 mw

It is of course possible to design a power transmission system at less than the maximum limit power. The cost per megawatt will be higher; the increase is modest down to about half of limit capacity and then tends to increase more dramatically. It also appears to be possible to exceed the nominal limit capacity by employing phase distributions that defocus the beam. Defocused systems thus far investigated are slightly less efficient than the focused system, but better phase distributions can probably be found. The degree to which defocused systems can meet stringent sidelobe standards also needs to be ascertained through further studies.

The selection of the klystron as the baseline RF amplifier was somewhat arbitrary. The klystron provides:

- High gain (40 db)
- Good efficiency (85% estimated)
- Good filtering (5 tuned cavities)
- Good controllability, incuding load following by beam current control

Magnetrons, acting in an injection-locked directional amplifier mode, would provide:

- Somewhat less gain
- Probably slightly better efficiency
- Comparable filtering (tests needed to discriminate)
- Probably less controllability

In addition, there are other amplifier types: gyrocons; solid-state. Although the klystron is considered an adequate baseline, further research is necessary before a firm selection is made.

Phase conjugation at the individual klystron level was selected over control at the subarray level. Finer granularity in phase conjugation reduces the losses associated with random and systematic tilts of subarrays and with curvature of subarray surfaces. The improvement in efficiency is very conservatively estimated at 1%. Since the cost of the spaceborne segment is of order 10^{10} dollars, the savings value is of order 10^8 dollars. The cost of phase control receivers is estaimted as roughly $500 each. Since there are 10^5 klystrons, each requiring one receiver, the available savings from reduced granularity cannot exceed 5×10^7 dollars and the efficiency improvement due to klystron-level phase control is economically justified.

4.0 MASS AND MASS BASIS

The transmitter mass estimate is the sum of element masses and is included in the comprehensive mass statement under WBS 1.1.

5.0 COST AND COST DETAILS

The transmitter cost estimate is the sum of element estimates and is included in the comprehensive cost statement under WBS 1.1. Cost details are given in element descriptions in the following pages.

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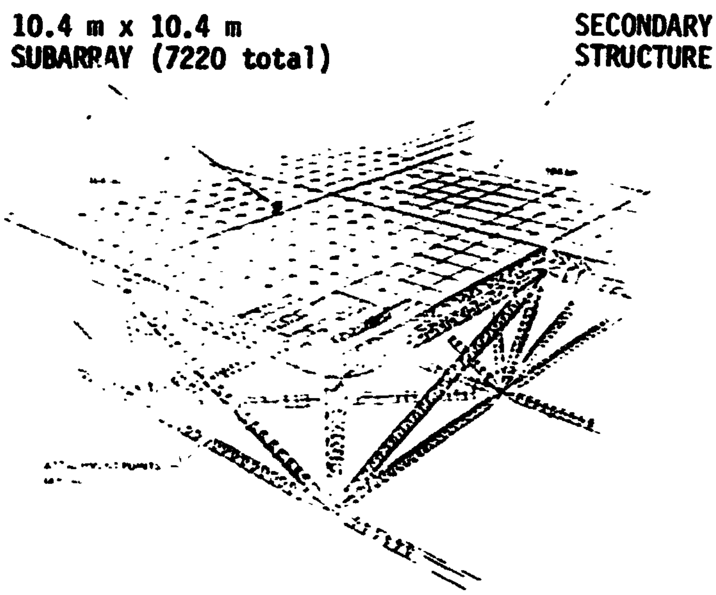
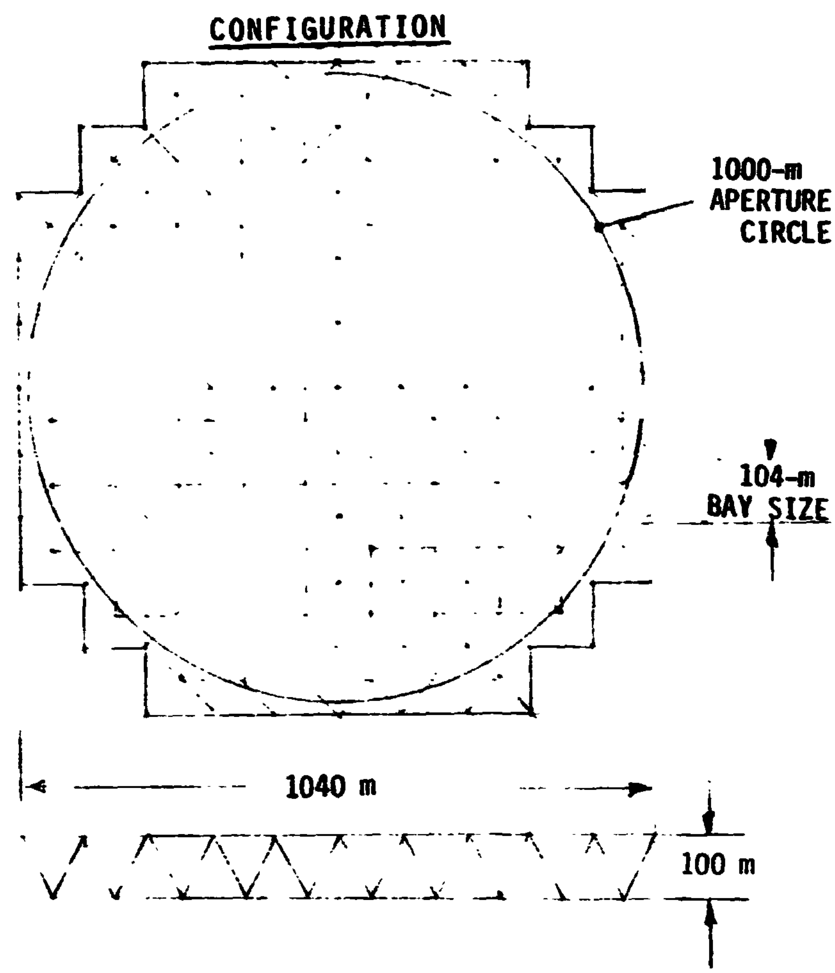
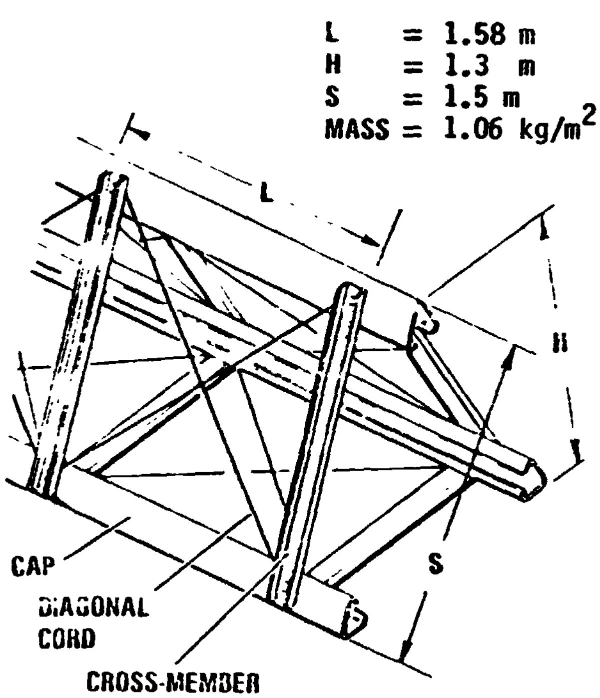






1.0 WBS DICTIONARY

The primary structure is the main structure that provides overall shape and form to the transmitter.

2.0 DESCRIPTION

The primary structure is a pentahedral truss made up of 1.5 meter tribeams fabricated in space by a beam machine. Feedstock for the beam machine is a graphite filamentary composite thermoplastic material shipped from Earth in roll and/or nested form. The beam elements are protected with thermal control and ultraviolet screen coatings and by selective multilayer insulation in the area where the transmitter head dissipation creates a thermal environment that would otherwise exceed the temperature capability of the material. Beam sections are terminated in centroidal fittings with mechanical attachments that include joint-slop takeup provisions to maximize structure rigidity.

3.0 DESIGN BASIS

The transmitter primary structure provides the stiffness to maintain the overall transmitter aperture flat within ±3 minutes of arc. Adjustment of subarrays on initial installation can be used to meet this tolerance initially, hence the main criterion for this structure is stability. A pentahedral truss was selected over tetrahedral truss and A-frame options as the best compromise for rigidity, efficiency, and maintenance accessibility. Graphite composites were selected for thermal stability. The truss size provides a reasonable bridging span for the secondary structure. The transmitter self-induced thermal environment can exceed 300°C (from the klystron thermal radiators) near the transmitter center. Accordingly, it is estimated that about 1/3 of the total structure requires selective blanketing by multilayer insulation.

4.0 MASS BASIS

Mass Basis:

88 sets of pyramid legs @ 124 m/leg = 4 x 88 x 124	= 43.69 km
196 x 104 m face plane members	= 20.38 km
156 x 104 m back plane members	= 16.22 km
88 sets of back plane diagonals @ 147 m	= 12.94 km
	93.23 km

Beam unit mass = 1.06 kg/m scaled from SCAFEDS beam to 1.5 m.

Total struc. mass = 1.06 x 93.23 and add 10% for joints	= 108.7 metric tons
Thermal protection 30 km x 3 m x 0.5 kg/m^2	= 45.0 metric tons
Total	153.7 Tons

WBS 1.1.2.1.1 SPS TRANSMITTER PRIMARY STRUCTURE (cont'd)

5.0 COST AND COST BASIS

5.1 Cost Summary

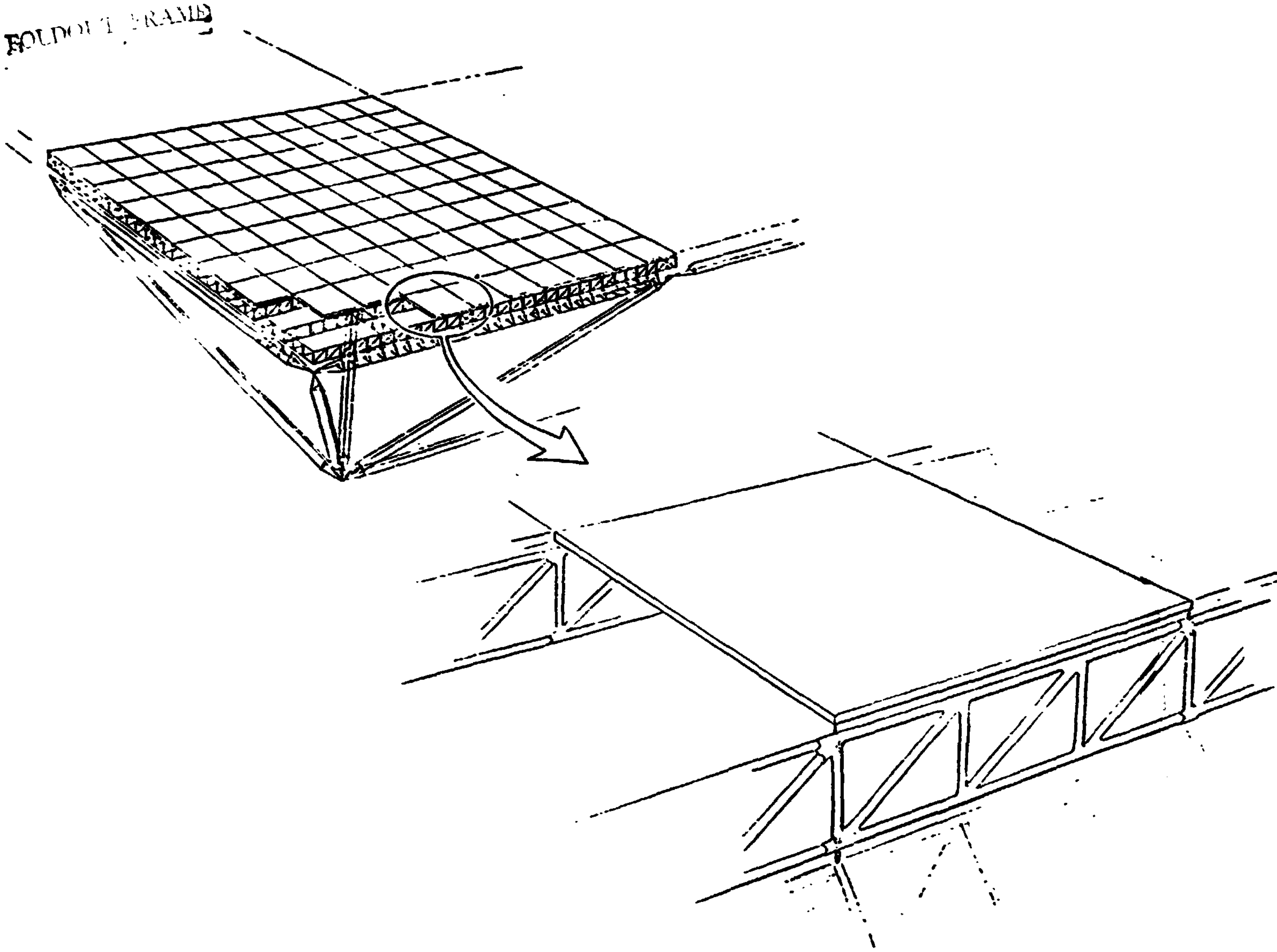
o Research	--
o Engineering Evaluation	20
o Demonstration	288.6
o Investment 263	
o Production 25.6	

5.2 Cost Details

o Research o carried under array structure	--
o Engineering Evaluation o Equal to arracy structure	20
o Demonstration o 60% of adjusted DDT&E of $439/M plus demo hardware about equal to production cost	288.6
o Investment o 60% of adjusted DDT&E of $438/M	263
o Production o Primary structural feedstick 108.7MT @ $66/KG = $7.174M @ 120 = 5.4M	25.6
o Secondary structure 171MT @ $76/KG = 13M	

Production costs allocated to this WBS item are for the beam machine feedstock and prefabricated fittings. A manufacturing estimate for similar hardware was reported in Solar Power Satellite System Definiton Study, Part II, Vol. 6 (Boeing Document D180-22876-2), pp 166-171. This estimate was $55/kg in 1977 dollars. It is adopted for the transmitter primary structure, corrected to $66/kg in 1979 dollars. Multilayer insulation was costed as $120/kg based on parametric cost model results. The costs of beam machines and fabrication operations are allocated to space construction (WBS 1.2).

108.7 tons x $66/kg	=	$ 7,174,000
45 tons x $120/kg	=	$ 5,400,000
Total		$12,574,000



1.0 WBS DICTIONARY

This element includes all members necessary to support the transmitter subarrays and other power transmission subsystems on the primary structure.

2.0 DESCRIPTION

The secondary structure provides a bridge on the MPTS primary structure and provides the base for mounting the transmitter subarrays, which are installed on a three point mount. The basic element is a 10.4 meter beam, 2.5 meters in depth, space fabricated from graphite composite materials. The secondary structure is continuous around the perimeter of the antenna. In one direction the member spacing between rows is the width of one subarray and is the width of two subarrays in the orthogonal direction.

3.0 DESIGN BASIS

Low density is an important design driver because it relates directly to low structure mass, leading to lower material and transportation costs. Also, it interferes less with efficient radiation of waste heat from thermal radiators.

High rigidity minimizes deformation due to attitude control, maneuvering, pointing and temperature changes. Thus, good RF beam integrity requires a rigid platform.

High first oscillation mode frequency determines to what extent large oscillations will be excited by low frequency vibrations induced by docking, attitude control, pointing yoke movement, or other operations. These low frequencies should not couple to the antenna in a manner that would disturb MPTS operation.

In addition, selected structure must be based on materials and processes that are compatible with a low absolute pressure, variable heat loads due to daily attitude/changes and esclipses, and particulate and UV radiation.

The selected concept is simpler to produce and install, provides better access for maintenance, and provides less thermal blockage than other designs studies.

4.0 MASS AND MASS BASIS

B.·· · Element

(2 x 10.4) + (3 x 2.5) + (3 x 4.27) = 41.11 meters.
10% fillets and doublers = 4.11; total length = 45.22 M.
Material width = 32 cm, thickness = 0.5 mm.
Mass = (0.32)(0.0005)(45.22)(1600 Kg/Ms) = 11.576 kg.

Elements/Structural Bay

(10 x 10) + (5 x 10) = 150

Number Of Bays = 88

Elements To Close Out Perimeter = 20 x 10 = 200

Total Elements = (150)(88) + 200 = 13,400

Assembly And Installation Hardware (10%) = 15,512.

Total Mass = 155,118 + 15,512 = 170,630 kg.

5.0 COST

5.1 Cost Summary and Details

Research - carried under array structure

Engineering Verification - EVTA does not require a secondary structure

Demonstration - $20.6 DDT&E plus $13M for flight hardware

Investment - None

Production - Feedstock costed at $76/kg (this will be a high-temperature composite for total per SPS of $13M)

1.0 WBS DICTIONARY

This element includes all elements installed on the subarray as well as the structure and waveguides that form the basic subarray configuration.

2.0 DESCRIPTION

The subarrays are the basic power radiating elements of the transmitter. There are ten types of subarrays corresponding to the ten power intensity levels of the transmitter illumination taper. These ten types use the same equipment, but the arrangement and numbers of equipment elements vary with the number of klystrons.

Klystrons, control circuits, and the wiring harness are described on lower level description sheets. The radiating waveguides, distribution waveguides, and structure are an integral production unit and are described at this level.

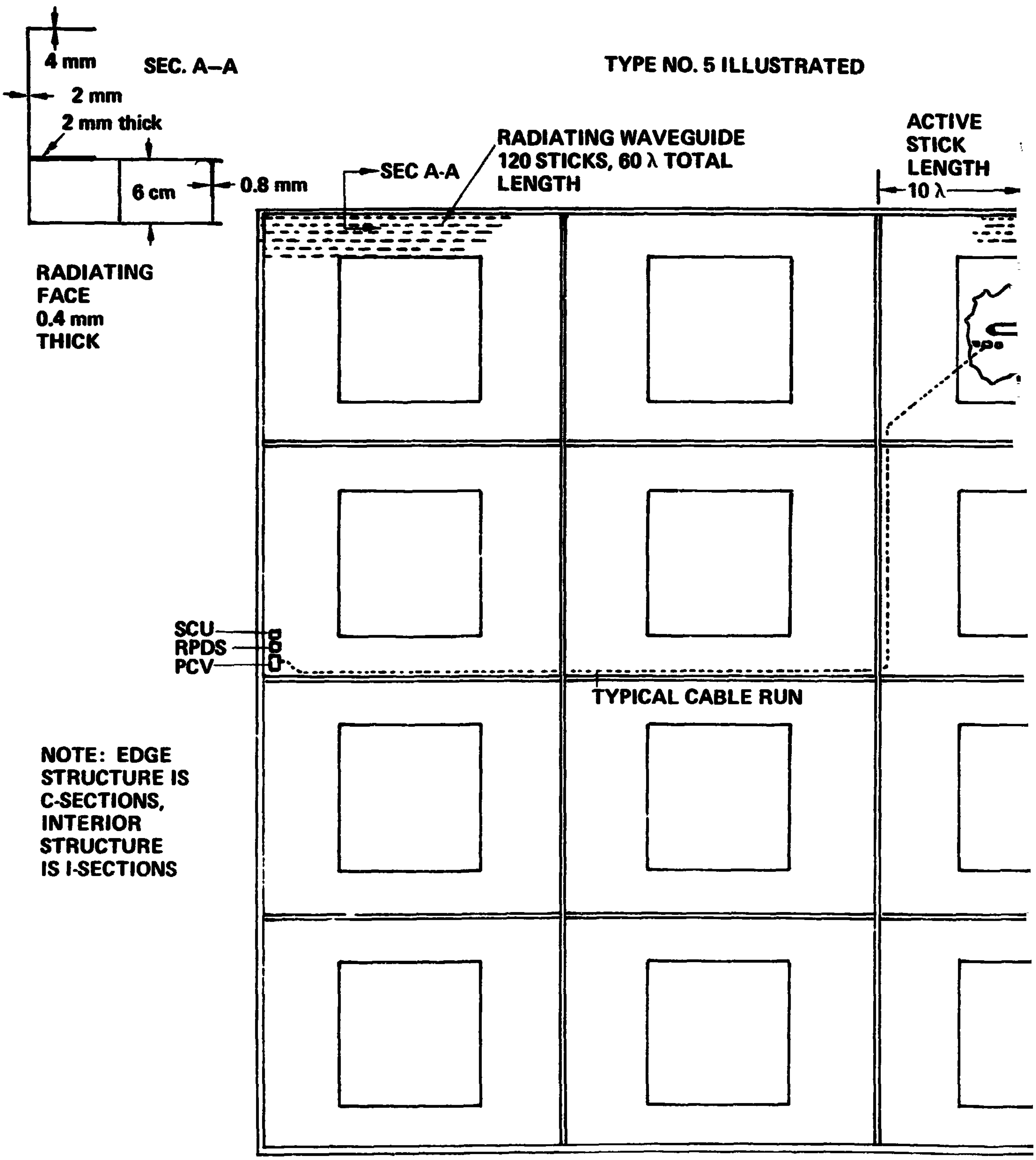
Thicknesses are as follows: radiating waveguide faces - 0.4 min; stick dividers - 0.6 min; distribution waveguide - 0.8 min. Other dimensions are shown on the sketch.

Each subarray includes 120 radiating waveguide "sticks" each 60 wavelengths in total length. The sticks geometry is selected so that the stick wavelength is twice the stick width, yielding a subarray 10.43 meters square. The arrangement of klystrons and RF power distribution waveguides is selected to minimize continuous stick length subject to the constraint that each stick be an integral number of wavelengths. Sheets within the sticks set the length of each radiating element. Pertinent discussions are given in the descriptive sketch. Minimizing stick length provides 3 advantages:

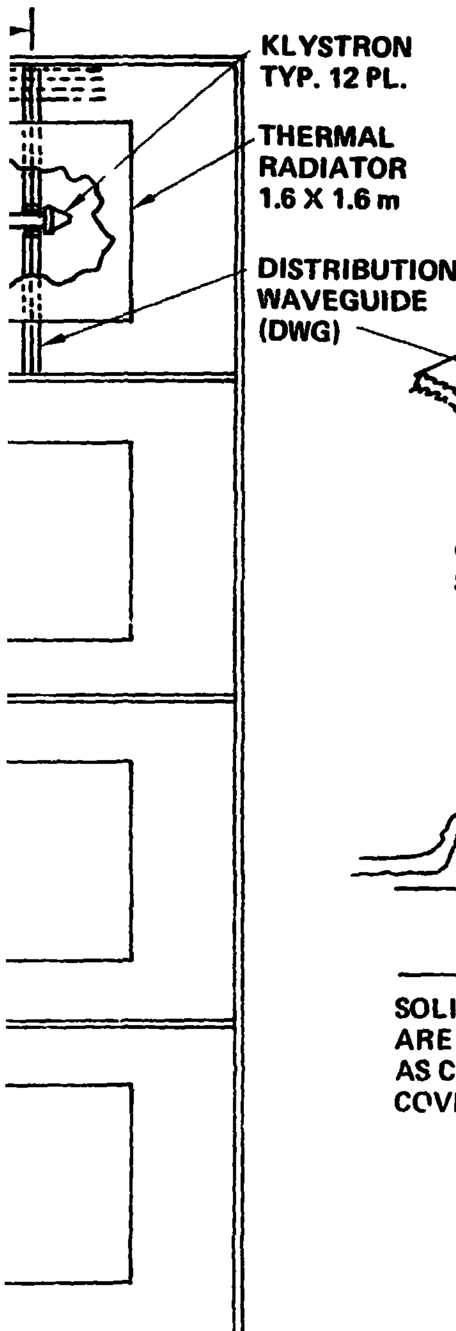
- o Reduced sensitivity to temperature
- o Greater slot offset, reducing scattering loss sensitivity to tolerances in slot offset
- o Reduced RF I^2R losses

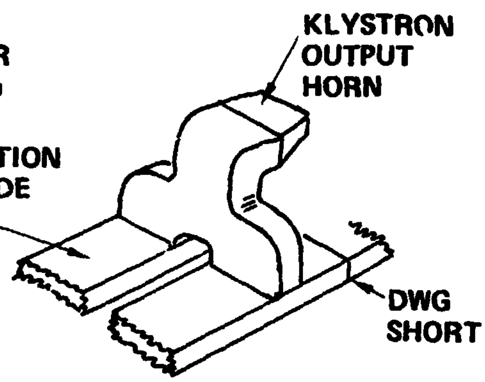
All of the subarray configurations are schematized in the sketch. All geometries except the 4 x 4 employ a split klystron output to cut active stick length in half. This cannot be done for the 4 x 4 configuration because 60 is not evenly divisible by 8.

The subarray distribution and radiating waveguides are assumed fabricated from graphite/aluminum metal matrix composites. The structure members are a high-temperature graphite plastic-matrix composite. Solid-state components are mounted on the radiating waveguide assembly under multilayer insulation so that the radiating waveguide serves as a cold plate. In addition, thermal insulation is used to force the klystron heat rejection system to radiate only out the back face of the antenna, alleviating the thermal environment for the solid-state components.

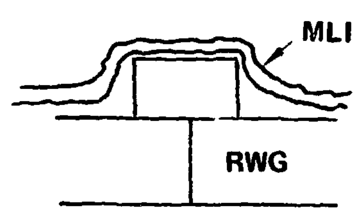


NOTE: ALL REFERENCE PHASE DISTRIBUTION CABLE RUNS ARE EQUAL LENGTH



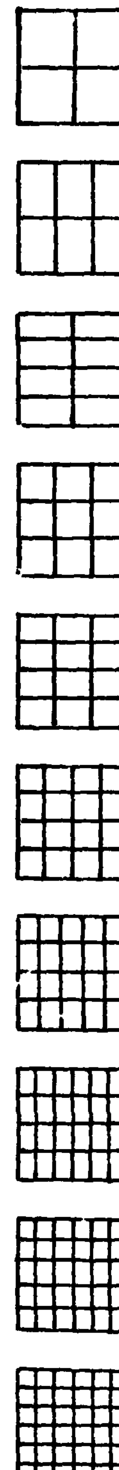


KLYSTRON DUAL-FEED OUTPUT–RADIATING STICKS ARE END-FED



SOLID-STATE BOXES ARE MOUNTED TO RWG AS COLD-PLATE AND COVERED WITH MLI

SUBARRAY ARRANGEMENTS



TYPE	NO. KLYSTRONS	RWG STICK LENGTH
1	4	15λ
2	6	10λ
3	8	15λ
4	9	10λ
5	12	10λ
6	16	15λ
7	20	6λ
8	24	5λ
9	30	5λ
10	36	5λ

NOTE: TYPE NO. 6 USES SINGLE-FEED OUTPUT

3.0 DESIGN BASIS

The subarrays are designed to be as self-containec ·, possible in order to allow as high as possible a level of assembly and checkout on the ground p·ior to launch. Connections to the subarray when installed on the transmitter i·. limited to (1) DC power cable; (2) reference phase distribution cable; (3) da:· ınagement system cable.

Metal-matrix composites were selected for stiffness, thermal stability, low mass, and high electrical and thermal conductivity.

4.0 MASS AND MASS BASIS

Mass was estimated based on:

(1) Waveguide and structure thicknesses shown on the layout and lengths shown in Table 1;

(2) Densities of 1.6 for plastic-matrix composites and 2.0 for metal-matrix composites;

(3) Component masses.

The table summarizes mass and cost for the ten subarray ty .s.

5.0 COST

5.1 COST SUMMARY

Costs were based on PCM runs for the structure and waveguide assembly, plus component costs, plus integration costs. Production costs were based on $76/kg for automated production of the structure and waveguide assembly, plus component productic n costs. Table 1 presents a production cost summary.

5.2 COST DETAILS

Other costs were as follows:

Research	Str & W/g	Components	Total incl comp.
Low-CTE	0.25		
Test Arrays	8.63		
Bandwidth	.75		
	9.63	97.77	107.4

Verification

Des & Dev	1.43		
Support & Integ	0.96	24.39	35.45
Test Hdwe	8.67		
EVTA Units	11.44	20.84	34.28
Support to EVTA	2.0		

TABLE 1 - SUBARRAY SUMMARY

SUBARRAY TYPE	NO. OF KLYSTRONS	SUBARRAYS OF THIS TYPE	LENGTH DISTR WG	LENGTH STICK SHORTS	LENGTH CABLE	LENGTH STRUCT
1	4	1028	40	50	33	60
2	6	1052	40	50	49	70
3	8	612	40	50	61	80
4	9	664	60	70	72	80
5	12	900	60	70	95	90
6	16	784	[illegible]	50	132	100
7	20	628	100	110	167	110
8	24	644	120	130	197	120
9	30	632	120	130	232	130
10	36	276	120	130	296	140

TOTAL NO. OF SUBARRAYS = 7220
TOTAL NO. OF KLYSTRONS = 101552

NOTE: LENGTHS IN METERS

SUBARRAY MASS SUMMARY (KG)

SUBARRAY TYPE	KLYSTRON MASS	PCR MASS	RTU MASS	RPDS MASS	PCU MASS	WAVEGUIDE MASS	CABLE MASS	STRUC MASS	FIXED MASS	TOTAL MASS	TOTAL ALL
1	276.0	4.4	1.0	1.0	9.6	27.2	3.7	51.8	262.0	637	654466
2	414.0	6.6	1.5	1.0	14.2	31.2	5.4	60.5	262.0	796	837760
3	5.2.0	8.8	2.0	1.0	18.8	35.2	6.9	69.1	262.0	956	584937
4	621.0	9.9	2.3	1.0	21.1	46.8	8.0	69.1	263.2	1042	692104
5	828.0	13.2	3.0	1.0	28.0	52.8	10.6	77.8	263.2	1278	1149750
6	1104.0	17.6	4.0	1.0	37.2	51.2	14.5	86.4	262.0	1578	1237019
7	1380.0	22.0	5.0	1.0	46.4	88.0	18.2	95.0	265.6	1921	1206526
8	1656.0	26.4	6.0	1.0	55.6	105.6	21.6	103.7	266.8	2243	1444273
9	2070.0	33.0	7.5	1.0	69.4	11.6	26.0	112.3	266.8	2704	1708675
10	2484.0	39.6	9.0	1.0	83.2	129.6	32.5	121.0	266.8	3167	873973
TOTAL (TONS)	7007.1	112	25	7	236	434	91	574	1903		10389

SUBARRAY COST SUMMARY (PRODUCTION)

SUBARRAY TYPE	KLYSTRON COST	PCR COST	RTU COST	RPDS COST	PCU COST	WAVEGUIDE COST	CABLE COST	STRUC COST	FIXED COST	ASSY&CO COST	TOTAL COST	TOTAL ALL
1	18800	2240	440	595	1404	2067	73	3940	19912	4947	54418	55 941,852
2	28200	3360	660	595	2106	2371	108	4596	19912	6191	68100	71,641,187
3	37600	4480	880	595	2808	2675	138	5253	19912	7434	81776	50 046,711
4	42300	5040	990	595	3159	3557	160	5253	20003	8106	89163	59,204,193
5	56400	6720	1320	595	4212	4013	212	5910	20003	9938	109323	98,390,714
6	75200	8960	1760	595	5616	3891	290	6566	19912	12279	135069	105,894,268
7	94000	11200	2200	595	7020	6688	365	7223	20186	14948	164424	103,258 187
8	112800	13440	2640	595	8424	8026	433	7880	20277	17451	191965	123,625,491
9	141000	16800	3300	595	10530	8938	521	8536	20277	21050	231546	146,337,042
10	169200	20160	3960	595	12636	9850	649	9193	20277	24652	271172	74,843,338
TOTAL (MILLIONS)	477	57	11	4	36	33	1	44	145	81	889	889

TOTAL FOR ALL SUBARRAYS.
889
(MILLIONS OF 1979 DOLLARS)

NOTE: RPDS Figures include Subarray Control Unit (SCU)

Demonstration

DELTA DDT&E	11.0	42	53.12
Demo Units	$428 M	375	803
Pilot Prod. Line		150	150
			1006

Investment

Subarray Plant	445	445
		160 (Final Assy)
		1570 (Other)
		2175 (Total)

Production

See Table 1.

5.3 MATERIALS AND ENERGY

Component requirements were discussed under components.

For the structure and waveguide assembly the approximate breakout per SPS is as follows:

Aluminum	1130 tons
Graphite	1561 tons
Plastic	144 tons
Misc.	72 tons (fasteners, etc.)

5.4 MANUFACTURING PROCESSES AND PRODUCTION RATES; CAPITAL FACILITIES

Automated production will be used to fabricate parts and assemble completed structure and waveguide assemblies from raw materials. Final assembly will be semi-automated with manual assist of installation of components. Testing will be automated. Roughly 160 labor hours average will be devoted to final assembly and test of each subarray. Testing will be fully automated except for power and signal connections. Subarray structure and waveguide production and final assembly will employ about 1500 direct labor people at the nominal production rate of 14,440 per year. The total labor force for subarray production including indirect and overhead personnel is estimated as 15,000 to 20,000.

5.6 QC AND QA

Automated testing will be employed.

5.7 PACKAGING AND SHIPPING

Subarrays will be crated for shipment to the launch site and transported by barge or ship (the c[illegible] will be too large for truck, train, or aircraft). Crates will be designed to provide environment protection and to integrate into payload pallets as a subelement. Crates will be returned to Earth for reuse.

6.0 TECHNOLOGY DESIGN STATUS

Metal-matrix composites are in exploratory development. The technology is presently being driven by other applications. It is anticipated that the basic materials technology will be ready in time, but that a manufacturing development effort will be needed to attain the requisite subarray precision and low cost. This effort is included in the cost for demonstrator units.

Technology/design status for subarray components is discussed under the components.

7.0 SUITABILITY FOR SERVICE

No problems are anticipated if the technology is developed as projected. See also discussion under components.

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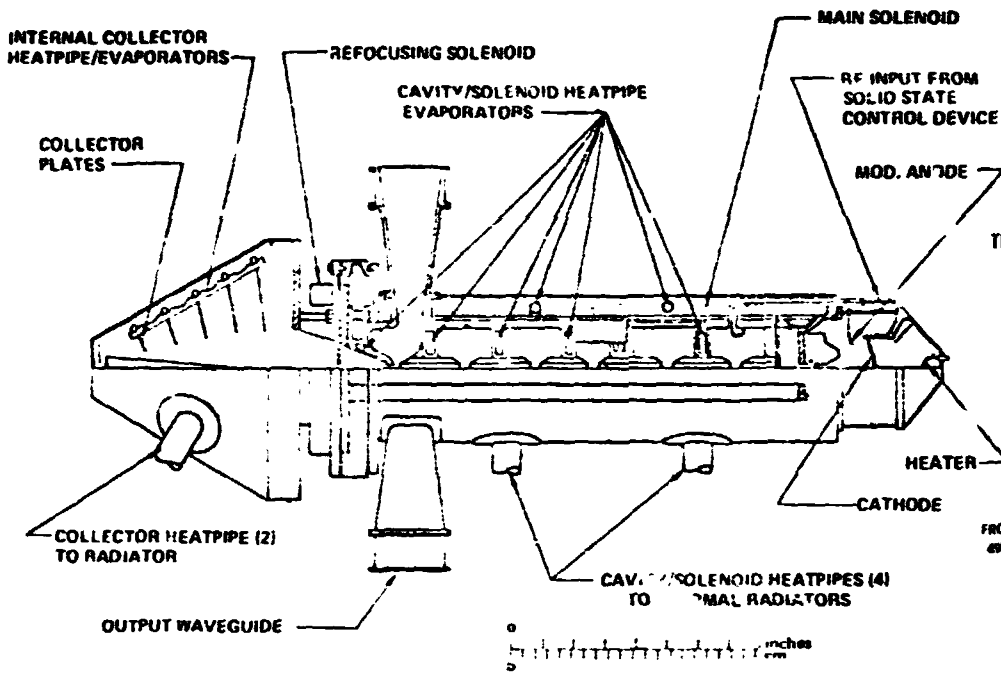
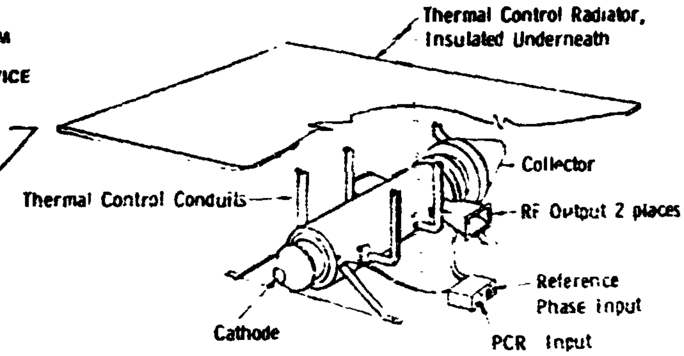
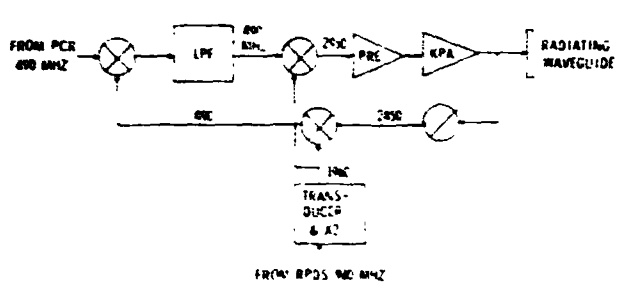


KLYSTRON MODULE SKETCH



KLYSTRON MODULE SCHEMATIC



1.0 WBS DICTIONARY

This element includes all the hardware and control circuits for the klystron rf amplifiers: the cathode subassembly, the rf circuit (body), the collector, the output waveguide and window (if required) and the solenoid for beam focusing. This module includes a solid-state preamplifier and through-phase stabilization unit, and the klystron thermal control system. External instrumentation and monitor circuits (both dc and rf) are also included.

2.0 DESCRIPTION

The basic klystron operates at 42 kv with 45-50 db gain using a compact efficient (82-85%) solenoid wound-on-body design approach with conservative design parameters (0.15 amps/cm^2 cathode loading) to achieve long life. The 5-stage depressed collector design provides an overall dc-rf conversion efficiency of 85%. The layout of the basic klystron building block module is shown above. The 6 cavity design, with a second harmonic bunching cavity for short length and high efficiency, features a dual output waveguide with 35 kw in each arm. The thermal control system is used to cool the output gap, the depressed collector and the solenoid with a design temperature of 300°C maximum on the body of 500°C on the collector. The driver for the final klystron power amplifier provides an output of about 3 watts cw for a 45 db output amplifier saturated gain. It is driven directly from phase regeneration circuitry at a power level of about a milliwatt. The driver is a multi-stage transistor amplifier with up to 10 db gain perstage at this frequency. Phase correction functions will be performed at low drive levels. Also shown in the configuration sketch are the thermal control system and a circuit block diagram. The klystron power amplifier receives reference signals at 490 MHz from the local phase control receiver and at 980 MHz from the phase distribution systems. The downlink baseband of 2450 MHz is synthesized from these two signals.

3.0 DESIGN BASIS

2 FOLDOUT FRAME

The klystron power amplifier module provides conversion of dc electric power into microwave RF power. Its principal requirements are (1) high efficiency; (2) long life; (3) low noise; (4) continuous operation; (5) ability to modulate output power by controlling beam current; (6) design for removal and replace during maintenance operations. The origin of these requirements is self-evident except for #5. This one arises because the SPS needs the capability to quickly and smoothly regulate power output over a range of 97% to 100% of rated power in order to assist in power network frequency regulation. For klystrons with modulating anodes operating at saturation, this is readily accomplished by modulating beam current.

The multicavity design of the tube contributes to noise and harmonics suppression. Additional filtering is provided by the antenna waveguides.

4.0 MASS AND MASS BASIS

Item	Mass Estimate	Rationale	Reference
Klystron Power Tube w/internal cabling & inst'l brackets	48 kg	Detailed Estimate	Contract NAS9-15196 Part II Report Vol 6 (D180-22876-6) pp 101-111
Baseband Synthesizer amd preamp	2 kg	Box size assumed 10x10x20 cm & unit density	None
Thermal Control System	14.5 kg	Detailed estimate plus 10% for inst'l particulars	Contract NAS9-15636 Phase I Report Vol 3 (D180-25037-3) p. 54
Cabling	0.5 kg	1 kg/m, estimated 1/2 m	None
Misc Structure & bracketry	4 kg	Guess	None
TOTAL	69 kg	Sum	——

5.0 COST

5.1 COST SUMMARY

Cost estimates were made using a detailed estimate for the research phase. The Boeing Parametric Cost Model was used for DDT&E estimated. Point estimates from earlier studies were updated to 1979 dollars for the investment and production phases. A summary is presented here; additional detail is provided on the following page.

Research	\$5.79M	Demonstration	\$533M
Engineering Verification (includes basic DDT&E)	39.05	Investment	\$1.5B
		Production	\$4,700 per unit \$477M per SPS

5.2 COST DETAILS

	Cost ($M except noted)	Ref. or Source
Research		
Basic Klystron	2.87	Research Planning
Cooling	1.10	Interim Report
Production Tech.	1.47	Additional Thermal
Improvements	0.35	Phase Control research is also applicable
Engineering Verification		
Design & Devel.	9.71	
SE&I & other support	5.58	
Other	5.78	PCM
Test Units	5.24	
EVTA Flights Units	5.24	
Support to EVTA prog.	7.5	Headcount x Time
Demonstration		
Delta DDT&E	14.53	PCM
Test Units	7.67	PCM
Pilot Prod. Line	150	Factor from Full Prod.
Pre-Prod. Units	11	PCM
Demonstrator Units	350	Production Rate
Investment		
Production Plant	1500	Update of 1977 Varian Estimate
Delta DDT&E & Production Testing	244.53	PCM
Production		
Production Units	477 per SPS	50% prototype factor $4700/unit, update of 197, Varian Estimate

5.3 MATERIALS AND ENERGY REQUIREMENTS

Material	In	Mass, kg	
Copper	Klystron Solenoid	16	
Copper	Thermal Control	12	
Copper	Klystron Cavities	7.2	
Copper	Cabling & Other	1	
			36.2
Iron/Steel	Klystron Pole Pieces	2.8	
Iron/Steel	Solenoid Shell	4.2	
Iron/Steel	Covers & Structure	8	
			15
Aluminum	Baseband Box	1	1
Solid State Components	Baseband Box	1	1
Refractory Metal (Tungsten or Molybdeuum)	Klystron Collector Plates	4.6	4.6
Alumina	Insulators	4.2	4.2
Misc. (Plastics, Steel, ceramics, copper)			7
			69

Energy requirements were not computed.

5.4 Manufacturing Processes and Production Rates; Capital Facilities

The manufacturing plant for the klystrons will require an estimated 200,000 m^2 and cost roughly $1.5 billions in 1977 dollars, based on a Varian estimate. This estimate is discussed in more detail in Vol. 4 of the reports on Part II of Contract NAS9-15696 (D180-22876-4), pp. A-26 to A-29. The production rate is about 17,000 assemblies per month. Final assembly of the tubes themselves takes place in an evacuated, automated assembly line.

5.5 Labor

The cost of the klystron assemblies is in three roughly equal parts: amortization of facilities, materials, and labor. Based on this, the labor force serving the Klystron production plant is roughly 5000 people. Most of these will be production line workers and technicians; the skill level will be relatively high.

5.6 QC & QA

It is assumed that automated QC and QA will be built into the production line. Incoming parts and materials will be inspected. Completed assemblies will undergo a 2-hour burn-in test that will verify through-phase control, efficiency, power output, thermal control operation, and noise and harmonics acceptability.

5.7 Packaging and Shipping

These assemblies will be shipped using methods appropriate to precision electronics equipment. The Klystron vacuum seal must be maintained as loss of vacuum will likely contaminate the inside of the tube. The klystrons will be assembled to the subarrays with a final test at the subarray level before shipment to space.

6.0 TECHNOLOGY DESIGN STATUS

Klystrons similar to the proposed design have been built for laboratory use. High-efficiency tubes have not been combined with depressed collectors, nor have flight-weight versions been tested. Research needs have been detailed in the Interim Research Planning Report for this contract, D180-25381-1. In general, the research program will develop a laboratory-type tube with the desired performance and develop the thermal control approach. This will be followed by proto-flight tube development to support initial tests in space. These tests will lead to further design refinement and development of a long-life, maintainable system for the demonstration program. An additional design refinement is assumed for the production prototype SPS.

7.0 SUITABILITY FOR SERVICE

7.1 Reliability & Availability

The klystron reliability model assumes a 25-year mean time between failure and a simple exponential failure rate model. Klystron repair and replace dominates the SPS maintenance scenario; see discussion at the SPS level.

7.2 Controllability

The klystron provides one important mechanism (beam mount) of SPS power control. This is best suited to the frequency regulation control domain where small, relatively rapid variations are needed.

WBS 1.1.2.2.2 Subarray Structure
WBS 1.1.2.2.3 Waveguides

These items were anlayzed as a part of the subarray itself. The radiating waveguides, distribution waveguides, and subarray structure are designed as an integral unit.

WBS 1.1.2.2.4 Thermal Control was allocated to other subsystems.

1.0 WBS DICTIONARY

This element includes all electrical and optical wiring harnesses on the subarray.

2.0 DESCRIPTION

The following harnesses are included:

Function	Type	Length	Number	Mass/Meter
980 MHz RPSR-PCR & BSPU	Optic	12	1 per klystron	.025
490 MHz PCR-BSPU	Optic	0.5	1 per klystron	.05
Klystron Power	Electric (DC)	7 (avg)	1 per klystron	.05
12-V to klystron-associated control	Electric (DC)	7 (avg)	1 per klystron	.01
12-V to RPSR & SCU	Electric (DC)	1	2 per subarray	.01
Data, SCU to klystron-associated units	Shielded Data Bus	7 (avg)	1 per klystron	.01
Data to PCU & RPSR	Shielded	1	2 per subarray	.01

Routing of these is depicted under control circuits.

3.0 DESIGN BASIS

The power cabling is normal design practice. Data bussing on the subarray will use shielded twisted-pairs. Low-level RF distribution is fiber optic to avoid electromagnetic interference. The 12-meter cables are precision, all equal length to minimize phase error.

4.0 MASS AND MASS BASIS

The mass of this cabling sums to 91 metric tons. Optical fibers are assumed jacketed.

5.0 COST AND COST BASIS

Development and prototype unit costs were estimated by PCM, at $537K design and development and $742K for four prototype test units. These figures are dominated by tooling.

Research Phase

Included in breadboarding tasks at subarray level.

Engineering Verification

Design and Development	$537K
Ground Test Units	$742K
Flight Test Units	$742K
Support to Flight Test	$500K

Demonstration

Delta DDT&E	$1,280K (first production unit and 80% learning)
Demo Units @	$6K $2.7 Million

Investment

None

Production

Mass production in automated wire shops assumed to reach cost of $20/kg for a total of $1.82M per SPS.

5.3 MATERIALS AND ENERGY REQUIREMENTS

The wiring harnesses are mainly copper and plastic.

5.4 MANUFACTURING

Use of conventional automated wire shops is assumed.

6.0 TECHNOLOGY DESIGN STATUS

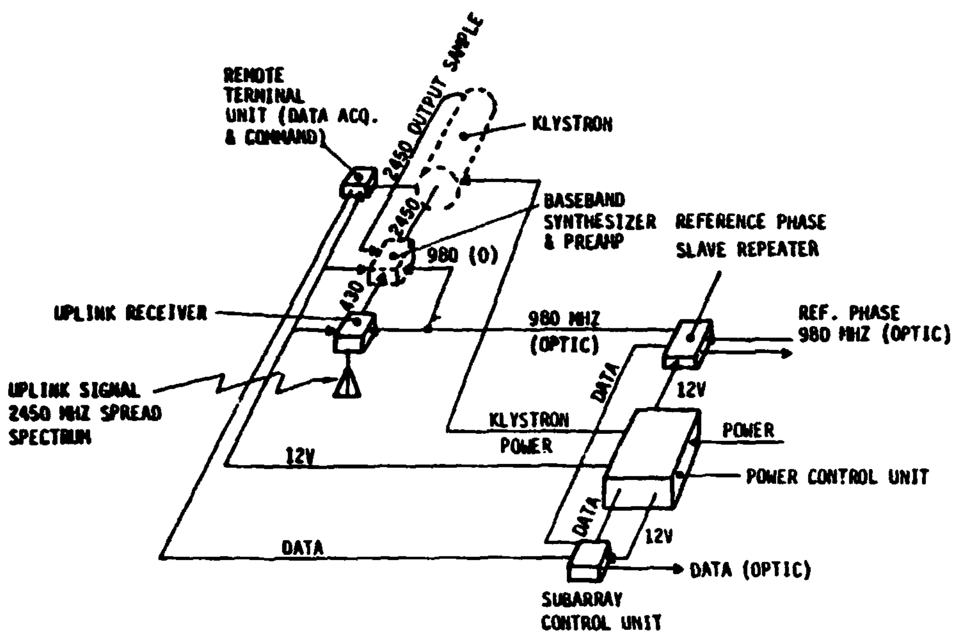
State of the art.

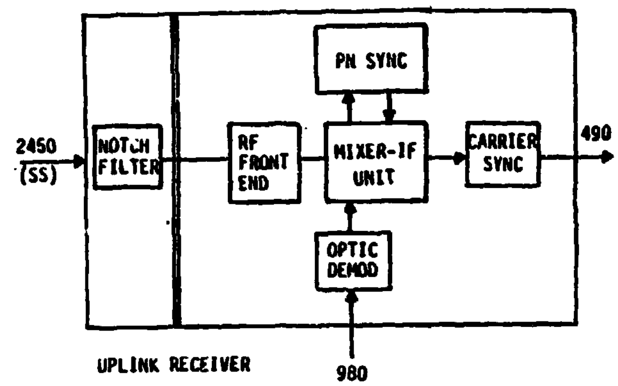
7.0 SUITABILITY FOR SERVICE

No problems are presently foreseen.

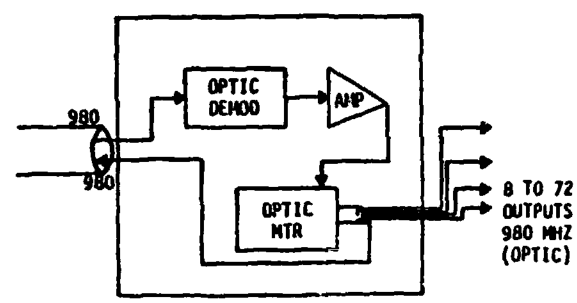
FOLDOUT FRAME 1

SPS-3039





UPLINK RECEIVER



REFERENCE PHASE SLAVE REPEATER

1.0 WBS DICTIONARY

The subarray control circuits include:

- o Phase control receivers (PCR's)
- o Klystron-level remote terminal units (RTU's)
- o Reference Phase Slave Repeater Units (RPSR's)
- o Subarray (Microprocessor) Control Units (SCU's)
- o Power Control Units (PCU's)

Wiring harnesses are a separate WBS entry.

2.0 DESCRIPTION

The subsystem-level wiring diagram above describes this system element. The Phase Control Receivers receive the uplink signal through uplink antenna apertures included in the subarray as receiving antennas that do not interrupt the continuity of the downlink aperture.

The reference phase is provided to the PCR's and RPSR's via fiber optics. These units provide IF signals to the Klystron modules, which provide phase conjugation to generate the downlink baseband signal.

The remote terminal units and subarray microprocessor control units provide all command and data handling functions at the subarray level. As an exmaple, if arcing occurs in the Klystron, these control units provide a mod anode clamp signal to the Klystron and cutoff signals to the Power Control Units. These latter units control the circuit breaker functions as necessary for arc protection for the Klystrons.

3.0 DESIGN BASIS

The subarray control circuits include those control functions most logically applied at the subarray level. These include:

(1) Phase control reception at the klystron level
(2) Receipt and distribution of the reference phase
(3) System status data handling and command functions
(4) Power electronics terminal switching

The subarray is a self-contained unit that requires as inputs, only:

(1) Phase control uplink signal (from Earth)
(2) Reference phase
(3) DC Electric Power

The control circuit design includes an adaptation of the LinCom spread-spectrum retrodirective phase control system.

4.0 MASS AND MASS BASIS

The mass of control circuits on a subarray varies with the number of klystons since some functions are provided on a per-klystron basis. Mass estimates were made by estimating the box size and assuming unit density. The density assumption provides $1 g/cm^2$ shielding by the box. Element masses are as follows:

Phase Control Receiver	1.1 kg (per klystron)
Remote Terminal Unit	0.25 kg (per klystron)
Reference Phase Slave Repeat	1 kg (per subarray)
Subarray Control Unit	0.25 kg (per subarray)
Power Control Unit	0.35 kg per subarray + 2.3 kg/klystron

Total (7220 subarrays; 101,552 klystrons) = 382 metric tons.

Mass and cost estimating details are presented below.

Item	CER	Mass (kg)
Phase Control Receiver		
Filter	Receiver	0.2
Receiver	Receiver	0.5
Optic Demod	Receiver	0.1
Mount & Box	Sec Struc	0.2
MLI	Therma Blkt	0.1 (0.5 ft^2)
Remote Terminal Unit		
Microprocessor	Sig Coro	0.05
Mount and Box	Sec Struc	0.1
MLI	Therm Blkt	0.1 (0.5 ft^2)
RPDS Slave Unit		
Optic Rcvr	Receiver	0.1
Slave Unit	Receiver	0.1
Optic Xmtr	Transmitter	0.2
Box and Mount	Sec Struc	0.5
MLI	Therm Blkt	0.1 (0.5 ft^2)
Subarray Control Unit		
Microprocessor	Computer	0.05
Mount and Box	Sec Struc	0.1
MLI	Therm Blkt	0.1 (0.5 ft^2)
Power Control Unit		
Microprocessor	Computer	0.05
Breakers	Pwr Cond	2 kg per klystron
Box and Mount	Sec Struc	0.3 per klystron
MLI	Therm Blkt	0.3 (2 sq. ft.)

5.0 COST

5.1 COST SUMMARY

Estimated costs in millions of 1979 dollars are as follows:

Ground-based research	5.38	Demonstration	30.03
Flight research*	86.6	Investment	75.2
Engineering Verification (includes basic DDT&E)	12.07	Production	108 per sps

* Large Aperture Phase Array Technology Satellite

5.2 COST DETAILS

	Cost ($M79 except noted)	Ref. or Source
Research		
Ground		
Spread Spec Research	.525	
Alternate Ph Con Options	1.05	Research
Breadboarding	1.62	Planning
Des & Dev Ph Con Sys Comp	1.62	Document
Breadboarding Sel. Tech	.565	
Space (LAPATS)	86.6	
Engineering Verification		
Des and Devel	0.566	
SE&I, etc.	0.334	
Other	1.88	PCM
Test Units	2.43	
EVTA Units	4.86	
Support to EVTA	2.0	Headcount x Time
Demonstration		
DDT&E	2.78	
Test Units	2.43	PCM
Pre-Pod	2.43	
Demo Units	17.37	Learning
Demo Support	5.0	Headcount x Time
Investment		
DDT&E	5.2	PCM
PCU Plant	70	ROM
Production		
PCR	560	Learning
RTU	110	and
RPDS	395 dollars	Production Rate
SMP	200	
PCU	351*	

$108M Per SPS

* With one breaker

5.3 MATERIALS AND ENERGY REQUIREMENTS

A detailed estimate cannot be made without detailed designs of the hardware. The predominant material will be aluminum. The remainder will be mainly solid state components, plastic, and copper. The only special material thus far identified is gallium arsenide for the laser optical transmitters. The quantity per SPS will be on the order of 100 kg.

5.4 MANUFACTURING

This hardware will be produced by normal electronics manufacturing methods. A special capital facility will be needed to produce the power control units (101,552 breaker sets per SPS); its cost has been estimated at $70M.

5.5 LABOR

Production of this hardware will employ approximately 2500 people.

5.6 QC AND QA

Parts and completed units will undergo automated testing during production.

5.7 PACKAGING AND SHIPPING

Normal electronics practices; these units will be installed on subarrays for shipment to space.

6.0 TECHNOLOGY AND DESIGN STATUS

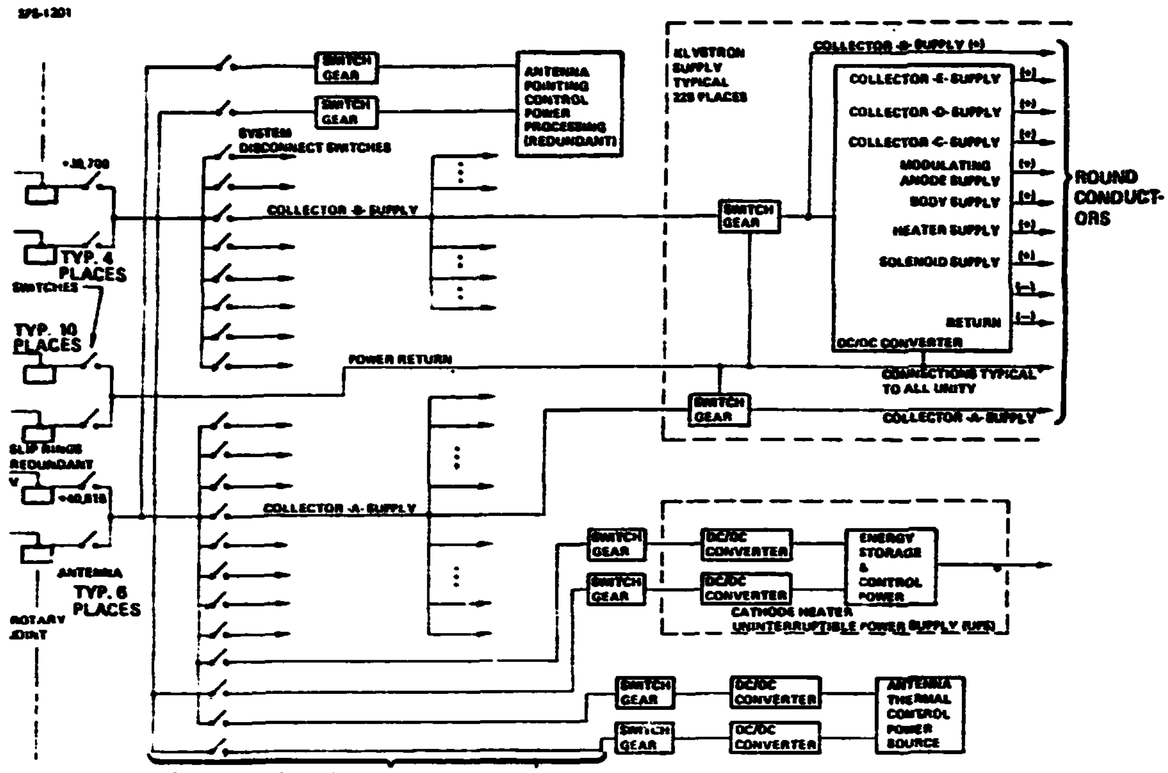
These systems have been designed to the detailed block diagram level. Exploratory tests have been conducted on phase distribution circuits; exploratory tests on a 980-MHz fiber optic link are underway. The circuitry techniques have been used in other applications. It is expected that most developmental effort will go to achieving the high degree of phase precision and stability required for beam efficiency. Comparable phase precision problems have been solved for radio telescope interferometry and the Stanford Linear Accelerator. Improvement in the temperature stability of laser diodes is thought to be necessary.

Early research will concentrate on laboratory development of precision and stability. Later development will support flight projects with flight qualified hardware.

7.0 SUITABILITY FOR SERVICE

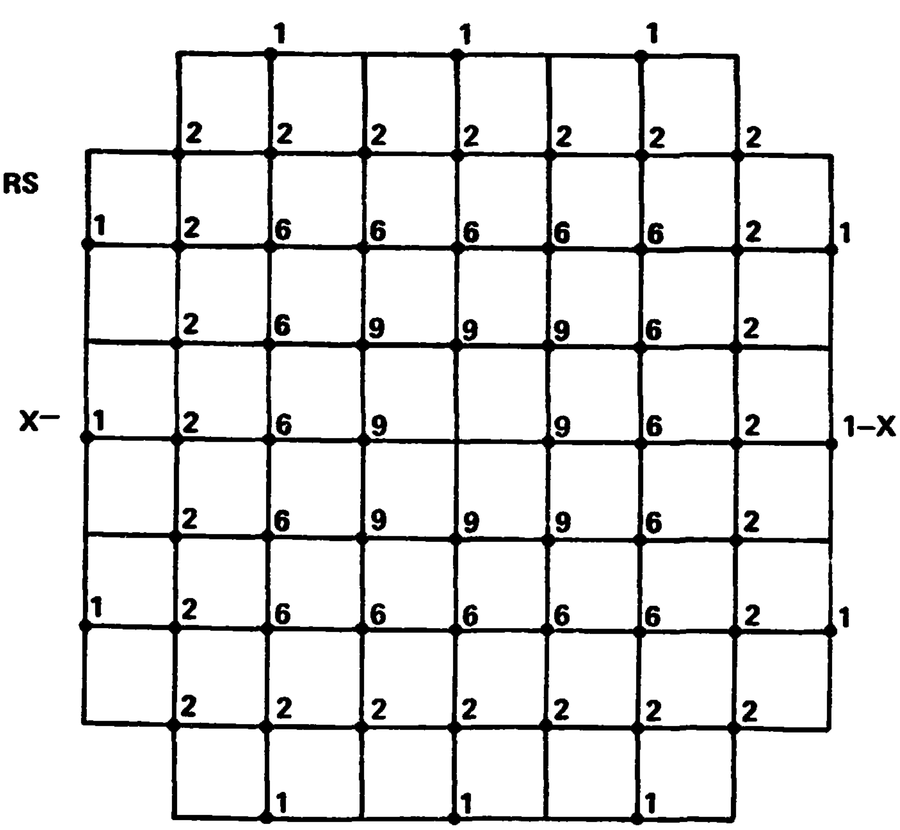
This hardware is not expected to contribute significantly to overall failure rates. It can be made redundant as needed with little extra cost and negligible extra mass.

FOLDOUT FRAME



DARKENED NODES SHOW LOCATION AND NUMBER OF DC/DC CONVERTERS 228 CONVERTERS

ANTENNA MOUNTED ON X-X AXIS



BACK SURFACE OF PRIMARY STRUCTURE SUBSTATION LOCATIONS

1.0 WBS DICTIONARY

This element includes the power conductors, switch gear, and conditioning equipment required to transfer power from the interface subsystem to the subarray wiring harnesses and to any other power consuming equipment located on the power transmission structure.

2.0 DESCRIPTION

The MPTS power distribution system provides power transmission, conditioning, control, and energy storage for all elements mounted on the antenna side of the rotary joint. The antenna is divided into 228 power control sectors, each of which provides power to approximately 440 Klystrons. The Klystrons require power at 9 different voltage levels. Two of the Klystrons' depressed collectors require the majority of the supplied power and are supplied directly from dedicated portions of the satellite power generation system. The rest of the Klystron supplied power and the power required for other power consuming equipment mounted on the power transmission structure is provided by DC/DC converters. Switch gear is provided for power control and fault protection. System disconnect switches are provided for equipment isolation for maintenance purposes.

Aluminum sheet conductors are used for power transmission from the interface subsystem to the power sector control substations and are routed along structural elements on the antenna primary structure farthest from the radiating waveguides. Round aluminum conductors provide power transmission from the substations to the antenna RF subarrays. Flexible connections are used to route power across the elevation joint between the antenna yoke and the antenna. Each power sector substation includes the required DC/DC converter, switchgear, disconnects, and energy storage.

3.0 DESIGN BASIS

The system design concept was selected based on the following criteria:

1. The power requirement of the Klystrons.
2. Loss of no more than 1% of the antenna ground power output for the failure of a single substation.
3. The optimization of MPTS power distribution and conditioning system design to minimize total satellite mass by selecting conductor operating temperatures and DC/DC converter switching frequency based on their mass contributions and the mass contributions of the additional array to compensate for their losses and of required thermal control systems.
4. Compatibility with the phase control system layout.
5. Provisions to support installation and maintenance requirements.
7. Provide energy storage to keep Klystron cathode heaters on and critical equipment powered during occultation.
8. Provide fault protection for system elements.

4.0 MASS AND MASS BASIS

ITEM	MASS ESTIMATE	RATIONALE	REFERENCE
Conductors	356.5 MT	See WBS 1.1.2.3.1	See WBS 1.1.2.3.1
Switchgear	222.1 MT	See WBS 1.1.2.3.2	See WBS 1.1.2.3.2
DC/DC Converters	1,111.5 MT	See WBS 1.1.2.3.3	See WBS 1.1.2.3.3
Processor Thermal Control	535.9 MT	See WBS 1.1.2.3.4	See WBS 1.1.2.3.4
Energy Storage	313.2 MT	See WBS 1.1.2.3.5	See WBS 1.1.2.3.5
Installation Structure	127.0 MT	5% of items above assumed	None
TOTAL	2,666.2 MT	Sum	----

5.0 COST

5.1 COST SUMMARY

	COST, $MILLIONS
o Research	15.2
o Engineering Verification	41.6
o Demonstration	742.5
o Investment	761.1
o Production	324.1

5.2 COST DETAILS

- Research - $15.2M from research planning document

- Engineering Verification - EVTA will use one 180 kw processor per 2 klystrons (5 total). Large processor is ≃ 1 kg/kw. Small (SEPS class, 2.5kw) ones run ≃12 kg/kw.

  So EVTA units may be ≃ 650kg vs. 4750 for full-sized ones.

  *Small processors on which CER is based are mostly electronics

  Scalint DDT&E by 0.75 power on weight yields $6.1M D&D for EVTA with 3.3 factor is $20 million.

  (This assumes that $C_1/C_2 = (W_1/W_2)^{0.75}$

The 3.3 factor roughly covers all support, test, and management functions.

Similarly scaling unit cost by 0.75 power yields $7.2M unit cost; need 3 flight units @ $21.6M.

- Demonstration

DDT&E from PCM run
$248.5M, includes 3 test units
Adopt full DDT&E for demo
and 60% for investment

Note that SPS Demo processor is somewhat different design than 5-GW in that all power must be processed (array output is ≃ 5kv). PPU input is ≃ 440μw. If each PPU drives 50 klystrons @ 85kw, (=4.25μw), we need 105 PPU's.

TFU is $32M (from PCM run)

Assume 80% leaning; CUM for 105 units is 23.4x32M = $749M Demo System

Apply platform 0.5 based on pilot production line pilot line ≃ 10% rate ≃ 20% cost (see below) for $120M and units with platform are $374M

Summing up Demonstration:

DDT&E	$248.5M
Pilot Line	$120M
Demo Units	$374
	$742.5

- Investment

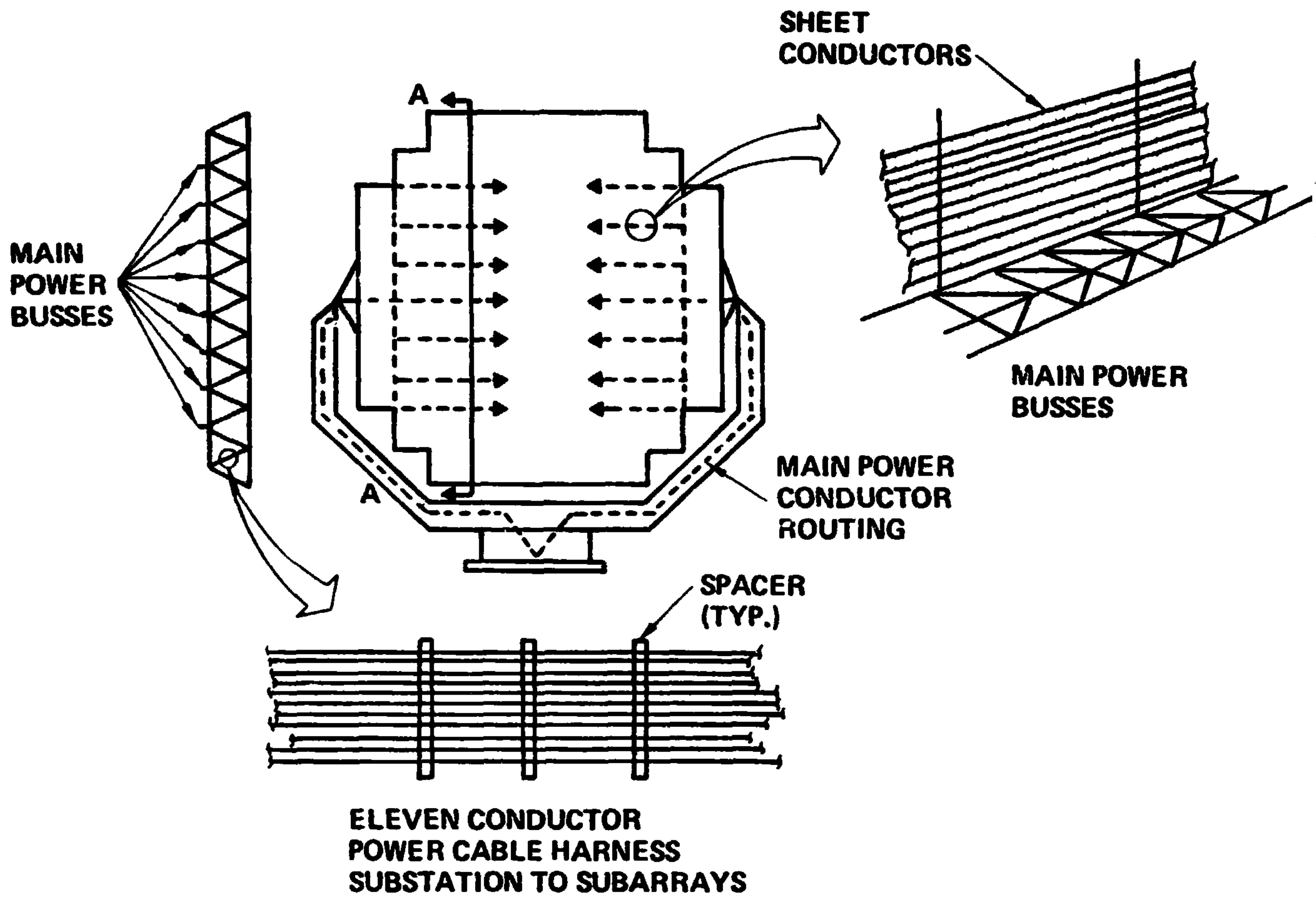
Platform factor of 0.5 was adopted for main processor because it is mostly magnetics.* This and its thermal control will require a production facility estimated as 1X annual production = 2x306 or $612M.

Delete DDT&E	= $149.1M
Total Investment	= $761.1M

o Production

Item	TFU (K)	#RQD	Factor	Ave. Cost/Unit	Per SPS (M)
Processor	23335	234	234th @ 70	763	178.5
			.5 Platform		
Switch	923	468	468th @ 70	43	20.1
Switch	1810	456	456th @ 70%	85	38.8
Disconnect	390	924	924th @ 70%	13	12.0
Pump Assy	308	234		20.1	4.7
Radiator	3088	234		202	47.3
Battery	328	234		21	4.9
					306.3
Power Distribution @ $50/lg					17.8
				Total	324.1

FOLDOUT FRAME



1.0 WBS DICTIONARY

This element includes the power conductors which are required to conduct power from the interface subsystem to the subarray wiring and to any other power consuming elements mounted on the power transmission system structure.

2.0 DESCRIPTION

Two types of power conductors are used in the MPTS power distribution system. The conductors from the rotary joint slip ring assembly to the power sector substations are one millimeter thick aluminum sheets. The conductors between the substations and the subarrays are round aluminum conductors. The conductors between the DC/DC converters and power consuming equipment other than subarrays mounted on the antenna are also circular aluminum conductors. All conductors are uninsulated and the surface emissivity is assumed to be 0.9.

3.0 DESIGN BASIS

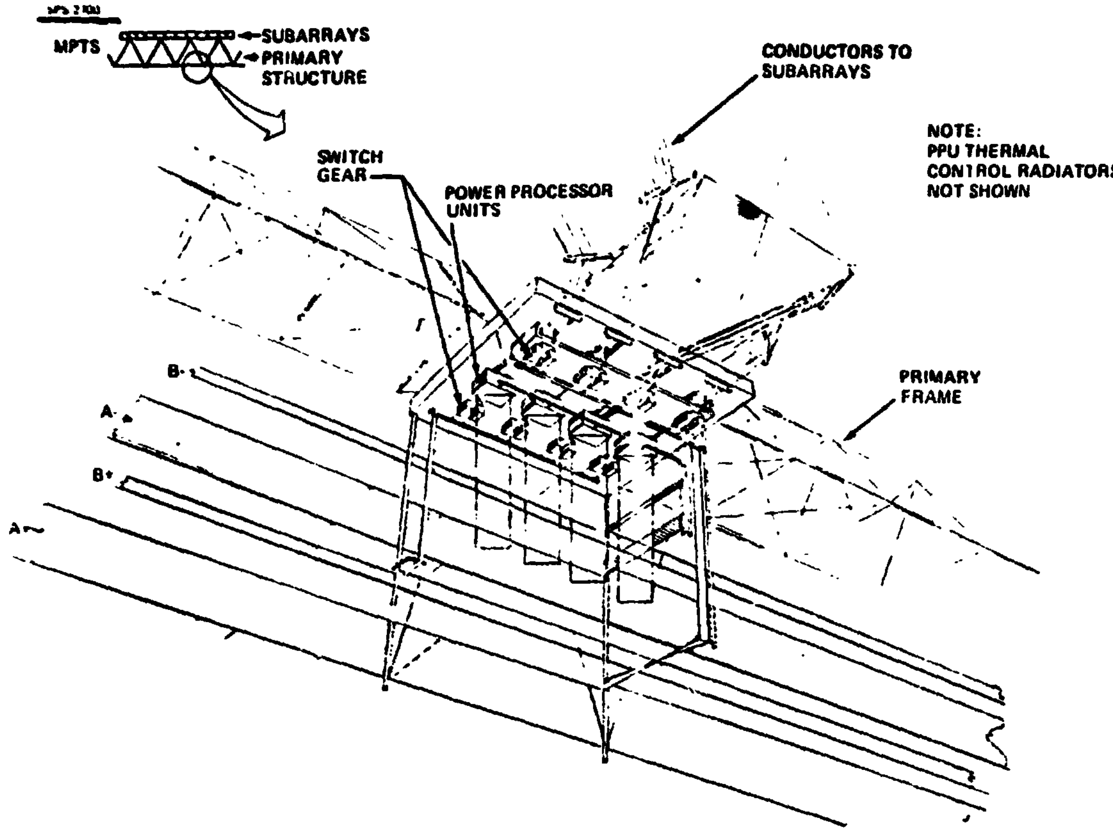
Sheet conductors were selected to maximize the ratio of surface area to cross-sectional area which maximizes the heat rejection capability of the conductors. Aluminum was selected for the conductor material. While the resistivity of aluminum is higher than copper, its density is considerably lower and its use as conductors on the SPS results in the minimum mass system when compared to other conductors. The Klystron requires nine different voltage levels. Eleven conductors are required to supply this power. Cable harness assemblies were designed to provide the power transmission from the substations (located at the back of the antenna primary structure) to the subarrays at the antenna face. The use of cable assemblies, fabricated on earth, simplifies the antenna construction processes. Conductors integral with the structure were not selected because of the large number of different voltages and the resulting complexity of the satellite structural design.

4.0 MASS AND MASS BASIS

ITEM	MASS ESTIMATE	RATIONALE	REFERENCE
Main Power Busses (Rotary Joint to Substation)	235.8 MT	Detailed estimate modified for new antenna/yoke structure (decreased line length)	NAS9-15196 Part II Report, Vol 4 (D180-22876-4) pp 128-135
Cable Harnesses (Substations to Subarrays)	109.7 MT	Detailed estimate	NAS9-15196 Part II Report, Vol. 4 (D180-22876-4) pp 135-150, p 160
Other Power Cabling	11.0 MT	10% of Klystron supply cabling	None
TOTAL	356.5 MT	Sum	----

5.0 COST

Element cost included in WBS 1.1.2.3.



1.0 WBS DICTIONARY

This element includes the circuit breakers and disconnect switches required for power control, fault protection, and circuit isolation required for power system protection, isolation for maintenance purposes, and operation for the power system located on the power transmission structure.

2.0 DESCRIPTION

The switchgear for the MPTS power distribution and control system are vacuum circuit breakers with associated communication circuitry. The switchgear for both the power sources are as follows:

Power Source	Voltage	Current	Quantity
A	40.8 KV	620 AMPS	456
B	38.7	290 AMPS	456

Redundant switchgear are provided at each location to improve system reliability and reduce power loss due to failures. System disconnect switches are provided at the input of each set of redundant circuitbreakers. Disconnect switches are opened only when no current is flowing and are used only for isolation and not for fault protection. The switchgear in this element are mounted at the power sector substations.

3.0 DESIGN BASIS

MPTS antenna contains over 101,000 dc/rf converters and 228 power sector control substations. During the conceptual design of the klystron, an effort to minimize the mass of the individual tube elements resulted in an overall lightweight tube. However, removing mass from the tube imposes the requirement that the probability of internal arcing must be minimized and, in the event that arcing should occur, rapid removal of the power sources is required. Preliminary requirements placed on the MPTS switchgear were extremely stringent—10 microseconds current interruption time. The development of switchgear to perform this task will require an improvement of two orders of magnitude in current interruption time over present switchgear capabilities (milliseconds to hundredths of milliseconds).

An additional circuit breaker is required which clamps the anode to the cathode at the klystron. Microsecond switching is required at 40KV and no current. A solid state circuit for the purpose is included in the subarray (WBS 1.1.2.2).

The antenna power distribution system fault protection scheme is as follows:

FAULT AREA	PROTECTION SCHEME
Main Bus	Remove All Satellite Power Sources
Antenna Sub-Distribution Bus	Open Appropriate Main Antenna Circuit Breaker
Antenna DC/DC Converter	Open Converter Circuit Breaker
Klystron Internal Arcing	Take Klystron Modulating Anode To Cathode Potential
Output Waveguide Arcing	Remove Klystron Input RF Drive

4.0 MASS AND MASS BASIS

ITEM	QTY	MASS ESTIMATE	RATIONALE	REFERENCE
Switchgear 38.7KV, 290A	468	52.5MT	GE Estimate 10 grams/kw	Contract NAS9-15196 Part II Report (D180-24071-1) p 69
Switchgear 40.8KV, 620A	456	114.2MT	GE Estimate 10 grams/kw	Contract NAS9-15196 Part III Report (D180-24071-1) p 69
Disconnects	924	55.4MT	Estimate 60kg/switch	None
TOTAL		222.1MT	SUM	–

5.0 COST

Element cost included in WBS 1.1.2.3

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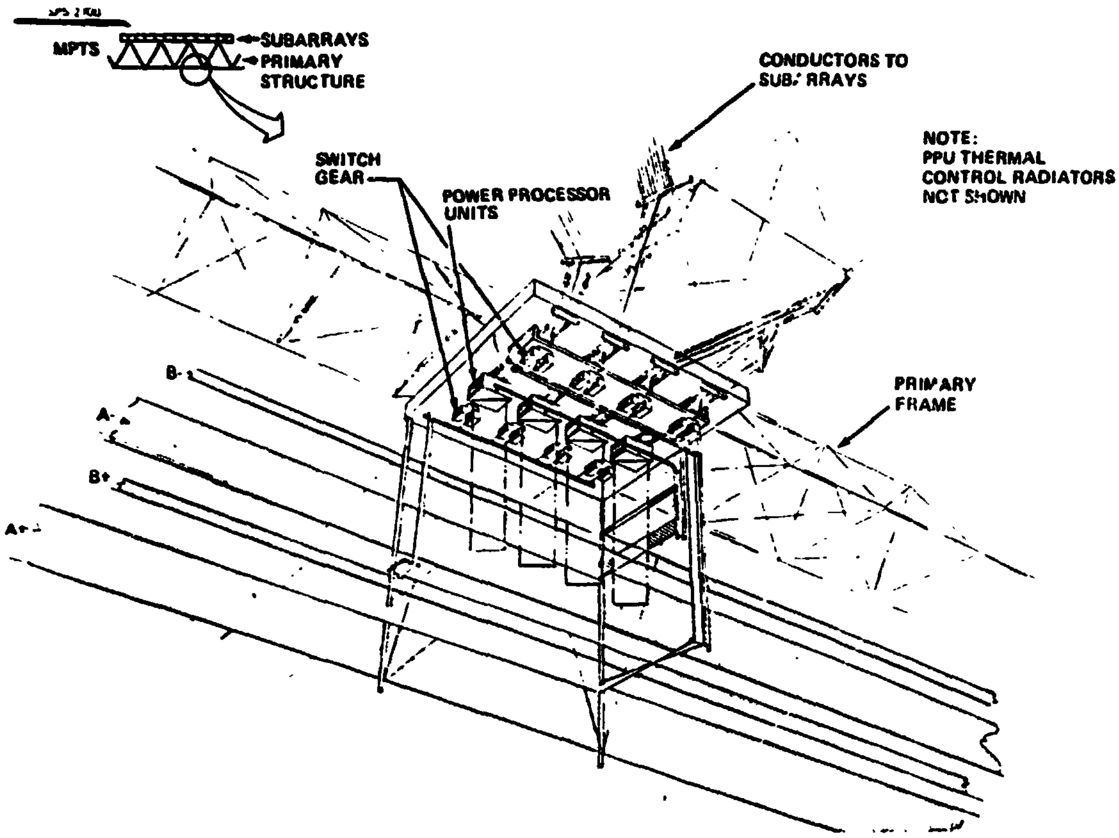
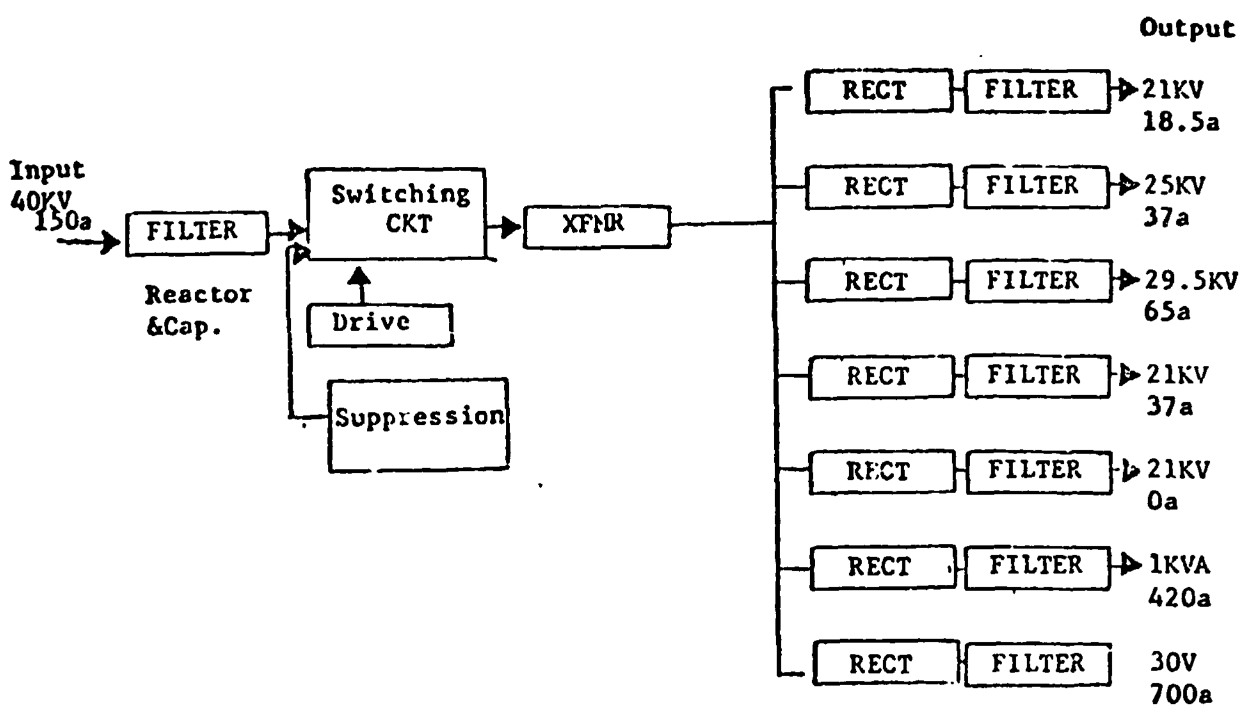


Power Sector Substation



Simplified DC/DC Converter Block Diagram

WBS 1.1.2.3.3 DC/DC CONVERTERS

1.0 WBS DICTIONARY

This element includes the MPTS antenna mounted dc/dc converters which supply any power processing required for power consuming equipment mounted on the MPTS antenna structure.

2.0 DESCRIPTION

The MPTS power control and distribution subsystem provides conditioned power for all MPTS elements. The five depressed collector klystron requires conditioned power on all inputs except the two collectors which utilize power directly from the SPS Collector A supplies and Collector B solar panel supplies. The power conditioning subsystem to provide these voltages is shown in block diagram at the left. The estimated input power to each dc/dc converter is about 5400 Kw. The selection of the particular switching circuit device has not yet been made but an analysis has shown that a switching speed of 20 KHz with SCR's or power transistors can yield a dc/dc conversion efficiency of about 95%.

3.0 DESIGN BASIS

The primary design drivers for the dc/dc converters are as follows:

- Klystron power requirements (Ref. NAS9-15196, Part II Final Report, Vol. 4, D180-22876-4, pp 121-126) (includes power and regulation)
- No more than 1% ground power output loss from failure of a converter
- Use of derated components to improve system reliability
- Converter chopping frequency selected to optimize overall satellite mass (15 KHz).
- Evaluation of semiconductor technology related to power switching (Ref. NAS9-15196, Part II Final Report, Vol. 4, Appendix B)
- Ability to control the voltage supplied to the klystron modulating anode to regulate the total power output of the combined SPS/rectenna.

4.0 MASS AND MASS BASIS

The mass of dc/dc converter is based on an estimate by GE (Ref. NAS9-15196, Part II Final Report, Vol. 4, D180-22876-4, Appendix B) modified for a liquid cooled transformer and derated dielectrics (Ref. NAS9-15636, Part I Final Report, Vol. 2, D180-25037-2, pp 200-206) the unit mass is 4,750 kilograms. The total mass is 234 (228 for klystron power + 6 for other system power) converters times 4,750 kilograms = 1,111.5 metric tons.

5.0 COST

Element cost included in WBS 1.1.2.3.

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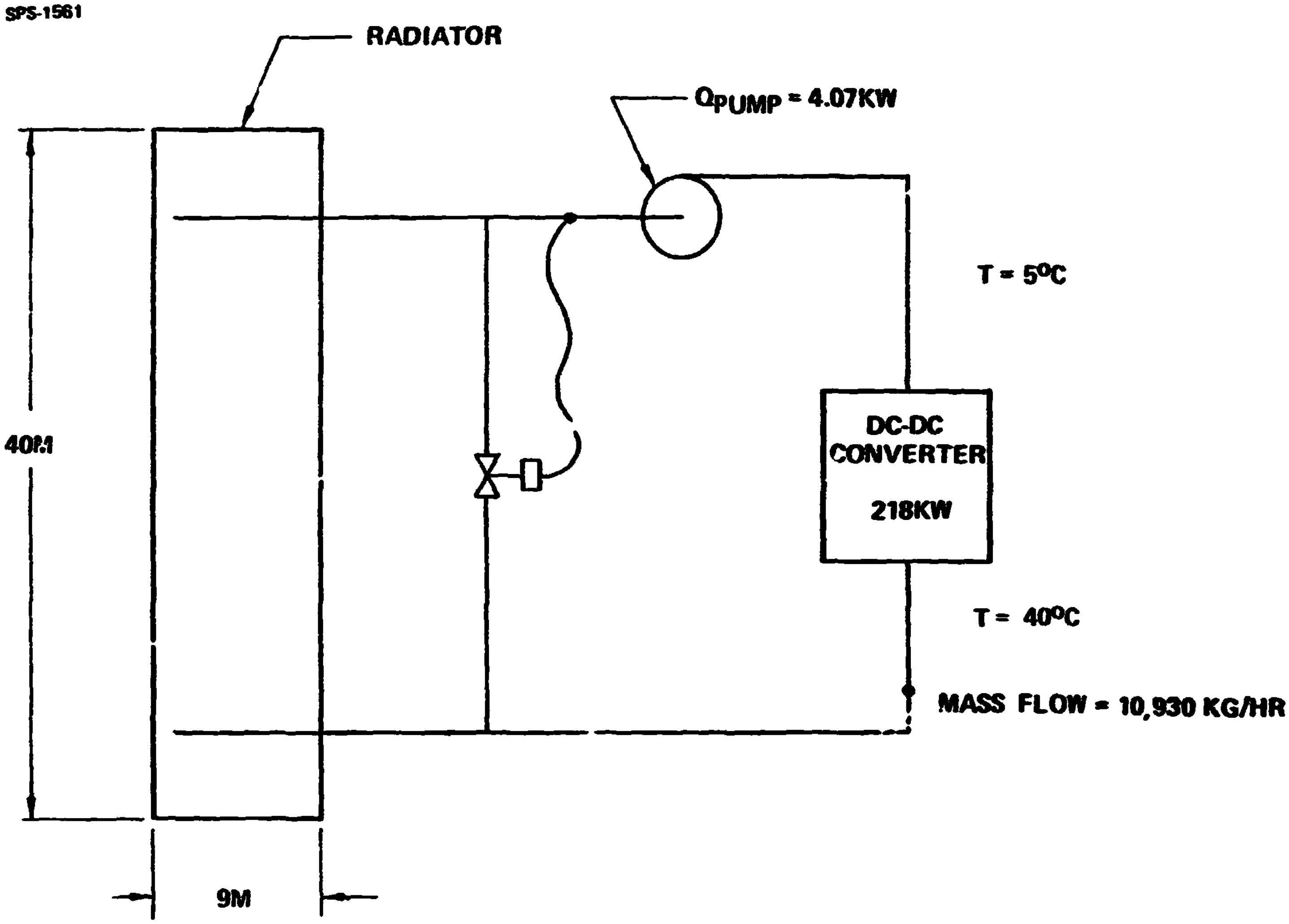

Power Processor Thermal Control

1.0 WBS DICTIONARY

This element includes the hardware required to collect and dissipate the waste heat flux from the power processing equipment installed on the MPTS structure.

2.0 DESCRIPTION

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

3.0 DESIGN BASIS

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

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

4.0 MASS AND MASS BASIS

The mass of the thermal control system is estimated to be 2.290 kilograms per dc/dc converter based on the results of a study by Vought using a two radiator system—one for the converter electronics (70%) and one for transformer and filters (200°C) with a total heat rejection of 280 Kw. Total mass is the product of 234 units times 2,290 Kg/unit weight = 535.9 MT.

5.0 COST

Element cost included in WBS 1.1.2.3

1.0 WBS DICTIONARY

This element includes the equipment required to store energy required for consumption, by equipment installed on the MPTS antenna structure, during periods of occultation.

2.0 DESCRIPTION

The MPTS energy storage system consists of nickel-hydrogen batteries installed at each power sector substation. The energy storage system provides power to keep the heaters in the klystrons on during occultation and to provide power to critical systems during this period.

3.0 DESIGN BASIS

Klystron life is impacted by cathode heater power on-off cycles. In order to increase the MTBF of the klystron, heater power is maintained during the period of time when occultation (caused either by the earth or other solar power satellites) is encountered.

It is anticipated that significant increase in the MTBF of klystrons can be achieved if thermal cycling of the klystron cathode heater can be minimized. There are 101,552 klystrons per antenna each requiring heater power of 50 watts at 30 VDC. Thus, a total of 5.08 megawatts of power is used for klystron heaters. If a distribution loss of 20% (because of the low voltage) and a period of 2 hours required for operation from stored energy are assumed, then 12.186 megawatt hours of stored energy are required.

Gas electrode (i.e., nickel hydrogen) battery systems offer the advantage of numerous recharge cycles and high energy densities. A nickel hydrogen battery system is selected for the reference configuration and should provide at least four times the service life of conventional nickel cadmium battery systems.

4.0 MASS AND MASS BASIS

With an energy storage system of this size, an energy density of 57.3 watt-hours/kg (26 WHr/lb) including tankage was derived. With a depth of discharge of 0.7 during a normal 2 hour operation, a density of 40.1 WHR/kg is used to determine the mass of the required energy storage system. The estimated mass for the energy storage system is 313.2×10^3 kilograms (313.2 metric tons).

5.0 COST

5.1 Cost Summary

		COST, $MILLIONS
o	Research	--
o	Engineering Evaluation	27.8
o	Demonstration	40.3
o	Investment	27.8
o	Production	12.5

5.2 Cost Details

COST, $MILLICNS

- o Research — –
  - o Covered under subarray control circuits
- o Engineering Evaluation — 27.5
  - o System developed at 100% of DDT&E
  - o Test units are enough to install on EVTA
- o Demonstration — 40.3
  - o DDT&E updated 100% (27.8M)
  - o Demo unit cost about equal to 5 GW system (12.5M)
- o Investment — 27.8
  - o DDT&E updated 100%
- o Production

Item	TFU*	#RQD	Factor	Ave Cost/Unit	Per SPS (M)
Master Ref Rcvr & ref phase xmtr	424K	3	None	924K	1.272
Cables	17K	60	60th @ 80% (.268)	4.6K	0.276
Slave Repeater	114K	400	400 cum @ 80% (=.22)	25.1	$10M.
Level 2 cables	17.5K	380	automated @ $100/kg	$2.5K	$0.95M
					$12.5M

Level 3 cables are common with area-subarray data harness (see WBS 1.1.3)

*Raw TFU + 10% for mgmt.

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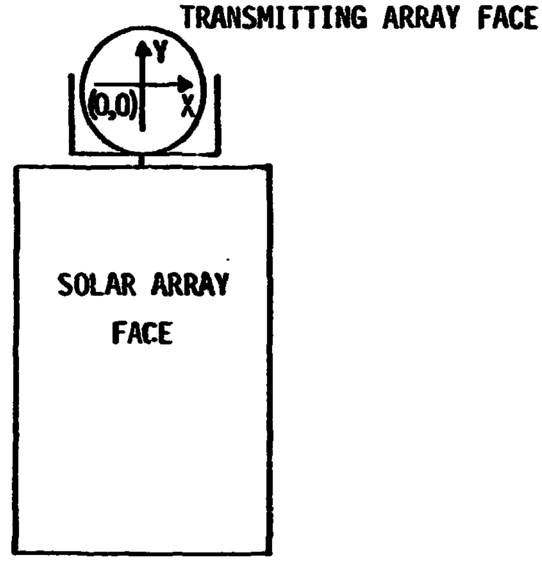

FIGURE A. MPTS COORDINATE SYSTEM

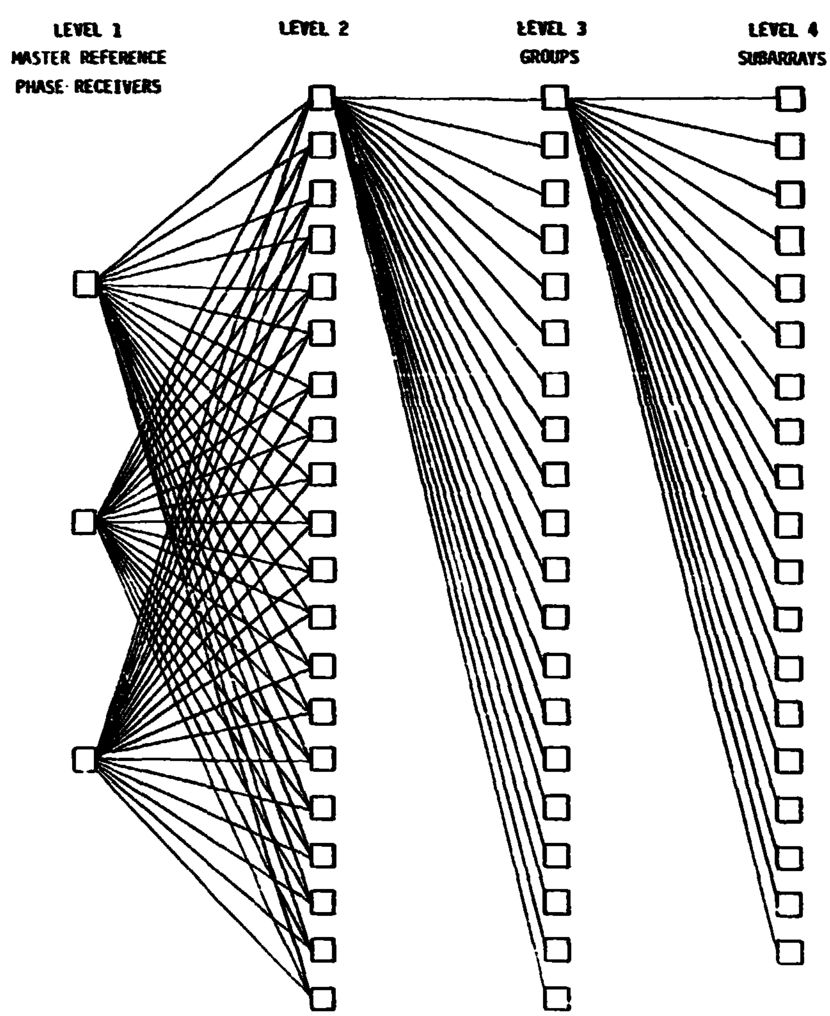

FIGURE B. REFERENCE PHASE DISTRIBUTION TREE STRUCTURE

1.0 WBS DICTIONARY

The reference phase distribution system includes all the elements involved in receiving the reference phase signal and distributing it to the subarray, except for the cabling, which is a separate WBS item.

2.0 DESCRIPTION

Transmitting antenna coordinates are denoted by (X, Y) where X is the direction parallel to the elevation axis of the antenna/yoke system and Y is perpendicular to X. X x Y = Z points along the direction of power transmission. When Z is facing the same direction as the solar array the direction -Y is towards the solar array. The point (0,0) is at the center of the array. Subarrays are numbered by their count from the array center in the fashion (X, Y) as illustrated on Figure A. Note that 0 is not an acceptable value for a subarray coordinate.

For purposes of reference phase distribution as transmitting antenna is divided into 20 sectors. Each sector is in turn divided into 20 groups with 19 subarrays each. (See Figure B)

Three Level One reference phase receivers on subarrays (-5, -2), (5, -2), and (-1, 5) each receive the Lincom derived spread spectrum reference phase signal from the pilot beam transmitter on the ground, demodulate it to the 980 MHz if frequency and transmit it to all 20 level two reference phase slave repeater units via actively delay-compensated twoway fiber optic cable links. (See Figure C)

Each Level Two reference phase slave repeater unit receives all three Level One input phase signals and selects from among them by automatic gain control (AGC) signal level weighted averaging (if they are all coherent with each other) or by two out of three rating logic (if they are incoherent). The resulting signal is then transmitted to 19 equivalent Level Three reference phase slave repeater units via actively delay-compensated two-way fiber optic links with doubly redundant electronics but non-redundant fibers.

The Level Three (Sector Group) reference phase slave repeater units take the AGC weighted average of the input signal if the two inputs are coherent and select the input with correct operating characteristics if they are incoherent. After amplification the signal is distributed to the Level Four reference phase slave repeater units that constitute the input to the nineteen subarrays in their group via a single two-way fiber optic link.

The reference phase receivers deconvolute basic satellite control commands from the spread spectrum reference signal as part of the receiving process. These commands are superposed on the fiber optic reference phase signals to the slave units and may override normal modes of operation. Any Level One reference phase signal may be explicitly ignored or enabled as true reference phase signal for Level Two slave units by explicit ground command, even though normal operating mode is to take the AGC weighted average.

Similarly, Level Two reference phase signal channels may be explicitly selected or disabled in an override of the normal automatic selection mode.

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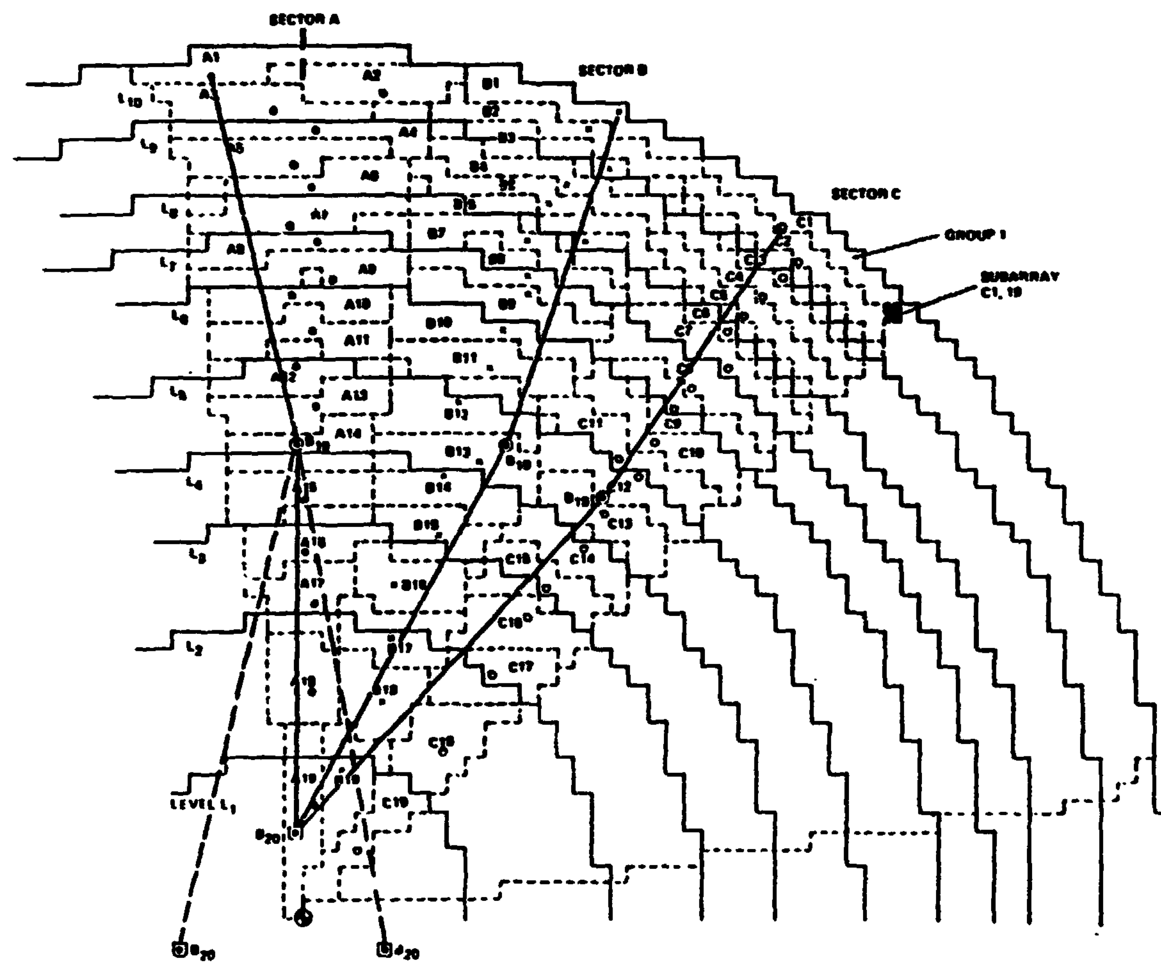

FIGURE C. PRELIMINARY LOCATION OF REFERENCE PHASE REPEATER STATIONS OF SECTORS AND GROUPS

3.0 DESIGN BASIS

The hardware design basis is advanced aerospace electronic design practice.

The function of the reference phase distribution system is to receive the spread spectrum pilot beam reference phase signal from the ground and distribute it to all subarrays with as little relative phase shift as possible. In addition, the system is to receive, deconvolute, and distribute the phase control commands which have been securely incorporated into the uplink signal. These commands are necessary to assure a well defined reference phase distribution system configuration. They must also be passed through all the slave units along with the reference phase signal, as they contain a subarray power amplifier emergency disable signal to be used as a backup to the normally used separate spacetenna/subarray control system. Reliabilities of greater than .99999, .9998 and .998 for Levels One through Three are desired over the thirty year lifetime, respectively, in order to assure safe and economical microwave power transmission.

The basic principle of operation of the active delaycompensated twoway fiber optic links is to return the transmitted signal along an equivalent link and compensate so that the total phase delay is a multiple of 2 . Note that in the scheme shown a half frequency (490 MHz) signal is also transmitted to provide compensation for the cabling phase shift ambiguities that the 980 MHz line length compensation circuit alone does not provide.

4.0 MASS AND MASS BASIS

4.1 Mass Summary

Item	Single Unit Mass	Number of Units	Total Mass (kg)
Level One			
Master Reference Receivers	24.0 kg	3	72.0
Reference Phase Transmitter (Slave Repeater Units)	3.0kg	3	9.0
Fiber Optic Cables	.1kg/m	60 x 250m	1500.0
Level Two			
Slave Repeater Units	3.0kg	20	60.0
Fiber Optic Cabler	.1kg/m	380 x 250m	9500.0
Level Three			
Slave Repeater Units	3.0kg	380	1140.0
Fiber Optic Cables	.1kg/m	7220 x 100m	72,200.0

Total Mass 84,481.0 Kg

Total Mass exluding cables 1,281.0 Kg

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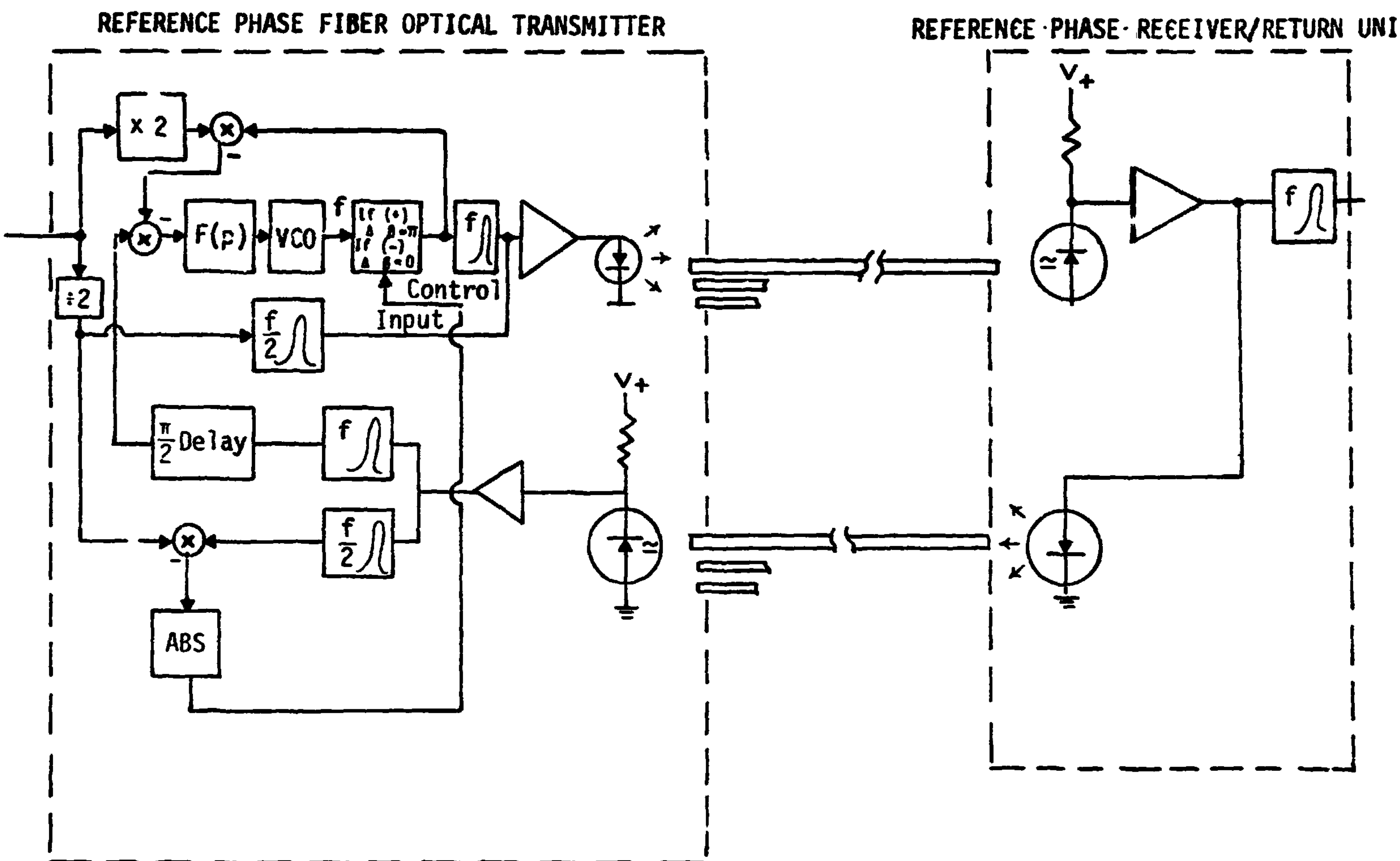

FIGURE D. REFERENCE PHASE DISTRIBUTION CIRCUITRY

4.2 MASS DETAILS

Item	Number of units	Mass (kg)
Master Reference Receiver		
Front End	2	2 x .5
Signal Processor	2	2 x 1.5
Command Identifier/Controller	1	2.0
Emergency Power Battery	1	10.0
Box and Mount	1	5.0
Connectors, Switches, Controller etc.	-	2.0
Multi Layer Insulation	$2M^2$	1.0
Total		24.0
Slave Repeater Units		
Fiber Optic Receivers	3	2 x 0.5
Line Length Compensating Fiber Optic Transmitters	40	40 x .04
Controller	1	.2
Box	1	.5
Multi Layer Insulation	$.2M^2$	.1
Connectors, Pilot Light, Misc.		.2
Total		3.0

5.0 COST

5.1 Cost Summary

Research – included under subarray control circuits

Engineering Verification – $27.8 million

Demonstration – $40.3 million

Investment – $28 million

Production – $12.5 million per SPS

(Cost Details)

DDT&E included the following test hardware:

- 6 master reference receivers
- 6 batteries
- 20 level 1 cables
- 120 slave receivers
- 120 level 2 cables

PRODUCTION ESTIMATE

ITEM	TFU	# RQD	FACTORS	AVG UNIT	PER SPS ($M)
Master Reference Receiver	424K	3	None	424K	$ 1.272
Level 1 Cables	17K	60	60th @ 80%	4.6K	0.276
Slave Repeaters	114K	400	400 cum @ 80%	25.1K	10.0
Level 2 Cables	17.5K	380	Automated @ $100/kg	2.5K	0.95
					12.5 M

Note: Level 3 cables are common with area-subarray data harness (see WBS 1.1.3)

5.2 Cost Details

Only two unique electronic components ("boxes") need to be developed. However, one of these units, the reference phase repeater unit, should be hard-wire configurable to Level One, Two, and Three configurations, which are all slightly different from each other.

Designing in this generality cuts cost compared to custom units for each level and also greatly simplifies maintenance, repair and logistics.

It is anticipated that three electronic integrated circuits will be designed for use on the reference phase control system, at an estimated development cost of $250,000 each. The most widely used of these will be for the line length compensating fiber optics transmitter circuit. The other two will be the slave repeater unit controller and the spread spectrum signal processor.

The remainder of the electronics is anticipated to be standard commercial components upgraded for spacerating.

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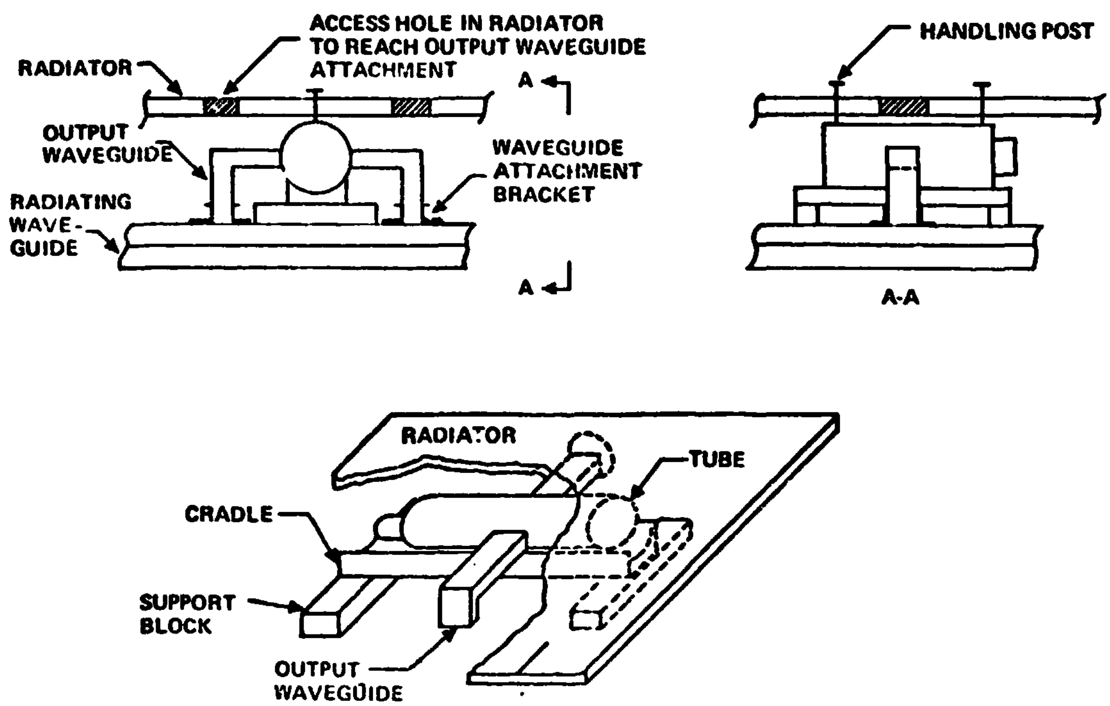

Figure A. Level of Replacement Selection

NOTE: THE PRIMARY AND SECONDARY STRUCTURES SHOWN IN THIS AND FOLLOWING FIGURES ARE OBSOLETE. HOWEVER, THE MAINTENANCE CONCEPTS DESCRIBED HEREIN DO NOT APPRECIABLY CHANGE DUE TO THE STRUCTURES SHOWN IN WBS 1.1.2.1.1 AND WBS 1.1.2.1.2

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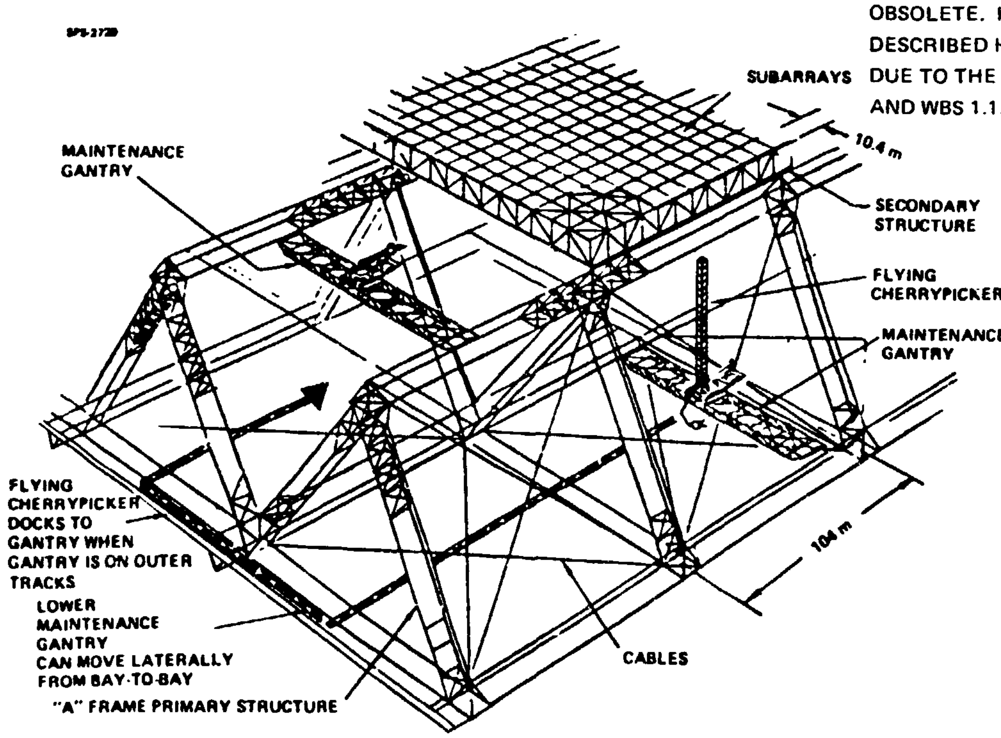

Figure B. Maintenance Gantries

1.0 WBS DICTIONARY

This element includes the built-in MPTS maintenance equipment that is used by the visiting maintenance crew.

2.0 DESCRIPTION

The MPTS maintenance operations require maintenance equipment to operate at both faces of the antenna.

Antenna Front-Face Maintenance Provisions

The level of replacement selected for the radiating surface of the MPTS is that of the klystron tube module plus its thermal control system as shown in Figure A. Actual removal of the tube module involves access through holes in the radiator to reach the distribution wave guide attachment bracket which secures the module to the distribution wave guide. Once this attachment is released the module is free to be removed.

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

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

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

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

The phase control system and some of the power distribution system elements are also accessed and replaced using the gantry and cherrypicker systems.

To enable the docking of the various maintenance system elements and to transfer cargo around the antenna, the antenna structure has been designed to incorporate a cargo distribution system and has structural additions to allow maintenance gantries to be positioned so they can be maintained and supplied with new klystron tube modules. The systems are shown as they relate to one side of one antenna in Figures F and G. Since two crews work on each satellite, these same systems are present on both sides of the antenna.

The actual distribution of the cargo around the antenna is accomplished through use of cargo transporters operating on the track system on two sides of the

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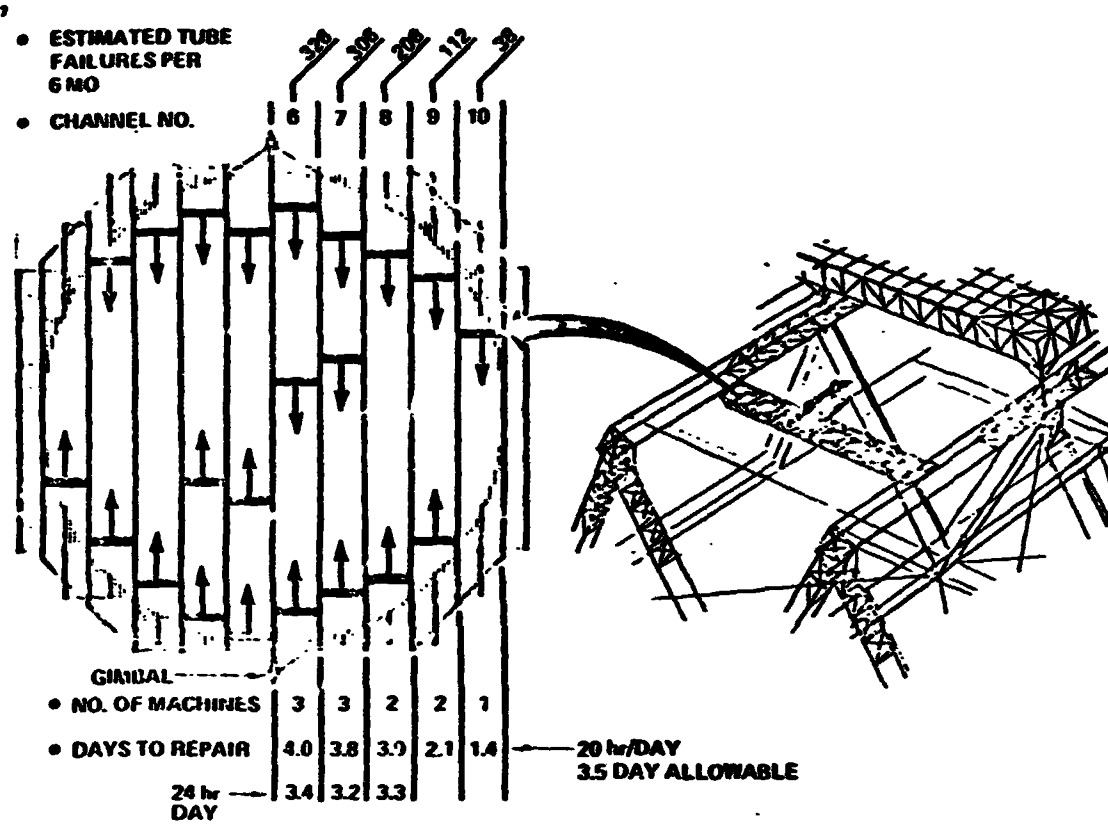

Figure C. Antenna Maintenance System Installation

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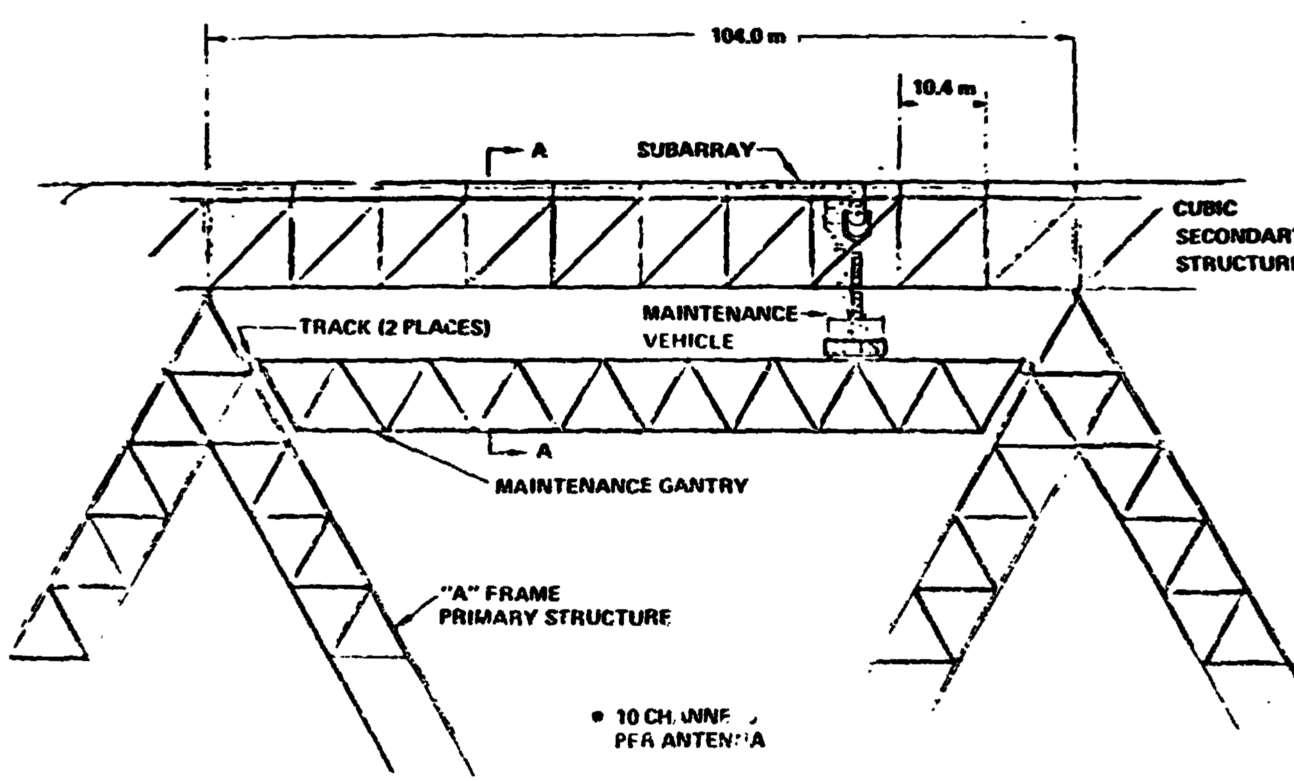

Figure D. Vertical Access for Tube Maintenance

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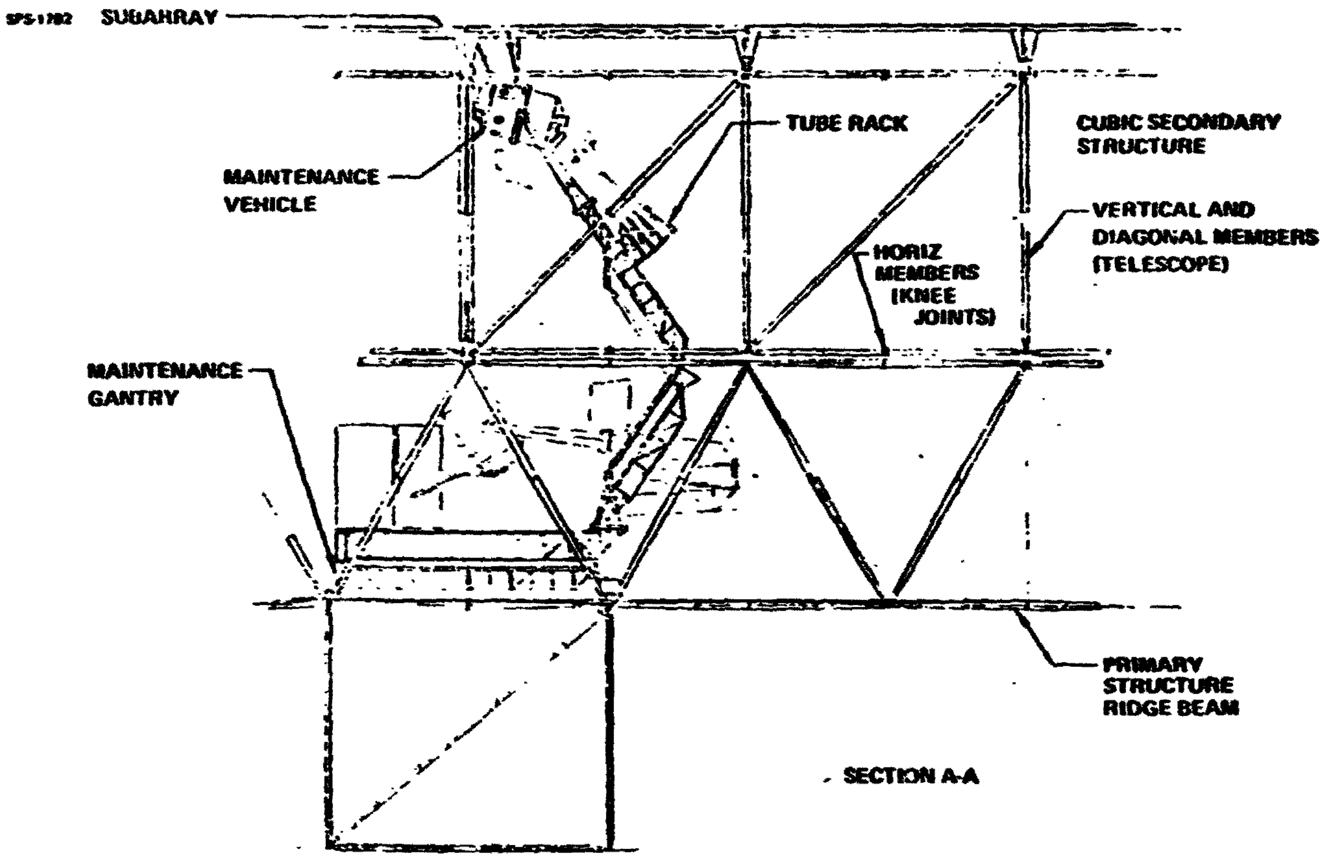

Figure E. Vertical Access Maintenance Vehicle

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OF POOR QUALITY

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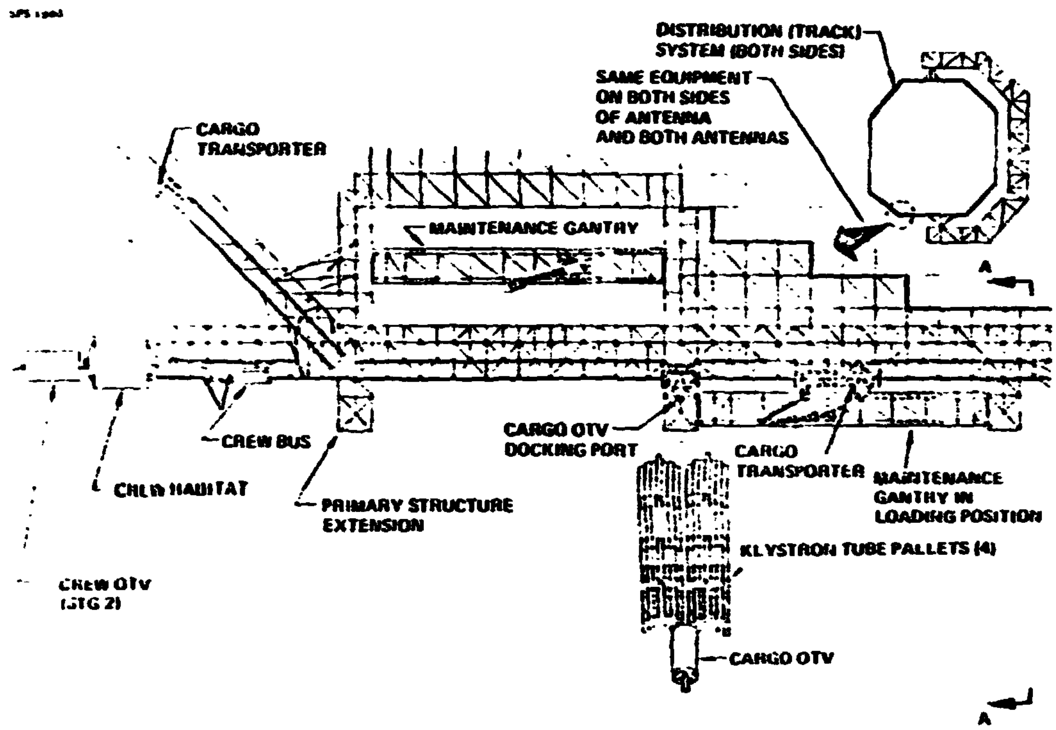


Figure F. Antenna Maintenance Systems

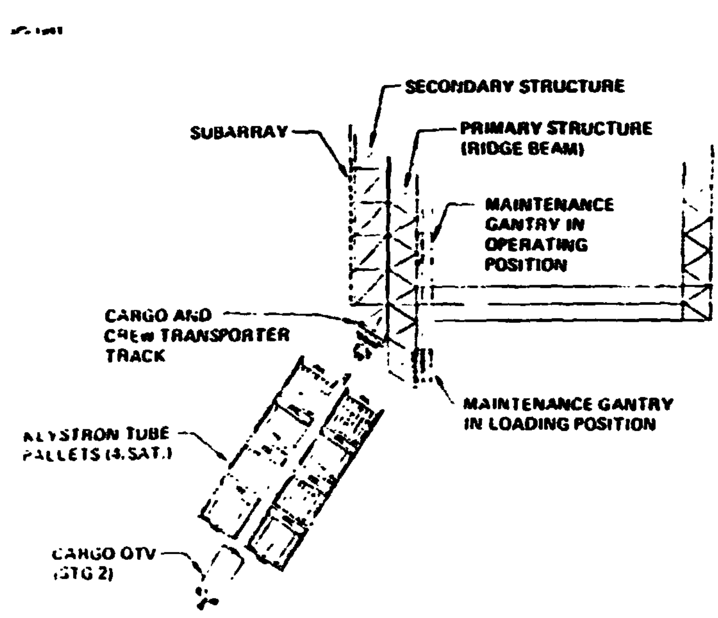


Figure G. Antenna Maintenance Systems

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

Antenna Back Surface and Mid-Plane Maintenance Access Provision

The antenna back surface is where the main power busses will be routed to electrical substations located at various primary structure nodal points. The maintenance access system selected for this application is illustrated in Figure B. Only one of these gantry/flying cherrypicker systems is warranted by the expected failure rates of the components located on the antenna back face. This system is also employed to replace the power conductors that are routed between the substations and the secondary structure.

Summary

The maintenance systems are summarized in Table A.

3.0 DESIGN BASIS

Refer to Section 13 of the Operations and Systems Synthesis document (D180-25461-3).

TABLE A
WBS 1.1.2.6 MAINTENANCE SYSTEMS

ITEM	QTY
o FRONT FACE MAINTENANCE EQUIPMENT	
o Cargo Distribution Tracks	
o Cargo Transporter/OTV Docking System	4
o Cargo Transfer Cherrypicker	2
o 24-Man Crew Bus	2
o Maintenance Gantry Tracks	TBD
o Maintenance Gantries	22
o Maintenance Vehicles	22
o BACK-SURFACE MAINTENANCE EQUIPMENT	
o Maintenance Gantry Tracks	TBD
o Maintenance Gantry with Flying Cherrypicker Carriage	1
Flying Cherrypicker (See WBS 1.2.3.1.2)	

4.0 MASS AND MASS BASIS

Mass was estimted by estimating mass of the components as summarized below.

TRANSMITTER MAINTENANCE SUMMARY

ITEM	No. RQD	Unit Mass (KG)	Total Mass (TONS)
GANTRY	22	1650	36.3
MRWS	22	2500	55
DOCKING PORTS	66	250	16.5
CREW BUS	2	15000	30
COMPONENT TRANSPORTER	4	1000	4
CARGO HANDLING CHERRYPICKER	2	2500	5
GROWTH & CONTING.	(20%)	29.4	29.4
TRACKS	22.4 km	2.42 kg/m	54
TOTAL			230.2

5.0 COST

5.1 COST SUMMARY

	Cost, $ Millions
o Research	-
o Engineering Evaluation	-
o Demonstration	446.5
o Investment	
o Production	503.9

5.2 COST DETAILS

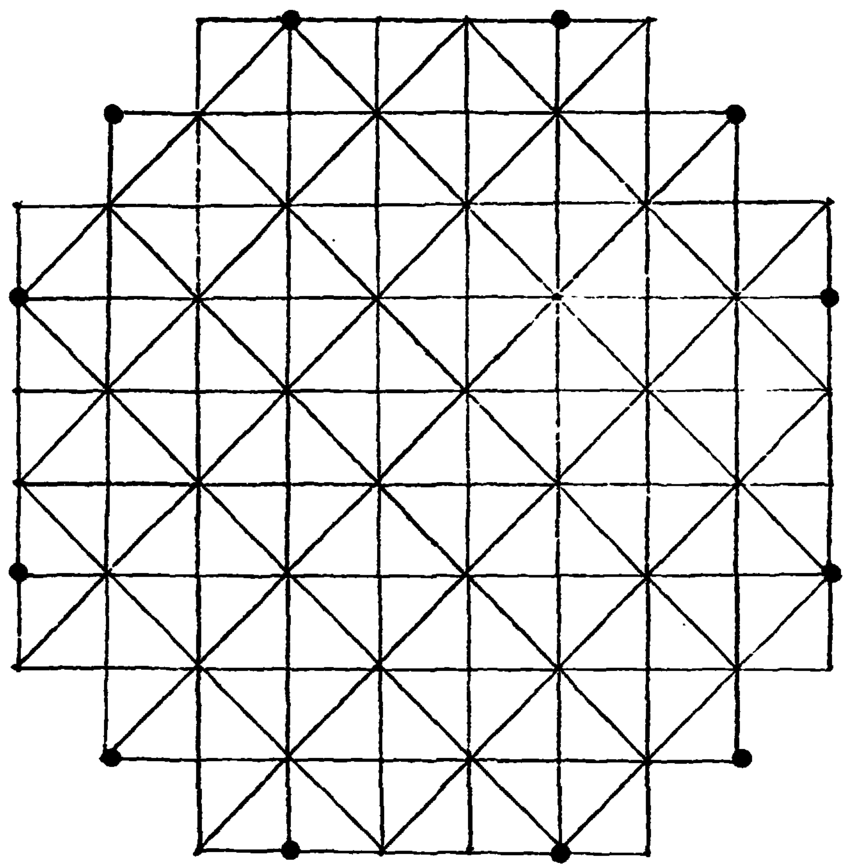
- o Research — -
  - o Covered under space construction
- o Engineering Evaluation — -
  - o Covered in LDL
- o Demonstration — 446.5
  - o Use 100% of DDT&E $159.6M
  - o Demo unit

8 gantries	@ $8M
8 MWRS's	@ 162.4M
24 docking ports	@ 800K = $19.2M
1 crew bus	@ $51M
1 transporter	@ $1.7M
1 cargo H.	@ 3.64M
Tracks	$41M
	$286.9

- o Investment
- o Production

Item	TFU	# RQD	Factors	Prod Unit	Per SPS
Gantry	1.03	22	22nd @ 85% (.48)	494K	10.9M
MRWS	29	22	22nd @ 90% & .7 frstripping (.44)	12.76	280.72
Docking Ports	1.09	66	66th @ 85% = .37	408K	26.9
Crew Bus	51	2	10th @ 90% = .7	35.7	71.4
Component x port	1.712	4	4th @ 85%	1.24	4.95
Cargo Handling Cherrypicker	3.64	2	10th @ 85% = .58	2.11	4.22
Growth & Cont.	(16% of above)				63.8
Tracks	$76/kg				41.0
					$503.89M

ANTENNA BACK SURFACE PLANE
(PLANAR MEMBERS ONLY SHOWN)



ANTENNA MECHANICAL POINTING CMG
INSTALLATION LOCATIONS

1.0 WBS DICTIONARY

This element includes the system of control moment gyros located on the power transmission structure and used to accomplish mechanical pointing of the antenna transmitting face toward the earth receiving antenna. Subarray pointing or positioning provisions are included in the subarray WBS 1.1.2.2.

2.0 DESCRIPTION

The Power Transmission System Attitude Control System provides fine control of antenna mechanical aiming. Control Moment Gyros (CMG's) are used to generate torques required for this fine control. Control of the CMG's is accomplished using the signals derived from pointing errors determined from the phase control system. Rough pointing to acquire the phase control signal is accomplished using star scanners to control the CMG's.

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

3.0 ELEMENT DESIGN BASIS

Antenna pointing is required to point the SPS antenna toward the ground rectenna to maximize the transfer of microwave energy from the SPS to earth. Three options were investigated:

- Propulsive systems - rejected because of possible exhaust plume interference of the RF beam, exhaust contamination of the power transmission system elements, and life cycle costs for propellant resupply.
- Mechanical drive - rejected because of achievable accuracy
- Control moment gyro's - selected based on achievable accuracy, life, costs, freedom from contamination

The CMG's were located on the outer perimeter of the antenna because of the higher temperatures near the antenna center.

4.0 MASS AND MASS BASIS

MASS SUMMARY

Item	No. Req'd	Unit Mass (KG)	Total Mass (MT)
CMG's	12	10,657	127.9
Star Tracers	3	5	.015
Inst. Structure	12	533.3	6.4
			134.3MT

A

5.0 COST AND COST BASIS

5.1 COST SUMMARY

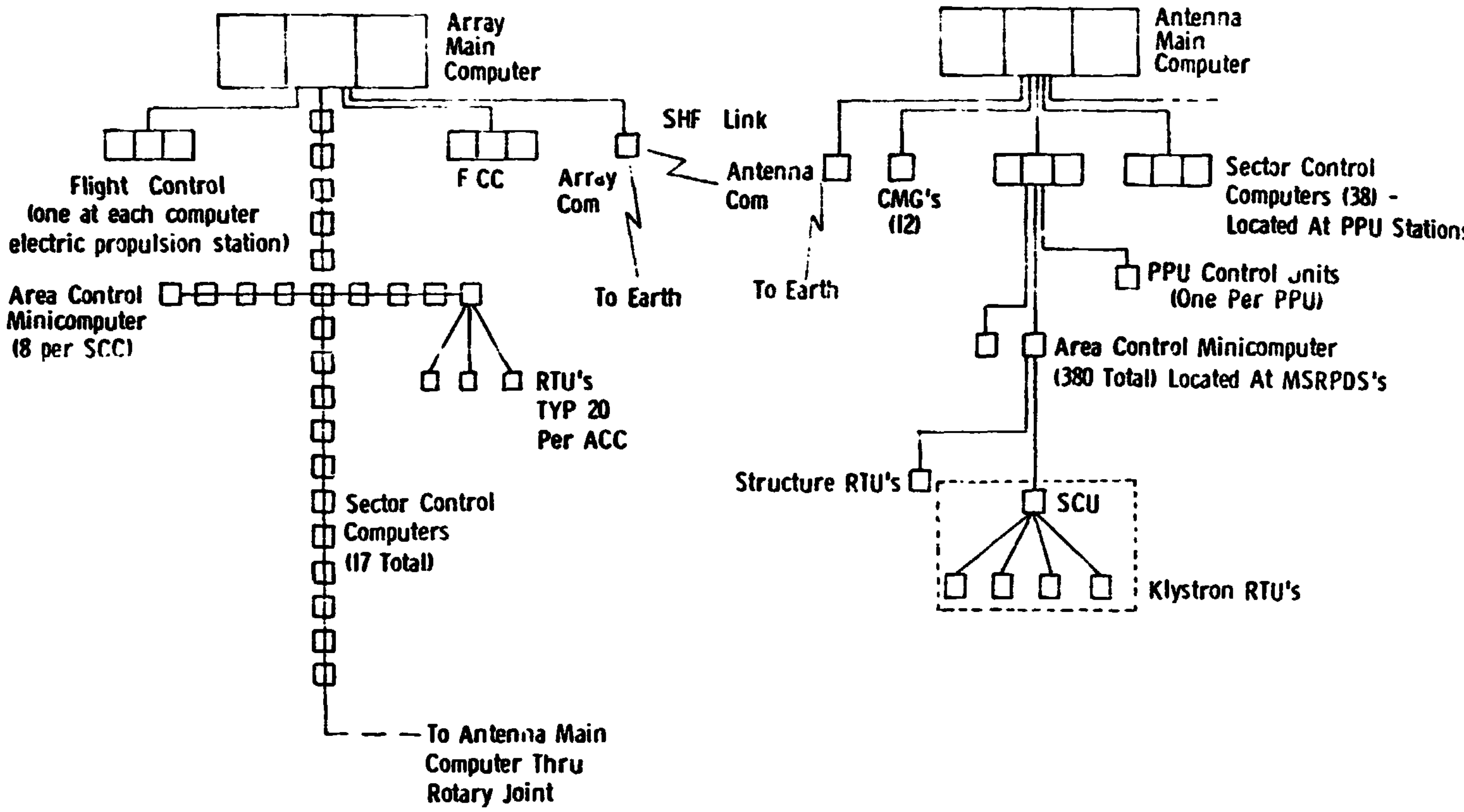
	COST, $MILLIONS
o Research	2.8
o Engineering Evaluation	25
o Demonstration	27.6
o Investment	137
o Production	

5.2 COST DETAILS

- o RESEARCH — 2.8
  - o Sensors 150K + 920K
  - o CMG Design 326K
  - o Wheels, bearings, motors 816K
  - o Other actuators 615K

    $2827K
- o ENGINEERING EVALUATION — 25
  - o EVTA will use smaller wheels, probably state-of-the-art, cost approximately $10M
  - o Lab work on test hardware for larger wheels @ $15M
- o DEMONSTRATION — 845
  - o Incurs DDT&E of $534M
  - o 3 prototypes @ $311M
- o INVESTMENT — --
  - o None
- o PRODUCTION — 137
  - o $11.4M each for total of $137M

FOLDOUT FRAME



1.0 WBS DICTIONARY

The Information Management and Control System (IMCS) includes all computers and centralized and decentralized data processing required for overall onboard management of the satellite configuration operation, flight control, and power transmission systems.

2.0 DESCRIPTION

The Central Processor Unit (CPU) manages data traffic to and from the ground, formats telemetry for transmission and checks commands for bit errors. Other functions of the CPU include maintaining stored commands for operating and testing the data subsystem in the absence of ground control and control of telemetry data storage for later transmission. Critical computers are triple-redundant and cost-strapped.

Each tier monitors operation of the tier below, instigates check on subordinate units and establishes priority for upward communication. The lowest tier interfaces the IMCS to other subsystems through sensor readings, digital data transfers and command outputs. An upper tier may also override a command by a lower tier in order to restore operation or diagnose apparent failures if its information on the status of the Remote Technical Unit (RTU) involved, or information from another RTU, warrants such action.

Fiber optics were selected for harnesses because such a system is of lighter weight, is more fault tolerant, (because it is a non-conductor it does not propogate faults), has a wide-band multiplexing capability, is inherently immune to EMI and arc discharges, and the raw materials required are in ready supply and inexpensive. It is recognized, however, that a considerable amount of development in fiber optics will be required.

A code format which contains the clock has been selected because the long distances over which the data must be transmitted not only make synchronization with a separate clock signal very difficult, but also results in an appreciable increase in complexity and cost.

3.0 DESIGN BASIS

The large numbers of telemetry points and commands required by each satellite made it apparent that if all telemetry data were transmitted to the ground, either very large numbers of ground personnel would be required to monitor the data and generate commands, or the equivalent work would have to be accomplished by automatic processing It also became apparent that if automatic processing had to be used, it could be done by a distributed processing ssystem in the satellite with processors located near the equipment being monitored and commanded. This system provides two other advantages, the amount of data transmitted throughout the satellite and to the ground would be reduced, and the delay time between detection of an anomaly and receipt of a correcting command would be reduced. In view of these considerations the hierarchical on-board processing system was selected.

In order to process telemetry data and generate commands locally within the satellite, numerous microprocessors and memories are required, distributed throughout the satellite. These processors are organized into groups, each of which is monitored by a processor that is one of another tier or processors. This tiering process continues up to a Central Processor Unit which manages the data traffice to and from the ground.

The recommended approach is essentially two systems connected by a limited data link. The reasons for this approach are:

a. The large amount of information which must be handled

b. Transmission of large amounts of data at high rates across the slip rings may be difficult

c. A redundant link with the ground is provided

4.0 MASS AND MASS BASIS

Total Mass = 96 Metric Tons

Antenna Mounted

Computers	#	kg ea	Total
Main	3	50	150
Sector Control	114	8	912
Area Control	380	2	760
Struc. RTU's	2000	0.5	1000
			2822

Cables	#	Length	kg/m	kg ea	kg Total
Main - Sector	76	500	0.1	50	3,800
Main - CMG	12	500	0.1	50	600
Main - COM	2	1000	0.1	100	200
Sector - PPU	234	10	0.1	1	234
Sector - Area	380	250	0.1	25	9,500
Area - Subarrays	7220	100	0.05	5	36,100
Area - Struc RTU's	2000	100	0.05	5	10,000
					60,434

Array Mounted

Computers	#	kg ea	Total
Main	3	25	75
FH Con	12	8	96
Sector	17	2	34
Area	136	1	136
RTU's	2720	0.5	1360
			1701

Cables	#	Length	kg/m	kg ea	kg Total
Spine Bus	1	17000	0.1	1700	1,700
Trans Bus	17	5500	0.1	550	9,350
Area - RTU	2720	50	0.1	5	3,600
Main - FCC	4	3000	0.1	300	1,200
Main - FCC	4	12000	0.1	1200	4,800
Main - Com	2	10	0.1	1	2
					30,652

5.0 COST

5.1 COST SUMMARY

Research $6.82M

Engineering Verification $25M for EVTA FCC

Demonstration

5.2 COST DETAILS

Research program covers flight control and system control.

No engineering verification is planned. $25 million is allocated for a flight control computer for the engineering verification test article (EVTA). This will be a conventional system.

Demonstration	Cost ($M)	
DDT&E		Demo Unit
Computers & Data Acq.	35.2	$156M investment
Harnesses	37.9	Delta DDT&E $110M
SE&I & Software	164.2	
Test Hdwe	82.5	
Prog Mgmt, etc.	48.5	
	368.4	

Production	Cost ($M)
Computers & Data Acq.	27.9
Harnesses	15.7
Prog Mgmt, etc.	4.4
	48.0

5.3 MATERIALS AND ENERGY REQUIREMENTS

A detailed estimate cannot be made without detailed designs of the hardware. The predominant material will be aluminum. The remainder will be mainly solid state components, plastic, and copper.

5.4 MANUFACTURING

This hardware will be produced by normal electronics manufacturing methods.

5.5 LABOR

Production of this hardware will employ approximately 300 people.

5.6 QC & QA

Parts and completed units will undergo manual and automated testing during production.

5.7 PACKAGING AND SHIPPING

Normal electronics practice; the antenna mounted units will be installed on subarrays for shipment to space, and the array mounted units will be installed in space separately.

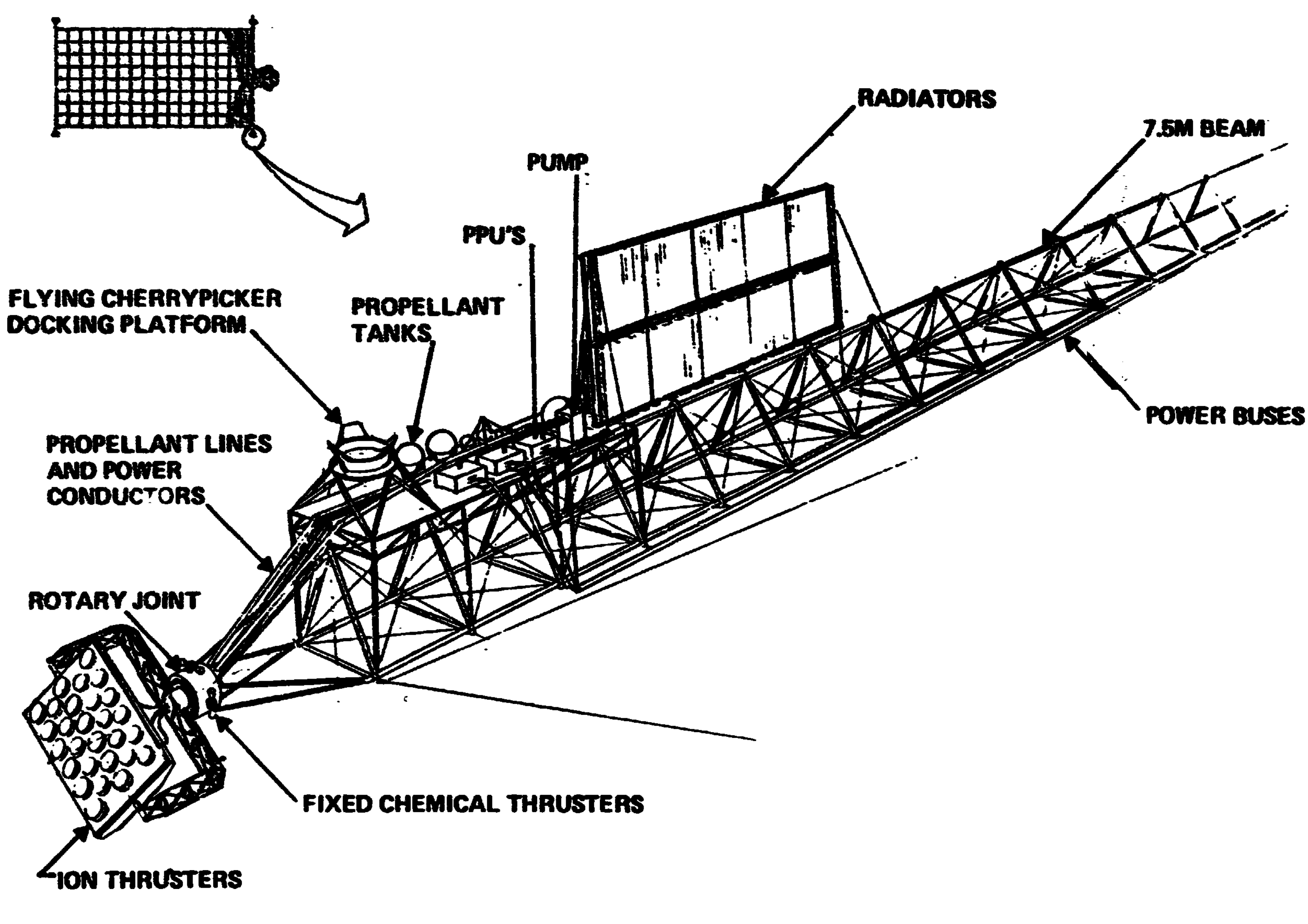
6.0 TECHNOLOGY AND DESIGN STATUS

These systems have been designed to the block diagram level. The computers are expected to be available industrial technology but not space-rated hardware. The fiber optic cable will be of the same technology as the phase distribution of the SPS wiring harness. It is expected that most developmental effort will be to achieving the high degree of reliability and redundance required for commercial utilities. Similar problems are often solved in the chemical engineering industry. The bulk of the development will adapt existing equipment to support flight projects with flight qualified hardware.

7.0 SUITABILITY FOR SERVICE

This hardware is not expected to contribute significantly to overall failure rates. It can be made redundant as needed with some extra cost.

SPS-769B


RADIATORS
7.5M BEAM
PUMP
PPU'S
FLYING CHERRYPICKER DOCKING PLATFORM
PROPELLANT TANKS
POWER BUSES
PROPELLANT LINES AND POWER CONDUCTORS
ROTARY JOINT
FIXED CHEMICAL THRUSTERS
ION THRUSTERS

WBS 1.1.4 ATTITUDE CONTROL AND STATIONKEEPING

1.0 WBS DICTIONARY

This element includes the components required to orient and maintain the satellite's position and attitude in geosynchronous orbit. Included are sensors, reaction wheels, chemical and electric propulsion hardware and propellants.

2.0 DESCRIPTION

The attitude control system includes attitude sensing and an electric propulsion system with four installations, one at each corner of the SPS energy conversion system. A typical corner constallation is illustrated in Figure 1.1.4-1. The attitude control system includes thrusters, power processors, structure, propellant feed and control systems and instrumentation and control. Chemical propulsion is provided for control during equinoctal occultations or unexpected loss of electric power.

The approach for collector control makes use of multiple thrusters providing a total force equal to the solar pressure. Individual thrusters are modulated above or below their bias level to provide the control torques needed to offset gravity-gradient disturbance torques. In essence, there is no additional propellant penalty for collector attitude control. Single axis (pitch) rigid body control only is shown. Thruster location will be at the nodal points of one of the lower modes to minimize excitation of that particular flexbile mode. Active damping of other modes will be achieved by superimposing additional thrust modulation signals on the attitude control thrust level commands. These signals are derived from the outputs of multiple rate sensors which are processed to isolate the rigid body and lower bending mode components of motion.

Thrusters include the primary electric thrusters for maintenance of attitude control, and auxiliary chemical thrusters required for establishment of attitude control when electric power is not generated by the SPS. The electric thrusters are 120 centimeter diameter ion thrusters operated on argon as primary propellant. Approximately 50,000 kg per year is required, as established by the need to eliminate orbit perturbations introduced by solar pressure. All other flight control can be accomplished by modulation of the solar pressure counter-thrust. The chemical propulsion system employs liquid hydrogen and liquid oxygen. The propellant containers are spherical aluminum tanks located near each thruster installation and are sized to hold a one year propellant supply plus a 20% margin. The oxygen and hydrogen tanks tankage includes 20,000 kilograms of maneuvering reserve propellants in addition to the normal control propellant.

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

The structure consists of a cable stayed 7.5 meter beam with the necessary support structure for system installations. The gimbal system is a two-axis, motor-driven, slow-rate gimbal system whose commands are derived from the instrumentation and control system.

The power processors are solid state and convert the 40,000 V from the SPS to lower voltages required by thrusters and other subsystems.

3.0 ELEMENT DESIGN BASIS

Velocity control is required to maintain orbit station by offsetting solar pressure and orbital drift toward the neutral point. Attitude control is required to provide Sun orientation of the collector and high accuracy Earth rectenna pointing of the two antennas. In additionm to countering the gravity-gradient disturbance torques, the control concept must avoid unstable interaction of the antenna and collector control loops and structural flexibility effects.

Attitude control requirements are at GEO dominated by gravity gradient effects. Orbit trim requirements are dominated by solar pressure. A good flight control strategy combines the corrections, using unbalanced couples to provide translation corrections for solar pressure while applying torque to counter gravity gradients.

The mass penalty for gravity gradient control includes: 1) thrust production hardware; thrusters plus power processing; 2) generating capacity required to power the thrusters; 3) propellant required. The correct propellant quantity penalty reflects the time value of the cost of propellant resupply; the penalty should be the net present value (in economic terms) of the lifetime propellant requirement. The penalty value ranges from 10 years' annual supply (10% discount for 30 years) to 14 years' annual supply (7-1/2% discount, infinite life).

Propulsion system Isp is a variable, assuming electric propulsion. As Isp is increased, propellant mass penalty decreases but hardware penalty increases. Accordingly, an optimum occurs and 20,000 seconds Isp is selected as a representative value. Chemical propulsion will be needed to provide control during equinoctal occultations. Despite the low Isp (400 sec), only 1 to 1-1/2 tons of propellant is needed annually due to the small duty cycle. Complete reliance on chemical propulsion would result in a propellant requirement of about 2100 tons per year. Thus electric propulsion is nearly mandatory for flight control at GEO.

4.0 MASS AND MASS BASIS

WBS		MASS ESTIMATE	RATIONALE	REFERENCE
1.1.4.1	Sensor Systems	(1,000 Kg)	Guess	None
1.1.4.2	Electric Propulsion	(178,811 Kg)	Sum	----
	Thrusters (112)	5,600 Kg	Scale from 30 cm thruster	NAS9-15196, Part I Vol. 5 P 175
	Propellant	50,00 Kg	Consumption + Reserve	NAS9-15636, Phase I Vol 3. P 708
	Propellant Tanks (8)	3,750 Kg	7-1/2% of propellant mass	None
	Propellant Feed (4)	1,000 Kg	2% of propellant mass	None
	Power Processors (12)	112,327 Kg	1.3 Kg/kw estimate	See WBS 1.1.2.3.4-.4
	Installation Hardware (4)	6,133 Kg	5% of above (-) propellants	None
1.1.4.3	Chemical Propulsion	(26,143 Kg)	Sum	----
	Thrusters (30)	102 Kg	Estimate	OTV Study
	Propellant	22,000 Kg	Consumption & Reserve	NAS9-15636, Phase I Vol 3., P 111
	Propellant Tanks (4) & Feed System	3,960 Kg	18% of propellant mass (pressure fed thrusters)	FSTSA Study
	Installation Hardware (4)	81 Kg	2% of tank+thrusters+feed	None
1.1.4.4	Structure and Installation Hardware	(6,156 Kg)	Sum	----
	Beams (4)	5,343 Kg	(4.11)(325)(4)	See WBS 1.1.1.1.1
	Cables (12)	8 Kg	(571 + 742 + 879) (.0031)	See WBS 1.1.6.1
	Installation & Assy (4)	255 Kg	5% of the above	None
	Gimbals (4)	550 Kg	Guess	None
	TOTAL	((212,110 Kg))	Sum	----

5.0 COST

5.1 COST SUMMARY

	COST, $ MILLIONS
o Research	—
o Engineering Verification	59
o Demonstration	494
o Investment	248
o Production	160

5.2 COST DETAILS

o Research —

- o Electric propulsion carried as part of space transp.

o Engineering Verification 59

DDT&E $51.5M
Flight hardware $7.5M

o Demonstration 494

DDT&E $414M
Flight hardware 80M

o Investment 248

Delta DDT&E 60% of that
for demonstration program

WBS 1.1.4 ATTITUDE CONTROL AND STATIONKEEPING (cont'd)

	COST $ MILLIONS
o Production	160
o Thrusters 160 x $10,000*	= $1.6 Millions
o Processors $3.57M Each x 12	= $42.84 MILLION
o Installation	= $25.0 MILLION
o TANKS	= $ 5.8 MILLION
o Control	= $12.6 MILLION
o Chemical Propulsion	= $12.0 MILLION
o Tank Insulation	= $10.0 MILLION
o Feed Systems	= $16.0 MILLION
o Computer	= $ 8.0 MILLION
o Power Distribution	= $ 8.0 MILLION
	$139.0 MILLION
	1.5 Inflation Factor
	$160.0 MILLION

*Low cost results from commonality with GOTV thrusters. They are the same except for acceleration voltage optics.

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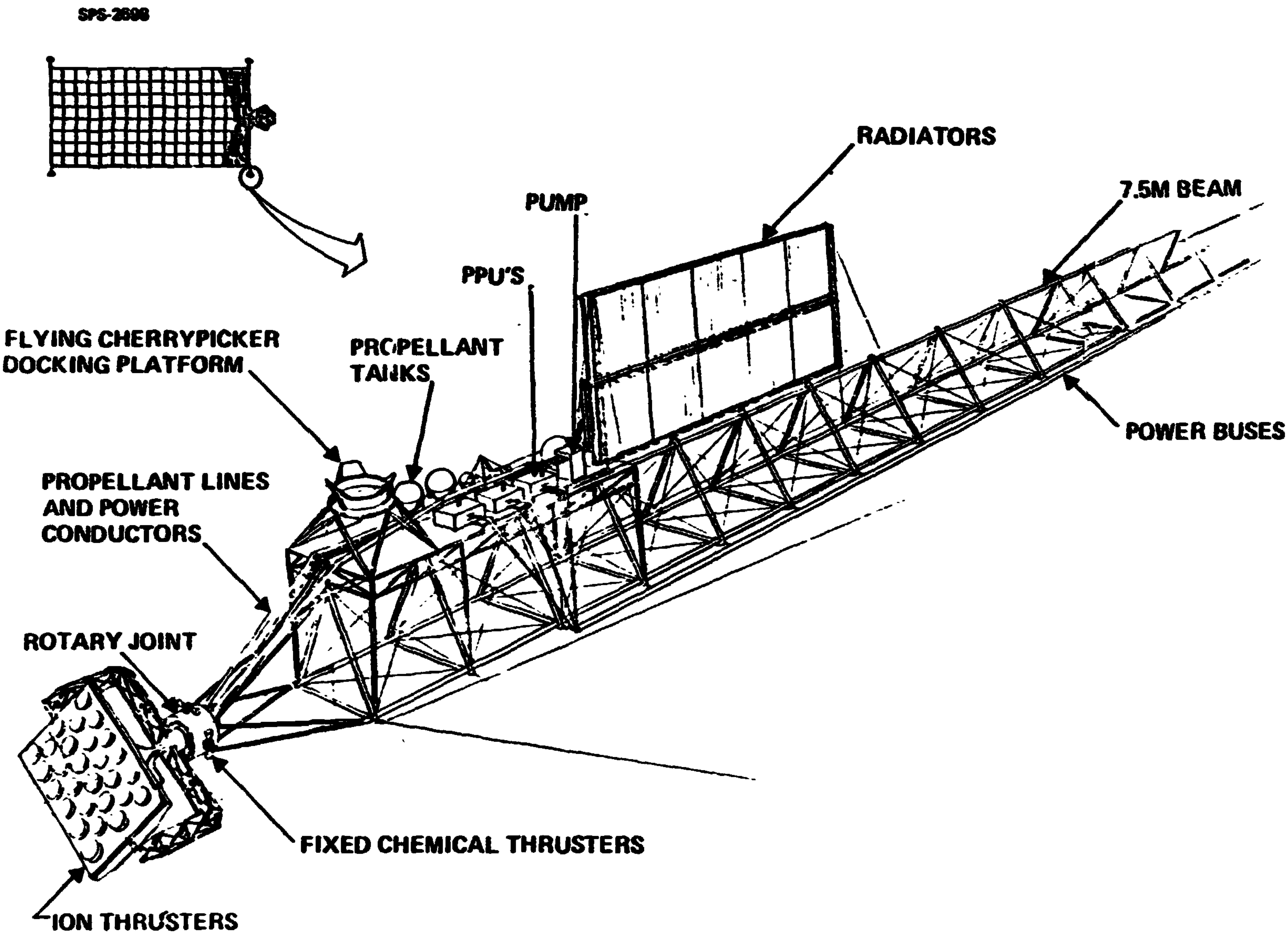


Figure A. SPS Attitude Control System

1.0 WBS DICTIONARY

This element includes the flying cherrypicker docking platform on the attitude control system.

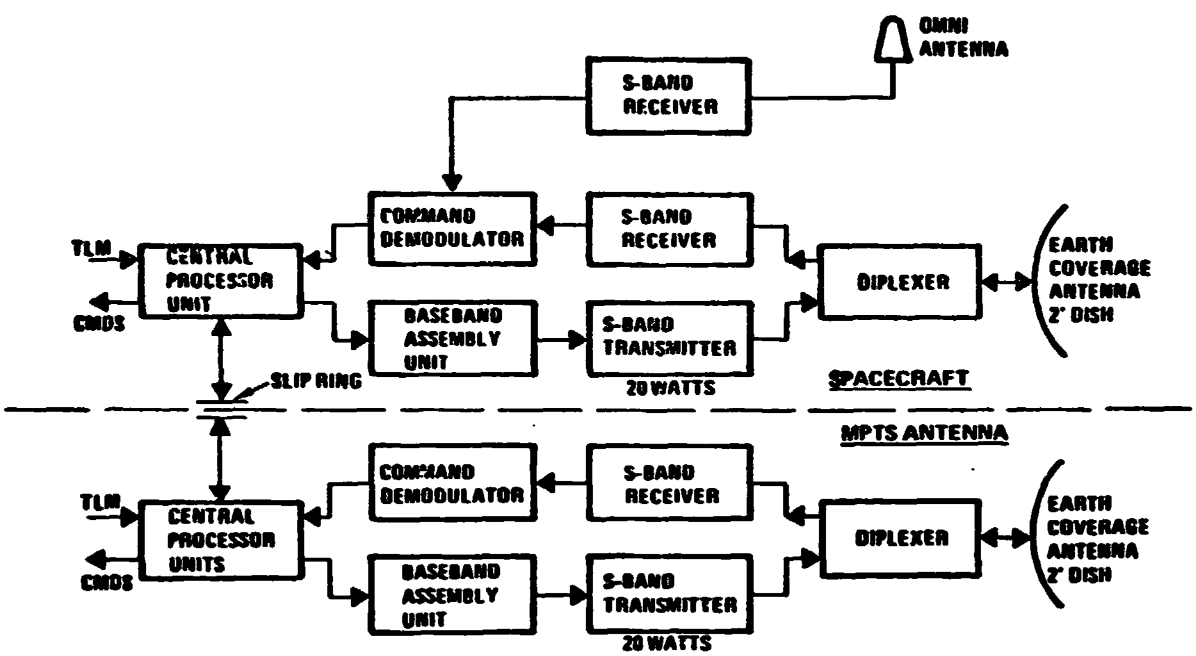
2.0 DESCRIPTION

The satellite attitude control system is a complex of electric and chemical thrusters, propellant tanks, power processors, and thermal control system components located on the tip of beams that extend outboard of the satellite body (see Figure A). To access these components, a flying cherrypicker docking platform is located amidst the complex as shown in the figure.

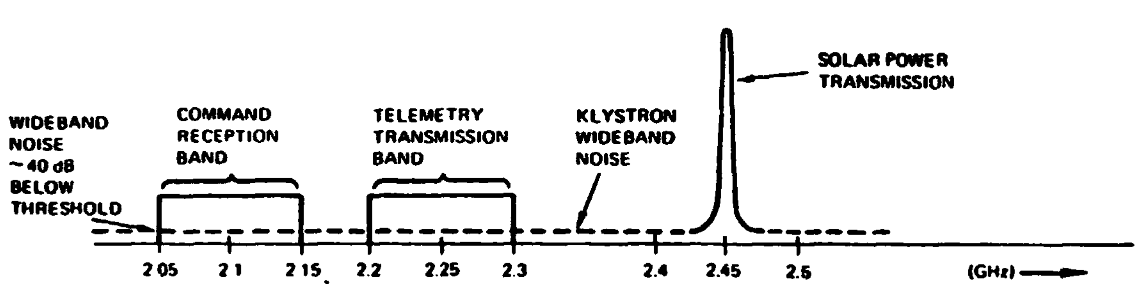
3.0 DESIGN BASIS

Refer to Section 13 of the Operations and Systems Synthesis document (D180-25461-3).

FOLDOUT FRAME



SPS Communication Subsystem



Communication Subsystem Frequency Plan

FOLDOUT FRAME

1.0 WBS DICTIONARY

This element includes the hardware to transmit and receive intelligence among the various SPS elements. This includes communication of both data and voice between the SPS and the control center as well as among the various cargo and personnel vehicles. Excluded is intravehicular and intrasatellite communications.

2.0 DESCRIPTION

The communication system configuration consists of a spacecraft system and an MPTS antenna system which have a limited data link by the data bus through the slip rings. The IMC system is such that approximately one megabit/sec. rate is required for both the command uplink and the telemetry downlink. Both subsystems have a two foot parabolic antenna each providing an earth coverage gain of 18 dB at S-band. An omni-antenna is located on the spacecraft to provide for command reception in the event of a major error in spacecraft attitude control. The configuration with a 20 watt transmitter will transmit up to 20 Mbps and receive up to 10 Mbps.

With the proposed frequency plan, uplink command information will be received by the satellite in the 2.050 to 2.150 GHz band. Telemetry data will be transmitted in the 2.200 to 2.300 GHz band.

3.0 DESIGN BASIS

The design of the communication subsystem must take into consideration not only normal but also contingency operations. In developing the recommended system two of the first alternatives considered were use of the uplink pilot signal from the rectenna for transmittal of commands and modulation of one of the MPTS antenna klystrons for transmission of telemetry. Both of these techniques have the disadvantage that the MPTS antenna beam is deliberately despoiled in the event of loss of attitude control, thus severely degrading the communication link at a critical period of operation.

A concern in the frequency plan is that of noise transmitted from the MPTS power transmission klystrons falling within the 2.050 to 2.150 GHz reception band. A typical klystron transmits AM and FM noise in the vicinity of the RF carrier. At about one megahertz from the carrier, the noise characteristic is relatively constant at a value of 130 dB/KHz below the carrier component. Beyond the klystron's passband (typically 10 MHz) the noise characteristic is further attenuated by the rolloff characteristic of the klystron cavities. For a six cavity klystron, approximately 400 MHz away from the carrier (at the uplink command reception band), the rolloff characteristic of the klystron is approximately 220 dB (six octaves). The output noise from the 100,000,70 KW klystrons at the edge of the klystron passband is 10 dBW, while within the command reception band it is 220 dB below this value or -210 dB (-180 dBM). A typical phase-lock loop command receiver has a sensitivity or threshold of -140 dBM. Under the above assumptions, then, the wideband klystron noise is approximately 40 dB below the command receiver threshold. Had this not been the case, some other frequency band, such as the 11.0 to 14.0 GHz band could have been selected. Higher frequencies may be desirable to minimize band crowding and interference in the SPS time frame.

4.0 MASS AND MASS BASIS

ITEM	MASS ESTIMATE	RATIONALE	REFERENCE
Receivers (6)	24 Kg	Scaled Estimate	IUS Avionics Receiver Mass
Transmitters (4)	47 Kg	Scaled Estimate	IUS Avionics Transmitter Mass
OMNI Antenna (2)	3 Kg	Scaled Estimate	IUS Antenna
Dish Antenna (4)	9 Kg	Scaled Estimate	Lunar Rover Dish Antenna
Diplexer (4)	7 Kg	Estimate	IUS Diplexer
Command (4)	15 Kg	Scaled Estiamte	IUS Command Decoder
Demodulator			
Baseband (4) Assembly Unit	45 Kg	Estimate	Guess
Cabling	30 Kg	Guess	None
Installation & Assembly (10%)	18 Kg	Guess	None
Total	180 Kg	Sum	-

5.0 COST

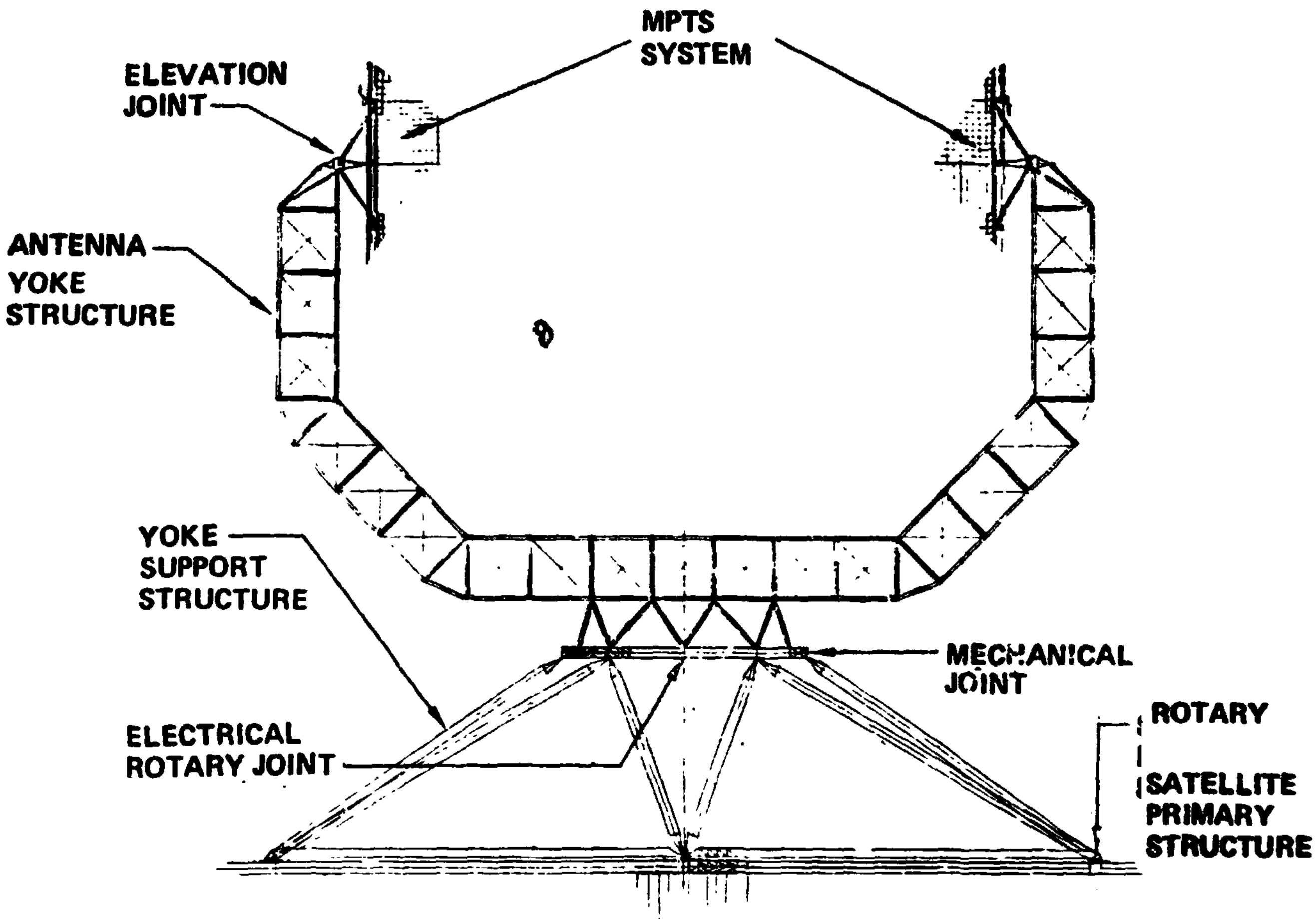
5.1 COST SUMMARY

	COST, $ MILLIONS
o Research	--
o Engineering Evaluation	18
o Demonstration	27.6
o Investment	12
o Production	8

5.2 COST DETAILS

o RESEARCH	--
o None	
o ENGINEERING EVALUATION	18
o Modify existing system @ $10M o Add $8M for flight article	
o DEMONSTRATION	27.6
o Use 100% of DDT&E @ $19.6M o Add 1 unit cost @ $8M	
o INVESTMENT	12
o Use delta DDT&E of $12M	
o PRODUCTION	8
o From PCM	

SPS-3066



/ -T FRAME

WBS 1.1.6 INTERFACE (ENERGY CONVERSION/ /POWER TRANSMISSION)

1.0 WBS DICTIONARY

This element provides the movable interface between the energy conversion subsystem and the power transmission subsystem. A 360° rotary joint and an antenna elevation mechanism are required to maintain proper alignment of the transmitter with the ground receiving station. Included are structure, mechanisms, power distribution, thermal control, and maintenance hardware.

2.0 DESCRIPTION

The interface element is composed of the yoke support structure, which provides for translation from the modular energy conversion structure to the support structure for the circular mechanical drive ring and the electrical slipring assembly, the yoke structure, the mechanical turntable, the electrical rotary joint, and the antenna elevation joint. All structural members used in the yoke support structure are 12.7M beams. The antenna yoke structure is a 135M truss constructed using 7.5M beams with Kevlar tension cables. The mechanical rotary joint is a 350 meter diameter drive ring with twelve roller drive assemblies and 36 idler assemblies. The electrical slip-ring assembly is 16 meters in diameter and contains twenty slip-rings.

3.0 DESIGN BASIS

The MPTS antenna-to-satellite interface requires 360° rotation about the spacecraft central axis with limited motion for elevation steering while maintaining structural and electrical integrity between the satellite and the antenna. The concept was selected based on the ability to meet its intended function, constructability within the height constraints of the construction base. maintaining a clear area for access to the rear surface of the antenna for maintenance purposes, and placement of the mechanisms in a more benign thermal environment than located directly behind the antenna.

4.0 MASS AND MASS BASIS

ITEM	MASS ESTIMATE	RATIONALE	REFERENCE
Structures	175.4 MT	See WBS 1.1.6.1	See WBS 1.1.6.1
Mechanisms	38.4 MT	See WBS 1.1.6.2	See WBS 1.1.6.2
Power Distribution	21.8 MT	See WBS 1.1.6.3	See WBS 1.1.6.3
Total	235.6 MT	Sum	

5.0 COST

5.1 COST SUMMARY

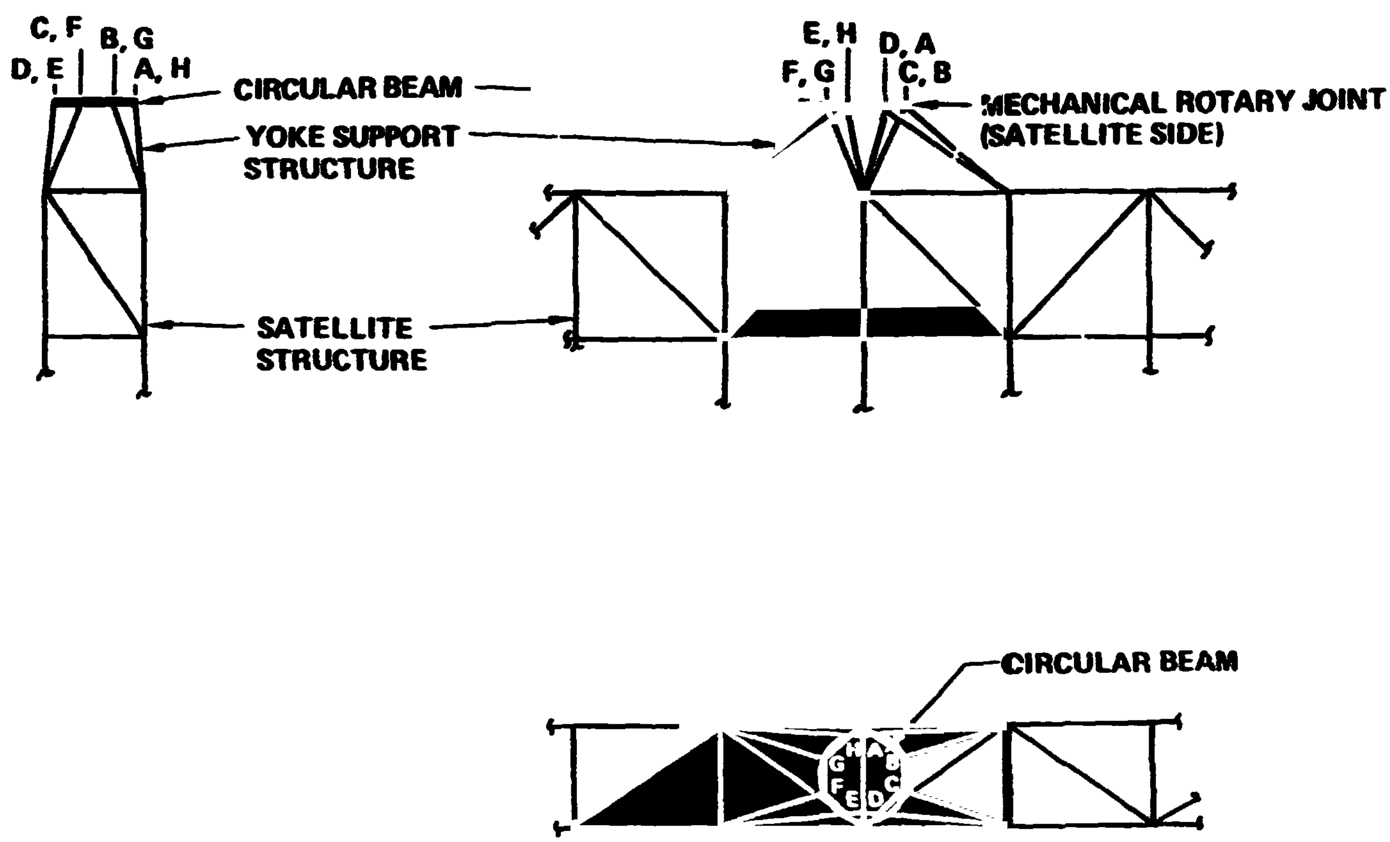
	COST, $ MILLIONS
o Research	--
o Engineering Evaluation	20
o Demonstration	310
o Investment	419
o Production	101.6

5.2 COST DETAILS

- RESEARCH — --
- ENGINEERING EVALUATION — 20
    - Interface for EVTA will have no commonality (except technology) with full size SPS
    - By scaling, DDT&E, and unit for EVTA, est. $20M
- DEMONSTRATION — 310
    - Yoke 80%, TTD - 50%, Ring - 20%
    - By scaling, DDT&E = $260M
    - Unit = $50M
- INVESTMENT — 419
    - Delta DDT&E = $419M (20% off for commonality with demonstrators)
- PRODUCTION — 101.6

Structure Feedstock is $76/kg x 175^000^KG	= $13.3M
Double for fittings and connectors	= $26.6M
TTD	= $46M (cost model output)
Rotary Joint	= $20M (cost model output)
Add	$9M for assy & c/o of TTD & R/J
Total (1 sps)	= $101.6M

SPS-1944



PTS. A, B, C, D, E, F, G, H ARE THE MECHANICAL ROTARY JOINT CIRCULAR BEAM ATTACHMENT POINTS.

FOLDOUT FRAME

WBS 1.1.6.1 STRUCTURES

1.0 DICTIONARY

This element includes all members necessary to provide a mechanical interface between the primary structures of the energy conversion subsystem and the power transmission subsystem. It includes beams, beam couplers, cables, tensioning devices, and secondary structures. Excluded are elements of the drive assembly which are included in mechanisms (WBS No. 1.1.6.2).

2.0 DESCRIPTION

The structural members used between the energy conversion structure and the mechanical rotary joint and the octagonal structure which supports the mechanical and electrical rotary joint are 12.7 meter beams. All beams used in the yoke structure are 7.5 meter beams. Tension cables used in the yoke structure are Kevlar and are 6.3 millimeters in diameter.

3.0 DESIGN BASIS

The energy conversion/power transmission interface requires 360° rotation about the spacecraft central axis with limited motion for elevation steering while maintaining structural integrity. The mechanical interface which provides for the 360° rotation is a 350 meter diameter turntable. When the antenna is operated at the maximum elevation angle of 7° the interface unit must provide sufficient standoff such that the microwave power beam from the antenna is not blocked by any portion of the energy conversion system. Material selection is discussed in WBS 1.1.1.1.

FOLDOUT FRAME

4.0 MASS AND MASS BASIS

Lengths

12.7 Meter Beams.

Yoke Support structure - Beam Length.
2 (4) (363.8) + 4 (639.7) + 4 (701.1) + 687.1 = 8,192.6 Meters.
Ring Support Structure - Beam Length
2 (8) (134) + (2) (350) = 3,544 Meters
Total Length = 11,736.6 Meters @ 7.48 Kg/Meter

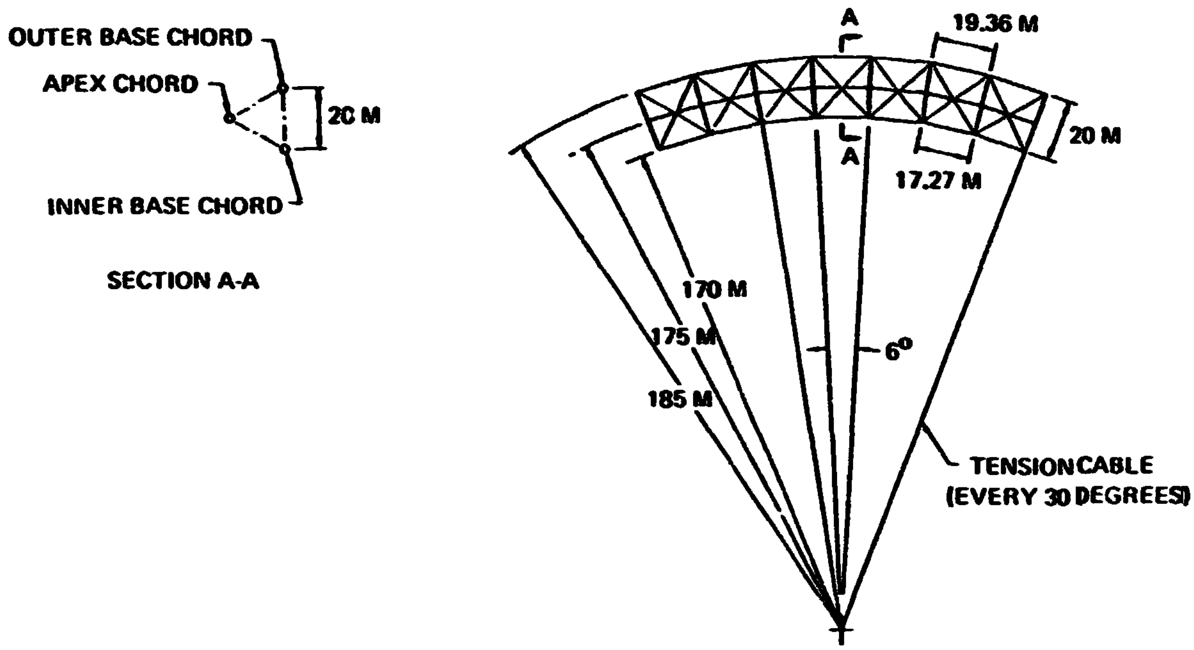
7.5 Meter Beams.

Yoke to Ring structure - Beam Length
(8) (210) + 4 (180) + 2 (60) + 2 (112.5) = 2.745 Meters
Yoke Structure - Beam Length
Longitudinals
(19) (3) (135) + (2) (67.5) = 7830
End Transition Beams
2 (2) (90) + 135 = 630
Battens
(24) (3) (140) = 10,080

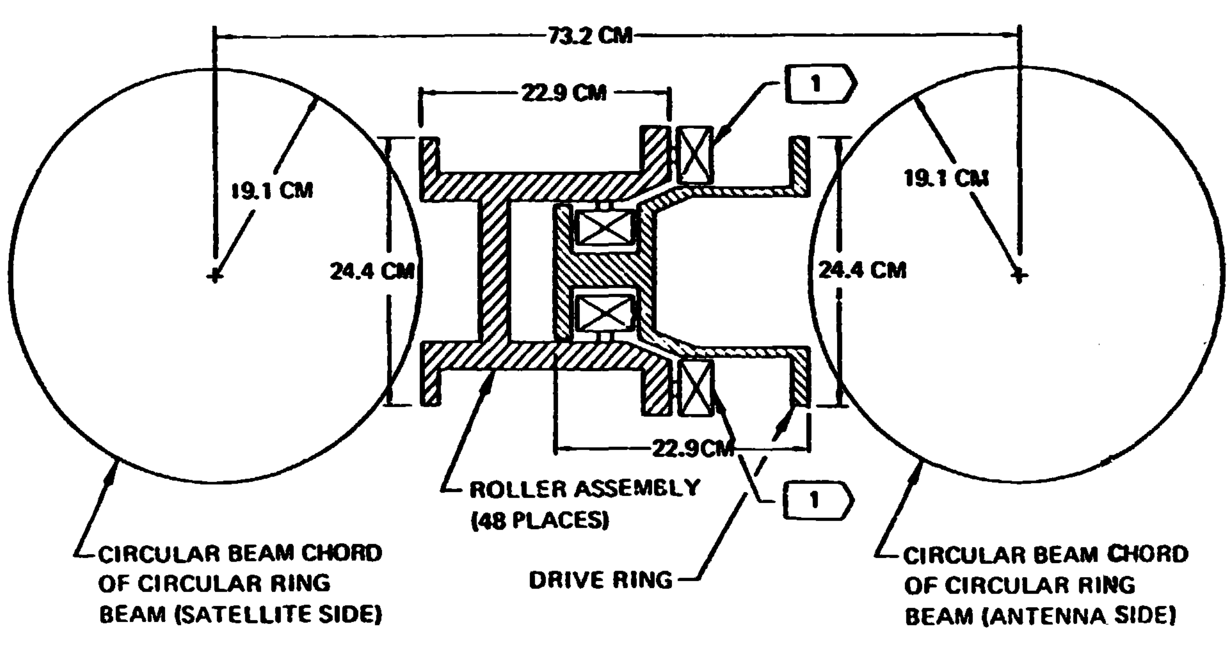
Total Length = 21,285 @ 4.11 Kg/Meter

2 FOLDOUT FRAME

FOLDOUT FRAME



Circular Ring Beam Geometry



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

Drive Ring and Roller Assembly Location Relative Base Chords of Circular Ring Beams

WBS 1.1.6.2 MECHANISMS

1.0 WBS DICTIONARY

FOLDOUT FRAME

This element includes the components required to rotate and elevate the power transmission subsystem. Included are the drive ring, bearings, gear drives, and drive motors.

2.0 DESCRIPTION

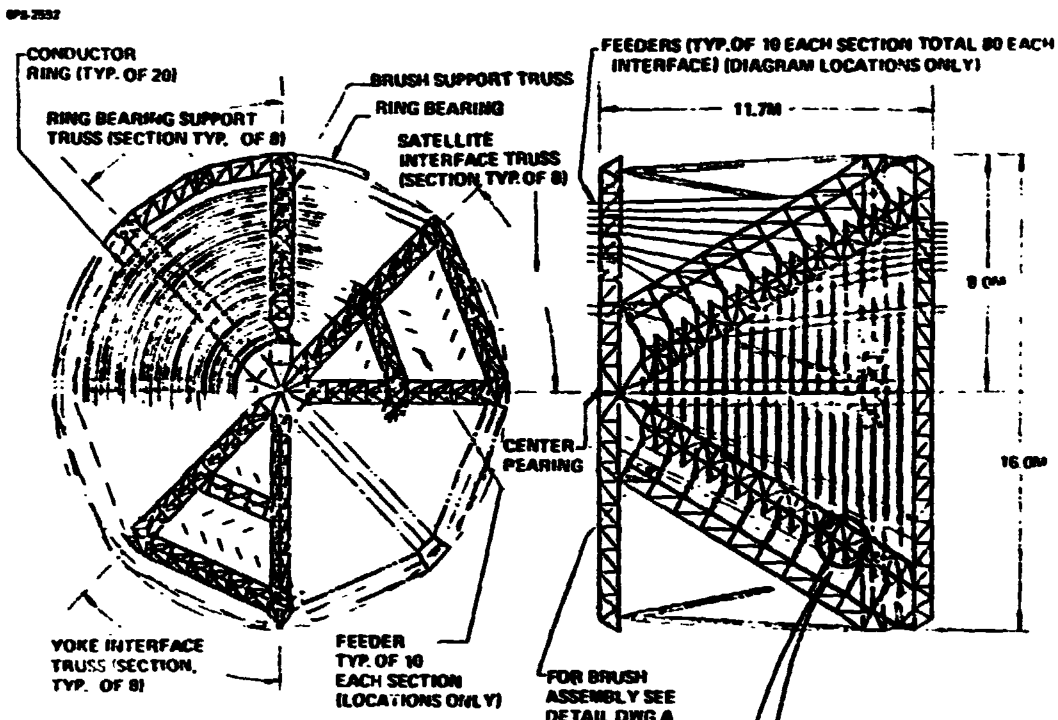
The mechanical drive ring provides 360° rotation between the energy conversion and the power transmission portion of the SPS. The mechanical rotary joint is composed of two segmented circular beams (one on the satellite side and one on the yoke side). Each circular beam is supported at eight points, every 45 degrees, to its adjacent support structure. The inner and outer base chords of each circular beam are arranged adjacent to each other. Between each set of base chords, a drive ring and roller assembly is attached to provide relative movement between the satellite and MPTS system. The antenna yoke attaches to its circular beam in a similar method as described for the yoke support structure. Elevation control is provided at each of the two yoke to antenna gimbal attachment points.

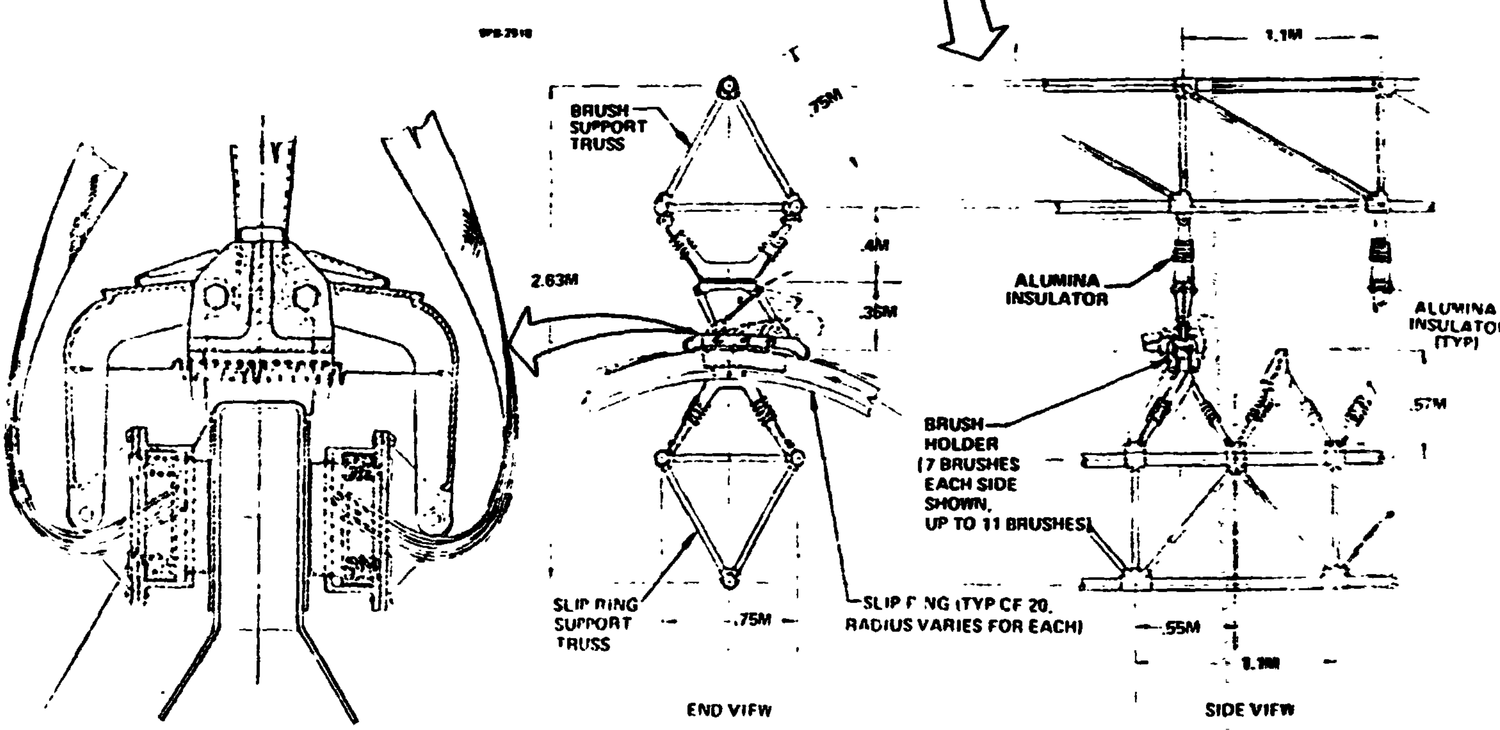
3.0 DESIGN BASIS

The mechanical rotary joint concept was developed to be compatible with the yoke concept selected for the energy conversion/power transmission interface. The size was selected in part to provide sufficient room for access to the electrical slipring assembly for maintenance and for routing of the aluminum sheet power busses to the slipring assembly. The materials for the drive ring were selected for strength and the required life.

4.0 MASS AND MASS BASIS

ELEMENT	MASS ESTIMATE	RATIONALE	REFERENCE
Circular Ring Beams (2)	9,640 kg	Detailed Estimate	
Drive Ring	18,380 kg	Detailed Estimate	NAS9-15196, Part
Roller Assemblies (48)	670 kg	Detailed Estimate	II, Vol. VI, D180-22876-6,
Roller/Drive Assemblies (12)	950 kg	Detailed Estimate	pp. 23-28
Support Fittings (120)	600 kg	Detailed Estimate	
Assembly and Installation Hardware	160 kg	Guess	None
Contingency (10%)	3,000 kg	Guess	None
Elevation Joint	5,000 kg	Guess	None
Total	38,40 kg	Sum	--


CONDUCTOR RING (TYP. OF 20)
BRUSH SUPPORT TRUSS
RING BEARING
RING BEARING SUPPORT TRUSS (SECTION TYP. OF 8)
SATELLITE INTERFACE TRUSS (SECTION TYP. OF 8)
FEEDERS (TYP. OF 10 EACH SECTION TOTAL 80 EACH INTERFACE) (DIAGRAM LOCATIONS ONLY)
11.7M
16.0M
CENTER BEARING
YOKE INTERFACE TRUSS (SECTION, TYP. OF 8)
FEEDER TYP. OF 10 EACH SECTION (LOCATIONS ONLY)
FOR BRUSH ASSEMBLY SEE DETAIL DWG A


BRUSH SUPPORT TRUSS
.75M
.4M
.35M
2.63M
SLIP RING SUPPORT TRUSS
.75M
SLIP RING (TYP OF 20, RADIUS VARIES FOR EACH)
END VIEW
1.1M
ALUMINA INSULATOR
ALUMINA INSULATOR (TYP)
.57M
BRUSH HOLDER (7 BRUSHES EACH SIDE SHOWN, UP TO 11 BRUSHES)
.55M
SIDE VIEW

1.0 WBS DICTIONARY

This element provides for the transfer of electrical power through the interface. It includes slip rings, brush assemblies, feeders and insulation. It excludes main power busses.

2.0 DESCRIPTION

The selection of the multiple bus system for SPS power distribution requires that a mulitple slip-ring electrical rotary joint to transfer power between the power generation and power transmission portion of the SPS. Twenty slip-rings accomplish power transfer for the 10 pairs of power busses. Coin silver (90% silver and 10% copper) was selected for the slip-ring material and a silvermolybdenum disulfide brush with 3% graphite was selected. The characteristics of this combination yield low brush/slip-ring voltage drops. With a design using a brush current density of 20 amps/cm^2 only about 40 kW of power is dissipated in the rotary joint. Brush assemblies are designed for symmetrical loading of the sipping due to brush pre-load. Insulators for brush assemblies, slip-rings, and feeders are alumina.

3.0 DESIGN BASIS

The concept was developd based on the following requirements:

1. Twenty separate slip-ring assemblies.
2. Normal slip-ring current capabilities.
3. Maximum brush current density of 20 amperes per square centimeter.
4. Brush feeder current density of 400 amperes per square centimeter.
5. Brush pressure of 25.9 Kpa (4 psi).
6. Coin silver slip-ring (90% silver and 10% copper).
7. Silver-molybdenum disulfide-graphite (85% Ag, 12% MOS_2, and 3% Graphite) brushes.
8. Maximum outside diameter of 16 meters (fits inside HLLV payload bay).
9. Earth assembled.
10. Minimum spacing between different conductor systems of 0.7 meters.
11. Positive retraction of the brush assembly from the slip-ring contact surface.
12. All feeder conductors to have maximum surface exposure to free space for thermal dissipation purposes.

4.0 MASS AND MASS BASIS

Item	Mass Estimate	Rationale	Reference
Slip-rings (20)	11,810kg	Detailed Estimate	NAS 9-15196, Part II
Brushes (832)	540kg	Detailed Estimate	Vol VI, D180-22876-6,
Brush Wire	270kg	Detailed Estimate	PP 45-50 except for
Brush Holder (80)	2,160kg	Detailed Estimate	Brush holders used
Feeders	3,840kg	Detailed Estimate	27kg/Holder Ref. p 48.
Structure	1,862kg	(10% of Above)	None
Assembly and Installation	372kg	(2% of Above	None
Contingency	931	(5% of Above)	None
Total	21,785kg	Sum	

FOLDOUT FRAME

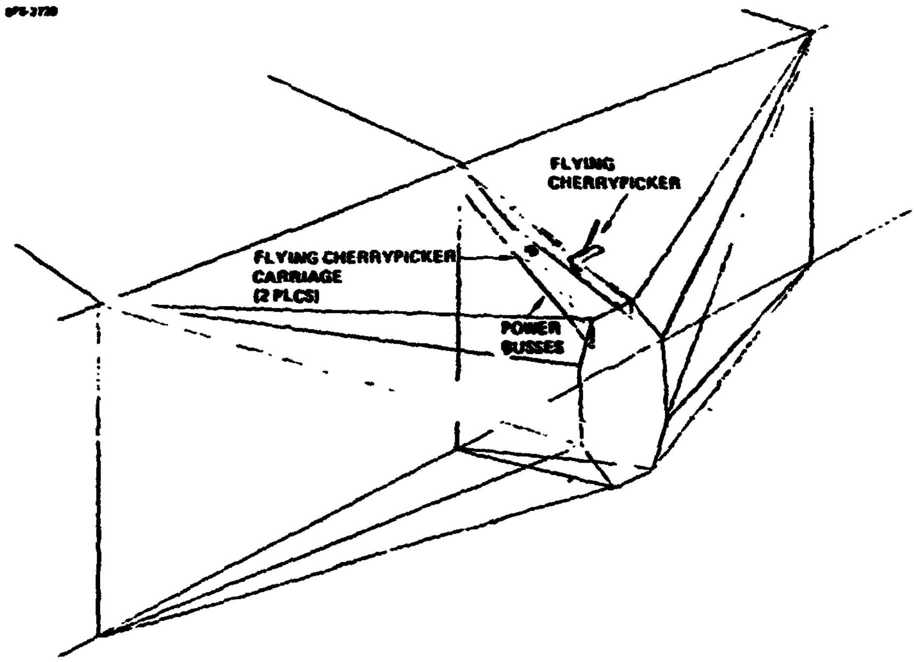


Figure Interface Structure Maintenance Access System

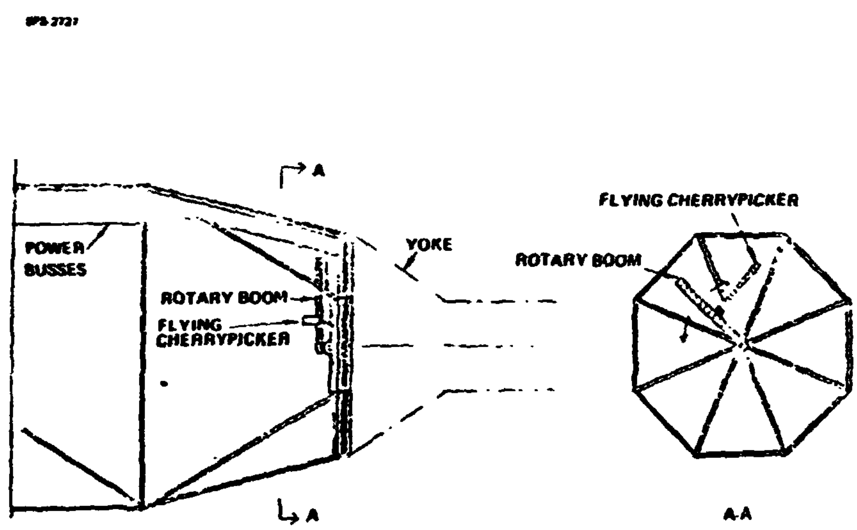


Figure Mechanical Rotary Joint and Slip Ring Assembly Maintenance Access System

1.0 WBS DICTIONARY

This element includes the interface structure main power bus, mechanical rotary joint/slipring assembly, and yoke maintenance access provisions.

2.0 DESCRIPTION

Interface Structure Main Bus Access

The main power divides into two sets at the end of the power collection module mid-line. These two power bus sets are suspended from beams which run down to the structure surrounding the mechanical rotary joint. Access to these stacks of power busses is provided by putting tracks on the upper beams and mounting a flying cherrypicker carriage on each track (see Figure A). Dedica[illegible] ...nance cherrypickers are not warranted.

Mechanical Rotary Joint and Slipring Assembly Access

After examining several alternative access concepts, the concept that was chosen was one that employs a built-in rotating boom and flying cherrypicker (see Figure B). This configuration provides the capability for accessing all of the power busses, mechanical rotary joint components, and slipring components on both the interface structure and on the yoke. Again, a dedicated maintenance cherrypicker is not warranted due to the low failure rates of these components.

Yoke Access

The power busses and elevation joint assembly components will be accessed by a flying cherrypicker that mates with a carriage mounted on built-in tracks on the yoke (see Figure C).

3.0 DESIGN BASIS

See Section 13 of the Operations and Systems Synthesis document (D180-25461-3).

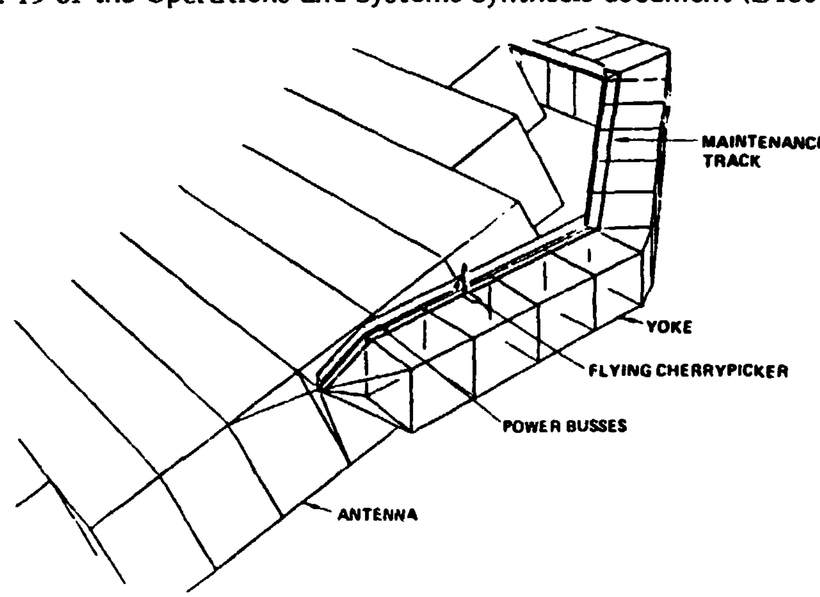
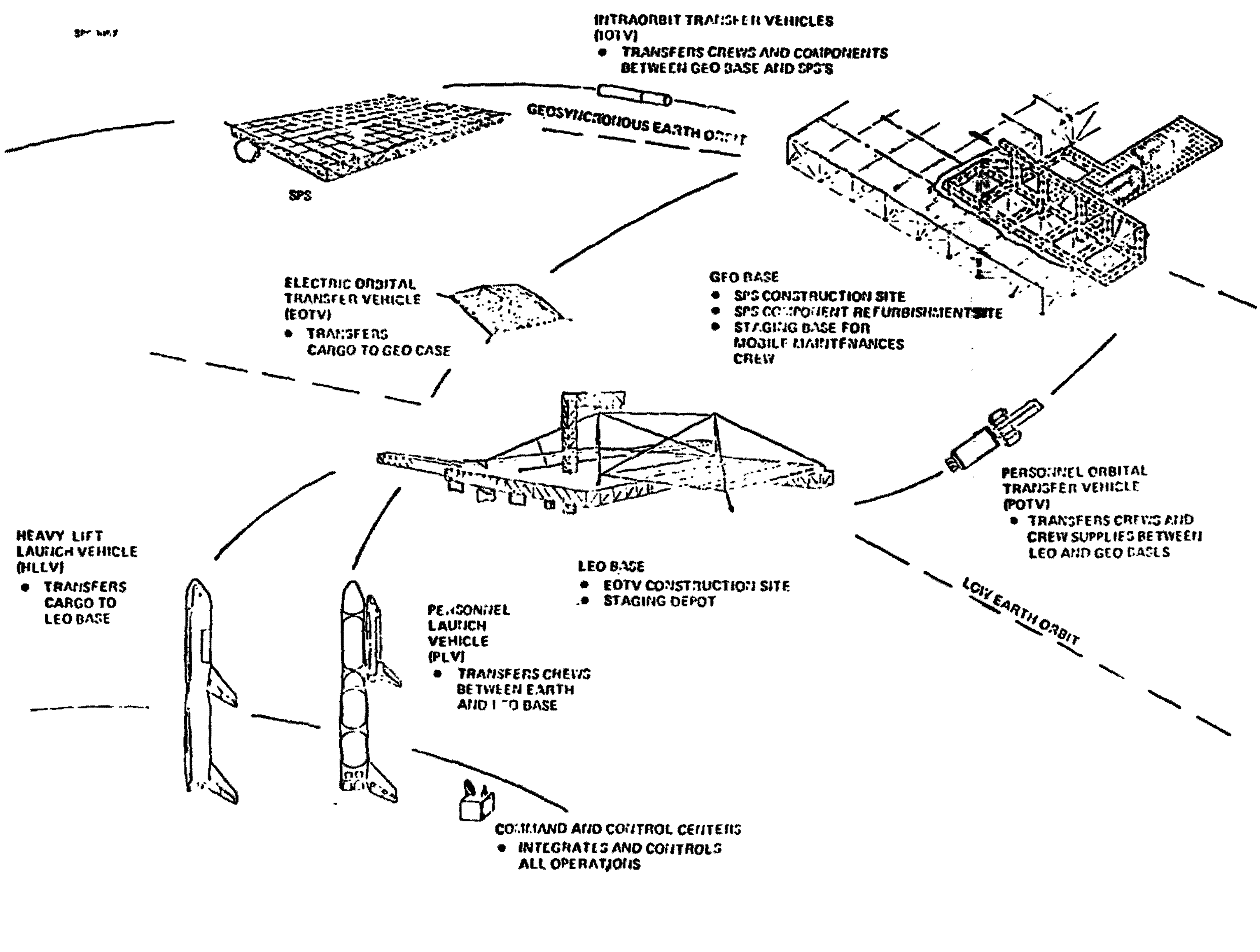


Figure Yoke Maintenance Access System


INTRAORBIT TRANSFER VEHICLES
(IOTV)
• TRANSFERS CREWS AND COMPONENTS BETWEEN GEO BASE AND SPS'S
GEOSYNCHRONOUS EARTH ORBIT
SPS
ELECTRIC ORBITAL TRANSFER VEHICLE (EOTV)
• TRANSFERS CARGO TO GEO BASE
GEO BASE
• SPS CONSTRUCTION SITE
• SPS COMPONENT REFURBISHMENT SITE
• STAGING BASE FOR MOBILE MAINTENANCES CREW
PERSONNEL ORBITAL TRANSFER VEHICLE (POTV)
• TRANSFERS CREWS AND CREW SUPPLIES BETWEEN LEO AND GEO BASES
HEAVY LIFT LAUNCH VEHICLE (HLLV)
• TRANSFERS CARGO TO LEO BASE
LEO BASE
• EOTV CONSTRUCTION SITE
• STAGING DEPOT
LOW EARTH ORBIT
PERSONNEL LAUNCH VEHICLE (PLV)
• TRANSFERS CREWS BETWEEN EARTH AND LEO BASE
COMMAND AND CONTROL CENTERS
• INTEGRATES AND CONTROLS ALL OPERATIONS

1.0 WBS DICTIONARY

This element includes all hardware and activities required to assemble, checkout, operate, and maintain the satellite system. Included are space stations, construction facilities, support facilities and equipment, and manpower operations.

2.0 DESCRIPTION

The baseline construction concept entails constructing a 5 GW photovoltaic SPS at geosynchronous orbit (GEO) using electric orbital transfer vehicles (EOTV's) to haul cargo between a low Earth orbit (LEO) base and a GEO base.

Cargo is delivered to the LEO base by heavy lift launch vehicles (HLLV's). There would be eight HLLV flights every week. Seventy five crewmembers are transferred between Earth and the LEO base by the Personnel launch vehicle (PLV) fourteen times every 90 days.

The LEO base is used to construct the EOTV's and is also used as a staging depot for transferring cargo and crews to the vehicles which will deliver them to GEO. During the EOTV construction operations there would be about 200 people at the LEO base. During the on-going cargo handling phase there would be about 135 people.

Cargo is transferred between the LEO base and the GEO base in approximately 180 days using the EOTV's. Crews and crew supplies are transferred to the GEO base in approximately 6 hours using chemical (LO_2/LH_2) orbital transfer vehicles (OTV's).

The SPS's are constructed at GEO using a 4-bay-wide end builder construction base. The GEO construction base will construct one 5 GW SPS in approximately 6 months employing a crew of approximately 400 people.

The GEO base is also used as a place to refurbish failed SPS hardware and is the home base of maintenance crews and their mobile maintenance systems that travel to operational SPS's.

3.0 DESIGN BASIS

The baseline space construction and support system, is designed to provide the capability of constructing 2 of the 5 GW SPS's per year and 8 EOTV's per year. SPS construction at GEO was specified by NASA. EOTV construction at LEO was selected based on cost (see Sec. 1.3.2 in Boeing document D180-25037-2).

4.0/5.0 MASS AND COST

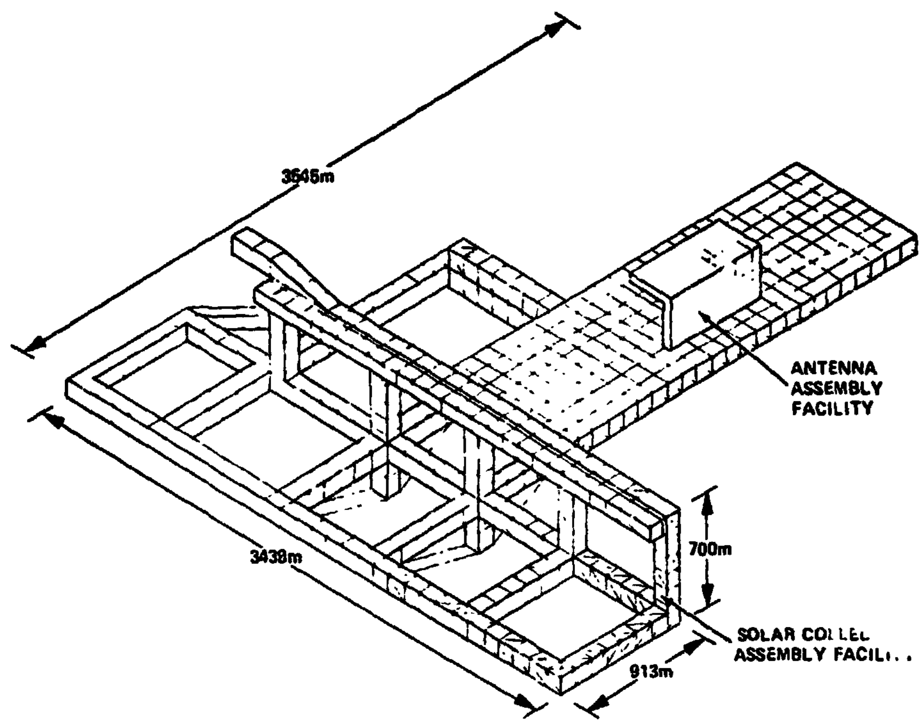
Refer to Table A for mass and cost summary. See the subelement descriptions for mass and cost basis.

TABLE A

WBS 1.2 SPACE CONSTRUCTION AND SUPPORT
COMPREHENSIVE MASS & COST SUMMARY

WBS	Element	Mass, MT	DDT&E Cost $ Millions	Unit Cost $Millions
1.2.1	GEO Base	6656.5	3816	9008.2
1.?.2	LEO Base	1832.4	5005.1	3419.5
	Totals	8488.9 MT	$8821 M	$12,427.7 M
1.2.3	Mobile Maint. System	522 MT	TBD	426.6M
Annual				
1.2.1	GEO Base	1125 MT/Yr		$1,297 M/Yr
1.2.2	LEO Base	533.5 MT/Yr		625.2 M/Yr
	Totals	1658.5 MT/Yr		$1,[illegible].2 M/Yr
1.2.3	Mobile Maint. Sys.	103.8 MT/Yr		$118.5 M/Yr

4 BAY END BUILDER CONSTRUCTION BASE



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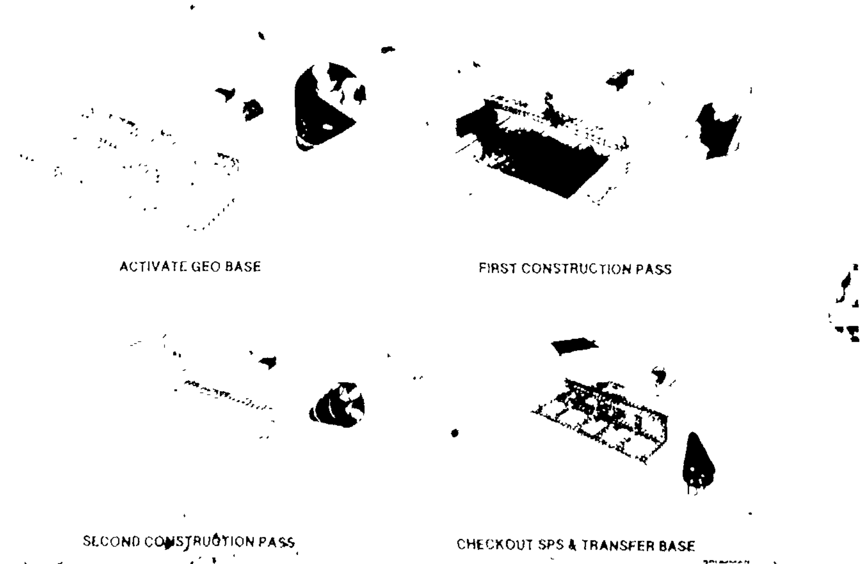
A

SPS — 4 BAY END BUILDER CONSTRUCTION



FOLDOUT FRAME

1.0 WBS DICTIONARY

This element includes the facilities, equipment, and operations required to assemble and check out the satellite system. Included are fabrication and assembly facilities, cargo depots, and operations.

2.0 DESCRIPTION

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

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

The GEO base is also the location of SPS component refurbishment facilities and is a staging base for mobile maintenance crews and transport vehicles.

3.0 ELEMENT DESIGN BASIS

The GEO construction base is designed to construct 5 GW SPS's at a rate of 2 satellites per year. The 4-bay end builder construction base concept was selected from several options (see trade study in Boeing document D180-25037-2, Section 1.2) because of its production rate growth capability.

4.0/5.0 MASS AND COST

Refer to Table A for mass and cost summary. See subelement descriptions for mass and cost basis.

WBS 1.2.1 GEO BASE COMPREHENSIVE MASS AND COST SUMMARY

TABLE A

WBS No.	Element	Mass, Tons	DDT&E Cost $M79	Unit Cost $M79
1.2.1	GEO Base	6656.5	3816	9008.2
1.2.1.1	Work Support Fac.	5028**	999	3574**
1.2.1.1.1	Structure	2927	107	337
1.2.1.1.2	Construction Equipm't	460	396	1800
1.2.1.1.3	Cargo Handling & Distrib. System	399	207	430
1.2.1.1.4	Subass'y Factories	38	54	323
1.2.1.1.5	Test & Checkout Facil.	20	25	170
1.2.1.1.6	Transportation Vehicle Maint. Facilities	3	No unique equipment	9.5
1.2.1.1.7	SPS Maintenance Support Facil.	63.5*	148	243*
1.2.1.1.8	Base Subsystems	938	60	322
1.2.1.1.9	Base Facilities & Equipmt. Maint.	242 (5%)	No unique	182 (5%)
1.2.1.1.10	Command & Control Sys. (antennas only)	1	2	1
1.2.1.2	Crew Support Facil.	1628.5	681	2554
1.2.1.2.1	Crew Quarters Modules	1215.5	227	1923
1.2.1.2.2	Work Modules	413	454	631

(Cont'd)

* With 20 SPS in orbit

** Does not include 1.2.1.1.7

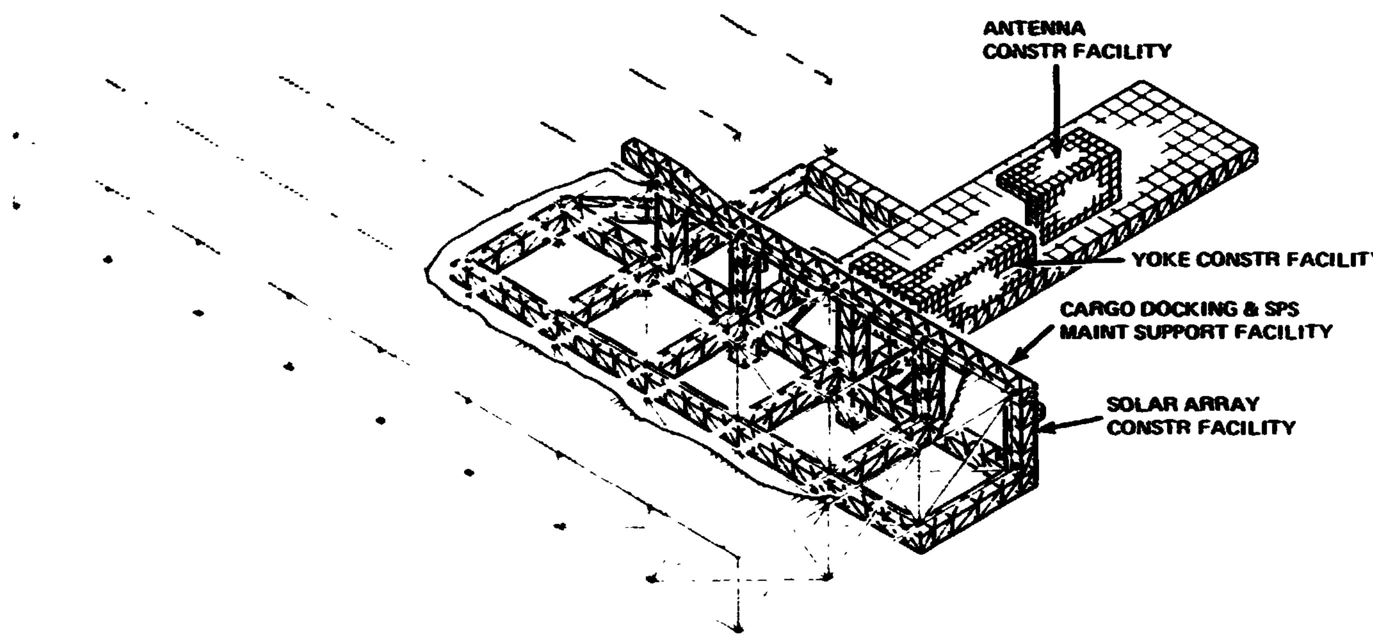
WBS 1.2.1 GEO BASE COMPREHENSIVE MASS AND COST SUMMARY (cont'd)

TABLE A

(Continued)

WBS No.	Element	Mass, Tons	DDT&E Cost $M79		Unit Cost $M79
	Wrap-Around Factors		2136		2880.2
	Spares		[1] 548	(15%)	919.2
	Instl., Assy, & C/O			(16%)	980.5
	SE&I		[1] 548	(7%)	429
	System Test (Delta Test)		378	(3%)	183.8
	GSE (added to LEO Base)		189	(4%)	245.1
	Software		[1] 330		-
	Logistics		[1] 99		-
	Liaison		[1] 44		-
	Project Management			(2%)	122.6
	Annual				
	. Resupply	1125 MT/Yr			$636.2 M/Yr
	. Salaries & Training				661
					$1297 M/Yr

[1] Apply 2.9 ($\frac{\text{GEO Base}}{\text{LEO Base}}$ Unit Cost Factor) to corresponding LEO Base DDT&E wrap-around cost.



1775-015W

4 BAY END BUILDER

1.0 WBS DICTIONARY

This element includes the facilities and equipment required for satellite assembly and check out. Included are beam fabricators, manipulators, assembly jigs, installation and deployment equipment, and cargo storage depots. Facilities for transportation vehicle maintenance and SPS maintenance support are also included. Excluded are the facilities related to crew support.

2.0 DESCRIPTION

The GEC base has contiguous facilities for concurrent assembly and subsequent mating of the satellite energy conversion system and its power transmission antenna. To implement these construction operations, the base structure serves as an assembly jig which also supports the construction equipment, cargo handling and distribution system, subassembly factories, test and checkout facilities, transportation vehicle maintenance and base subsystems. When SPS Power Transmission Operations begin, the GEO base will also support SPS maintenance facilities. Crew support facilities, which are included on the GEO base, are described in Section 1.2.1.2.

3.0 DESIGN BASIS

2 FOLDOUT FRAME

The major construction facilities of the GEO base are tailored to the structural cross section and support requirements for assembling their respective SPS systems. The energy conversion assembly facility is designed to provide a fully assembled 8x6 bay reference system after two 4-bay wide longitudinal construction passes. The power transmission assembly facility in turn, is arranged for progressive build-up of the microwave antenna, i.e. assembling one row at a time until the 11 row planform is fully constructed. See the Boeing/Grumman Phase I Systems Analysis & Tradeoffs (Doc D180-25037-2).

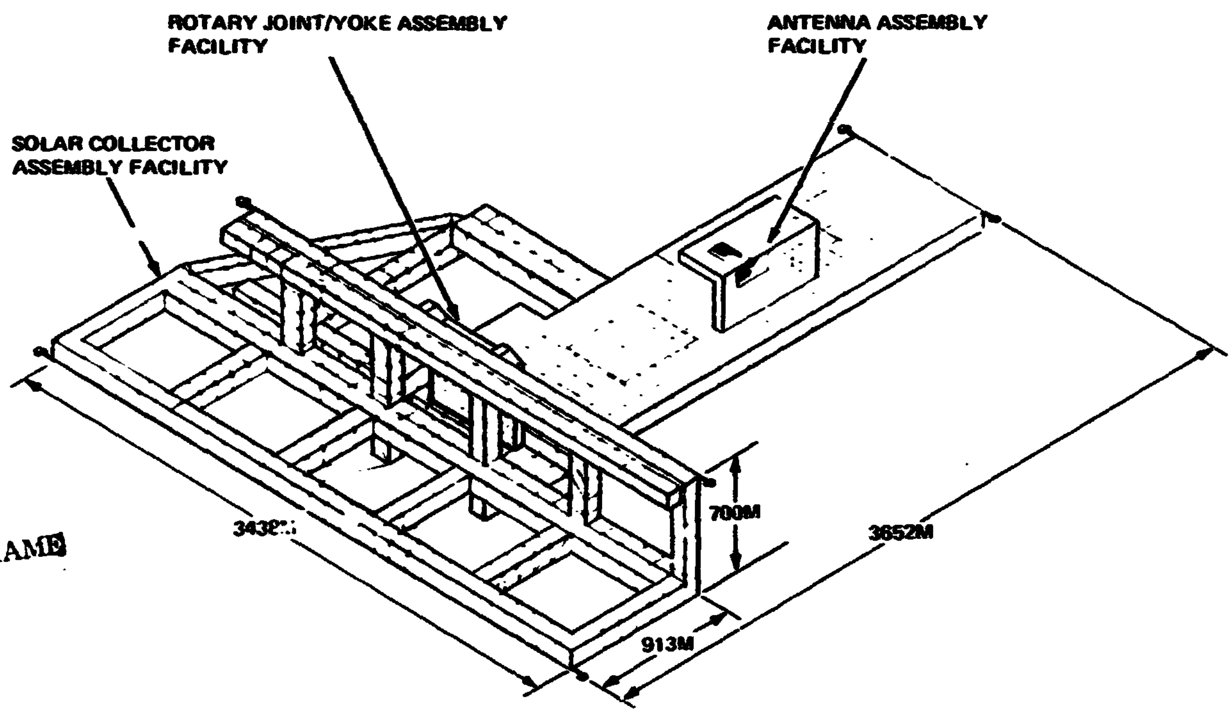
SUBELEMENT			MASS-MT	COST-$M	
				DEV	PROD
WBS	1.2.1.1.1	STRUCTURE	2927	107	337
	1.2.1.1.2	CONSTRUCTION EQUIPMENT	460	396	1800
	1.2.1.1.3	CARGO HANDLING/DISTRIBUTION SYSTEM	399	207	430
	1.2.1.1.4	SUBASSEMBLY FACTORIES	38	54	323
	1.2.1.1.5	TEST/CHECKOUT FACILITIES	20	25	170
	1.2.1.1.6	TRANSPORTATION VEHICLE MAINTENANCE	3	–	9.5
	1.2.1.1.7	SPS MAINTENANCE SUPPORT FACILITIES	63.5*	148	243*
	1.2.1.1.8	BASE SUBSYSTEMS	938	60	322
	1.2.1.1.9	BASE FACILITIES & EQUIPMENT MAINTENANCE	242	–	182
	1.2.1.1.10	COMMAND & CONTROL SYSTEMS	1	2	1
WBS	1.2.1.1	WORK SUPPORT FACILITIES	5028**	999	3574**

1775-001W

* With 20 SPS's IN ORBIT
** DOES NOT INCLUDE 1.2.1.1.7

4.0 MASS & COST BASIS

Refer to WBS 1.2.1.1.1, 1.2.1.1.2, 1.2.1.1.3, etc.



FOLDOUT FRAME

1775-01EW

1.0 WBS DICTIONARY

This element includes the primary and secondary structure of the GEO base.

2.0 DESCRIPTION

The GEO base structure supports the emerging satellite during all phases of construction. The SPS energy conversion system is assembled during two successive passes by the L-shaped framework shown above. The width of this framework (3.42 km) encompasses a 5-bay segment of the energy conversion structure to provide a one bay overlap for lateral and longitudinal indexing operations. The 700 m high open truss is sufficient to house beam fabrication stations, solar blanket installation equipment, bus installation mechanisms, crew facilities, docking, storage, intra-base transport, etc. The other leg of the facility (900 m long) guides and supports the satellite until all systems are mated and checked out. The antenna assembly platform, which is located at the rear of the base, is arranged to facilitate the construction and attachment of the antenna and rotary joint interface. This open truss platform (2.72 km x 1.65 km) also supports the antenna/yoke assembly during the lateral index and mating operations with the assembled 8 x 16 bay energy conversion system. The framework provided for the rotary joint facility, yoke assembly facility and antenna assembly facility is sufficient to house the construction equipment and machines as needed.

3.0 DESIGN BASIS

The primary structure of the GEO base is nominally assembled with a 100 m square framework which includes diagonal shear members on each face. The small assembly facilities, which are used to build the yoke and antenna, are assembled with a 50 m lattice. All structural members used in these frameworks are fabricated by automatic beam machines developed to build the operational SPS. It is assumed that both 7.5m and 12.7m triangular section, closed-chord composite beams are used. Ground fabricated fittings and deployable members are also expected to be used on the base structure.

2 FOLDOUT FRAME

4.0 MASS AND MASS BASIS

ITEM	MASS ESTIMATE	RATIONALE	REFERENCE
Solar Collector	1239×10^3Kg	ESTIMATE ▷1	D180-25037-3
Assy Facility		(247800m)	
Rotary Joint Facility	TBD		
Antenna Assy Platform	1200×10^3Kg	ESTIMATE ▷1 (240000m)	D180-25037-3
20% ALLOWANCE	488	UNDEFINED ITEMS	D180-25037-3
	2927×10^3Kg	▷1 ASSUMES 5Kg/m	

1775-002W

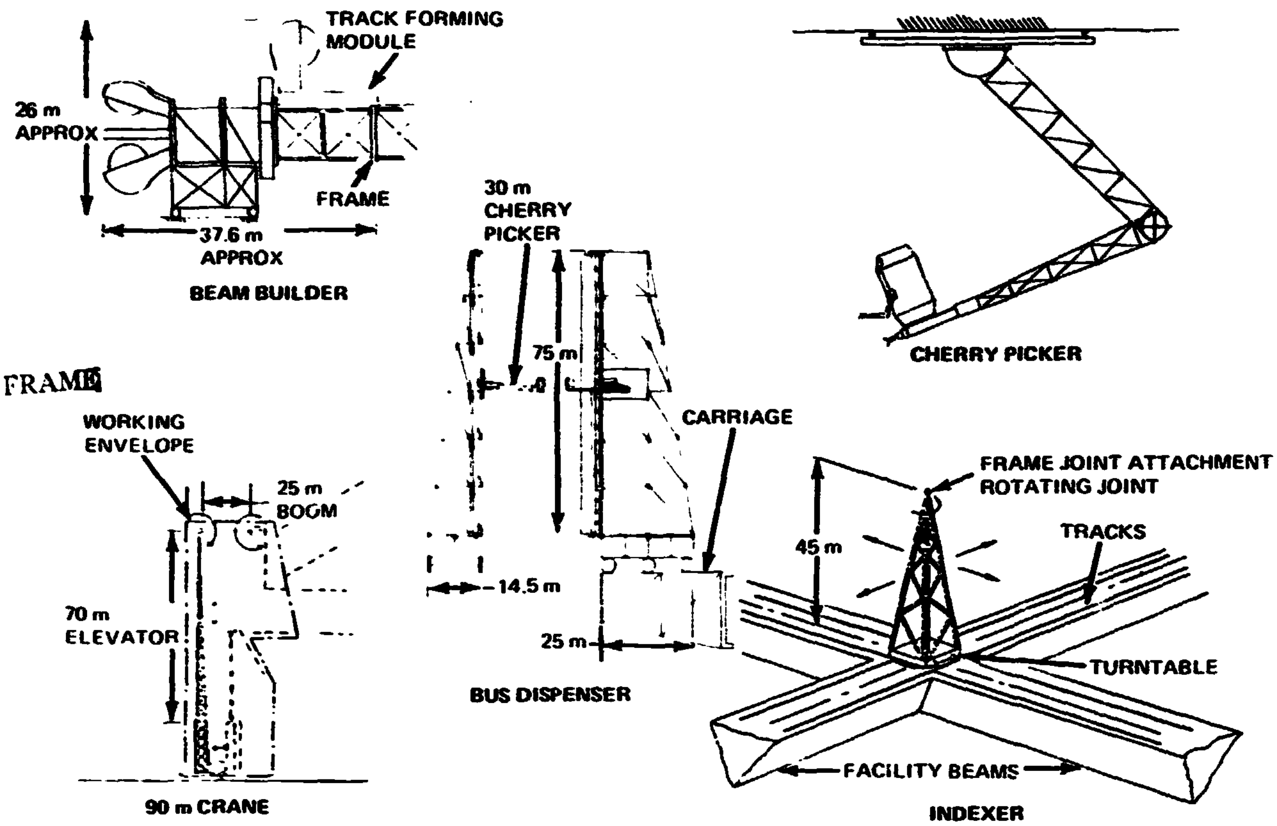
5.0 COSTS

The parametrically derived DDT&E cost for structure is $107 M. The production cost of $337 M was derived by escalating the previously used 1977 cost of $100/Kg (Ref. D180-22876-3) to 1979 dollars.

5.4/5.7 MANUFACTURING PROCESS AND PRODUCTION RATES; CAPITAL FACILITIES/LABOR/QC & QA/PACKAGING AND SHIPPING

This element can be manufactured for the GEO construction base by normal aerospace production practices. No unusual requirements are envisioned for the manufacturing facility or the work force. Standard methods of quality control and quality assurance will be utilized. Present methods of packaging for shipment to orbit will be used.

FOLDOUT FRAME



1775-017W

1.0 WBS DICTIONARY

This element includes all equipment items dedicated to construction of the SPS with the exception of equipment utilized in subassembly operations (the latter are included in WBS 1.2.1.1.4).

2.0 DESCRIPTION

SPS construction equipment includes automatic machinery for fabricating large structural beams in space. These beam machines build three sided open truss beams from tightly rolled strips of composite material to avoid the higher costs incurred in transporting low density structures to GEO. General purpose manned cherry pickers, provided with dextrous manipulators. are used to assemble these light weight beams and install the required subsystem components in the energy conversion and power transmission systems. During construction, the major elements of the satellite are supported by indexers which can be moved across the base as needed. Additional equipment is also provided to facilitate the deployment of large sheet metal power buses, anchoring solar array blanket containers, and installing antenna systems.

3.0 DESIGN BASIS

The GEO base construction equipment concepts are derived to support all stages of SPS assembly operations. The following table provides a summary listing of the major equipment types and where they are used.

2- FRAME

CONSTRUCTION EQUIPMENT MASS AND COST SUMMARY

ITEM	QTY ▷1 M	A	Y	T	MASS, 10^3kg EA.	SUB TOTAL	COST $\$10^6$ TFU	AVE EA.	SUB TOTAL	DDT&E
WBS 1.2.1.1.2.1 BEAM MACHINES										
• 7.5 mSYNCH TRAVEL	10			10	11	110	40.3	32.2	322	159.6
• 7.5 m GIM.MOBILE, MANNED	2	2	2	6	15	90	74.8	61.4	368	
• 12.7 m GIM. MOBILE, MANNED	1			1	21	21	86.3	86.3	86	
WBS 1.2.1.1.2.2 CHERRYPICKERS								▷2		
• 30 m	8		2	10	2.5	25	29.9	21.9	219	115.7
• 90 m	4	2		6	5	30	41.4	32.3	194	
• 120 m		2	1	3	7	21	43.7	40.0	120	
• 250 m		1		1	9	9	47.2	44.9	45	
WBS 1.2.1.1.2.3 INDEXERS										
• 15-45m	5			5	1.3	6.5	4.4	3.5	27	96.0
• 130 m		6	8	14	3.0	42	6.9	5.3	74	
• 230 m		2		2	5.5	11	12.1	11.5	23	
WBS 1.2.1.1.2.4 BUS DEPLOYER										
• 90 m (ALSO 80 m)	1	1	1	3	8.0	24	28.8	25.5	77	110.7
WBS 1.2.1.1.2.5 SOLAR ARRAY DEPLOYMENT EQUIPMENT										
• PROXIMAL ANCHORS	176			176	TBD	TBD			TBD	TBD
WBS 1.2.1.1.2.6 ANTENNA DEPLOYMENT PLATFORM		1		1	28	28	92	92	92	178
ADD 10% ALLOWANCE FOR UNDEFINED EQUIPMENT						42			163	-
						460×10^3kg			\$1800M	▷3 \$396M

▷1 USED ON
M - SOLAR ARRAY SYSTEM
A - ANTENNA
Y - YOKE & ROTARY JOINT
T - TOTAL

▷2 AVE. UNIT COSTS BASED ON TOTAL QTY OF EA SIZE USED THROUGH-OUT THE BASE

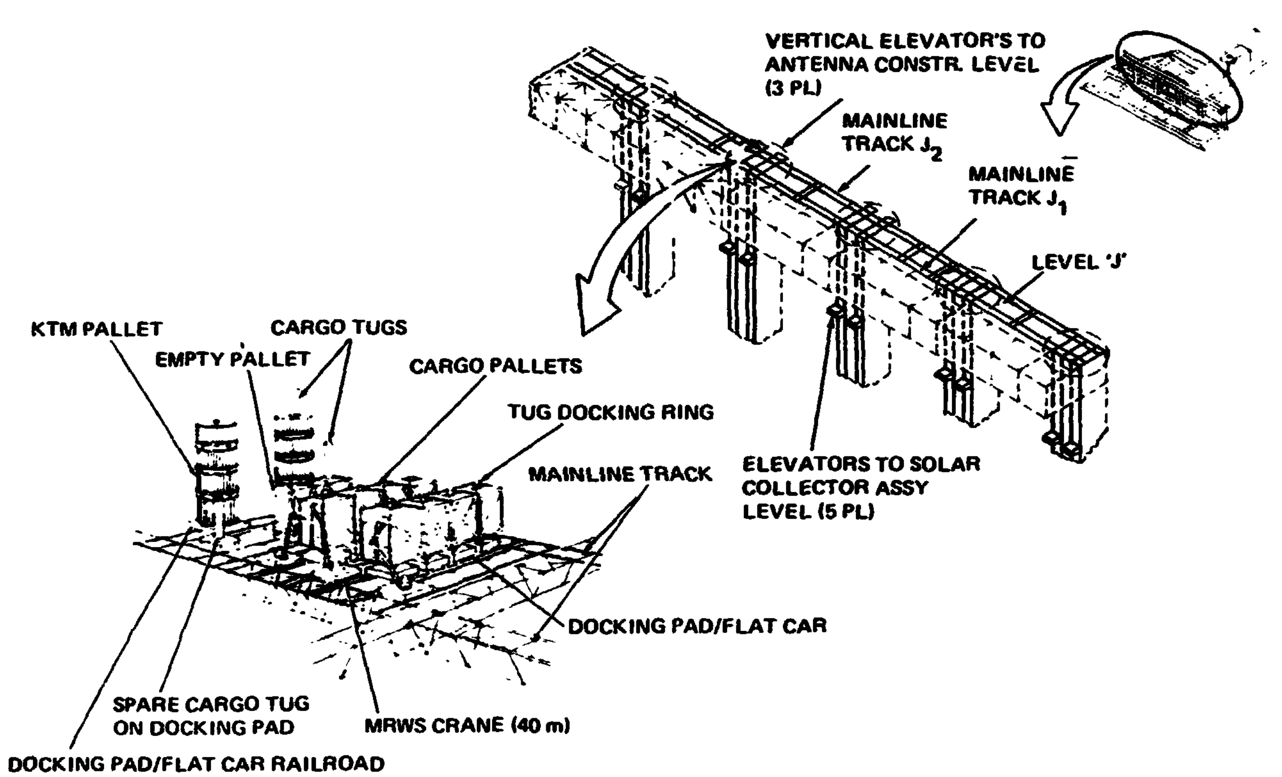
TOTAL CONST EQUIPMENT MASS

TOTAL CONST. EQUIP. COST

▷3 -TOTAL OF \$660M MULTIPLIED BY 60% (ESTIMATED COMMONALITY WITH LEO BASE EQUIPMENT).

1775 003W

/ FOLDOUT FRAME



1775-018W

1.0 WBS DICTIONARY

This element includes the hardware used for docking the various cargo and crew vehicles, the systems used to offload/reload these vehicles, the cargo and crew transporters, the cargo sorting and storage systems, and the track network used to move the cargo, crews, and equipment around the base.

2.0 DESCRIPTION

A rail guided transportation system is used on the GEO base to transfer materials and personnel from one work station to the next and between the various levels of the base as needed. Docking facilities are provided on the upper deck of the base, at level J, for EOTV cargo transfer and GEO crew rotation. Pressurized crew buses are used to move base personnel throughout the base in shirt-sleeved conditions. The dual rail system includes a redundant elevator network on each stanchion to facilitate inter level transfer operations. EOTV cargo pallets are berthed to rail guided remote controlled transporters, which move the pallets to the unloading area. SPS construction materials, base supplies and OTV supplies are off-loaded by man operated cranes for temporary storage and subsequent distribution by other remote controlled transporters. When SPS operations begin, this system can be expanded to handle the delivery of SPS maintenance components and equipments. The empty cargo pallets are returned to the berthing area for transfer back to the EOTV.

WBS 1.2.1.1.3 CARGO HANDLING & DISTRIBUTION SYSTEM

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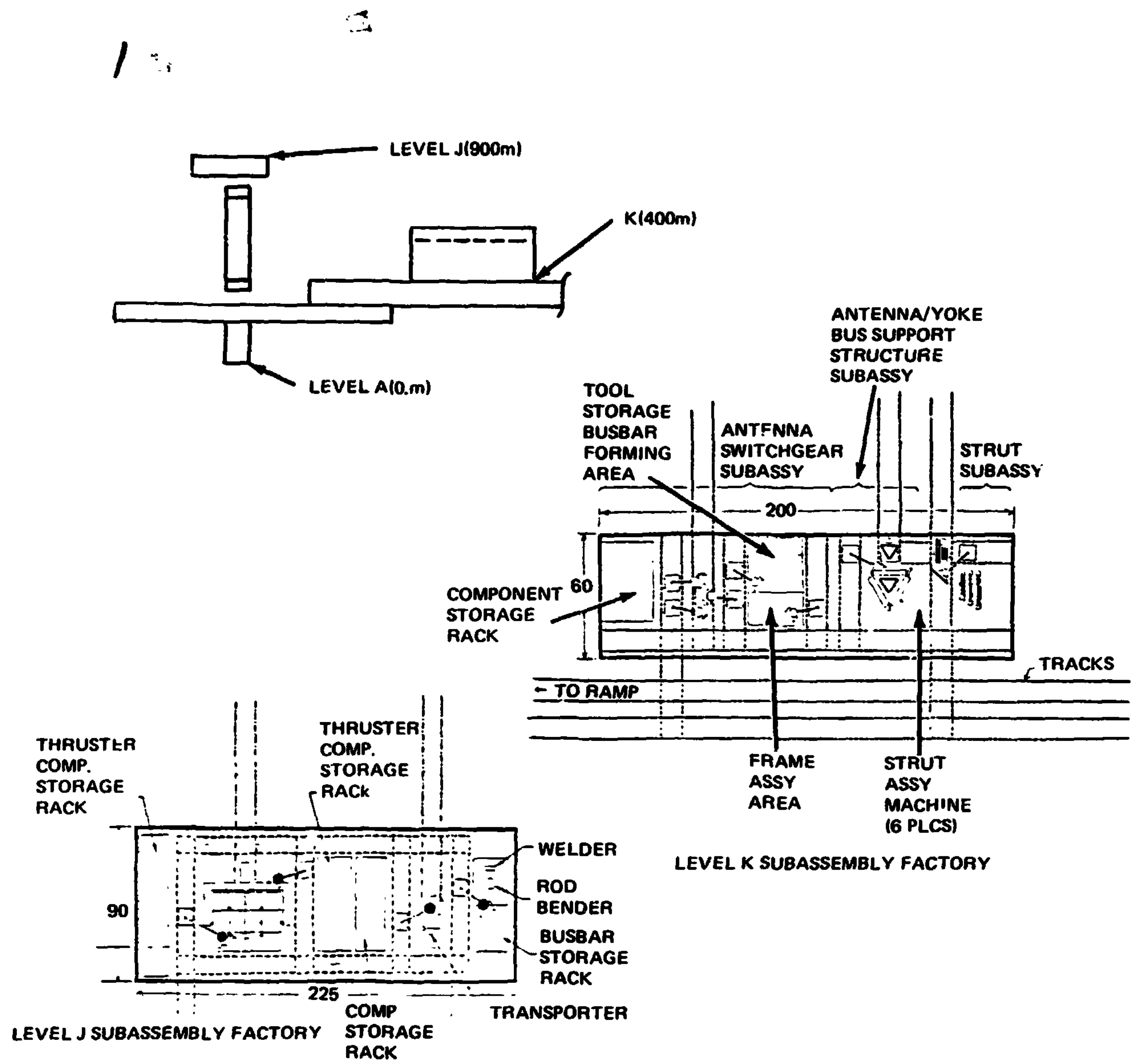
4.0/5.0 MASS AND COST SUMMARY

SUBELEMENT	QYT	MASS EST.MT	MASS RATIONALE	PROD COST (1979$) TOTAL $M	PROD COST (1979$) RATIONALE
WBS 1.2.1.1.3.1 VEHICLE DOCKING SYS.					
• POTV DOCKING	4	4	GUESS	10.4	GUESS
• CARGO TUG DOCKING	2	1	PROPORTIONAL TO POTV	3.1	PROPORTIONAL TO POTV
• IOTV DOCKING	8	8	SAME AS POTV	20.8	SAME AS POTV
• PROPELLANT STORAGE/ DISTRIBUTION		35	SAME AS LEO	17.3	SAME AS LEO BASE
WBS 1.2.1.1.3.2 VEHICLE LOADING/ UNLOADING					
• CARGO PALLET HANDLING JIG	2	1	GUESS	2.0	GUESS
WBS 1.2.1.1.3.3					
•TRANSPORTERS	20	20	PROP TO 45 M	45.8	PROP TO 45m
•30M CHERRYPICKER	3	7.5	INDEXER	65.7	INDEXER
WBS 1.2.1.1.3.4 CARGO SORTING SYSTEM	3	75	PROP TO 30m C.P.	79.8	PROP TO 30m C.F.
WBS 1.2.1.1.3.5 CARGO STORAGE SYSTEM	6	30	GUESS	5.7	GUESS
WBS 1.2.1.1.3.6 CARGO DISTRIBUTION	87KM	174	2Kg/m- ESTIMATE	40.0	$230/Kg- BOEING EST.
WBS 1.2.1.1.3.7 CREW TRANS-PORTERS					
• 10 MAN BUS	3	15	PROP TO PASS MOD	58.7	SCALED TO PASS MOD
• 24 MAN BUS	3	36	PROP TO PASS MOD	146.7	SCALED TO PASS MOD
WBS 1.2.1.1.3 CARGO HANDLING & DISTRIBUTION		407 MT		$496M	

1775-004W DOT&E = 40% OF LEO BASE CARGO HANDLING EQUIPMENT DOT&E = $207M



1.0 WBS DICTIONARY

This element includes the facilities and equipment dedicated to preassembly of SPS subassemblies prior to delivery to the final installation facilities.

2.0 DESCRIPTION

Subassembly factories are included on GEO base levels "K" and "J" in order to support the main assembly operations for the antenna and solar array collector, respectively. The antenna subassembly factory on level K, for example, is equipped with component storage racks, manned cherry pickers and various subassembly jigs. This factory preassembles beam end fittings, switch gear set ups and power bus support structures for the antenna and its rotary joint/yoke interface. The level J factory provides similar subassemblies which are tailored to be installed in the energy conversion system. The level J factory is also used to presassemble major components of the attitude control thrusters and major elements of required satellite maintenance equipment (e.g. solar array blanket annealing gantries).

4.0 MASS AND MASS BASIS

ELEMENTS	MASS - MT		REF.
	LEVEL J	K	
COMPONENT STORAGE RACKS	TBD	TBD	
30M CHERRY PICKERS (6 & 9)	15.	22.5	
BUS BAR WELDERS	TBD	TBD	D180-25037-3
BEAM END FITTING JIG	TBD	TBD	
STRUT ASSEMBLY MACHINES	TBD	-	
TOTAL	15.	27.5	

1775-005W

5.0 COSTS

The subassembly factory cost of $323 M was derived by escalating the previously used 1977 cost of $281 M, shown in Ref. D180-22876-3, to 1979 dollars.

DDT&E SAME AS LEO BASE SUBASSEMBLY FACTORY DDT&E = $54M

1.0 WBS DICTIONARY

This element includes all facilities and equipment on the GEO base that are dedicated to test and checkout of SPS components or subassemblies.

2.0 DESCRIPTION

The major test and checkout facilities/equipment that have been identified are the following:

- o Subarrays Test System
  - Use base power off-peak
  - 1-20 m c/p @ 2.5 tons
  - 2 ppu @ 6 tons each: 12 tons
  - Test station and support equipment - 5 tons
- o Thruster Test
  - Test on SPS after installation
- o Slipring Test
  - Test on SPS, otherwise rely on carefuly inspection.
    NOTE: If slipring is assembled in space, then must provide test stations fixtures.
- o Solar Array Test
  - Test on installation

4.0/5.0 MASS AND COST

Mass	=	20 MT	(est.)
Unit Cost	=	$170 M	(est.)
DDT&E Cost	=	25 M	(est.)

TABLE A

TRANSPORTATION VEHICLE MAINTENANCE

AT GEO BASE

VEHICLE [1]	MAINTENANCE ACTIVITY
EOTV	o Solar array annealing
	o Minor and unplanned maintenance (LEO Base is prime location for scheduled maintenance)
POTV	o Minor and unplanned maintenance (LEO Base is prime location for scheduled maintenance)
IOTV	o All scheduled and unscheduled maintenance
CARGO TUG	o All scheduled and unscheduled maintenance

[1] Mobile construction equipment and intrabase cargo transporter maintenance included in WBS 1.2.1.1.9

TABLE B

SPACE VEHICLE MAINTENANCE SUPPORT EQUIPMENT

90M Cherrypicker [2]
Electrical Power Test Set
Electrical Load Banks
Communications Test & Checkout Equipment
Guidance & Navigation Test & Checkout Equipment
Control & Data Acquisition Console
EMI Test Equipment
Memory Load & Verify Unit
Electronics Calibration Equipment
Engine Handling Kit
Engine Alignment Fixture
Engine Actuator Support Fixture
Engine Actuator Adjustment Kit
Insulation Handling Kit
APS Pressure Instrumentation Kit
Main Propulsion System Checkout Accessories Kit
APS Checkout Accessories Kit
Inspection Equipment
Ultrasonic Scan Unit
Radiography Unit
Mass Spectrometer Leak Detection Unit
Acoustic Leak Detection Unit
Borescope and Fibre Optics
Theodolite
Ground Servicing Umbilical Set

[2] - Cherrypicker is included in the total quantity identified in WBS 1.2.1.1.2.2.

WBS 1.2.1.1.6 TRANSPORTATION VEHICLE MAINTENANCE SYSTEMS

1.0 WBS DICTIONARY

This element includes the equipment and facilities dedicated to transportation vehicle maintenance operations. The maintenance operations are included in WBS 1.2.1.3.

2.0 DESCRIPTION

The vehicles to be maintained at the GEO Base and the nature of the maintenance is shown in Table A.

There are no dedicated vehicle maintenance facilities as the vehicles are maintained on their docking pads. Access is provided for cherrypickers both for maintenance and operational purposes. Vehicle components that are removed for refurbishment are taken to the Maintenance Module (see WBS 1.2.1.1.7). This Maintenance Module is jointly used by the vehicle maintenance, base equipment maintenance, and SPS component maintenance operations.

The equipment identified in Table B is required to support the vehicle maintenance operations.

The EOTV solar array annealing is remotely controlled from the GEO Base Operations Center. The annealing control subsystems are accounted for therein.

3.0 DESIGN BASIS

The requirements for vehicle maintenance facilities, equipment, crew, and operations were established by the operations analysis given in Section II of the Operations and Systems Synthesis document (Boeing doc. no. D180-25461-3).

4.0 MASS AND MASS BASIS

Item	Quantity	Mass	Basis
90m Cherrypicker	1	-	Not dedicated to this operation, shared with other operations.
Misc. Tools/Fixtures/ Jigs/Etc	1 set in	3	See Table C WBS i.2.2.1.6
	Total	3MT	

5.0 COST AND COST BASIS

Investment cost of the tools/fixtures/jigs/etc., was estimated to be $9.5m (see Table C in WBS 1.2.2.1.6).

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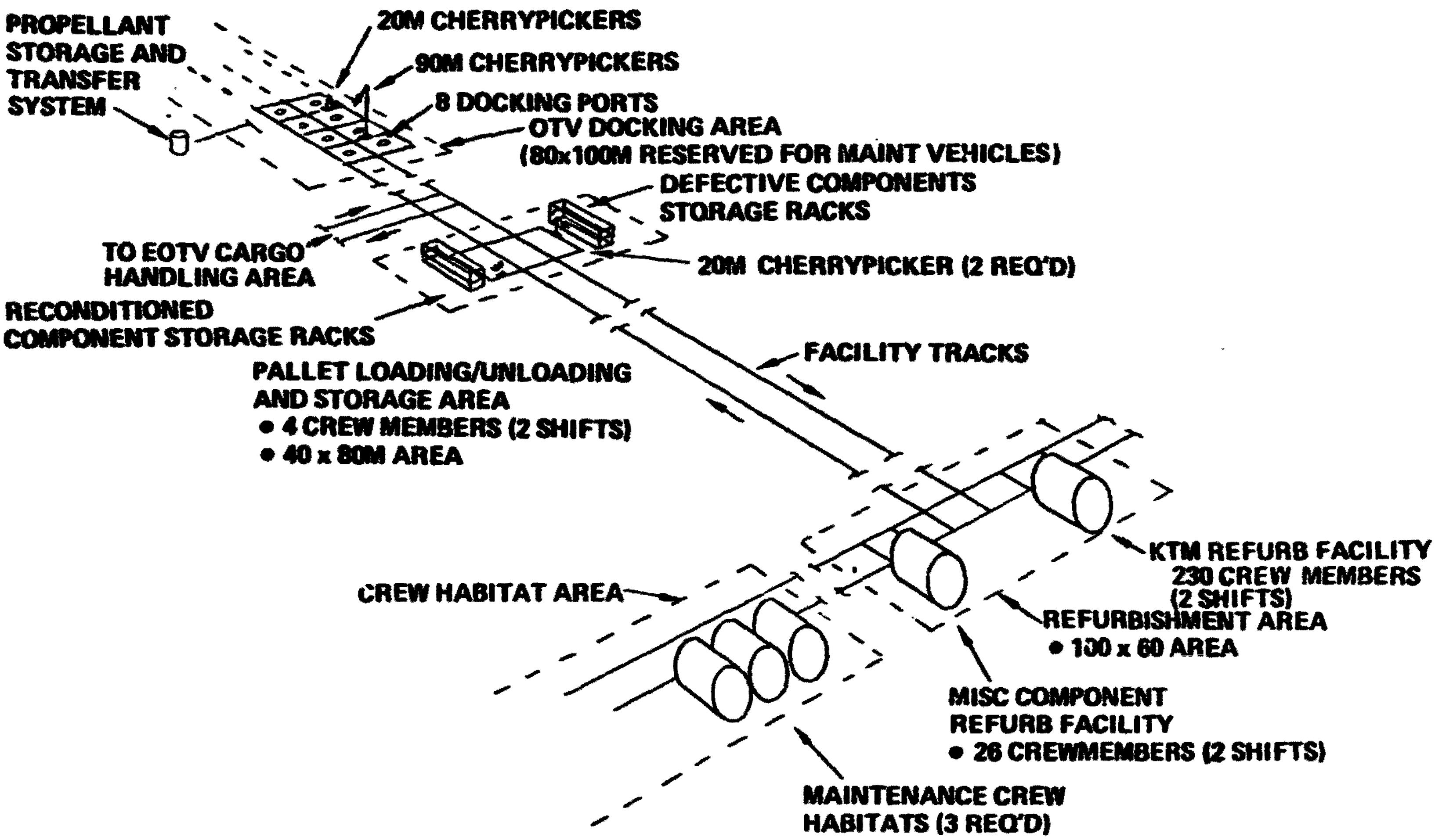

Figure A—Satellite Maintenance Support Provisions at the GEO Base

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1.0 WBS DICTIONARY

This element includes the facilities, systems, and support equipment dedicated to SPS maintenance support operations. The SPS maintenance support operations are included in WBS 1.2.1.3.

2.0 DESCRIPTION

Figure A shows the maintenance support provisions at the GEO base. There are three major maintenance support operational areas: 1) OTV operations area, 2) pallet loading/offloading and storage operations area, and 3) refurbishment operations area.

In the OTV operations area (this is integral with the OTV operations required to support the construction operations), the POTV's are docked and the crews transferred to their assigned habitat via a crew bus. During the time between the maintenance visits to the SPS's, there will be four maintenance IOTV's located in the OTV operations area. The vehicles include a crew module transporter OTV, a flying cherrypicker transporter OTV, and two component transporter OTV's. There are cherrypickers located in the OTV Operations Area that are used to stack payloads onto vehicles and to maintain the vehicles.

In the Pallet Loading/Offloading and Storage Operations Area, the replacement parts cargo pallets arriving from the EOTV cargo tug handling area, the defective components arriving from the OTV operations area, and the reconditioned components arriving from the refurbishment facilities are processed. Incoming goods are offloaded from pallets onto storage racks. These goods are eventually loaded onto transporters to be taken to the refurbishment facilities. The reconditioned components coming back from the refurbishment facilities are offloaded onto storage racks. Eventually, these components are loaded onto cargo pallets. These pallets are delivered to the OTV operations area for loading onto IOTV's which will deliver the goods to the satellites being visited by the traveling maintenance crew.

In the Refurbishment Operations Area, the defective components are processed to recondition them for use. The major refurbishment operation is that associated with processing 6612 klystron tube modules (KTM's) each month. The defective KTM's are offloaded from the cargo transporters and then each one is run through a fault isolation test to diagnose its problems. The KTM's pass through a refurbishment production line where they are torn down to the extent necessary to replace the defective components. After the KTM's are repaired. each one is run through an active operational test to verify the fix. Figure B shows the production line integrated into the KTM Refurbishment Module. Table A describes the stations, support equipment, etc. for this facility. Table B summarizes the support equipment required. When they have passed inspection, the KTM's are loaded onto a transporter to be returned to the storage area.

Other miscellaneous components (e.g., switchgear, disconnect switches, power processors, etc.) are reconditioned in a second module, see Figure C. This module and its support equipment is also used to refurbish GEO Base equipment and transportation vehicle components.

The maintenance operations and crew sizing are described in WBS 1.2.1.3.

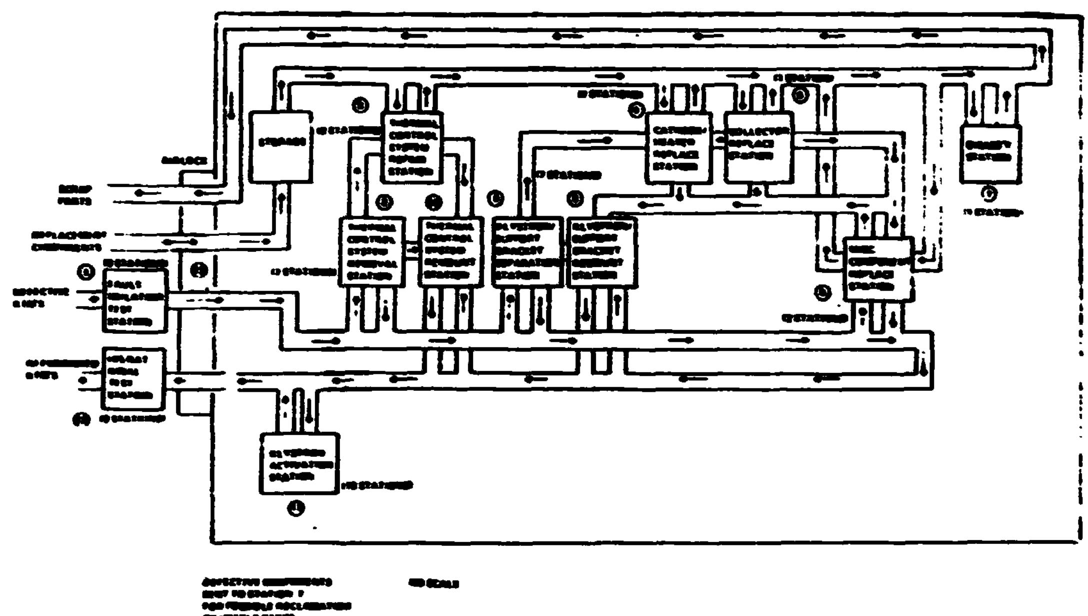

Figure B—Klystron Tube Module Refurbishment Facility

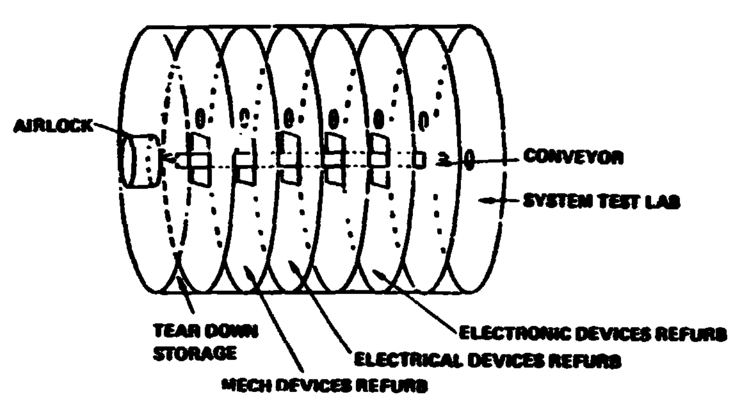

Figure C—Miscellaneous Components Refurbishment Facility

3.0 DESIGN BASIS

The SPS maintenance support facilities, systems, and support equipment requirements are based on maintaining 20 operational satellites. The derivation of these requirements are detailed in Section 13 of the Operations and Systems Synthesis document (Boeing doc. no. D180-25461-3).

TABLE B

BASELINE KTM REFURBISHMENT SUPPORT EQUIPMENT

ITEM	QTY
o Gantry-mounted cherrypickers	6
o Test Stands & Systems	18
o Fluid purge/refill system	7
o Welders - Radiator	2
o Klystron bakeout/vacuum system	18
o Misc. hand and power tools	TBD
o Storage provisions	TBD
o Conveyors	3

SPS-3041

Table A—Klystron Refurbishment Facility Stations, Support Equipment, and Crew

REF. NO.	STATION OR LOCATION	SUPPORT EQUIPMENT	CREW/ SHIFT	REMARKS	TIME REQ'D. MIN.	FLOOR AREA, M^2	%	NO. OF STATIONS	TOTAL FLOOR AREA	CREW
1	Fault Isolation Test	Power supply Wiring harness Multitest system Microwave absorber fixture Cherrypicker	2	High voltage, microwave, and x-ray hazard	30	4 [•]	100	9	36 [•]	[illegible]
2	Thermal Control System Removal	Valve actuator Fluid purge system Wrenches	1	Close valves on either side of disconnect Attach purge fittings Open purge valves Disconnect fluid lines	30	4	80	7	28	7
3	Klystron/Support Bracket Separation	Nut driver Wrenches Screw driver	1	Disconnect conductors Disconnect distribution waveguides Disconnect mechanical fasteners	30	4	80	7	28	7
4	Cathode/Heater Replace	Cathode/heater Removal tool	1	Remove cathode/heater assembly Install new assembly into klystron tube	30	4	EST. 80	7	28	7
5	Collector Replace	Collector removal tool Storage provisions	1	Remove collector Replace with new collector	30	4	5	.4 = 1	4	1
6	Miscellaneous component replacement	Nut driver Wrenches Screw drivers Storage provisions	2	Includes phase control components	30	8	20	1.76 = 2	16	4
7	Disassembly station	Nut driver Wrenches Screw drivers Storage provisions Scrap parts container Saw Shears	1	Reclaim usable components; scrap the rest	60	4	5	.88 = 1	4	1

[•] · Outdoor Activity

Table A— (Cont'd)

REF. NO.	STATION OR LOCATION	SUPPORT EQUIPMENT	CREW/ SHIFT	REMARKS	TIME REQ'D	FLOOR AREA, M^2	%	NO. OF STATIONS	TOTAL FLOOR AREA	CREW
8	Klystron remount	Nut driver Wrenches Screw drivers	1	Connect conductors Connect waveguides to klystron Connect mechanical fasteners	30	4	80	7	28	7
9	Thermal control system repair	Fluid purge system Welder Nut drivers Wrenches Storage provisions	2	Repair motors and pumps Seal microcracks or punctures in radiators	60	8	10	1.78 = 2	16	4
10	Thermal control system remount	Valve actuators Wrenches Fluid supply system	1	Refill or top off fluid after assembly	30	4	80	7	28	7
11	Klystron activation	Valve actuator Vacuum gage system Vacuum pump system Power supply Oven Cathode activation system	2	Bake out the tube Pump down and then vent to open space to achieve final vacuum Activate cathode (no RF)	60	8	100	17.6 = 18	144	36
12	Operational test	Power supply Wiring harness Multi-test system Microwave absorber Heavy fixture picker [1]	1	High voltage, microwave, and X-ray hazards Use stressed pulse test	30	4 [1]	100	9	36 [1]	9
13	Airlock/storage area	Pallet manipulators Component manipulators Air supply/purge system Door actuators	1	Load/offload components between pallets and conveyors Move pallets into/out of airlock		100		1	100	1
14	Conveyor system	Conveyors Conveyor pallets Conveyor junctions				18		7 DECKS	126	

TOTAL 560 M^2

TOTAL CREW 109/SHIFT

[1] - Same cherrypicker as used in Station 1

7 DECKS X 200 M^2/DECK = 1400 M^2 AVAILABLE

4.0 MASS AND MASS BASIS [1]

ITEM	QTY [2]	MASS, MT	BASIS
o IOTV docking ports, cherrypickers, and tracks have been included in WBS 1.2.1.1.3	-	-	-
o Maint modules and maint crew habitats have been included in WBS 1.2.2	-	-	-
o Storage racks	2	10	See Table C in WBS 1.2.2.1.3
o 20M cherrypickers	2	4	See Table A and C in WBS 1.2.2.1.2
o Gantry mounted cherrypickers	7	14	Estimated to be same as 20M CP's
o Test stands & systems	28	14	Guess - .5 MT ea
o Fluid purge/refill system	8	4	Guess - .5 MT ea
o Welders	3	1.5	Guess - .5 MT ea
o Klystron bakeout/ vacuum system	18	9	Guess - .5 MT ea
o Misc, Hand and power tools	TBD	1	Guess
o Storage provisions	TBD	2	Guess
o Conveyors	4	4	Guess
	TOTAL MASS	63.5 MT	

5.0 COST AND COST BASIS [1]

ITEM	QTY [2]	COST, $M	BASIS
o IOTV docking ports, cherrypickers, and tracks have been included in WBS 1.2.1.1.3	-	-	-
o Maint modules and maint crew habitats have been included in WBS 1.2.2	-	-	-
o Storage racks	2	1.6	See Table C in WBS 1.2.2.1.3
o 20M cherrypickers	2	39.2	See Table A and C in WBS 1.2.2.1.2
o Gantry mounted cherrypickers	7	137.2	Estimated to be same as 20M CP's
o Test stands & systems	28	28	Est. $2000/kg
o Fluid purge/refill system	8	8	Est. $2000/kg
o Welders	3	3	Est. $2000/kg
o Klystron bakeout/ vacuum system	18	18	Est. $2000/kg
o Misc, Hand and power tools	TBD	Neg	
o Storage provisions	TBD	Neg	
o Conveyors	4	8	Est. $2000/kg
	TOTAL COST	$243 M	

[1] Based on 20 SPS's in orbit.

[2] Includes items used in or around both the KTM maintenance module and the miscellaneous maintenance module.

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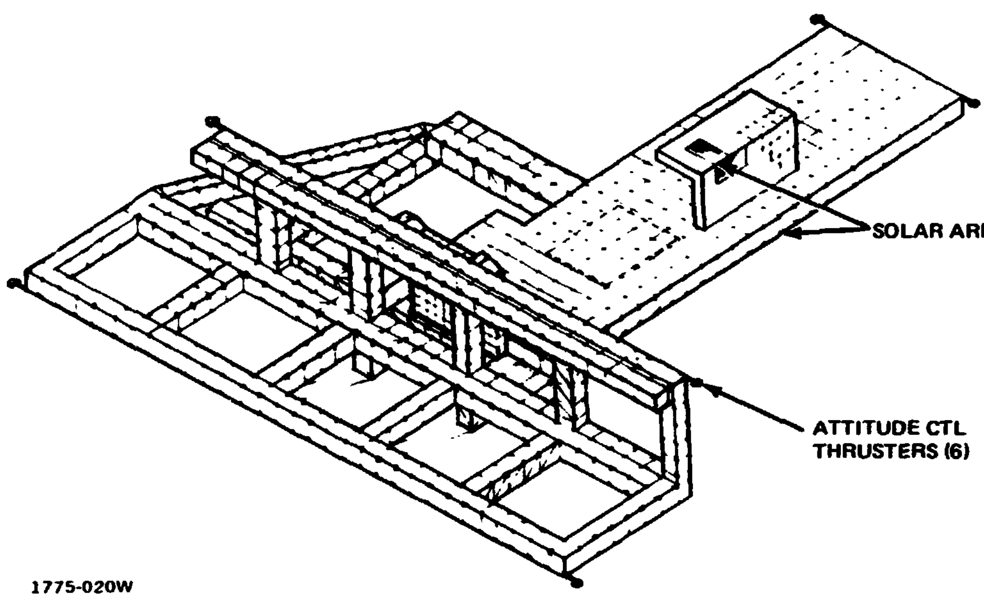

1.0 WBS DICTIONARY

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

2.0 DESCRIPTION

Electrical power and flight control systems are provided on the GEO base so that all work facilities and crew support facilities can operate as needed. Both subsystems are required to function while the SPS solar array blankets are maintained in an off-sun attitude during construction, and also in the on-sun attitude for final checkout and separation. Preliminary analyses show that it is feasible to meet this requirement by orienting the satellite/GEO base configuration perpendicular to the orbital plane (POP). The operational SPS also uses this flight attitude. However, even though the POP attitude has been selected for the reference GEO base system, other flight attitude concepts should be examined in the future to assess their impact on base system design and operational interfaces (e.g. earth oriented gravity gradient stabilized modes).

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

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

3.0 DESIGN BASIS

The GEO base electrical power requirements are derived from the previous Boeing study which defined SPS LEO construction methods (Report D180-24071-1). Estimated power requirement for operating construction equipment (150KW) and providing associated external lighting (320KW) are used directly from that report. Power requirements for crew modules, however, have been revised (1030KW) to reflect 15 modules (vs 10) due to added crews for SPS operational maintenance support. It also reflects a proportional reduction in ECLS power commensurate with the updated weight estimate for a 100 man system (22.8 vs 60 kg). The 14,400KW requirement for flight control assumes that no more than four ion thruster modules would be fired simultaneously. Hence, depending upon whether chemical or ion thrusters are used, the average base load varies from 1500 KW to 15,900 KW, respectively. When secondary power recharging loads and system losses are included, the total base power generation requirement becomes 2440KW for chemical thruster control modes (SPS on-sun) and 24,820 KW for ion thruster control modes (SPS off-sun).

The GEO base flight control system was analyzed for the SPS off-sun POP attitude during the first and second construction pass. Seven phases of satellite construction are defined, which include the effects of wide mass property changes during the 6 month build up scenario. EOTV ion propulsion modules provide sufficient thrust (838N) for the GEO base to control combined disturbances due to gravity gradient and solar pressure forces. These thrusters are also used to perform station keeping and base transfer maneuvers. This system uses about 50000kg of propellant during the 6 month construction cycle.

4.0 MASS AND MASS BASIS

Electric Power Element	Mass kg	Rationale	Reference
Solar Arrays	102200	Estimated .426Kg/m^2	D180-25037-3
NiH_2 Batteries	34600	Estimated 52WH/Kg	Contract NAS8-31993 Part III Rept Vol 5
Power Conditioning	4000	Scaled to SPS Mass	D180-25037-3
Power Distribution	53600	Scaled to SPS Mass	D180-25037-3
TOTAL	194400Kg		
Flight Control Element			
6 Thruster Modules	744000Kg	Same size as EOTV	D180-25037-3
TOTAL	744000Kg		
Combined Subsystem			
1775-006W TOTAL	938400Kg		

5.0 COST

SUB SYSTEM	PRODUCTION COST IN 1979 $ M	REMARKS
• ELECTRIC POWER	(79.4)	
- SOLAR ARRAYS	9.7	BASED ON $40.25/m^2
- NiH_2 BATTERIES	33.7	PARAMETRIC
- POWER CONDITIONING	7.2	PARAMETRIC
- POWER DISTRIBUTION	28.8	PARAMETRIC
• FLIGHT CONTROL	(243.0)	
- 6 ION THRUSTER ASSY'S	243.0	BASED ON BOEING ION THRUSTER COST ESTIMATE
1775-007W TOTAL	$322 M	DDT&E = 1/2 LEO BASE SUBSYSTEMS DDT&E = 60M

5.4/5.7 MANUFACTURING PROCESS AND PRODUCTION RATES; CAPITAL FACILITIES/LABOR/QC & QA/PACKAGING AND SHIPPING

This element can be manufactured for the GEO construction base by normal aerospace production practices. No unusual requirements are envisioned for the manufacturing facility or the work force. Standard methods of quality control and quality assurance will be utilized. Present methods of packaging for shipment to orbit will be used.

1.0 WBS DICTIONARY

This element will include all systems and facilities necessary to conduct maintenance on all elements permanently associated with the GEO base.

2.0 DESCRIPTION

The base facilities and equipment maintenance element will provide a capability to monitor the condition the work support facilities, crew support facilities and their equipments and to provide maintenance, repairs and/or replacement of base facility components, as required. No work has been done on this element to date.

1.0 WBS DICTIONARY

This element is limited to the communication antennas located on the base. Other Command and Control functions, such as Data Processing & Communications, are included in WBS 1.2.1.2.2. No work has been done on this element to date.

4.0/5.0 MASS AND COST

Estimate mass = 1 MT (antennas only)
Unit cost = $1M
DDT&E = $2M

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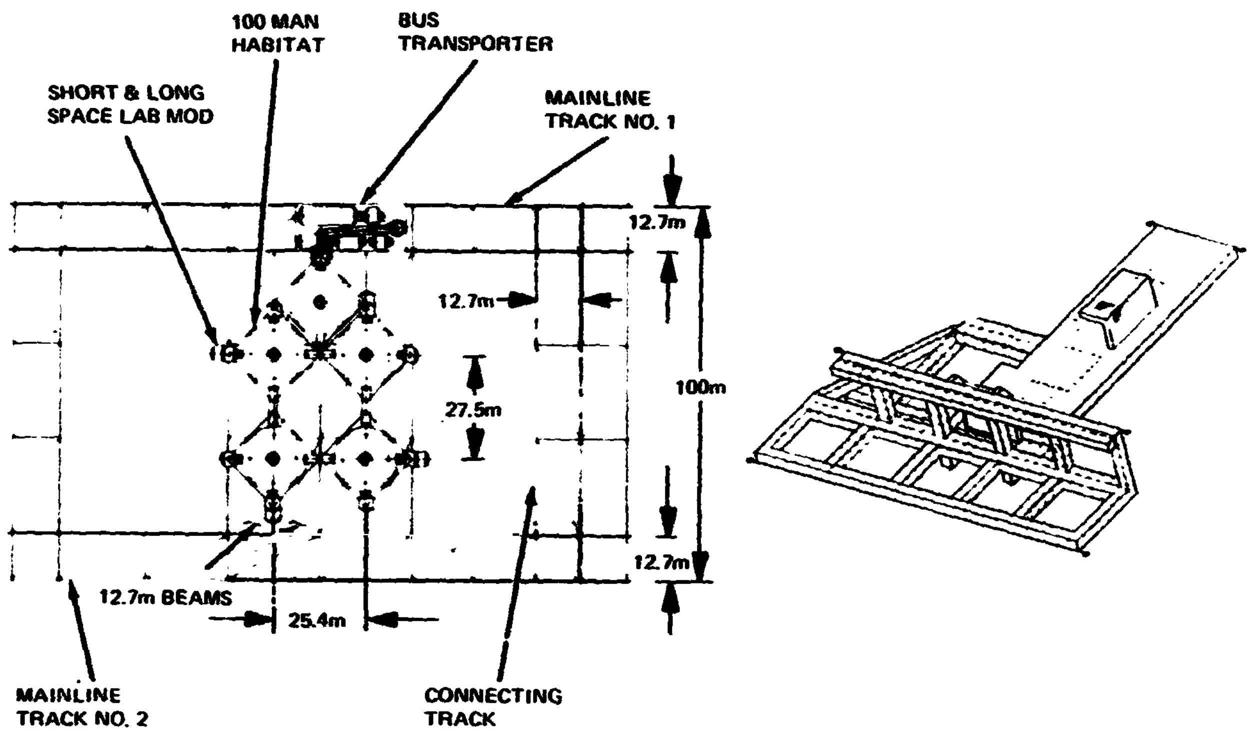

1775-021W

1.0 WBS DICTIONARY

This element includes the facilities and equipment required for the life support and well-being of the crew members. Included are living quarters, central control facilities, recreation facilities, and health facilities needed to perform satellite construction. It also includes crew facilities added to support SPS operational maintenance.

2.0 DESCRIPTION

The GEO base crew support facilities are provided on level J which is also the focal point for cargo handling and distribution, OTV docking and servicing, and SPS operational maintenance support. Eight pressurized crew modules (23m x 17m dia) are provided for SPS construction operations. These modules are used to house 444 crewmen, accommodate transient crew rotation situations, and support essential functions for base command and control, base maintenance and training. These modules are clustered in the middle of level J and interconnected with pressurized transfer tunnels where ever practical. Pressurized air locks are also provided for IVA transfer to awaiting crew buses for further intra base travel. When SPS maintenance operations begin, additional crew habitats, transient crew quarters, and required SPS component repair modules will be added. For example, six additional modules will be needed to maintain 20 operational satellites, twelve additional modules for 40 satellites and eighteen extra modules for 60 satellites. Once 60 reference satellites are built, dedicated construction crew modules will become available to also support the SPS maintenance operations.

3.0 DESIGN BASIS

All GEO base crew quarter modules and work modules are designed to fit within the HLLV payload bay (23m x 17m dia). Each module is to be designed for at least 30 years life, provide meteoroid and solar storm radiation protection, and be compatible with zero gravity operations. To prevent crew disorientation, all interiors will be designed to a common reference. A normal one-g arrangement is preferred for ground operations and is also satisfactory for space activities. Based on the Navy projection for support ships, GEO base crew accommodations are planned to include 75% male and 25% female.

SUBELEMENT	MASS - MT		COST $M		
	INITIAL	MAINT DELTA	DDT&E	PROD	MAINT DELTA
WBS 1.2.1.2.1 Crew Quarters Modules	1215.5	972.4 to 2917.2	2271 [1]	1923	1538 to 4615.2
WBS 1.2.1.2.2 Work Modules	413	354 to 1062	454 [2]	631	646 to 1938
WBS 1.2.1.2 Crew Support Facilities	1628	1326 to 3979	681	2554	2184 to 6553

1775-008W

[1] 10% DELTA TO LEO BASE CREW QUARTERS DDT&E FOR SHIELDING

[2] 20% DELTA TO LEO BASE WORK MODULES DDT&E FOR ARRANGEMENT DELTAS

4.0 MASS AND COST BASIS

Refer to WBS 1.2.1.2.1 and 1.2.1.2.2

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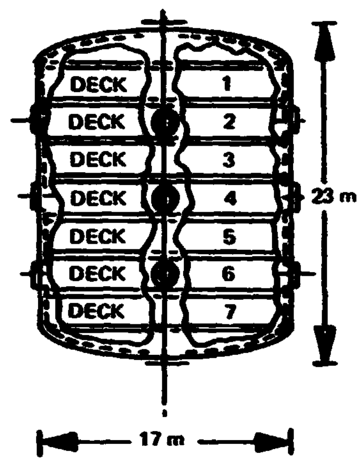
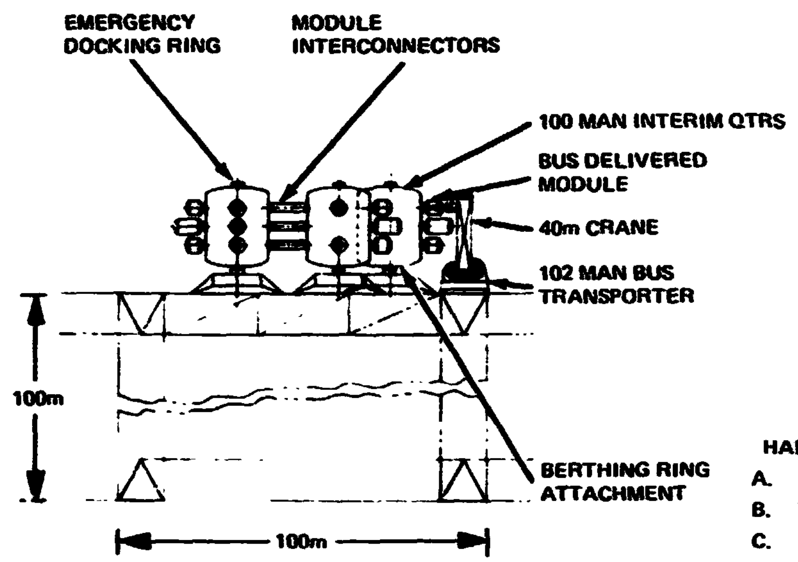
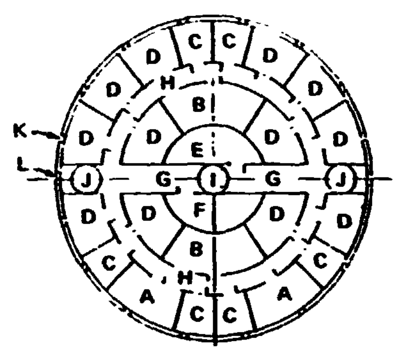
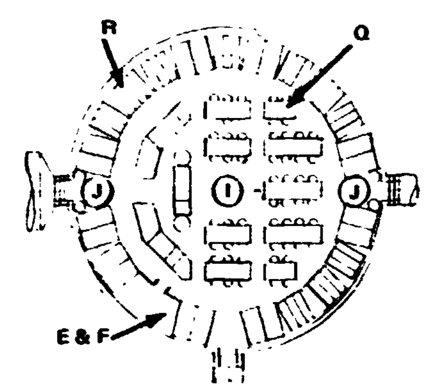


CREW MODULE





DECK 3
CREW QUARTERS



DECK 4
GALLEY/DINING AREA/STORM SHELTER

HABITAT AREAS:

A. ONE-PERSON STATEROOM
B. TWO-PERSON STATEROOM
C. ONE-PERSON CREW QUARTER
D. TWO-PERSON CREW QUARTER
E. WASTE MANAGEMENT
F. PERSONAL HYGIENE
G. CENTRAL PASSAGEWAY
H. TORUS AISLEWAY
I. THRU-DECK ACCESS
J. INTERDECK ACCESS
K. CABIN WINDOWS
L. VIEW WINDOWS
M. EMU/EVA PREP ROOM
N. COMPUTER RACKS
O. CONTROL CENTER
P. CONFERENCE ROOM
Q. DINING AREA (56 PERSONS)
R. FOOD STORAGE
S. LOUNGE
T. LAUNDRY/SUPPLIES
U. RECREATION/GYN GYMN
V. BARBER SHOP/POST OFFICE
W. LIBRARY/STUDY
X. THEATER/CHAPEL
Y. SICK BAY/DENTIST
Z. EP EX
Z. EXPENDABLES
Z1. SUBSYSTEMS
Z2. AGRICULTURAL STUDY
Z3. COMPACTED WASTE

1775-022W

1.0 WBS DICTIONARY

This element includes the crew modules designated as crew living quarters.

2.0 DESCRIPTION

Four habitats and 1 transient crew quarter are provided to house all members of the two shift GEO construction crew (444). When 20 satellites must be maintained, the GEO support crew (383) will require three more habitats and another transient crew quarter. These supporting crew modules will eventually increase to nine habitats and three transient crew quarters when 1149 people are needed to maintain 60 satellites.

Each module is sized to accommodate about 100 people depending upon the number of single and double occupancy staterooms provided. The 23m x 17m diameter domed end cylinder is arranged with seven decks, each having a 2.2m floor to ceiling height. Three decks are allocated to living quarters for male and female personnel. Galley and dining areas are provided on another deck which also serves as a radiation storm shelt for 100 to 110 people. The other decks can be arranged to include backup control center/subsystem functioning/recreational/physical fitness/services areas, and subsystem equipment rooms as needed. Each deck is accessible to the adjacent decks via three 1.5 in. diameter openings. Alternate decks are provided with external hatches that can either lead to interconnected crew modules, berthed crew transfer vehicles, or attached airlocks.

3.0 DESIGN BASIS

Each crew module operates almost independently except for primary electrical power and orbital attitude which are provided by the base. Emergency power, environmental control, life support and information subsystems are self contained within each module. The 100 man module described in D180-25037-3 had been scaled from prior study on 12 man unitary space stations. The internal crew arrangement, environmental control/ life support, and radiation protection requirements were re-examined and updated in phase 2. Crew area allocation studies indicate that accommodations for 100 people in a 7 deck module compare favorably with U.S. Navy current ship design practice and requirements from prior studies. A regenerative ECLS subsystem, which includes closed water and oxygen loops, is defined to provide life support and thermal control for 100 men. The subsystem is able to maintain sea level pressure conditions with minimal expendibles. A multi-layer cabin wall (2.6 gm/cm^2 aluminum) protects the crew against micrometeorites and trapped electron radiation. Protection against solar flares is provide by a storm shelter using 20gm/cm^2 shielding.

4.0 MASS & MASS BASIS

ELEMENT	MASS MT	RATIONALE	REFERENCE
STRUCTURE	69.7	GRUMMAN PREL EST	D180-25402-1
ENVIRON PROTECTION	68.3	GRUMMAN PREL EST	D180-25402-1
ELECTRICAL POWER SUPPLY	5.0	BOEING SCALED EST	D180-25037-3
ECLS	22.8	GRUMMAN ANAL	PH-2 MPR-NO 6
ATMOS REVITAL	(9.8)	DETAIL ESTIMATE	
WATER MGT	(2.6)	DETAIL ESTIMATE	
WASTE MGT	(4.3)	DETAIL ESTIMATE	
THERMAL CTL	(6.1)	PART EST & GUESS	
CREW ACCOMMODATIONS	11.0	BOEING SCALED EST	D180-25037-3
COMM/DATA HDLG	6.0	BOEING SCALED EST	D180-25037-3
GROWTH/CONTINGENCY	60.3	33%	
TOTAL	243.1 MT		

1175-009W

5.0 COST DETAILS

	COST $M	SOURCE
INVESTMENT		
MANUFACTURING PLANT	(800)	GRUMMAN ESTIMATE
DELTA DDT&E	(1204)	GRUMMAN PCM
- STRUCTURE	252	
- ENVIR. PROTECT	124	
- COMM/DATA HDL	529	
- ECLS	215	
- CREW ACCOM	52	
- FUEL CELL PWR	32	
TEST UNITS	(267)	FACTOR FROM PRODUCTION
PRODUCTION HABITATS		
CONSTR MODULES (5)	1923	GRUMMAN PCM
MAINT MODULES (4 to 12)	1538 TO 4615	GRUMMAN PCM

1775-010W

5.4 MANUFACTURING PROCESSES AND PRODUCTION RATES; CAPITAL FACILITIES

The floorspace requirements for assembling the 100 men crew module are estimated to be 177,200m^2. This consists of an eight story high bay assembly area of 4800m^2, a two story high bay subassembly area of 22,400m^2, and a 150,000m^2 single story area for detail fabrication and processing. The estimated cost is $92M for the buildings and $708M for machinery and equipment adding to a total facility cost of $800M.

5.5/5.7 LABOR/QC & QA/PACKAGING AND SHIPPING

This element can be manufactured for the GEO construction base by normal aerospace production practices. No unusual skill requirements are envisioned for the manufacturing work force. Standard methods of quality control and quality assurance will be utilized. Present methods of packaging for shipment will also be used.

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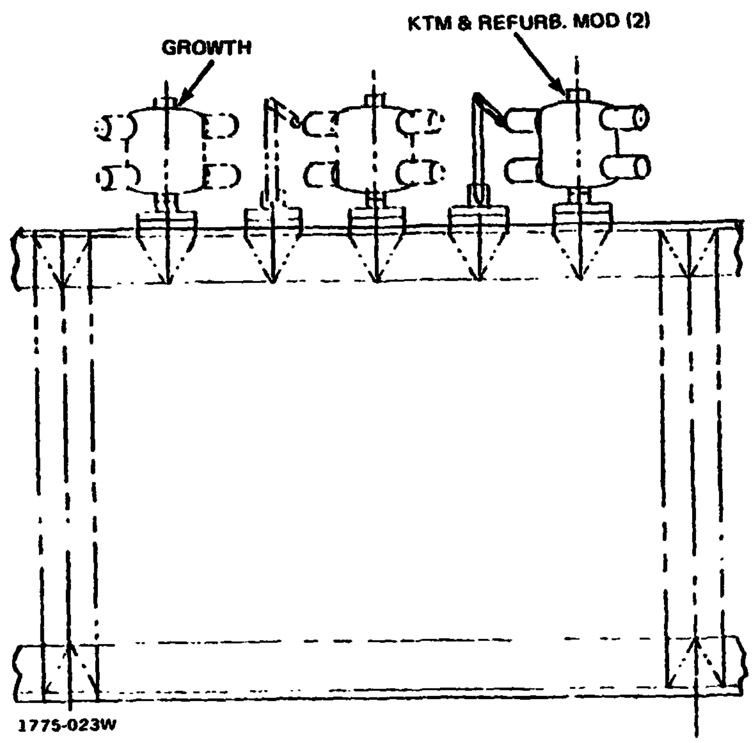

1.0 WBS DEFINITION

This element includes the crew support facilities used for base command and control operations, maintenance and other support functions.

2.0 DESCRIPTION

The GEO base includes three work modules to support satellite construction operations. GEO base command and control operations are centered within one module, base maintenance and test are within another; and one extra module is included to cover training, storage and other undefined activities. Special maintenance modules for satellite component repair will be added when SPS operational maintenance support begins. For example, two special maintenance modules will be included on level J when 20 SPS are operating. When 60 reference satellites become operational, six special modules will be needed.

3.0 DESIGN BASIS

All work modules have the same general configuration and subsystems described for the crew modules. For example, each work module will protect the crew from micrometeorites and trapped electron radiation. Protection from solar flares, however, is only provided in the crew habitats. The mass breakdown for these modules has been adjusted to reflect the results of the latest weight estimate for the crew quarters modules.

4.0 MASS AND MASS SUPPORT

	OPS CTR	BASE MAINT	MISC SUPT	SPEC MAINT	REFERENCE/SOURCE
STRUCTURE	70	70	70	70	GRUMMAN ESTIMATE D180-25402-1
ELEC. POWER	7	3	7	10	D180-25037-3
ECLS	18	10	4	30	SCALED TO HABITAT
CREW ACCOMM	4	3	3	5	
INFORMATION	30	5		8	
GUID & CONTROL	1				D180-25037-3
SPECIAL EQUIP		5		10	
GROWTH CONTINGENCY	43	32	28	44	33%
TOTAL MASS-MT	173	128	112	177	

1775-011W

5.0 COST DETAILS

PRODUCTION COST $M		1979 $
• CONSTR MODULES	(631)	
- OPERATIONS CENTER	316	BOEING PCM
- BASE MAINTENANCE	173	
- MISC. SUPPORT CENTER	142	
• MAINT MODULES	(646 to 1938)	
- 2 SPEC MAINT OR - 6 SPEC MAINT	646 OR 1938	BOEING PCM

1775-012W

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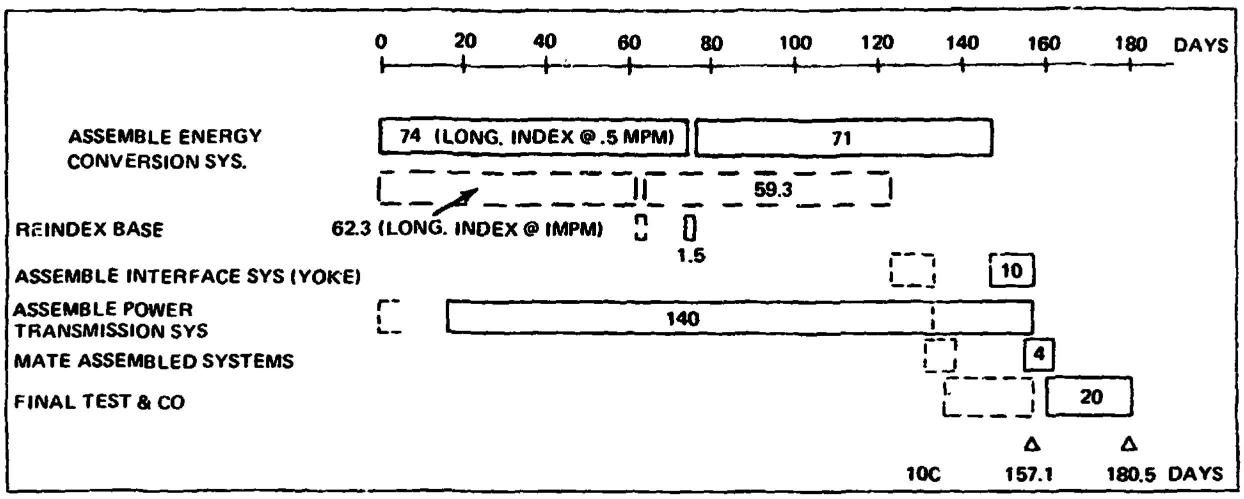

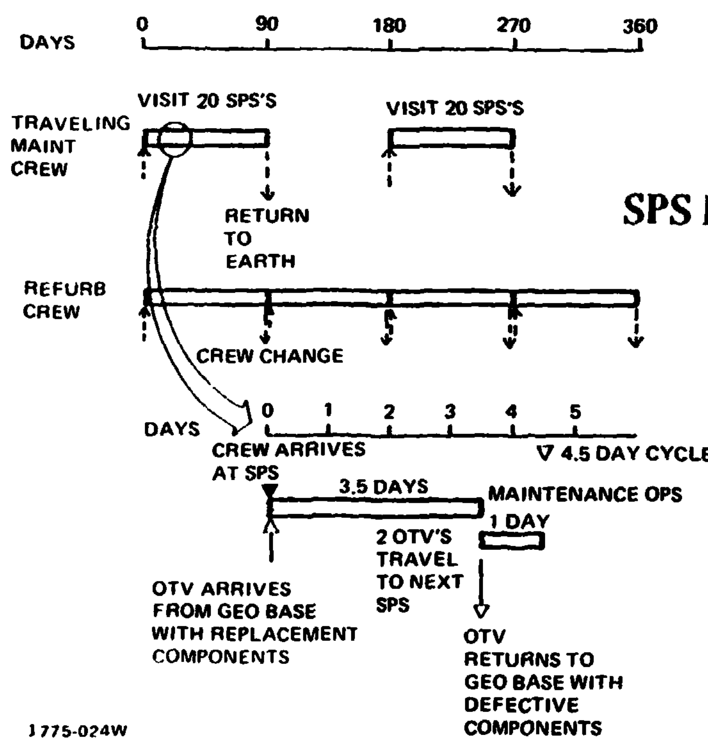

SPS Maintenance Timeline

WBS 1.2.1.3 OPERATIONS

1.0 WBS DICTIONARY

This element includes the planning, development, and conduct of operations at the GEO construction facility. It includes direct personnel, support personnel, base consumables, and expendable maintenance supplies required for satellite assembly operations and subsequent SPS maintenance support.

2.0 DESCRIPTION

The GEO base is staffed with 444 people to assemble and checkout one 5GW reference satellite every six months. The construction base operates on two 10 hour shifts per day for six days each week. The 4 bay wide construction base uses two passes to build the 8 x 16 bay energy conversion system; each pass provides a 4 x 16 bay module which contains the appropriate subsystems. Assembly of the energy conversion system is timed for simultaneous completion and mating with the power transmission system. Approximately 131 people are required to perform the construction activities on each shift. In addition to construction, other personnel are needed to perform base support system operations, maintain operations safety, provide flight transportation maintenance support, and implement base management. Up to 213 people may work on a single shift; multi-shift coverage is also provided around-the-clock for mission safety functions.

When SPS operational maintenance support is included, the GEO base crew complement will be increased to perform satellite component refurbishment and related crew support services. The number of personnel required for SPS maintenance and repair varies with the size of the operational fleet and the maintenance schedule adopted. It is presently planned that scheduled maintenance will be performed on each satellite twice a year, during the fall and spring seasons. When a 20 SPS fleet exists 83 people will be included in the mobile maintenance crew which operates from the GEO base. Another 300 people are needed to perform year around supporting component repair operations at the base. For a 60 SPS fleet, this complement will grow to 249 people on mobile maintenance and 900 people repairing equipment at the base.

3.0 DESIGN BASIS

The crew size defined for building two 5 GW satellites per year is derived from analyzing the major operational activities at the GEO base. These operations include construction and assembly operations related to the satellite systems (energy conversion, power transmission and interface), base command and control, cargo handling and distribution, base systems operations, base maintenance and transportation vehicle

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maintenance support. The two shift-6 day day per week construction crew defined in D180-25037-3 has been updated in D180-25402-1 to encompass multi-shift requirements for essential daily crew support functions (e.g., food service) and round-the-clock flight safety functions (i.e., flight control, paramedics, etc.).

During Phase II, the requirements for supporting EOTV maintenance and servicing GEO based OTV were defined. In addition, SPS support maintenance operations were defined for a fleet of 20 satellites.

GEO base consumable rates and expendable hardware requirements were established by analyzing the food and crew habitat ECLS to sustain 100 crew men for 90 days with 10% contingency. ECLS requirements for remote work stations were derived from the MRWS final reports (NAS9-15507). Resupply requirements for other subsystems and equipment were assumed to be equivalent to 2% of its dry weight every 90 days. Base flight control propellant usage was determined by analyzing a range of flight mode conditions during the 6 month satellite buildup scenario.

4.0 MASS & MASS BASIS

Resupply Item	ANNUAL RESUPPLY CONSTR OPS 444 CREW
• Crew Supplies	(418)
- Food	313
- Housekeeping & Other Items	105
• Crew Module Supplies	(190)
- ECLS O_2, N_2 & H_2O	99
- ECLS Life Limited Parts	80
- Other Subsys Parts	11
• Work Module Supplies	(126)
- OPNL CTR (O_2, N_2 & Parts)	36
- Maint Mod.	54
- Misc. Mod.	36
• Work Facility Supplies	(398)
- Constr Equip Parts	37
- Cargo Hdlg/Dist. Parts	32
- Crew Bus (O_2, N_2)	7
- SubAssy Factory, Parts	3
- Remote Work Sta. (O_2, N_2 & Parts)	145
- Base Subsys Parts	75
- Base Flt CTL Propellants	99
- Base Maint & Test Parts	TBD
- Transport Veh Maint Parts	TBD
- SPS Maint Supt Parts	-----
TOTAL	1125

1775-014W

5.2 CREW SIZE & COST DETAILS

OPERATION	MEN/ YR	RATIONALE	COST $M	RATIONALE
• GEO CONSTRUCTION			(661)	
- ORBITAL CREW	888	2 X BASE CREW	107	$120K/MAN-YR
- GROUND CREW	8880	10 X ORB CREW	444	$ 50K/MAN-YR
- TRAINING			110	20% SALARIES
• GEO MAINTENANCE SUPT			(570 TO 791)	
- ORB CREW (20 SPS) TO (60 SPS)	766 TO 2298	AS ABOVE	92 TO 276	AS ABOVE
- GRND CREW (20 & 60 SPS)	7660	10X20 SPS CREW	383	AS ABOVE
- TRAINING			95 TO 132	20% SALARIES

1775-013W

(W10% CONT)-MT SPS MAINT OPS 383 to 1149 CREW		RATIONALE	REF.
(361)	to (1081)		
270	809	Detail Est	PH-II MPR No. 6
91	272	Prior Studies	PH-II MPR No. 7
(151)	to (454)		
79	237	Estimate	PH-II MPR No. 6
64	193	Estimate	PH-II MPR No. 6
8	24	Guess (2%/QTR)	
(108)	to (323)		
-----	-----	Scaled to Habitat	PH-II MPR No. 7
108	323	Scaled to Habitat	PH-II MPR No. 7
-----	-----	Scaled to Habitat	PH-II MPR No. 7
(TBD)	(TBD)		
-----	-----	Guess (2%/QTR)	PH-II MPR No. 7
-----	-----	Guess (2%/QTR)	PH-II MPR No. 7
-----	-----	Shuttle Leakage	PH-II MPR No. 7
-----	-----	Guess (2%/QTR)	PH-II MPR No. 7
TBD	TBD	MRWS EST	PH-II MPR No. 7
-----	-----	Guess (2%/QTR)	PH-II MPR No. 7
-----	-----	Estimate	PH-II MPR No. 7
-----	-----		
-----	-----		
TBD	TBD		
620	to 2478		

WBS 1.2.1.3 RESUPPLY ITEMS

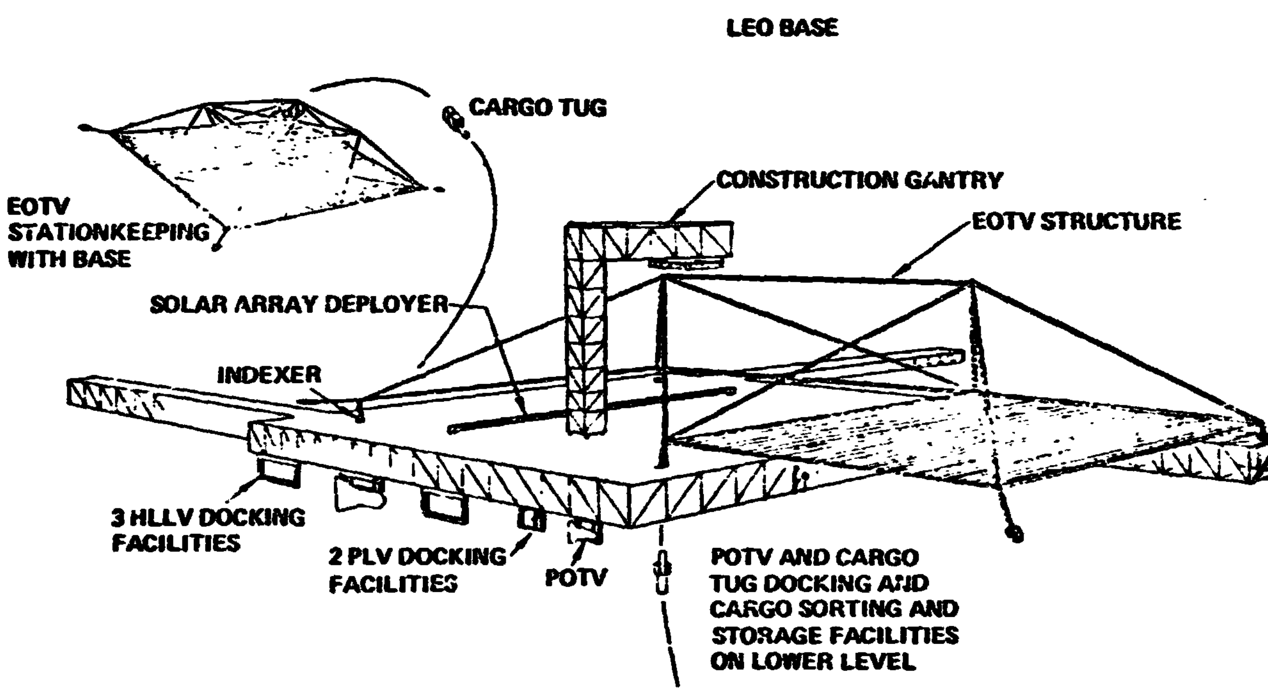
ITEM	ANNUAL RESUPPLY COST, $MILLIONS CONST	MAINT.	RATIONALE	REFERENCE
o CREW SUPPLIES				
- Food	1.4	1.2 to 3.7	$10/lb ($.54/kg)	Est.
- Housekeeping & others	.2	.2 to .6	$5/lb ($2.27/kg)	Est.
o CREW MODULE SUPPLIES				
- ECLS N_2, H_2O	neg. neg.	neg neg.	N_2: $.05/kg H_2O: $.01/kg	Factored from propellant costs
- ECLS Life Limited Parts	126.4	101 to 305	$1580/kg	Smeared avg. of total module cost ÷ total module mass
- Other Subsystem Parts	17.4	1.2 5o 3.8	$1580/kg	
o WORK MODULE SUPPLIES				
- Ops Center (O_2, N_2, Parts)	neg neg 2.8	neg neg	O_2: $.1/kg N_2: $.05/kg Parts: $1500/kg	Factored from propellant costs
- Maint. Module (O_2, N_2, Parts)	neg neg 4.2	neg neg 8.5 to 25.4	O_2: $.1/kg N_2: $.05/kg Parts: $1580/kg	
Misc. Modules (", ", ",)	neg neg 2.8	neg neg -	O_2: $.1/kg N_2: $0.5/kg Parts: $1580/kg	
o WORK FACILITY SUPPLIES				
- Const. Equip. Parts	144.8	-	$3913/kg	Smeared avg. of total equipment cost ÷ total equipment mass
- Cargo Handling/Dist. Parts	34.5	-	$1077/kg	Smeared average

(Continued)

WBS 1.2.1.3. RESUPPLY ITEMS

ITEM	ANNUAL RESUPPLY COST, $MILLIONS CONST.	MAINT.	RATIONALE	REFERENCE
o WORK FACILITY SUPPLIES				
- Crew Bus (H_2O, N_2)	neg neg	- -	H_2O: $.01/kg N_2: $.05/kg	
- Subassy factory parts	2.6	-	$8500/kg	Smeared average
- Remote Work Stations H_2O, N_2, Parts	neg neg 283.7	neg neg	H_2O: $.01/kg N_2: $.05/kg Parts: $3913/kg	
- Base Subsystem Parts	6.4	-	2% of unit cost	
- Base flight const. propellants	neg	-	A - 5¢/kg	
- Vehicle Supply Parts	9		$3000/kg	Smeared average
	$636.2 M/YR			

SPS-3040



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1.0 WBS DICTIONARY

This element includes the hardware, software and operations required in LEO to support the construction, operation and maintenance of the satellite system. Included are crew life support facilities, cargo and propellant depots, and vehicle servicing facilities necessary for the receiving, storage, and transfer of cargo and personnel destined for a construction base or operational satellite located in GEO. This element also includes hardware, software, and operations required to construct electrical orbital transfer vehicles (EOTV's).

2.0 DESCRIPTION

The LEO Base is shown in Figure A. It is used to construct EOTV's and it serves as a staging depot for cargo and crews destined for GEO.

The base gets its planform configuration from the requirements imposed by the EOTV construction operations. The main deck size is approximately the size of one EOTV bay. The outriggers provide the capability for indexing the EOTV structure in one-bay increments in three different directions during the construction process. The construction gantry and an assortment of construction equipment operate from the upper surface of the base.

The LEO base serves as a staging depot for cargo being transferred from HLLV's to EOTV's. The EOTV's will stationkeep with the LEO base during the cargo transfer operations conducted by cargo tugs.

The LEO base also serves a staging depot for the crews on their way between Earth and the GEO base. This requires transient crew quarters and the docking facilities and support equipment for the Earth-to-LEO crew vehicles (PLV's) and the interorbital crew transfer vehicles (POTV's).

3.0 DESIGN BASIS

The LEO Base facility, systems, equipment, and operations, are based on the following:

- o EOTV construction elements - based on constructing the EOTV configuration described in WBS 1.3.2 at the rate of one unit every 45 days. Refer to Operations and Systems Synthesis document (Boeing doc. no. D180-25461-3, Section 9).
- o Vehicle staging system elements - Refer to the following sections in the Operations and Systems Synthesis document: Sections 5, 7, 8, 9, 10, 11, and 15.

4.0/5.0 MASS AND COST

Refer to Table A for comprehensive mass and cost summary. Refer to subelement descriptions for mass and cost basis.

TABLE A

WBS 1.2.2 LEO BASE

COMPREHENSIVE MASS AND COST SUMMARY

WBS No.	Element	Mass, MT	DDT&E Cost, $ Millions	Unit Cost, $Million
1.2.2	LEO Base	1832.4	5005.1	3419.5
1.2.2.1	Work Support Facil.	1023	1515.1	1306.6
1.2.2.1.1	Structure	380	145.4	43.7
1.2.2.1.2	Const. Equip.	266	420.3	582.6
1.2.2.1.3	Cargo Handling/Dist. Equip.	165.5	517.1	342.8
1.2.2.1.4	Subassy's Factories	10	54.0	4
1.2.2.1.5	Test & C/O Facil.	-	-	-
1.2.2.1.6	Space Transp. Support	73	257.3	158.3
1.2.2.1.7	Base Maint.	48.7	-	62.2
1.2.2.1.8	Base Subsyst.	69.8	117	63
1.2.2.1.9	C&C	10	2	50
1.2.2.2	Crew Support Facilities	809.4	2271	1499
Wrap-Around Factors				
	Spares		(5%) 189	(15%) 196
	Inst., Assy, C/O			(16%) 209
	SE&E		(5%) 189	(7%) 91.5
	Proj. Mgmt. (10% of others)		111	(2%) 26
	Syst. Test		(10%) 378	(3%) 39.2
	GSE		(5%) 189	(4%) 52.2
	Software		(3%) 114	-
	Logistics		34	-
	Liaison		15	-
			1219	6613.9
Annual				
	o Resupply	533.5 MT/YR		$284 M/Yr
	o Salaries & Training			$341.2 M/Yr
				$625.2 M/Yr

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TABLE A

WBS 1.2.2.1 SUBELEMENTS

- WBS 1.2.2.1.1 Structure
- WBS 1.2.2.1.2 Construction Equipment
  - WBS 1.2.2.1.2.1 Beam Machine System
  - WBS 1.2.2.1.2.2 Cherry Pickers
  - WBS 1.2.2.1.2.3 Bus Deployment Machines
  - WBS 1.2.2.1.2.4 Indexers
  - WBS 1.2.2.1.2.5 Solar Array Deployment System
  - WBS 1.2.2.1.2.6 Construction Gantry
- WBS 1.2.2.1.3 Cargo Handling/Distribution Systems
  - WBS 1.2.2.1.3.1 Cargo Loading/Unloading Systems
  - WBS 1.2.2.1.3.2 Cargo Transporters
  - WBS 1.2.2.1.3.3 Cargo Sorting Systems
  - WBS 1.2.2.1.3.4 Cargo Storage Systems
  - WBS 1.2.2.1.3.5 Cargo Distribution System
  - WBS 1.2.2.1.3.6 Crew Transporters
- WBS 1.2.2.1.4 Subassembly Factories
- WBS 1.2.2.1.5 Test/Checkout Facilities
- WBS 1.2.2.1.6 Space Transportation Support Systems
  - WBS 1.2.2.1.6.1 Vehicle Docking Systems
  - WBS 1.2.2.1.6.2 Assembly System
  - WBS 1.2.2.1.6.3 Propellant Storage and Distribution System
  - WBS 1.2.2.1.6.4 Maintenance Systems
- WBS 1.2.2.1.7 Base Maintenance Systems
- WBS 1.2.2.1.8 Base Subsystems
  - WBS 1.2.2.1.8.1 Electrical Power System
  - WBS 1.2.2.1.8.2 Flight Control Systems
- WBS 1.2.2.1.9 Command and Control Systems

1.0 WBS DICTIONARY

This element includes the facilities and equipment required to provide construction and logistics support in LEO. Included are EOTV construction facilities and equipment, HLLV/PLV/POTV/CARGO TUG docking stations, payloads handling equipment, cargo and propellant storage depots and vehicle maintenance support systems. Excluded are facilities related to crew element support.

2.0 DESCRIPTION

The subelements of the Work Support Facilities are listed in Table A. Refer to the description sheets for these elements for details.

3.0 DESIGN BASIS

The LEO Base was designed to meet the requirements and ground rules listed in Table B.

4.0 MASS AND MASS BASIS

Mass summarized in WBS 1.2.2.

5.0 COST

Cost summarized in WBS 1.2.2.

TABLE B
LEO BASE REQUIREMENTS AND GROUND RULES

1. Provide Electric Orbit Transfer Vehicle (EOTV) construction facilities equipment, and operations that enable EOTV's to be constructed at the rate of one vehicle every 45 days.

2. EOTV construction operations to be performed:

   a. Frame assembly
   b. Solar Array deployment
   c. Power bus system installation
   d. Thruster system installation
   e. Cargo platform assembly
   f. Avionics system installation
   g. Annealing machine assembly and installation
   h. Test and checkout
   i. Subassembly operations
      1) Thruster subassembly
      2) Switchgear subassembly
      3) Power bus support structure subassembly
      4) Structural fitting subassembly

3. Provide docking and payload handling systems for the following space vehicles:

   a. Heavy Lift Launch Vehicles (HLLV's)
   b. Personnel Launch Vehicles (PLV's)
   c. Cargo Tugs
   d. Personnel Orbital Transfer Vehicles (POTV's)

4. Provide equipment and systems for maintaining the Cargo Tugs, POTV's, and EOTV's.

5. Provide propellant transfer and storge systems for the base attitude control system.

6. Provide cargo sorting, storage, and transfer systems and equipment.

7. Provide the following types of crew modules:

   a. Crew Living Quarters Modules
   b. Maintenance Module
   c. Operations Module
   d. Transient Crew Quarters Module
   e. Training Module

8. Free-flying of assemblies or construction and logistics equipment is to be avoided.

9. Provide a common base logistics track network for moving cargos, crew, and construction equipment. The logistics track will have a gauge compatible with the size of the base framework beams. Provide alternate pathways to every facility location. Ensure that there will not be competition for a specific track location. All vehicles self-powered and operator driven.

TABLE B
LEO BASE REQUIREMENTS AND GROUND RULES (CONT'D)

10. Ensure that relative motion between the facility/construction equipment and the parts being assembled are compatible with the accuracy and time constraints involved in the construction operations.

11. Provide for base attitude control and station keeping. Thruster installation and thrust level to accommodate mass and CG excursions during construction operations. Thrust level not to exceed $5 \times 10^{-5}g$. Thrust will be constant thus allowing burn time to vary.

12. EVA construction tasks should not be required, except for infrequent maintenance and inspection tasks.

13. Mobile beam machines operating autonomously are to be used to produce the various lateral, vertical and diagonal beams as needed to complete the EOTV structure.

14. Structural beam segments are to be transported and installed by cherry pickers (elbow type cranes with Manned Remote Work Stations) at each end. These cherry pickers are:

    - controlled by one operator in the MRWS
    - self propelled by onboard power supply
    - Operated from a rail track system on the construction facility.

15. Construction operations will be performed during two ten hour shifts per day and at 75% efficiency.

16. The GEO construction base interfaces with the energy conversion system structure via indexing/support machines that provide the capability to index in orthogonal directions. Those indexers are:

    - Mobile towers with mechanisms for attachment to hard points on the energy conversion system structure.
    - Self powered with onboard power supply
    - Remotely controlled/monitored from base command and control center and can be slaved
    - Operated from a rail track system on the construction facility.

17. Construction equipment rates ranging from 0.5 to 20 mpm, shown in Table A-1, are assumed to be reasonable. Low equipment utilization should be avoided.

18. Provide systems and equipment for command and control operations.

TABLE A-1 - EQUIPMENT OPERATING TIMES & RATES

BEAM MACHINE	
Aim Beam Machine - rotate in yaw 90° - elevate 45° or 90°	5 min
Average Beam Fabrication Rate	5 m/min
Install End Fittings	10 min
Inspect	*
Handoff	5 min
Travel	20m/min
CHERRY PICKERS	
Install Beam	10 min
Travel	50 m/min
INDEXER/SUPPORT	
Attach	TBD
Index/Travel	10 m/min

* Included in beam fabrication time

FOLDOUT FRAME

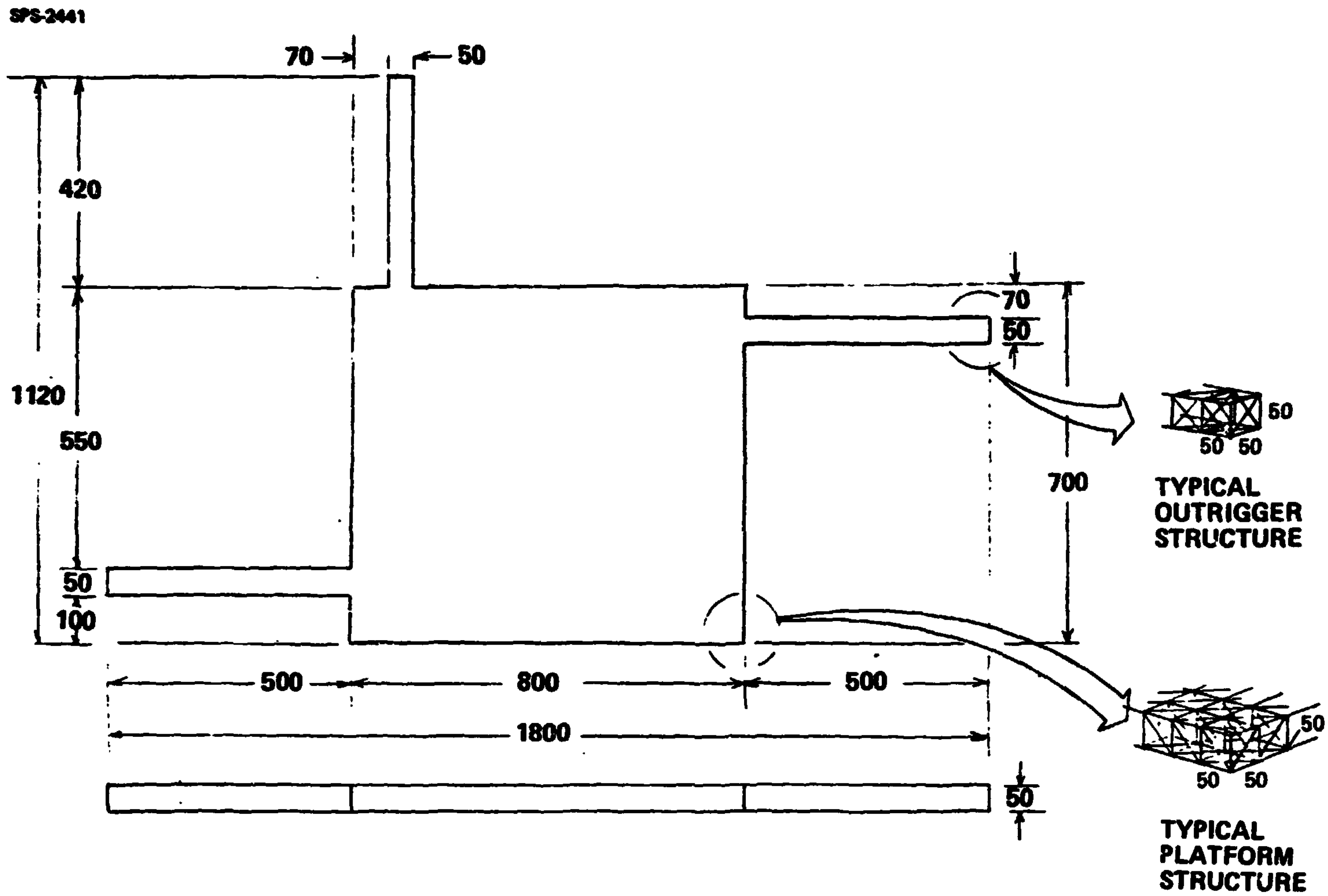

Figure A—LEO Base Structural Envelope

WBS 1.2.2.1.1 STRUCTURE

1.0 WBS DICTIONARY

This element includes the primary and secondary structure of the LEO Base.

2.0 DESCRIPTION

The LEO Base structural configuration has not been defined below the level of detail shown in Figure A. The structural beam size and type is TBD.

3.0 DESIGN BASIS

The planform was established by track pattern required to facilitate the EOTV and construction gantry indexing operations during EOTV construction. Refer to WBS 1.2.2.3 for the indexing maneuver description and to WBS 1.2.2.1.3.5 for the track pattern.

The 50 meter vertical dimension and the 50 meter wide outrigger dimensions were arbitrarily specified.

When the base structure is detailed in the future, in addition to providing the necessary structure for the track network, the structural design should be based on both static and dynamic stiffness criteria (see ground rule 10 in Table B in WBS 1.2.2.1) and on providing structural interfaces for all facility-attached systems.

4.0 MASS

The structural mass is estimated to be 5 kg/M x 76000 M = 380 MT.

5.0 COST

Unit Cost

$115/kg x 380 MT = $43.7 M

DDT&E

Based on repetitive unit 50x50x50M
(1400 cells total)

o	Design	$10 M	
o	System Engin. and Integ.	34	
o	Software	35	Scaled from
o	Unit (10%)	4.4	Antenna
o	Logistics and Data	10	Structures
o	Ground Test	24	DDT&E
o	Sustaining Engin.	17	
		134.4 M	
o	10% for program Mgmt and Integ	13	
		147.7 M	

o By-phase costing done at base level

FOLDOUT FRAME

Table A—Construction Equipment Mass and Cost Summary

Item	Quantity	MASS, MT Each	MASS, MT Subtotal	COST, $Millions Average	COST, $Millions Subtotal
o 7.5m Gimballed, Mobile, Manned Beam Machines	2	15	30	53.4	106.8
o 20M Cherrypicker [1]	10	2	20	17.0	170
o 50m Cherrypicker [1]	5	3.5	17.5	26.4	132
o 90m Cherrypicker	1	5	5	28.1	28.1
o 230m Cherrypicker	1	9	9	39.4	39.4
o 45m Indexer	6	1.3	7.8	3	18
o Bus Deployer	1	8	8	22.2	22.2
o Solar Array Deployment System	1	11	11	40	40
o Construction Gantry	1	169	169	22	22
Totals			266mt		$578.5m

[1] Total no. of cherrypickers include those required for construction, subassembly, cargo handling, and maintenance opeı ations.

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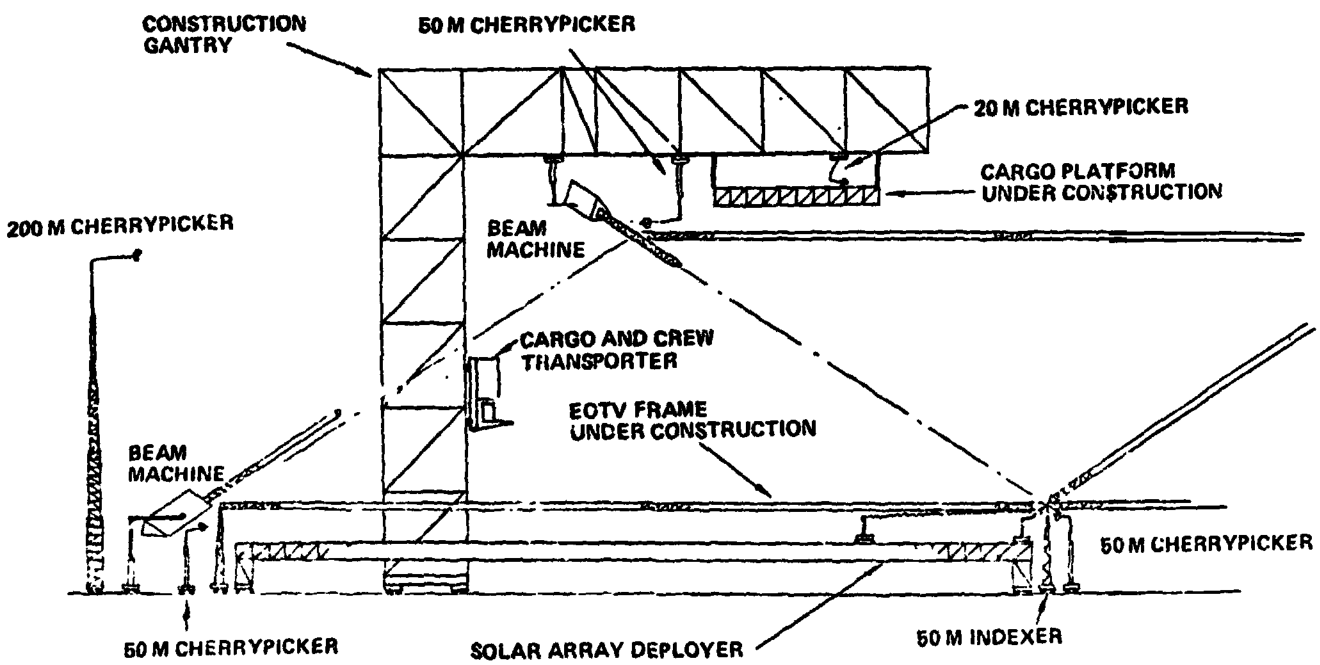

Figure A—Construction Equipment Locations

1.0 WBS DICTIONARY

This element includes all equipment items dedicated to construction of the EOTV with the exception of equipment utilized in subassembly operations (the latter are included in WBS 1.2.2.1.4).

2.0 DESCRIPTION

Table A provides a summary of the equipment types, quantities, mass, and cost.

The general location of the construction equipment is shown in Figure A. The integrated construction operation encompasses solar array deployment, power bus installation, thruster system installation and payload pallet assembly. Refer to WBS 1.2.2.3.1 for description of the operations that use the construction equipment.

The beam machines, cherry pickers, indexers and bus deployers are essentially identical to those described for the GEO Base (see WBS 1.2.1.1.2) so they are not described on the following pages. Detailed descriptions of the solar array deployment equipment and construction gantry are found in the Operations and Systems Synthesis document (D180-25461-3), Section 9.1.

3.0 DESIGN BASIS

The construction equipment concepts were adapted for the EOTV construction operation from concepts defined for various SPS construction concepts. It is highly desirable to use SPS construction equipment wherever feasible in order to minimize development costs. Using the same types of construction equipment also will provide a means to test and verify the equipment and procedures prior to the SPS construction operations.

4.0 MASS AND MASS BASIS

See Table A

5.0 COST

Unit Cost

Refer to Table A $582.6 M

DDT&E

DDT&E = 3.67583 kg .3794 = $420.3 M

o By-phase costing development base level

FOLDOUT FRAME

TABLE B: WBS 1.2.2.1.2 CONSTRUC
MASS AND COST ESTIMATI

WBS NO.	ITEM	QTY [2] L	G	T	MASS, MT	MASS, METRIC TONS RATIONALE
1.2.2.1.2.1	**BEAM MACHINES**					
	o 7.5m Sync. Travel	-	10	10	11	Proportional to GIM. MOB. MAN
	o 7.5m Gimballed, Mobil, Manned	2	6	8	15	o Control CAB MWRS o BEAM Machine Scaled from SFDS o Carriage/Yoke/ Etc. Estimate by BAC
	o 12.5 GIM.MOB. MAN.		1	1	21	Scaled from above
1.2.2.1.2.2	**CHERRYPICKERS**					
	o 30M	10	10	20	2.5	o Control Cab From MWRS o Carriage/Boom-/ etc. Estimate by
	o 90m	6	6	12	5	Proportional to 30m CP
	o 120m	-	3	3	7	Proportional to 30m CP
	o 250	1	1	2	9	Proportional to 30m CP
1.2.2.1.2.3	**INDEXERS**					
	o 45m	6	5	11	1.3	ROM est
	o 130m	-	14	14	3	Proportional to 4SM Ind.
	o 230m	-	2	2	5.5	Proportional to 4SM Ind.
1.2.2.1.2.3	**BUS DEPLOYER - 90m**	1	3	4	8	Proportional to beam machine
1.2.2.1.2.5	**SOLAR ARRAY DEPLOYMENT SYSTEM**	1	-	1	12	Proportional to beam machine
1.2.1.1.2.6	**ANTENNA DEPLOYMENT SYSTEM**	-	1	1	28	Proportional to beam machine

[1] Use 90% learning curve

[2] L = Total required at LEO Base
G = Total required at GEO Base
T = Combined total used for cost estimate.

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WBS 1.2.2.1.2 CONSTRUCTION EQUIPMENT (CONT'D)

:TION EQUIPMENT
ING DATA

REF.	TFU	AVE [1]	COST, $ MILLIONS RATIONALE	REF
BAC/ GAC	35	28	Proportional to GIM.MOB.MAN.	BAC/GAC
BAC/ GAC	65	53.4	o Control CAB Scaled from MWRS	BAC/GAC
			o BEAM Machine Scaled from SFDS	
			o Carriage/Yoke/ Etc. Estimate by	BAC
BAC/ GAC	75	75	Scaled from above	BAC/GAC
BAC/ GAC	26	19	o Control Cab From MWRS	BAC/GAC
BAC			o Carriage/Boom-/ etc. Estimate by	BAC
BAC/ GAC	36	28.1	Proportional to 30m CP	BAC/GAC
BAC/ GAC	38	34.5	Proportional to 30m CP	BAC/GAC
BAC/ GAC	41	39	Proportional to 30m CP	BAC/GAC
BAC	3.8	3	ROM est	BAC
BAC	6	4.6	Proportional to 4SM Ind.	BAC
BAC			Proportional to 4SM Ind.	BAC
BAC	25	22.2	Proportional to beam machine.	BAC
BAC		45	Proportional to beam machine	BAC
BAC		80	Proportional to beam machine	BAC

FOLDOUT FRAME

TABLE A - SUBELEMENTS

SUBELEMENTS		QTY	RATIONALE
WBS 1.2.2.1.3.1	Cargo Loading/Unloading Systems		
o WBS 1.2.2.1.3.1.1	Cargo Pallet Handling Machine	3	o 1 per HLLV Docking system
o WBS 1.2.2.1.2.2	Cherrypickers - 20M	(4) ▷1	o 2 per cargo sorting system + 2 for cargo tug OPS
	Cherrypickers - 40M	(2) ▷1	o 1+1 spare for supply module handling
o WBS 1.2.2.1.3.1.2	Pallet Handling Jig	2	o 1 per cargo tug
WBS 1.2.2.1.3.2	Cargo Transporters	20	o 10 for cargo staging o 10 for construction
WBS 1.2.2.1.3.3	Cargo Sorting Systems	1	o Only 14 Pallets of EOTV components per year
WBS 1.2.2.1.3.4	Cargo Storage Systems	2	o Storage for contents of 2 Cargo pallets
WBS 1.2.2.1.3.5	Cargo Distribution System	18085 M	o See Level A and Level B track Patterns (Gantry-Attached Tracks accounted for in WBS 1.2.2.1.2.6)
WBS 1.2.2.1.3.6	Crew Transporters		
WBS 1.2.2.1.3.6.1	Crew Transfer Tunnel Systems	5	o 1 per each PLV and HLLV docking system
WBS 1.2.2.1.3.6.2	Crew Bus - 10 man	3	o 2 on base, 1 on
	Crew Bus - 24 man	3	o 3 required to offload PLV's and POTV's expeditiously

▷1 Cherrypickers have been accounted for in WBS 1.2.2.1.2

WBS 1.2.2.1.3 CARGO AND PERSONNEL HANDLING/DISTRIBUTION SYSTEMS

1.0 WBS DICTIONARY

This element includes the hardware used to offload/load transportation vehicles (the HLLV, cargo tug, EOTV, and POTV), transport cargo about the base, offload/load cargo pallets, store cargo, and transport crew about the base. Excluded are the docking systems associated with the transportation vehicles (these are covered in WBS 1.2.2.1.6.1)

2.0 DESCRIPTION

The cargo and personnel handling and distribution operations take place primarily on the lower level (level B) of the LEO base, see Figure A.

The cargo handling operations are depicted in Figure B. Cargo pallets are removed from and loaded into the HLLV cargo bay using the cargo pallet handling machine (WBS 1.2.2.1.3.1.1), shown in Figure C. The cargo pallets are placed onto cargo transporters (WBS 1.2.2.1.3.2), shown in Figure D, for transportation around the facility track network (WBS 1.2.2.1.3.5), shown in Figure A and E. Some of the cargo pallets are delivered to the cargo sorting/storage area (WBS 1.2.2.1.3.3 and 1.2.2.1.3.4), shown in Figure F. The EOTV construction components and other materials consummed at the LEO base, are then delivered to the construction equipment, subassembly factories, or other locations via cargo transporters. The transporters are offloaded by cherrypickers. The cargo pallets destined for GEO are transported to the cargo tug operations area. A cargo tug equipped with a pallet handling jig (WBS 1.2.2.1.3.1.2) removes the pallet from the transporter, see Figure G. The pallet is transferred to an EOTV (that is stationkeeping with the LEO base) and is installed onto the EOTV's cargo platform, see Figure H.

The spacecrews transfer from the PLV to a crew bus (WBS 1.2.2.1.3.6.2) via a crew transfer tunnel system (WBS 1.2.2.1.3.6.1), see Figure I. The crew bus delivers the crew to crew habitats. The GEO crewmembers are taken to the POTV operations area, see Figure J, where they are tranferred to the passenger module. The supply modules to be transported by the POTV were delivered to the LEO base by HLLV enclosed in a cargo pallet. They were removed at the cargo sorting area and transported to the POTV OPS area where they get installed onto the POTV via cherrypickers (see Figure J).

3.0 DESIGN BASIS

The requirements for the cargo and personnel handling and distribution system hardware elements were derived by operations analyses, see Table B.

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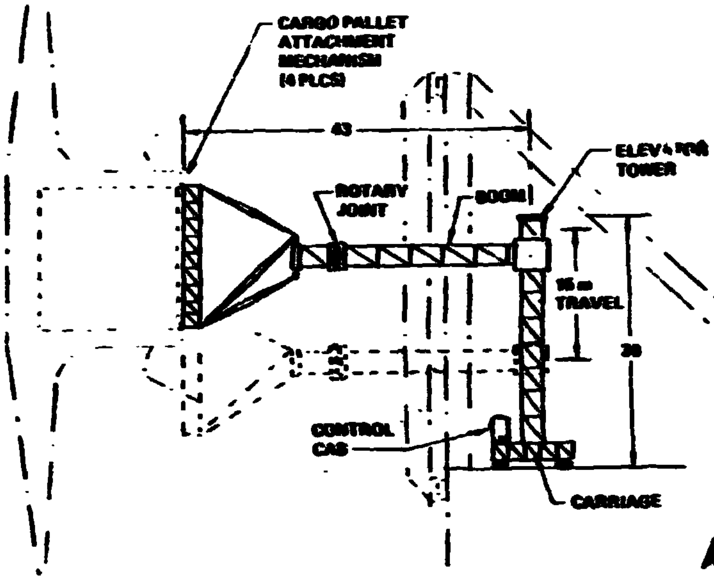
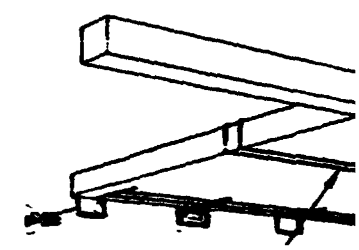
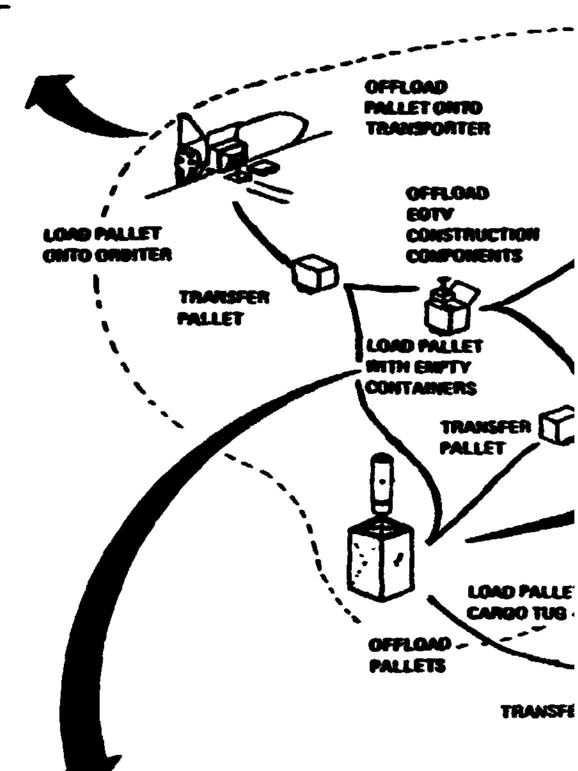


FIGURE C. CARGO PALLET HANDLING MACHINE (WBS 1.2.2.1.3.1.1)



LEVEL B TRACKS (WBS 1.2.2.1.3.5)

FIGURE B. CARGO



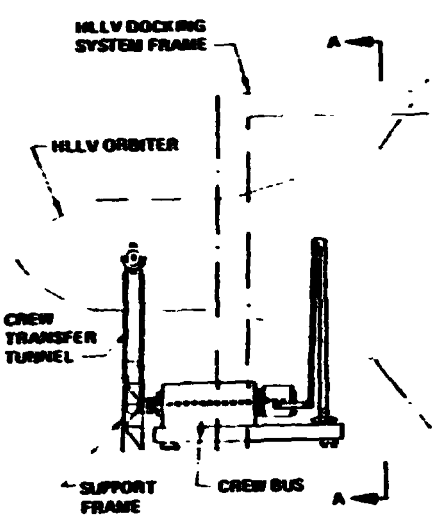


FIGURE I. CREW TRANSFER TUNNEL SYSTEM (WBS 1.2.2.1.3.6.1)

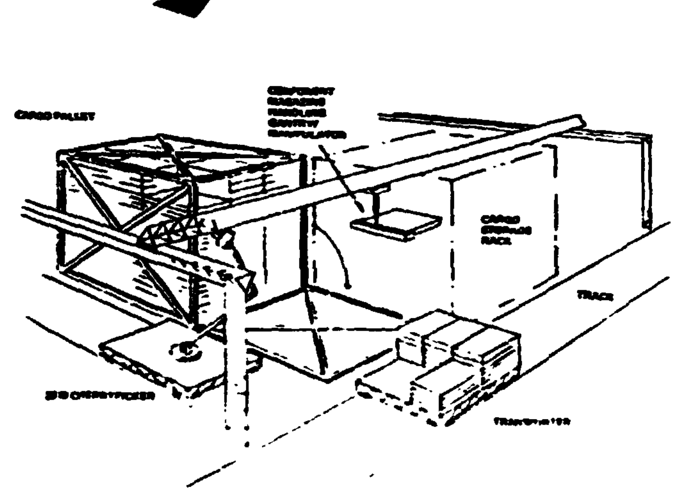
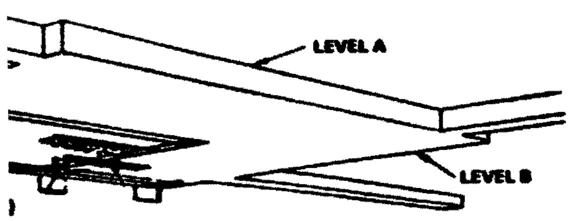


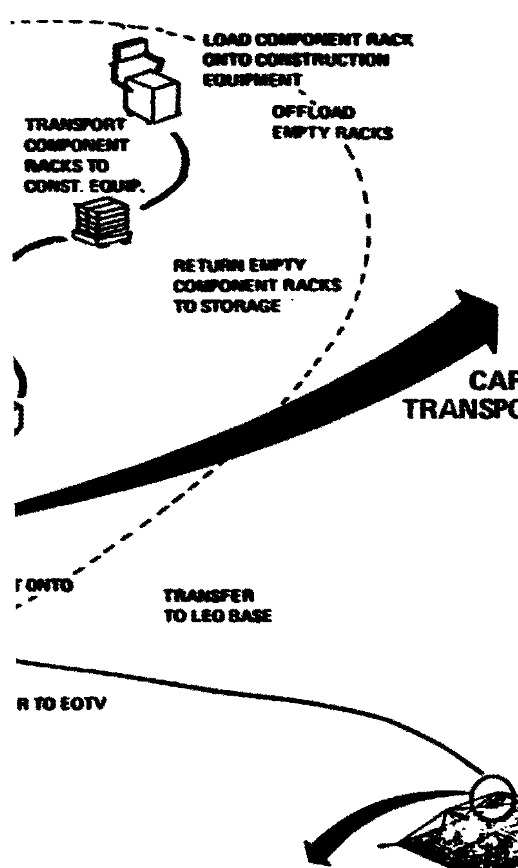
FIGURE F. CARGO SORTING/STORAGE AREA (WBS 1.2.2.1.3.3)

WBS 1.2.2.1.3 CARGO AND PERSONNEL HANDLING/ DISTRIBUTION SYSTEMS (CONT'D)

FIGURE A.



HANDLING OPS



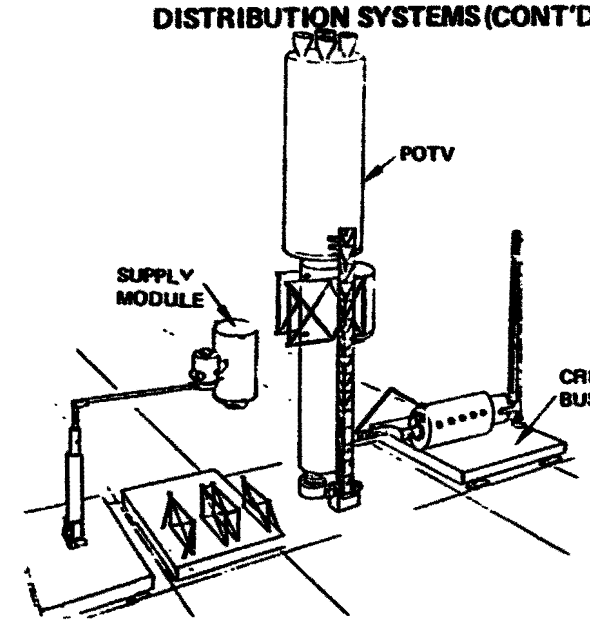


FIGURE J. LEO BASE PERSONNEL OTV SUPPORT SYSTEMS

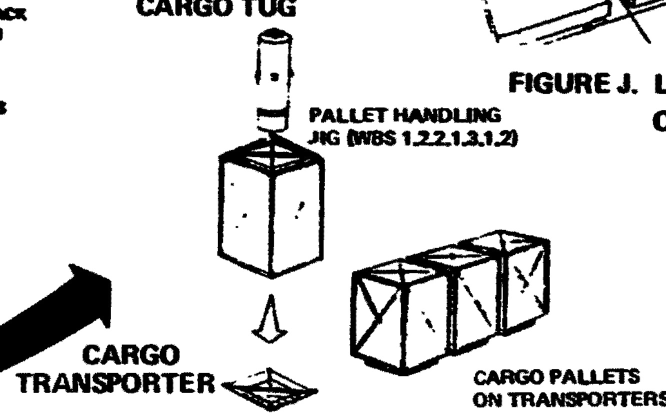


FIGURE G.

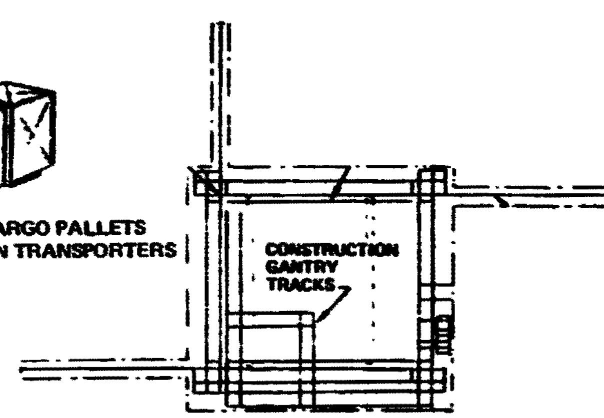


FIGURE E. LEVEL A TRACKS (WBS 1.2.2.1.3.5)

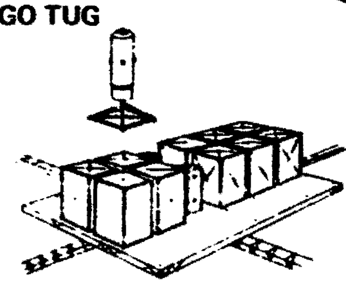


FIGURE H. EOTV CARGO PLATFORM

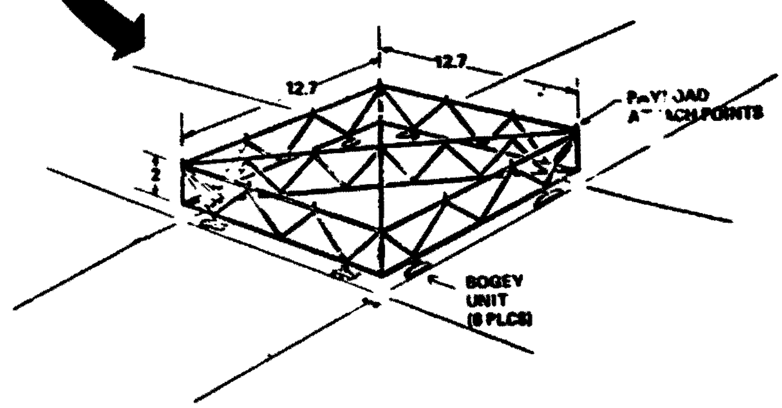


FIGURE D. CARGO TRANSPORTER (WBS 1.2.2.1.3

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TABLE B - SUBELEMENT DESIGN BASIS

SUBELEMENT		REQUIREMENTS DEFINED IN DOCUMENT
WBS 1.2.2.1.3.1.1	Cargo Pallet Handling Machine	Vol. III - Operations and Systems Synthesis, sections 5 and 6
WBS 1.2.2.1.3.1.2	Pallet Handling Jig	Ibid, Sections 5 and 10
WBS 1.2.2.1.2.2	Cherrypickers	Ibid, Sections 5, 7, 8, 9, 10
WBS 1.2.2.1.3.2	Cargo Transporters	Ibid, Sections 5, 7, 8, 9, 10
WBS 1.2.2.1.3.3	Cargo Sorting Systems	Ibid, Sections 5, 9
WBS 1.2.2.1.3.4	Cargo Storage Systems	Ibid, Sections 5, 9
WBS 1.2.2.1.3.5	Cargo Distribution System (Track Network)	Ibid, Section 5, 7, 8, 9, 10
WBS 1.2.2.1.3.6	Crew Transporters	Ibid, Section 7, 9

4.0 MASS AND MASS BASIS

The equipment mass is shown in Table C. The mass basis is given in Table D.

5.0 COST AND COST BASIS

5.1 COST SUMMARY

	Cost, $ Millions
o Research	
o Engineering Verification	
o Demonstration	
o Investment	342.8 (See Table C)
o Production	

5.2 COST BASIS

	Cost, $ Millions	Reference/Rationale
o Research		
o Engineering Verification		
o Demonstration		
o Investment	342.8	See Table D

TABLE C

WBS 1.2.2.1.3 CARGO AND PERSONNEL HANDLING/DISTRIBUTION SYSTEM MASS AND COST SUMMARY

			MASS, MT		COST, $ M	
ITEM		QTY	EA.	TOTAL	EA	TOTAL
WBS 1.2.2.1.3.1.1	Cargo Pallet Handling Machine	3	15	45	30.2	90.6
WBS 1.2.2.1.3.1.2	Cherrypickers	6		[1]		[1]
WBS 1.2.2.1.3.1.3	Pallet Handling Jig	2	.5	1	.9	1.8
WBS 1.2.2.1.3.2	Cargo Transporters	20	1	20	2	40
WBS 1.2.2.1.3.3	Cargo Sorting Systems	1	2.5	2.5	23.1	23.1
WBS 1.2.2.1.3.4	Cargo Storage Systems	2	5	10	.8	1.6
WBS 1.2.2.1.3.5	Tracks	18000 M	2 KG/M	36	$200/KG	7.2
WBS 1.2.2.1.3.6.1	10-Man Crew Bus	3	5	15	17	51
WBS 1.2.2.1.3.6.2	24-Man Crew Bus	3	12	36	42.5	127.5
TOTALS				165.5		342.8

[1] The cherrypickers have been included in the total cherrypicker count in WBS 1.2.2.1.2 - Construction Equipment

FOLDOUT FRAME /

TABLE D: WBS 1.2.2.1.3 CARGO AND PERSONNEL H/
MASS AND COST ESTIMA'

WBS NO.	ITEM	QTY [2] L	G	T	MASS, METRIC TONS MASS, MT	RATIONALE
1.2.2.1.3.1.1	CARGO PALLET HANDLING MACHINE	3	-	3	15	Proportional to cherrypicker
1.2.2.1.3.1.3	CARGO PALLET HANDLING JIG	2	2	4	5	Guess
1.2.2.1.3.2	CARGO TRANSPORTERS	20	20	40	1	Proportional to 45m Indexes
1.2.2.1.3.3	CARGO SORTING SYSTEMS	1	3	4	2.5	Proportional to 30m CP
1.2.2.1.3.4	CARGO STORAGE SYSTEMS	2	6	8	5	Guess
1.2.2.1.3.5	TRACK SYSTEM	18			2 KG/M	ROM est.
1.2.2.1.3.6.1	10-MAN CREW BUS	3	3	6	5	Proportional to const. equip.
1.2.2.1.3.6.2	24-MAN CREW BUS	3	3	6	12	Proportional to const. equip.

[1] Use 90% learning curve

[2] L = Total required at LEO Base
G = Total required at GEO Base
T = Combined total used for cost estimate

ANDLING AND DISTRIBUTION SYSTEMS
TING DATA

REF.	TFU	AVE [1]	COST, $ MILLIONS RATIONALE	REF
BAC est.	33	30.2	Proportional to cherrypicker	BAC est.
BAC	1	.9	Guess	BAC
BAC	3	2	Proportional to 45m Indexes	BAC
BAC	26	23.1	Proportional to 30m CP	BAC
BAC	1	.8	Guess	BAC
BAC	$200/KG		ROM est.	BAC
BAC	20	17.0	Scaled to PM	BAC
BAC	50	42.5	Scaled to PM	BAC

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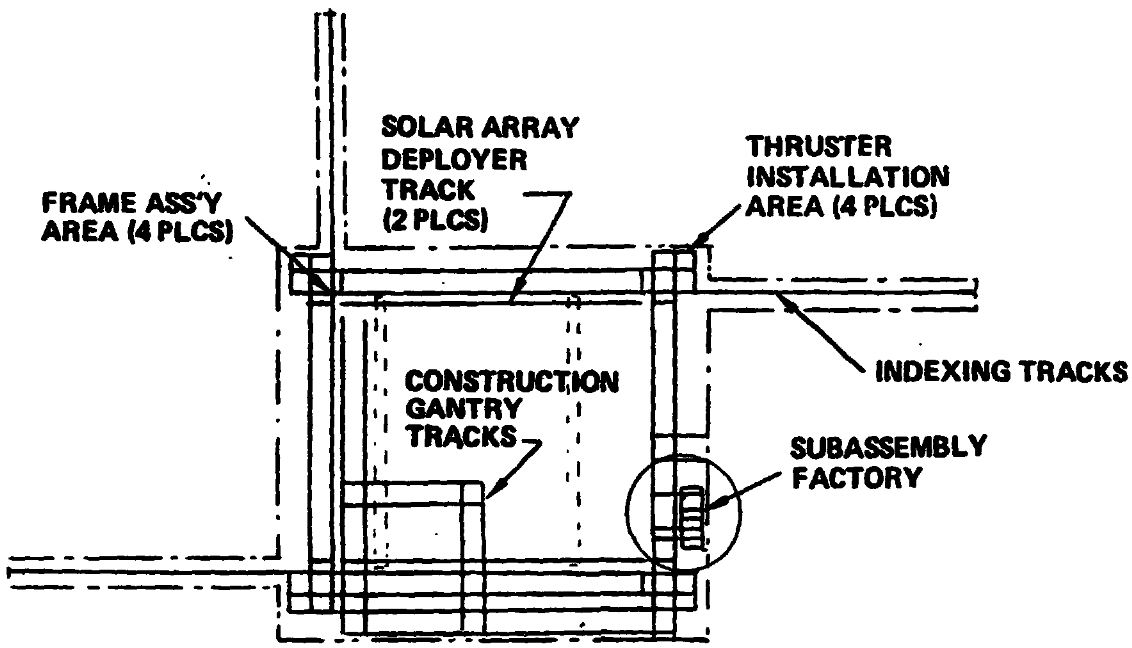


Figure A—Level A

1.0 WBS DICTIONARY

This element includes the facilities and equipment dedicated to preassembly of EOTV subassemblies prior to delivery to the final installation facilities.

2.0 DESCRIPTION

Figure A shows the location of the subassembly factory area on level A of the LEO Base. The EOTV subassemblies that are fabricated in this factory area are identified in Table A. This table also shows the configurations, identifies the quantity required per EOTV, and specifies the equipment and crew required to assembly the items.

3.0 DESIGN BASIS

The subassembly factory is located on level A so that the transportation of the very large subassemblies (thrusters, radiators) does not have to contend with a level B-to-level A transition.

The subassemblies to be fabricated in the subassembly factory are those that are 1) too complicated (i.e. too many types of components) to assembly in place on the EOTV, or 2) components that cannot be assembled by the beam machines or other mobile construction equipment.

The subassembly operations are co-located in one subassembly factory area to enable construction equipment and crew to be shared.

4.0 MASS AND MASS BASIS

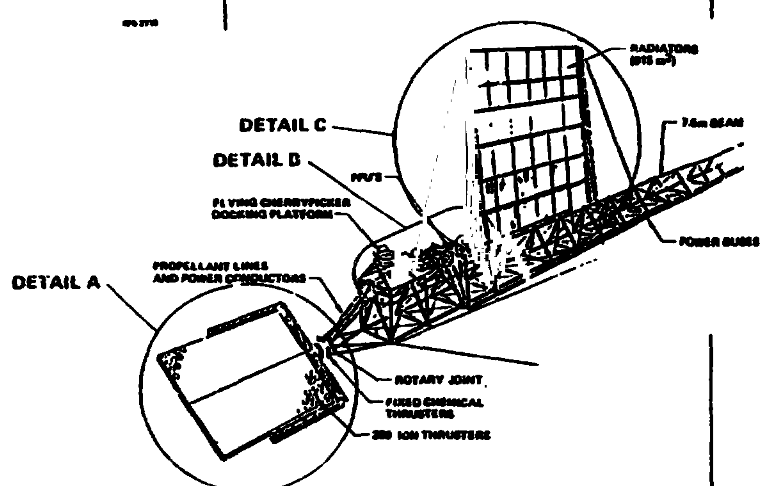
The mass of the subassembly factory equipment is estimated to be 10 MT (Cherrypickers excluded).

5.0 COST

The unit cost of the subassembly factory equipment is estimated to be $4M (Cherrypickers excluded).

DDT&E = 3.67583kg .3794 = $54M

TABLE A SUBASSEMBLY FACTORIES DATA



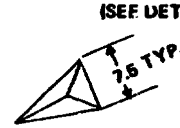
SUBASSY WBS NO.	SUBASSEMBLY NAME	CONFIGURATION	QTY/ EOTV	ASSEMBLY EQUIPMENT ITEM	ASSEMBLY EQUIPMENT QUANTITY	FLOOR SPACE MXM	NO. OF PEOPLE/ SHIFT
1.3.2.3	ELECTRIC THRUSTER/YOKE/ ROTARY JOINT/CHEM THRUSTER SUBASSEMBLY	(SEE DETAIL A)	4	• ASSY JIG/TRANSPORTER • 20M CHERRYPICKER • MISC. TOOLS	1 2 –	50 X 50	2 (PART TIME)
1.3.2.2	PPU/DOCKING PLATFORM PALLET SUBASSEMBLY	(SEE DETAIL B)	4	• ASSY JIG/TRANSPORTER • 20M CHERRYPICKER • MISC. TOOLS	1 2 –	15 X 30	2 (PART TIME)
1.3.2.3	RADIATOR SUBASSEMBLY	(SEE DETAIL C)	4	• ASSY JIG/TRANSPORTER • 20M CHERRYPICKER • TUBE WELDERS • MISC. TOOLS	1 2 2	50 X 50	2
1.3.2.1	BEAM END FITTINGS	 7.5 TYP.	83	• STRUT FORMING MACH. • ASSY JIG • CHERRYPICKER • MAGAZINE • TRANSPORTER	1 1 1 4 1	15 X 30	1

TABLE A (CONT)

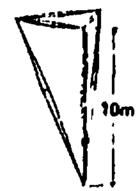
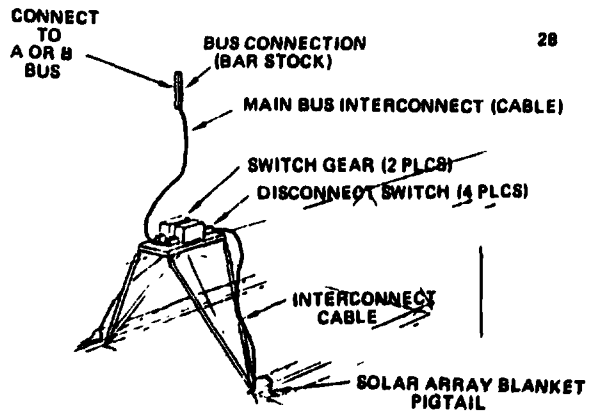
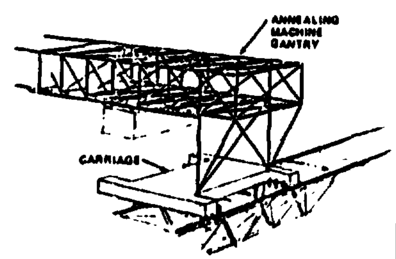
SUBASSY WBS NO.	SUBASSEMBLY NAME	CONFIGURATION	QTY/ EOTV	ASSEMBLY EQUIPMENT		FLOOR SPACE MXM	NO. OF PEOPLE/ SHIFT
				ITEM	QUANTITY		
1.3.2.2	POWER BUS SUPPORT BRACKETS		470	• STRUT FORMING MACHINE • ASSY JIGS • 20M CHERRYPICKERS • TRANSPORTERS	2 2 1 2	30 X 30	4
1.3.2.2	SWITCH GEAR PALLET SUBASSEMBLY		28	• ASSY JIG/TRANSPORTER • 20M CHERRYPICKER • MISC. TOOLS	2 2 (SHARED)	30 X 30	2 (PART TIME)
1.3.2.1	ANNEALING MACHINE (GANRTY SUBASSY)		4	• ASSY JIG • 20M CHERRYPICKER • MISC. TOOLS	1 1 (SHARED)	30 X 30	2 (PART TIME)

TABLE A (CONT)

WBS	NAME	CONFIGURATION	QUANTITY	EQUIPMENT	QTY	AREA	CREW
TBD		TBD	2	• ASSY JIG/ TRANSPORTER • 20M CHERRYPICKER (SHARED) • MISC. TOOLS	1 1 –	30 X 30	2 (PART TIME)
SUMMARY 6 SUBASSEMBLY AREAS WITHIN THE SUBASSEMBLY FACTORY				• TRANSPORTERS • 20M CHERRYPICKER • STRUT FORMING MACHINES • TUBE WELDERS • BEAM END FITTING MAGAZINES	9 6 2 2 4		

1.0 WBS DICTIONARY

This element includes the facilities and equipment on the LEO base that are dedicated to test and checkout of EOTV components or subassemblies.

2.0 DESCRIPTION

No dedicated test and checkout facilities and equipment have been identified at this time.

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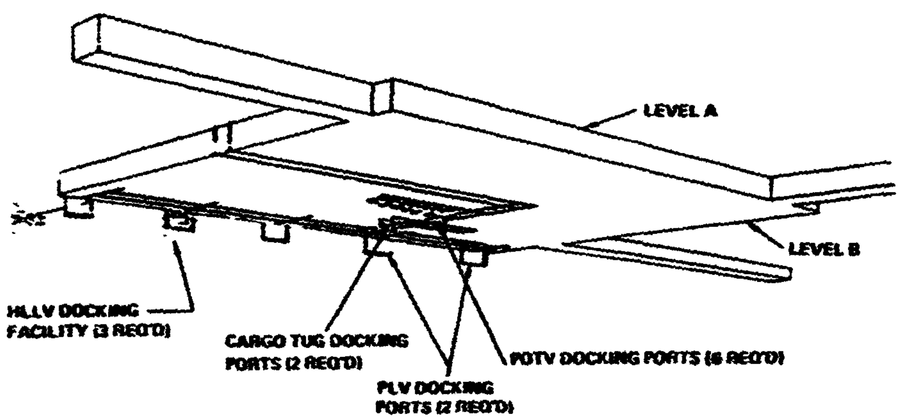

Figure A—Vehicle Docking Facilities

1.0 WBS DICTIONARY

This element includes facilities and equipment dedicated to support space transportation vehicles that interface with the LEO base. These items included are docking systems, assembly systems, propellant storage and distribution system and maintenance systems.

2.0 DESCRIPTION

The space transportation vehicles that interface with the LEO base are the HLLV, PLV, EOTV, POTV, and Cargo Tug. Figure A shows the operational interface locations for each vehicle.

WBS 1.2.2.1.6.1 Docking Systems

The HLLV docking system is shown in Figure B (3 are required). Figure C explains the operational concept. This type of docking system is also used by the PLV (2 are required) (the PLV docking system is scaled down approximately 50% from that shown in Figure B). The POTV docking/launching system is shown in Figure D (4 are required). When the cargo tug is not shuttling cargo pallet between the base and an EOTV, it is docked to the base as shown in Figure E (2 docking systems are required).

WBS 1.2.2.1.6.2 Vehicle Assembly Systems

The only vehicles that will require stage stacking and assembly are the POTV and Cargo Tug. However, the stacking of the various stages of these vehicles is done only upon initial delivery of the vehicle or for major overhaul. Cherrypickers will be used when necessary for vehicle assembly.

WBS 1.2.2.1.6.3 Propellant Storage and Distribution Systems

The EOTV and Cargo Tugs, are the only vehicles to be refueled at the LEO base. The Cargo Tug propellant delivery systems are shown in Figure E. The EOTV refueling concept entails a propellant pallet, (shown in Figure F), that is delivered to LEO via the HLLV. Figure G illustrates the propellant pallet handling operations at the base and Figure H shows the operations at the EOTV.

WBS 1.2.2.1.6.4 Vehicle Maintenance Systems

The space vehicle maintenance support equipment that is used on the LEO Base are summarized in Table A. There is also a flying cherrypicker, shown in Figure I, that is used to transport the EOTV thruster refurbishment machine, shown in Figure J. The cherrypicker installs the refurb machine on the EOTV thruster yoke as shown in Figure K.

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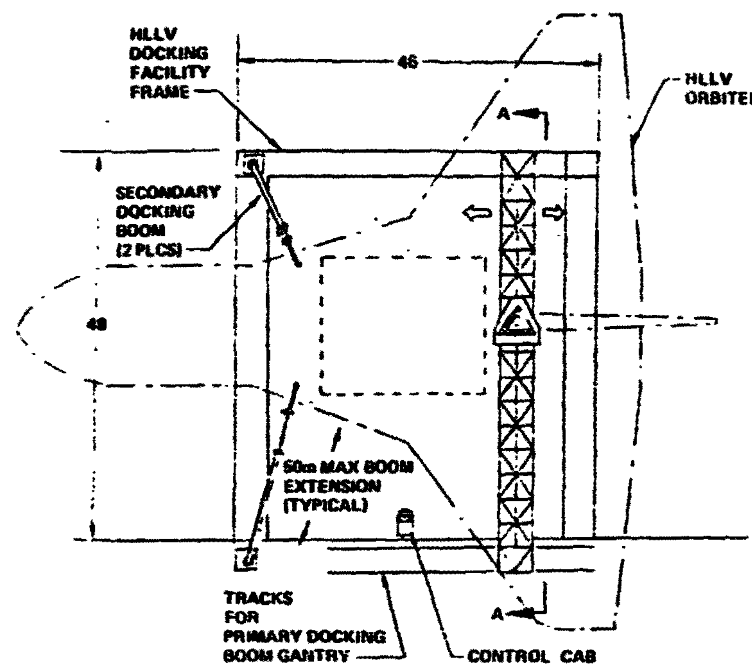

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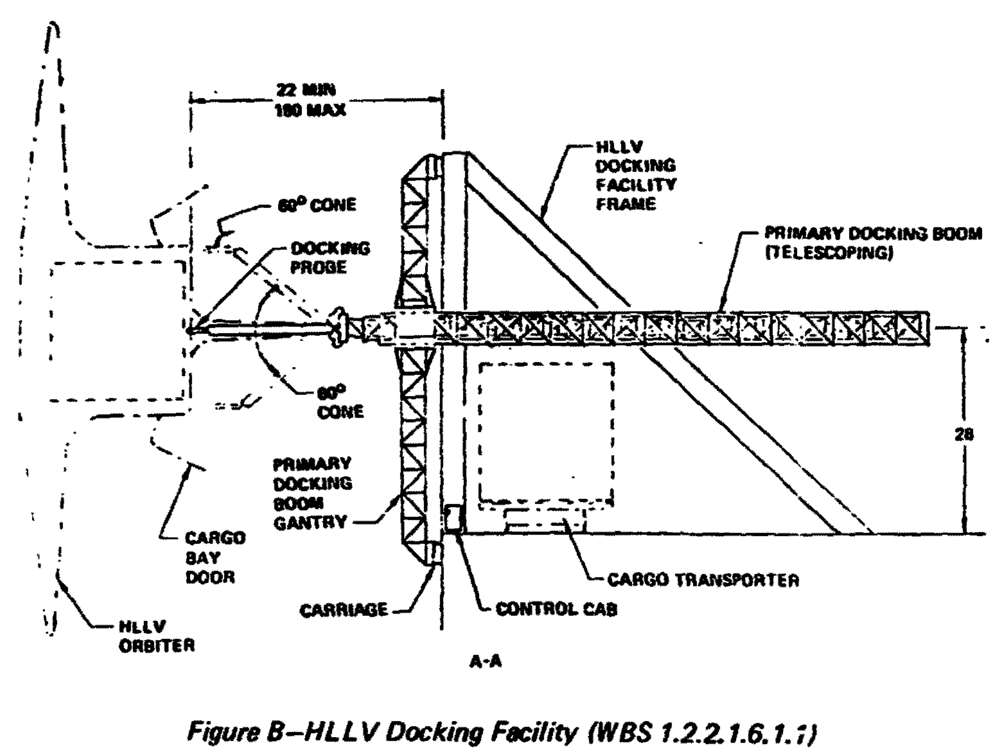

Figure B—HLLV Docking Facility (WBS 1.2.2.1.6.1.1)

3.0 DESIGN BASIS

SUBELEMENTS	REFERENCE
HLLV Support Systems	Operations and Systems Synthesis Document (D180-25461-2) Section 8
PLV Support Systems	Ibid., Section 7
Cargo Tug Support Systems	Ibid., Section 10
POTV Support Systems	Ibid., Section 7
Vehicle Maintenance Support Systems	Ibid., Section 11

4.0 MASS AND MASS BASIS

The equipment and systems mass is given in Table B. The mass basis is given in Table C.

5.0 COST

- Unit Cost

  See table B $158.3M

- DDT&E

  DDT&E = 3.67583 KG .3794 = $257.3M

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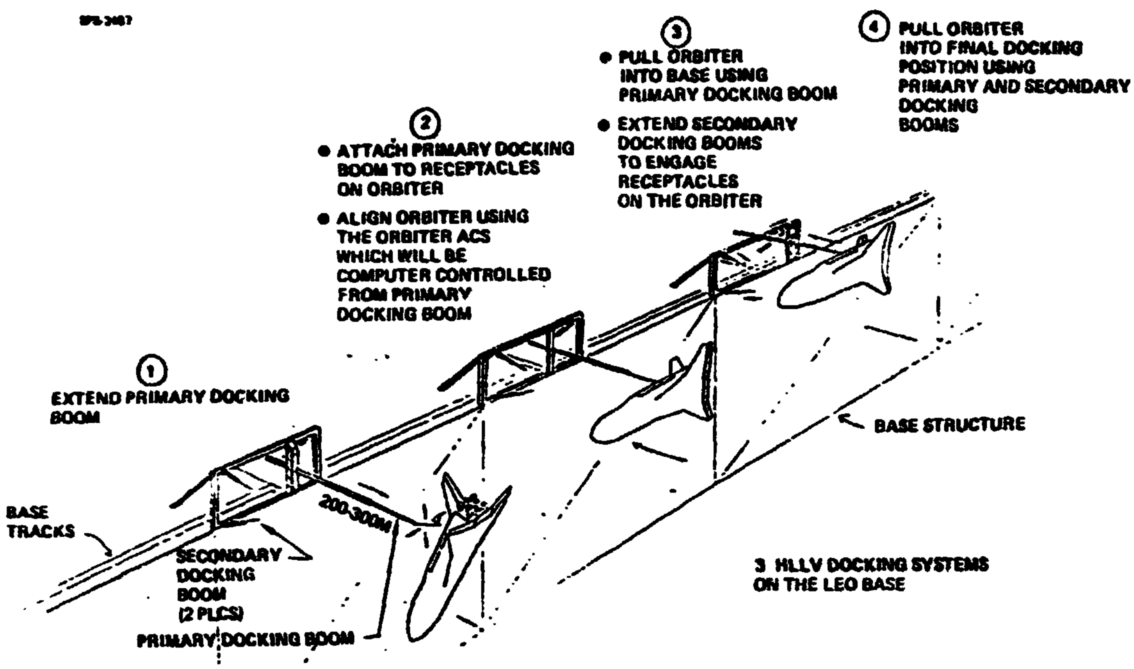

Figure C—HLLV Docking Systems on the LEO Base

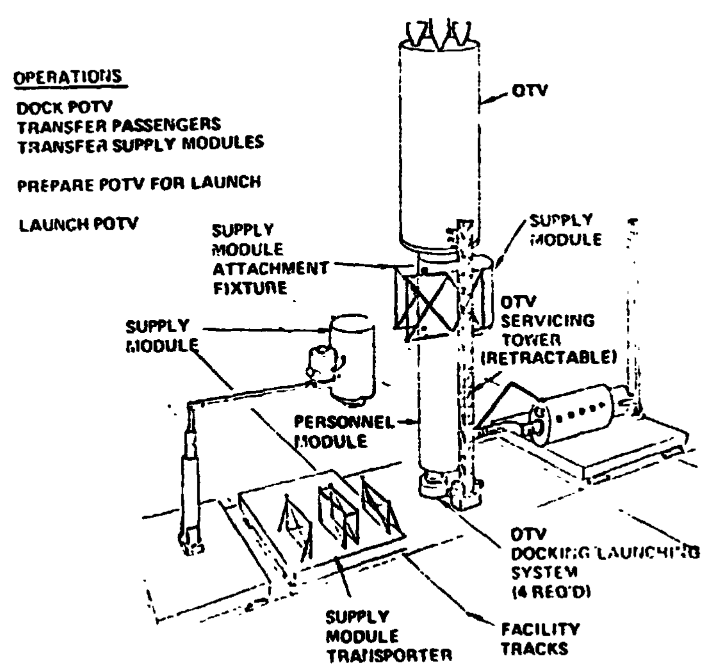

Figure D—POTV Support Systems and Operations (LEO Base)

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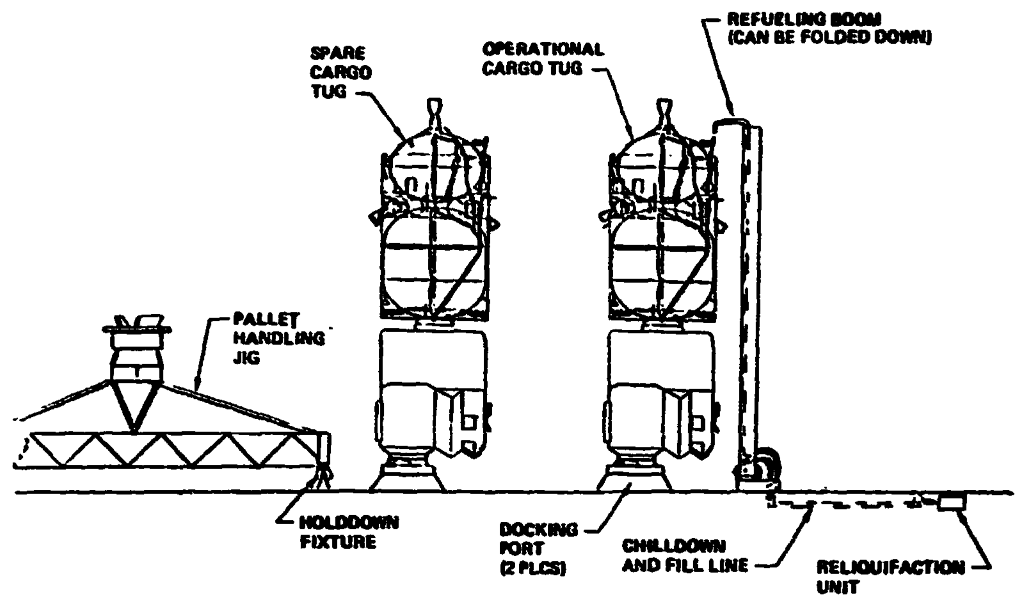


Figure E—Cargo Tug Docking and Propellant Loading Provisions

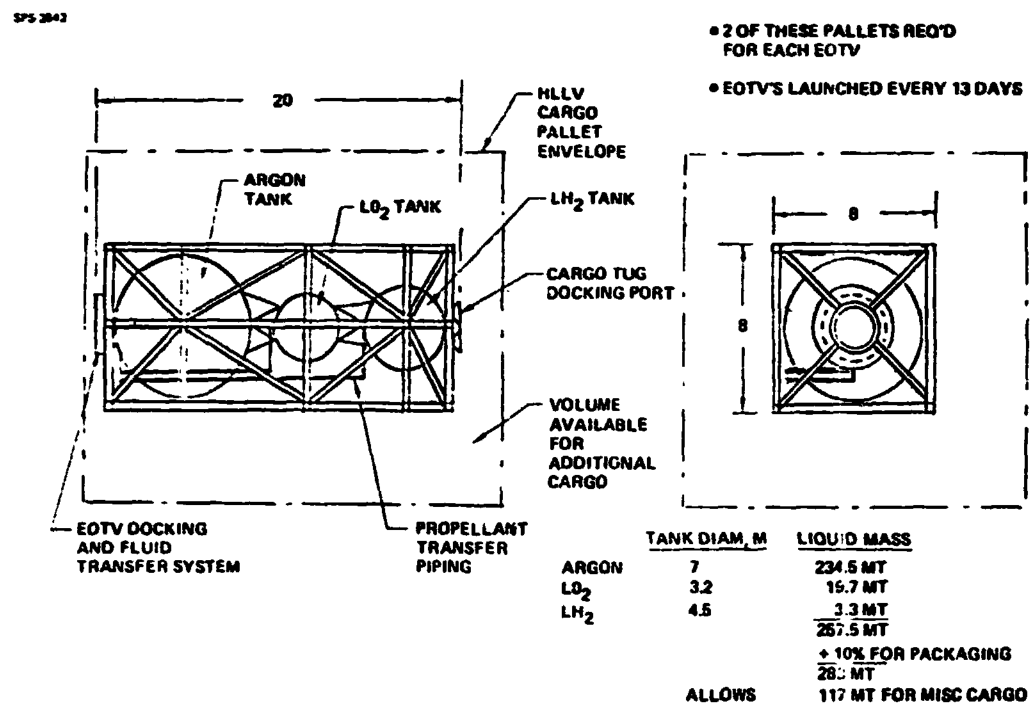


Figure F—EOTV Propellant Pallet Concept

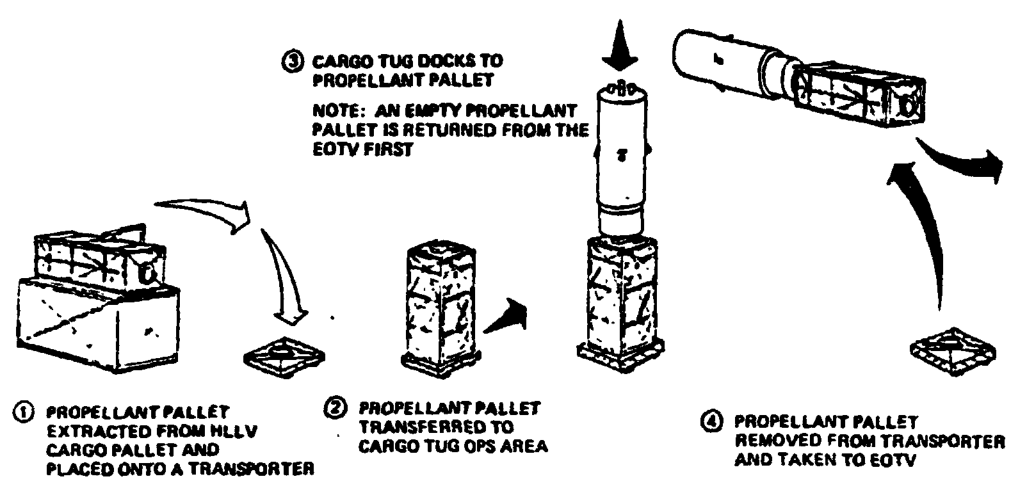


Figure G—EOTV Propellant Pallet Handling Operations at the LEO Base

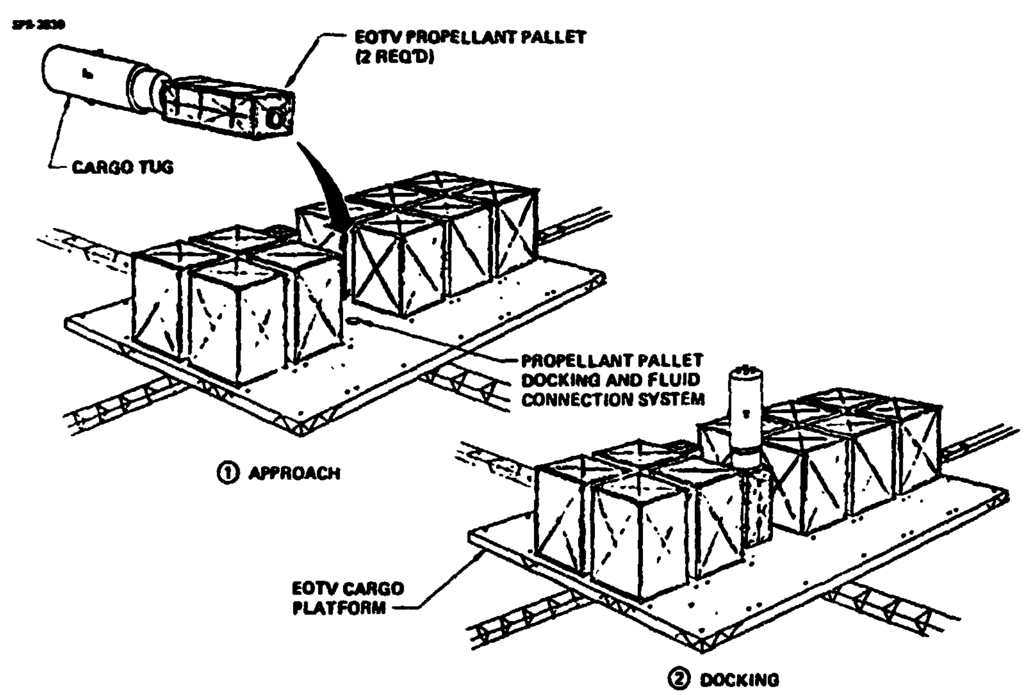


Figure H—EOTV Propellant Pallet Docking Operations at the EOTV

WBS 1.2.2.1.6 SPACE TRANSPORTATION SUPPORT SYSTEMS (CONT'D)

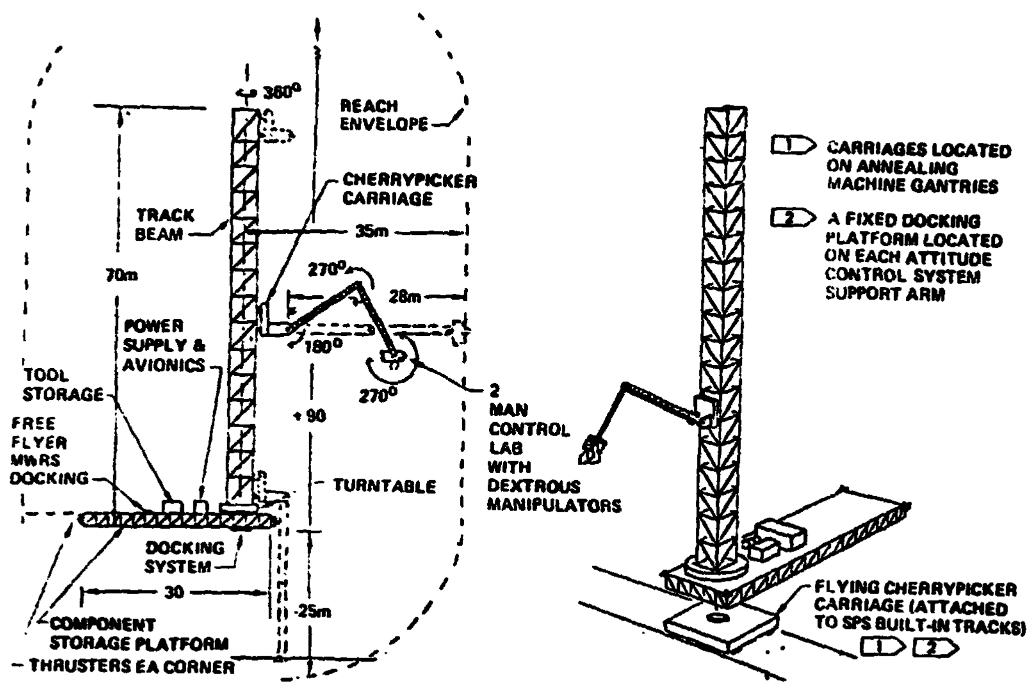
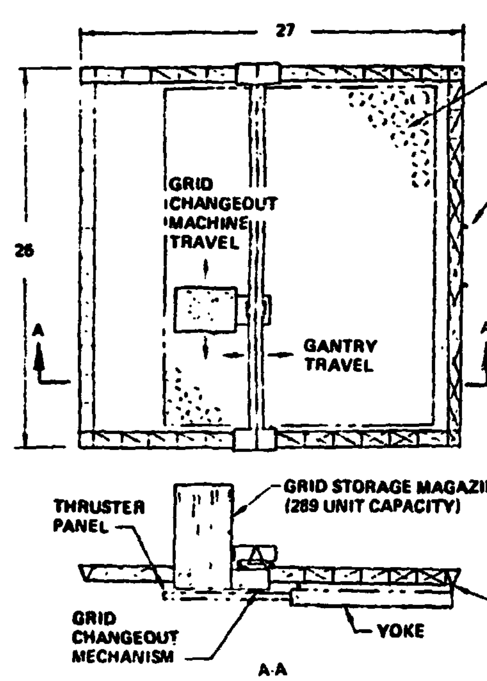


Figure I—Flying Cherrypicker



NOTES

- THIS MACHINE TRANSPORTED TO THE EOTV YOKE AND ATTACHED TO THE YOKE BY A FLYING CHERRYPICKER
- ONCE INSTALLED ON THE YOKE, THE GRID CHANGEOUT OPERATIONS ARE CONDUCTED AUTOMATICALLY UNDER MICROPROCESSOR CONTROL
- 289 ACCELERATOR GRIDS REPLACED IN 4 DAYS
- 4 OF THESE MACHINES ARE REQUIRED

Figure J—EOTV Electric Thruster Refurbishment Machine

Table A—Space Vehicle Maintenance Support Equipment

NAME
90M Cherrypicker
Electrical Power Test Set
Electrical Load Banks
Communications Test & Checkout Equipment
Guidance & Navigation Test & Checkout Equipment
Control & Data Acquisition Console
EMI Test Equipment
Memory Load & Verify Unit
Electronics Calibration Equipment
Engine Handling Kit
Engine Alignment Fixture
Engine Actuator Support Fixture
Engine Actuator Adjustment Kit
Insulation Handling Kit
APS Pressure Instrumentation Kit
Main Propulsion System Checkout Accessories Kit
APS Checkout Accessories Kit
Inspection Equipment
Ultrasonic Scan Unit
Radiography Unit
Mass Spectrometer Leak Detection Unit
Acoustic Leak Detection Unit
Borescope and Fibre Optics
Theodolite
Ground Servicing Umbilical Set

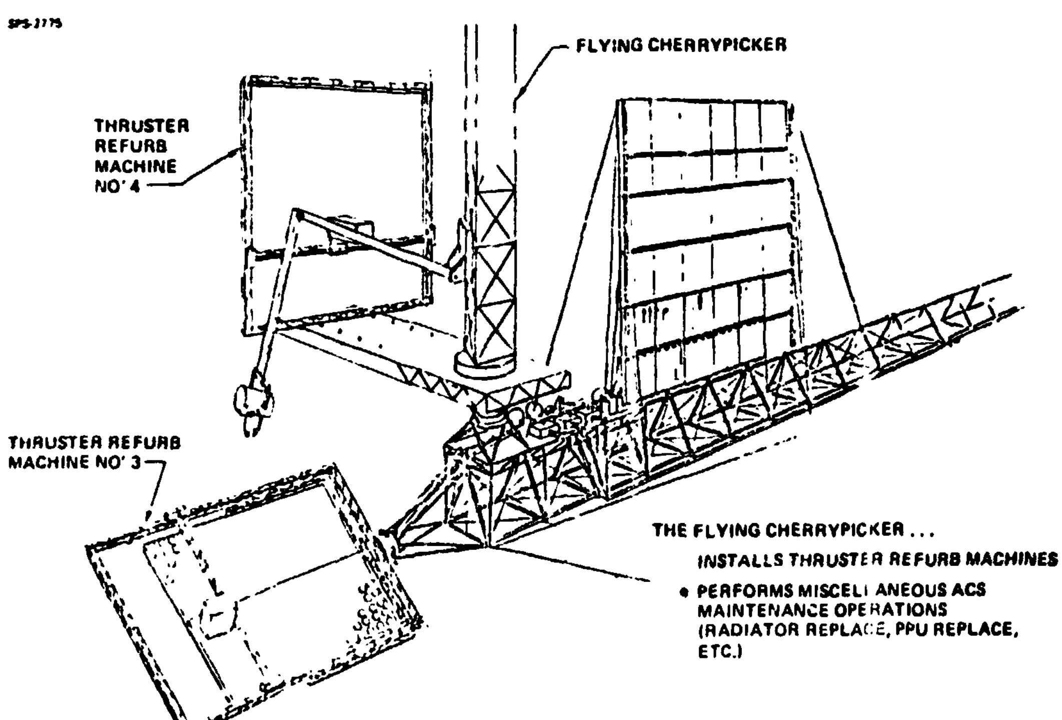


Figure K—EOTV Attitude Control System Maintenance Equipment

TABLE B

WBS 1.2.2.1.6 SPACE TRANSPORATION SUPPORT SYSTEMS MASS AND COST SUMMARY

ITEM		QTY	MASS, MT EACH	MASS, MT TOTAL	COST, $ M EACH	COST, $ M TOTAL
WBS 1.2.2.1.6.1	Docking Systems					
o	HLLV	3	4	12	9.2	27.6
o	PLV	2	3	6	7.6	15.2
o	POTV	4	1	4	2.5	10
o	Cargo Tug	2	.5	1	1.3	2.6
WBS 1.2.2.1.6.2	Vehicle Assy Sys	None Identified		-	-	-
WBS 1.2.2.1.6.3	Propellant Storage/Delivery System	1	35	35	15	15
WBS 1.2.2.1.6.4	Vehicle Maint Support Systems/Equip					
o	Flying Cherrypicker	2	5	10	35.6	71.2
o	Thruster Refurb Mach	4	.5	2	1.8	7.2
o	Misc. Tools/Fixtures/ etc.	1	3	3	9.5	9.5
	TOTALS			73		158.3

TABLE C: WBS 1.2.2.1.6 SPACE TRANSPORTATION SUPPORT SYSTEMS
MASS AND COST ESTIMATING DATA

WBS NO.	ITEM	QTY [2]			MASS, METRIC TONS			COST, $ MILLIONS			
		L	G	T	MASS, MT	RATIONALE	REF.	TFU	AVE [1]	RATIONALE	REF
1.2.2.1.6.1	Docking Systems										
	o HLLV	3	-	3	4	ROM Est.	BAC	10	9.2	ROM est.	BAC
	o PLV	2	-	2	3	Proportional to HLLV system	BAC	8	7.6	Proportional to HLLV System	BAC
	o POTV	4	4	8	1	Guess	BAC	3	2.5	Guess	BAC
	o Cargo Tug	2	2	4	.5	Proportional to POTV system	BAC	1.5	1.3	Proportional to POTV system	BAC
	o IOTV	-	8	8	1	Proportional to POTV system	BAC	3	2.5	Proportional to POTV system	BAC
1.2.2.1.6.3	Propellant Storage and Distribution System										
	o LEO Base System	1	-	1	35	BAC Estimate	BAC		15	BAC Estimate	BAC
	o GEO Base System	-	1	1	35	Same as LEO system	BAC		15	Same as LEO system	BAC
1.2.2.1.6.4	Vehicle Maintenance Support Systems										
	o Flying Cherry-picker	2	2	4	5	Proportional to 90M CP	BAC	40	35.6	Proportional to 90M CP	BAC
	o Thruster Refurb. Mach.	4	-	4	.5	Proportional to cargo pallet handling jig	BAC	2	1.8	Proportional to cargo pallet handling jig	BAC
	o Misc. Tools/Jigs/Etc.	1	1	2	3	Guess	BAC	10	9.5	Guess	BAC

[1] Use 90% Learning Curve

[2] L = Total at LEO Base
G = Total at GEO Base
T = Combined total used for cost est.

1.0 WBS DICTIONARY

This element will include all systems and facilities necessary to conduct maintenance on all elements permanently associated with the base.

2.0 ELEMENT DESCRIPTION

This element has not been defined at this time.

4.0 MASS

Estimates to be 5% of all other 1.2.2.1 items 48.7MT.

5.0 COST

Unit Cost - Estimated to be 5% of all other 1.2.2.1 items = $62.2M

DDT&E - Included at LEO Base level.

1.0 WBS DICTIONARY

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

2.0 DESCRIPTION

The LEO base subsystem elements are described in the following subsections.

WBS 1.2.2.1.8.1 Electrical Power System

WBS Dictionary
This element includes all systems necessary to generate and distribute electric power to be used by the LEO base.

Element Description
Primary power is provided by body mounted solar array blankets. Nickel hydrogen batteries provide power during occultations. Power requirements for the presently defined LEO base have been estimated as shown below:

- o Use SPS hardware

- o From GEO base elec power analysis
  3KW x 230 men = 690 kw
  Man

- o Batteries
  690 kw = 460 kwh of storage
  40 min (use SPS batteries)

- o Solar Array
  766 khr + 690 cwh = 1460 kwh
  for charging TOTAL

WBS 1.2.2.1.8.2 Flight Control Systems

WBS Dictionary
This element includes all systems necessary to determine, maintain and change the orbital position and attitude of the base.

Element Description
Included under the category of flight control are the guidance/navigation/attitude type sensors such as IRU, star trackers and horizon sensors and an LO_2/LH_2 propulsion system to perform attitude and orbit maintenance maneuvers. The orbit altitude to be maintained is 477 $\pm$ 1 Km. Sizing of the propulsion system for the present base has been estimated as shown below:

- o Use same ____ system as SPS (small, fired, pressure-fed thrusters; propellant storage and feed systems)

3.0 ELEMENT DESIGN BASIS—TBD

4.0 MASS AND MASS BASIS

Electric Power System

(from SPS) 1460 kwh 66 mt batteries
kg

$9000\ m^2 \times .42\ \frac{kg}{m^2}$ 3.8 mt array

TOTAL 69.8 mt

5.0 COST AND COST BASIS

Unit Cost

Electric Power

Batteries - use SPS factors	$1.05M
Power processors - use SPS factors	6.2M
Solar array - use SPS factors	1.8M
	$9.05M

ACS

Factores from SPS	$54M
TOTAL UNIT COST	$63M

DDT&E

o Batteries - no DDT&E - use SPS batteries	
o Power processors - use SPS factors	$63M
o Solar array - no DDT&E - use SPS array	
o ACS - use SPS factors	$54M
TOTAL DDT&E	$117M

FOLDOUT FRAME

Table A. Command and Control System Communication Lines

	EARTH OPS CONTROL	OPS MODULE	CREW HABITATS	MAINTENANCE MODULE	CREW BUSSES	CARGO TRANSPORTERS	CONSTRUCTION EQUIPMENT	EVA CREW	HLLV	PLV	CARGO TUG	EOTV	POTV	HLLV DOCKING FACILITY	PLV DOCKING FACILITY
EARTH OPS CONTROL CENTER															
OPERATIONS MODULE	123														
CREW HABITATS	12	123	123												
MAINTENANCE MODULE		123													
CREW BUSSES		13	1	1	1										
CARGO TRANSPORTERS		13		1	1	1									
CONSTRUCTION EQUIPMENT		13		1	1	1	13								
EVA CREW		13	1	1	1	1	1	1							
HLLV	13	13						1							
PLV	13	13			1			1							
CARGO TUG		13			1	1		1			3				
EOTV	3	13													
POTV	13	13			1			1							
HLLV DOCKING FACILITY		13			1	1		1	13					13	
PLV DOCKING FACILITY		13			1	1		1		13					13

KEY
1 – VOICE COMM LINK
2 – VIDEO COMM LINK
3 – DATA COMM LINK

1.0 WBS DICTIONARY

This element includes the intra-base and extra-base communication systems and the data management systems. Included are computers, voice/video/data communications networks and antennas. Excluded are those elements installed within crew modules (habitats, work modules, work stations, crew buses) which are accounted for within each of the elements.

2.0 DESCRIPTION

The execution of the LEO base command and control operations will require the voice, video, and data communication links between system elements shown in Table A. In almost all cases, the comm link will be accomplished by wireless transmission/reception. The only hardline links will be between the various crew modules that are colocated.

3.0 DESIGN BASIS

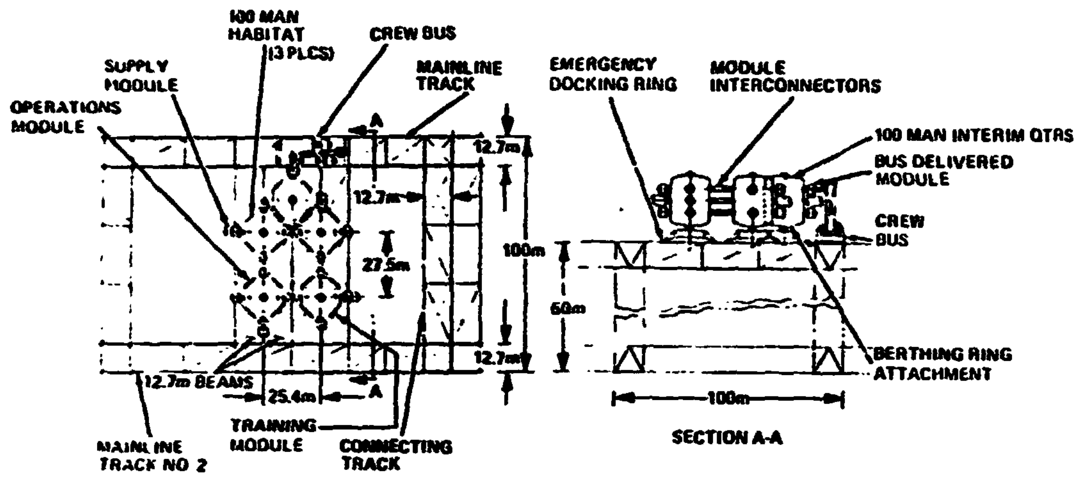
The command and control requirements for the various LEO base operations are identified in Section 13 of the Operations and Systems Synthesis document (D180-25461-3). The voice/video/data communications systems requirements were identified from the C&C requirements.

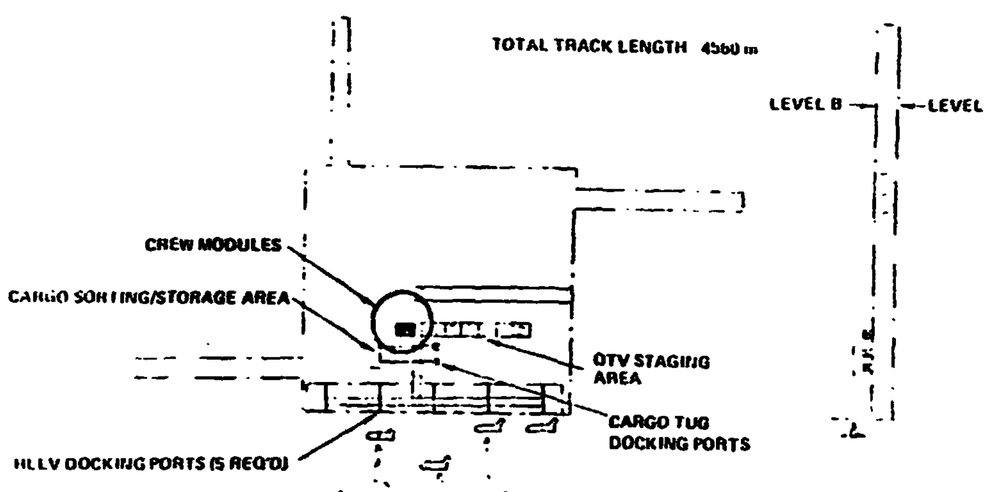
4.0 MASS AND MASS BASIS

The Hardware elements have not been identified. Mass will be assumed to be 10 mt.

5.0 COST AND COST BASIS

- o Cost will be estimated to be $50 million.
- o DDT&E est. to be $2 M





1.0 WBS DICTIONARY

This element includes the facilities and equipment required for the life support and well-being of the crew members. Included are the living quarters and work modules.

2.0 DESCRIPTION

A total of 5 crew modules will be required at the LEO Base:

- o 3 crew quarters modules
  - o These 3 100-man capacity habitats house the 230 LEO base crew and serve as a transient crew quarters
- o 1 operations and maintenance module
- o 1 training module

These 5 modules will be clustered as shown in Figure A on the LEO base level B near the cargo sorting/storage area, as shown in Figure B.

3.0 DESIGN BASIS

These modules will be identical to the corresponding GEO base crew modules with the exception that the storm shelter shielding has been deleted from the crew habitats.

4.0 MASS AND MASS BASIS

WBS	MODULE	QTY	MASS EA, MT	BASIS	TOTAL MASS MT
1.2.2.2.1	Crew Quarters Module	3	174.8	See WBS 1.2.1.2.1 (storm shelter deleted)	524.4
1.2.2.2.2	OPS & Main Module	1	173	See WBS 1.2.1.2.1	173
1.2.2.2.3	Training Module	1	112	See WBS 1.2.1.2.1	112
				TOTAL	809.4 MT

5.0 COST AND COST BASIS

WBS	MODULE	QTY	PRODUCTION COST,EA $M	BASIS	PRODUCTION TOTAL COST $M
1.2.2.2.1	Crew Quarters Module	3	347	See WBS 1.2.1.2.1 (storm shelter deleted)	1041
1.2.2.2.2	OPS & Main Module	1	316	See WBS 1.2.1.2.1	316
1.2.2.2.3	Training Module	1	142	See WBS 1.2.1.2.1	142
				TOTAL	$1499M

1.0 WBS DICTIONARY

This element includes the conduct of operations at the LEO base. It includes both the direct and support personnel and the consumable supplies required for the conduct of the operations.

2.0 DESCRIPTION

The LEO base operations are grouped into the 3 categories shown in Figure A. Each of these operations are described in detail in the sub-element descriptions that follow.

The total LEO base crew size and crew organization concept is shown in Figure B.

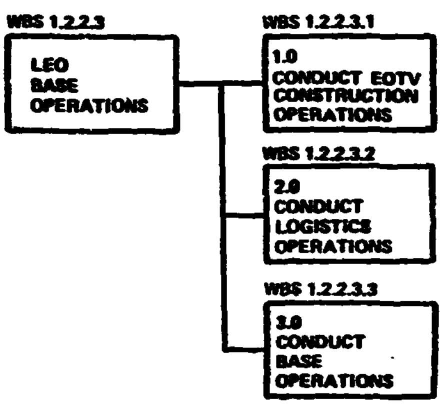


Figure A: LEO Base Operations

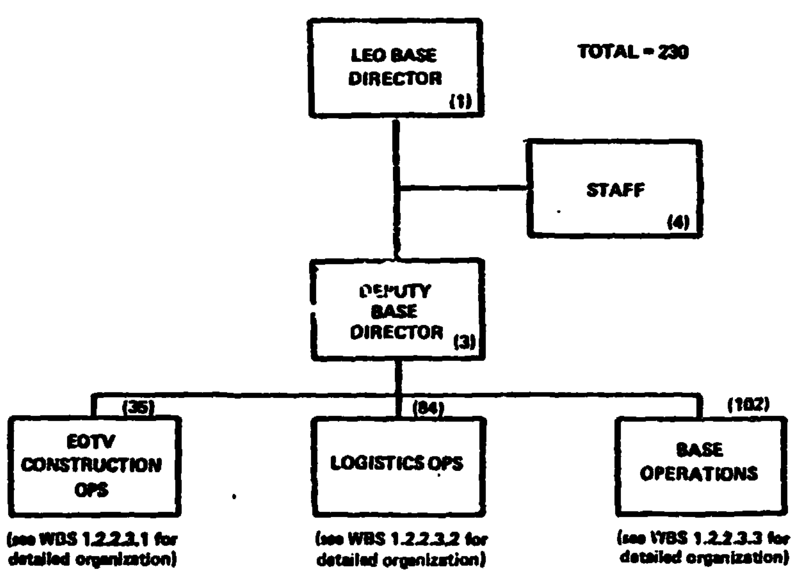


Figure B: LEO Base

4.0 MASS AND MASS BASIS

Resupply Item	Annual Resupply W/10% Cont	Rationale	Reference
o Crew Supplies			
o Food	(216.5)	Based on 230 People	WBS 1.2.1.3
o Housekeeping & Other Items	162.1	Proportioned from GEO Base Figures	
	54.4		
o Crew Module Supplies	(98.4)		
o ECLS N_2, & H_2O	51.3		
o ECLS Life Limited Pacts	41.4		
o Other Subsystem Parts	5.7		
o Work Module Supplies	(90)	Same as for GEO Base	WBS 1.2.1.3
o OPNL CTR (O_2, N_2 & Parts)	36	Modules of same type	
o Training Mod.	54		
o Work Facility Supplies	TBD		WBS 1.2.1.3
o Constr. Equip. Parts	20.6	Scaled from GEO Base	
o Cargo Hdlg/Dist. Parts	13.2	Estimates	
o Crew Bus (O_2, N_2)	7		
o SubAssy Factory, Parts	1		
o Remote Work Sta. (O_2, N_2 & Parts)	75		
o Base Subsys Parts	4		
o Base Flt CTL Propellents			
o Base Maint & Test Parts	-		
o Transport Veh Maint Parts	5.8		
TOTAL	533.5 MT/YR		

5.0 COST AND COST BASIS

o Crew Salaries

Operation	Men/Yr	Rationale	Annual Cost $M	Rationale
o LEO Base Orbital Crew	(452)	2 x Base Crew	(58.3)	$129K/Man year
o Construction OPS	70			
o Logistics OPS	168			
o Base OPS	214			
o Ground Crew	(4520)	10 x Orbital Crew	(226)	$50K/M[illegible]
o Training			(56.9)	20% of Salaries
		Total	$ 341.2M	

o RESUPPLY ITEMS

Item	Annual Cost $M/Yr	Rationale	Reference
o Crew Supplies			
o Food	.74	\$10/lb (\$4.54/kg) x 162.1 MT/yr	Estimate
o Housekeeping & Other Items	.12	\$5/lb (\$2.27/kg) x 54.4 MT/yr	Estimate
o Crew Module Supplies	Neg	N_2: \$.05/kg x 17.4 MT/yr	Factored from propellant
o ECLS N_2, & H_2O	Neg	H_2O: \$.01/kg x 33.9 MT/yr	costs/Guess
o ECLS Life Limited Parts	65.4	\$1580/kg x 41.4 MT/yr	Sineored average of
o Other Subsystem Parts	9	\$1580/kg x 5.7 MT/yr	Total module cost÷
			Total module mass
o Work Module Supplies			
o OPNL CTR (O_2, N_2 & Parts)	Neg	O_2: \$.1/kg x 13 MT/yr	Factored from propellant
	Neg	N_2: \$.05/kg x 5 MT/yr	costs
	2.8	Parts: \$1580/kg x 18 MT/yr	
o Training Module	Neg	Or: \$.1/kg x 19.5 MT/yr	
O_2, N_2, Parts	42.7	Parts: \$1580/kg x 27 MT/yr	

Resupply Items - (cont'd)

o Work Facility Supplies			
o Constr. Equip. Parts	45.1	\$2190/kg x 20.6 MT/yr	Smeared average of total equipment cost ÷ total equipment mass
o Cargo Hdlg/Dist. Parts	27.4	\$2072/kg x 13.2 MT/yr	Smeared average of total equipment cost ÷ total equipment mass
o Crew Bus H_2O, N_2	Neg	H_2O: \$.01/kg x 2 MT/yr	
	Neg	N_2: \$.05/kg x 5 MT/yr	
o SubAssy Factory Parts	.4	\$400/kg x 1 MT/yr	Smeared average of total equipment cost ÷ total equipment mass
o Remote Work Stations	Neg	H_2O: \$.01/kg x 10.5 MT/yr	
H_2O, N_2, Parts	Neg	N_2: \$.05/kg x 27 MT/yr	
	76.7	Parts: \$2190/kg x 35 MT/yr	
o Base Subsystem Parts			
o Base Flt Control Propellent	TBD		
o Transport Veh Supp. Parts	12.5	\$2160/kg x 5.8 MT/yr	

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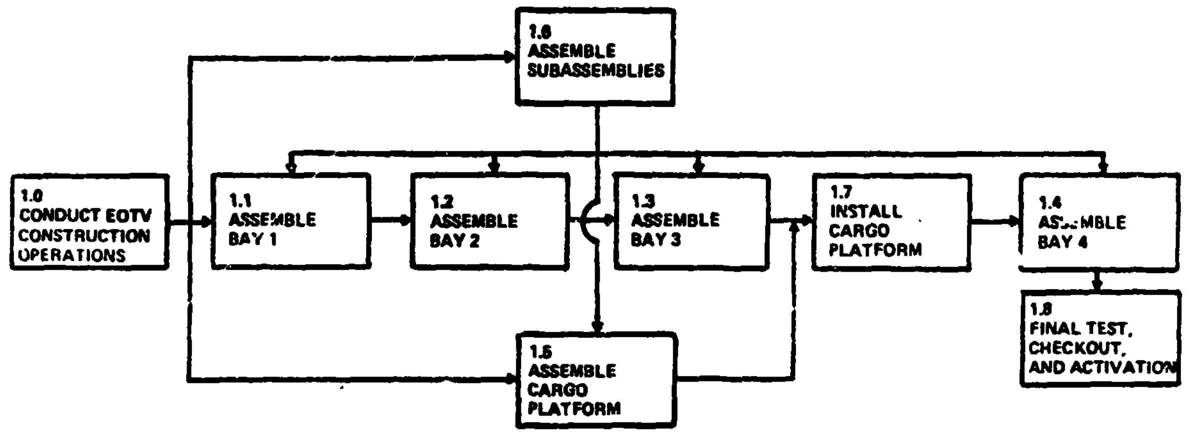

Figure A: EOTV Construction Operations

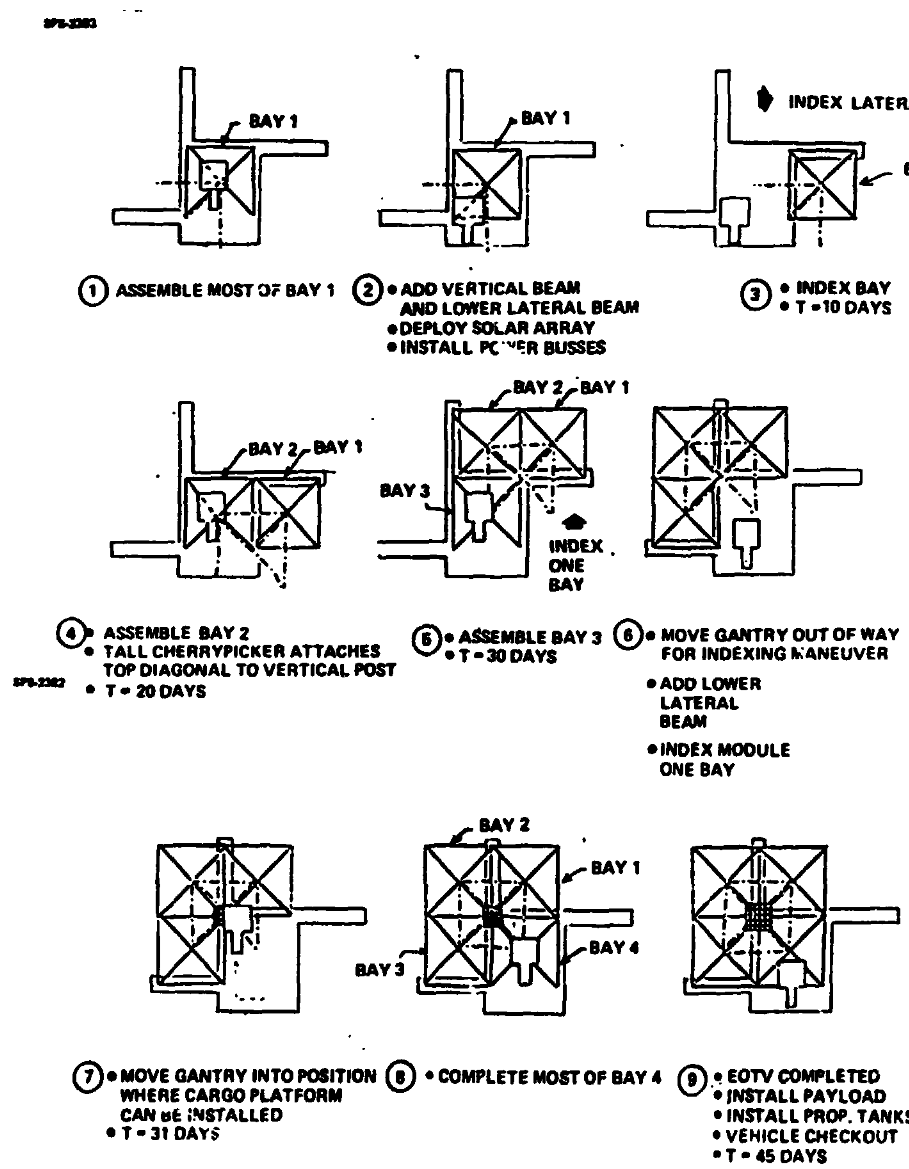

Figure B: EOTV Construction Sequence

1.0 WBS DICTIONARY

This element includes the direct construction operations required to assemble the EOTV's. Included are descriptions of the sub-operations, personnel requirements, and consumables requirements.

2.0 DESCRIPTION

The EOTV construction system is designed to construct EOTV's at the rate of 1 EOTV every 45 days (8 EOTV's per year). Figure A shows the construction functional flow. Figure B illustrates the construction sequence. Figure C shows the corresponding timeline.

The EOTV's are constructed on a bay-by-bay build-up basis wherein each of the 4 EOTV bays are assembled in 10 days each. Figure D shows the functional flow chart and Figure E shows the timeline for the assembly operations.

While the solar array and structure are being assembled, the cargo platf... assembled on the construction gantry. Figure F shows the functional flow dia... The cargo platform is installed after Bay 3 is completed.

The subassembly operations proceed in parallel with the assembly of Bays 1, ...nd 3. (WBS 1.2.2.1.4 describes the subassemblies.) Figure G shows the subassembly operation's functional flow.

Figure H shows the final test/checkout/activation functional flow chart.

The detailed descriptions of the construction operations are found in the operations and systems synthesis document (D180-25461-3), Section 9.

Crew Requirements - The EOTV construction crew size and organization are shown in Figure I.

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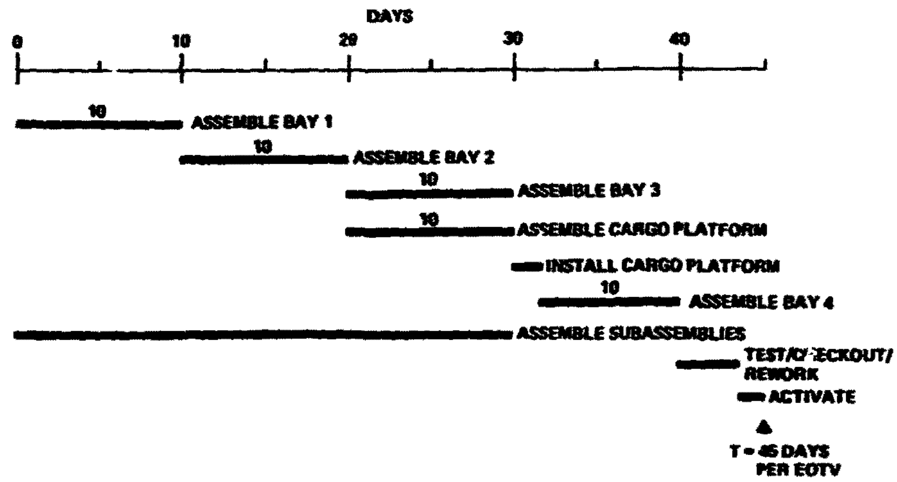

Figure C: EOTV Construction Timeline

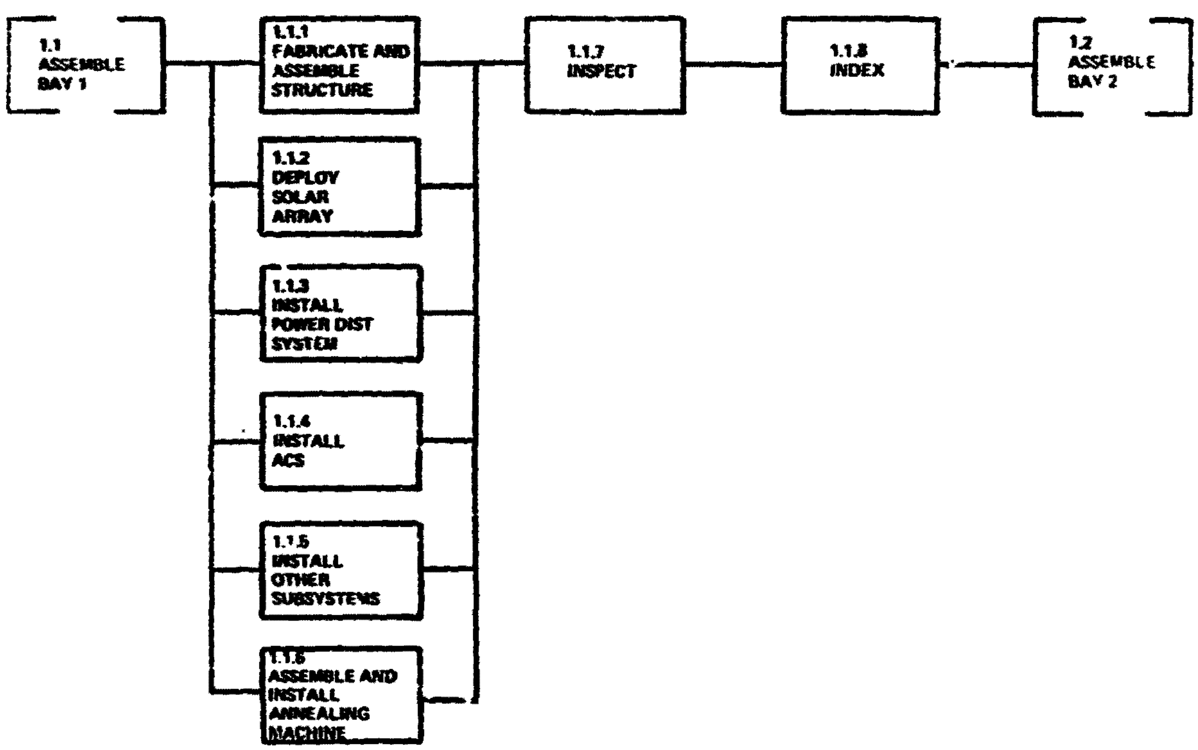

Figure D: Functional Flow Diagram for Construction of Each EOTV Bay

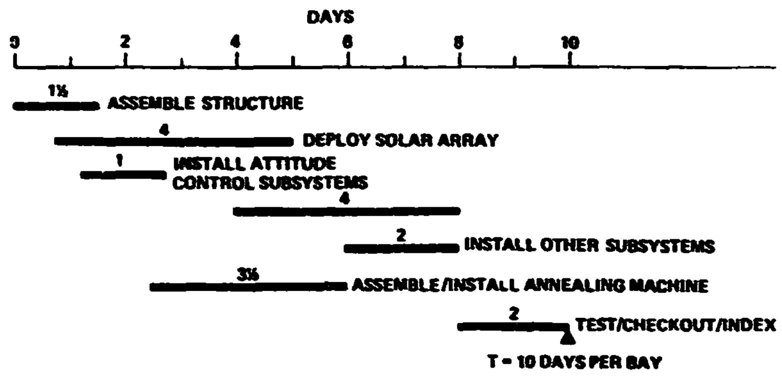

Figure E: Typical Construction Timeline for Each EOTV Bay

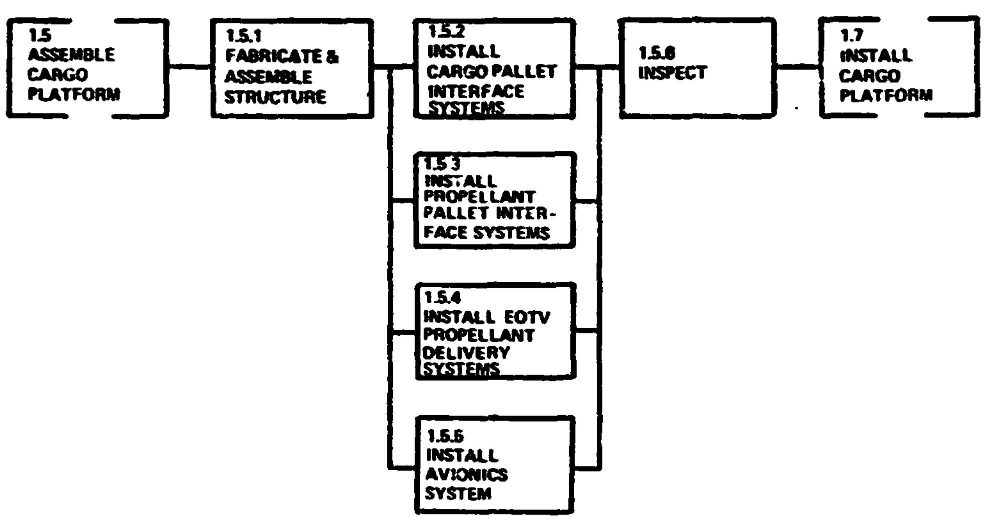

Figure F— Functional Flow Diagram for the Construction of the Cargo Platform

WBS 1.2.2.3.1 EOTV CONSTRUCTION OPERATIONS (CONT'D)

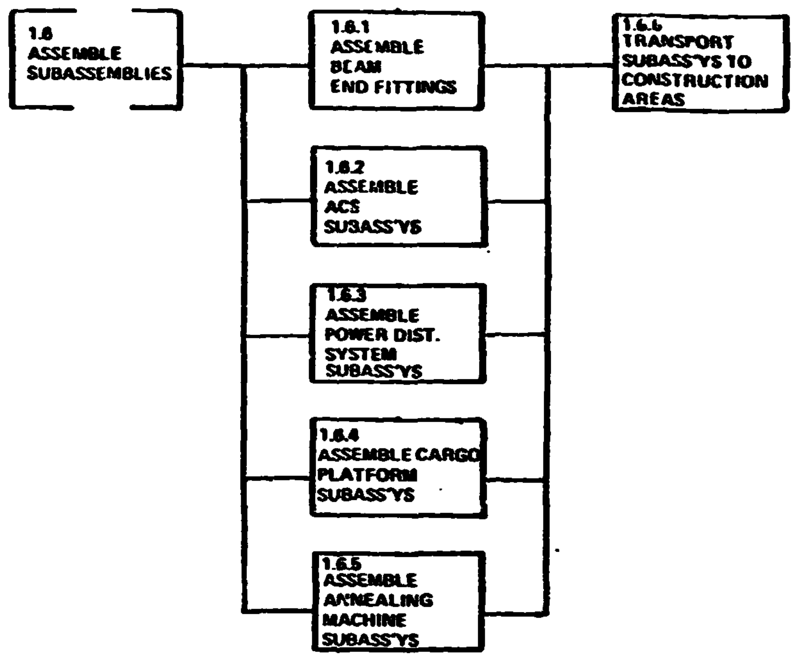

Figure E: Subassembly Operations

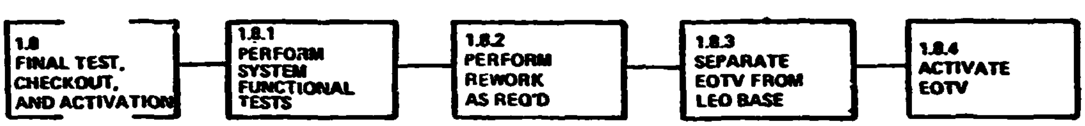

Figure H: Test/Checkout/Activation Operations

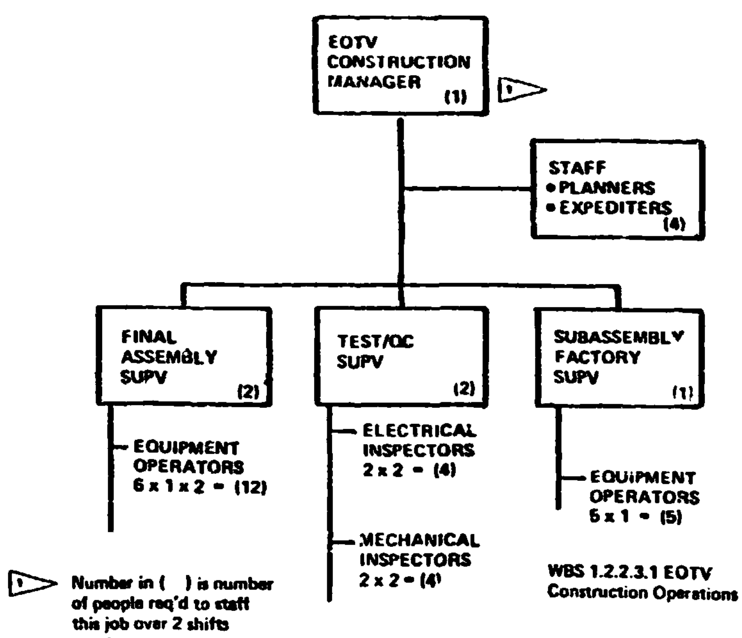

Figure I: Crew Size and Organization

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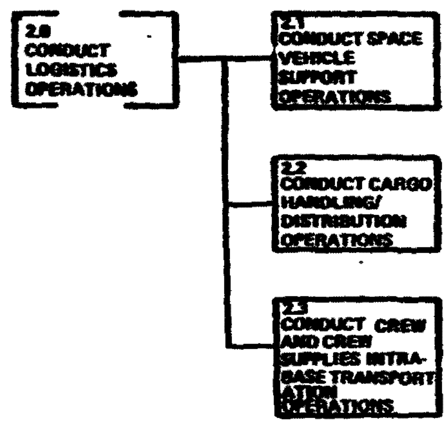

Figure A— Logistics Operations

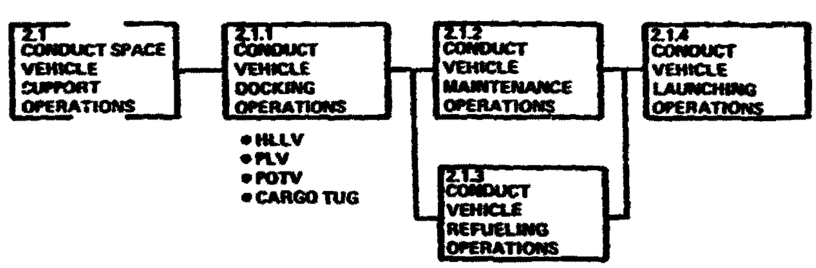

Figure B—

1.0 WBS DICTIONARY

This element includes the space vehicle support operations, cargo handling/distribution operations, and crew/crew supplies intra-base transportation operations at the LEO base. Included are the descriptions of the operations, personnel requirements, and consummables requirements.

2.0 DESCRIPTION

The three major logistics operations categories are shown in Figure A. These operations and their subelement operations are described below. The detailed operational descriptions are found in the Operations and Systems Synthesis document (D180-25461-3).

Space Vehicle Support Operations

The 4 major suboperational categories are shown in Figure B.

Vehicle Docking Operations—The HLLV and PLV docking operations are depicted in Figure C. The docking systems (WBS 1.2.2.1.6.1.1) are operated from a control station at each docking area. There will be 1 or 2 HLLV's arriving each day of the week (8 per week). There will be 1 PLV arrival per week. The rendezvous traffic control is provided by an operator at the LEO base OPS center.

The POTV flies into a nose-first docking. Figure D shows the POTV docked to the base. The on-board POTV flight crew controls the docking maneuvers.

The cargo tug also is flown into a nose-figre docking (see Figure E) under control of the on-board pilot.

The EOTV does not dock to the LEO base. It is placed into a stationkeeping attitude 1 or 2 km away from the base. The EOTV stationkeeping is remotely controlled from the LEO base operations center.

Vehicle Maintenance Operations—The transportation vehicles that will be maintained in space include the EOTV, POTV, Cargo Tug, and SPS Maintenance Support Vehicles (see Figure F). The fleet sizes the base(s) where the various vehicles are to be maintained, and their maintenance frequencies are shown in the Figure. Note that the HLLV and PLV orbiters are not to be maintained in-space.

In general, the vehicles will be subject to "On-condition" or "Condition Monitored" maintenance. On-condition maintenance relies on the determination of the condition of a component or subsystem at specified intervals via measurement or test without removal or disassembly. Condition monitored maintenance relies on the maintenance requirements being determined by the monitoring of operational flight instrumentation, analysis of in-flight data for trends, and the detection of statistically significant recurring problems on a fleet-wide basis. These two concepts are oriented towards detecting existing or incipient failures using the least amount of test and checkout. Actual operational experience would be used to provide the functional check or measurement of performance. This maintenance approach is contingent on the existence of necessary instrumentation for obtaining maintenance significant data.

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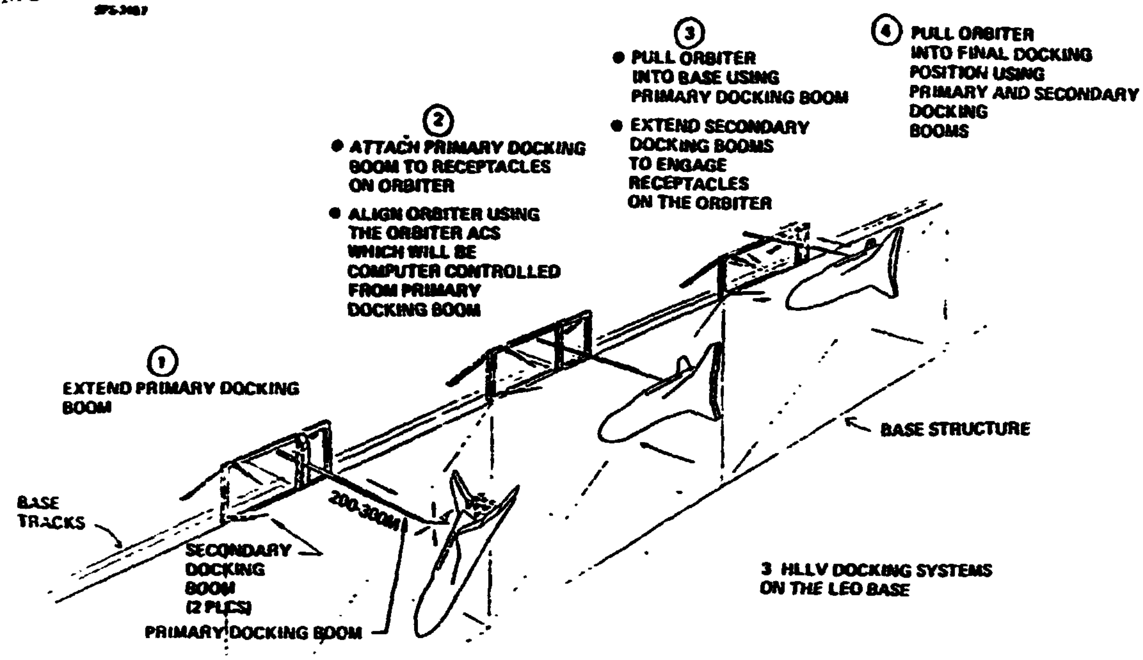

Figure C– HLLV and PLV Docking Operations

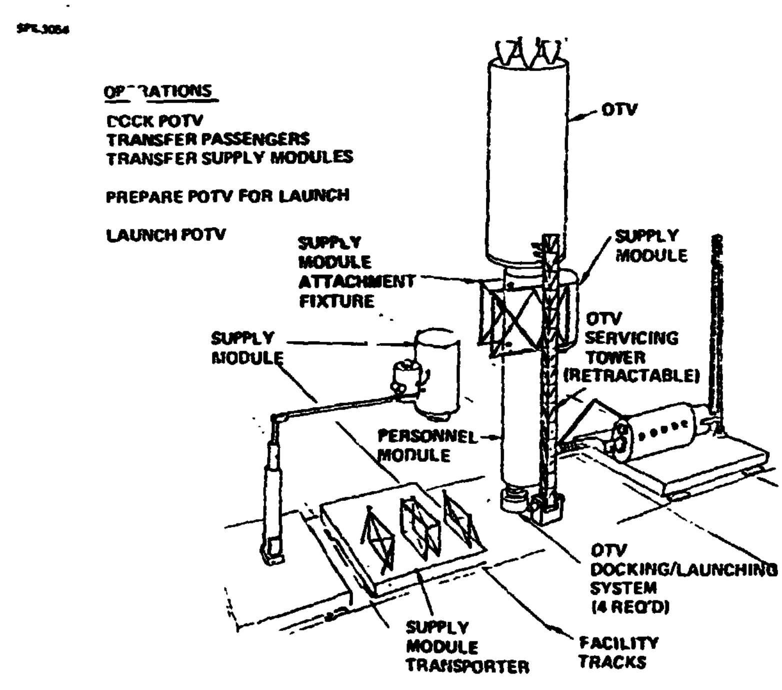

Figure D– POTV Operations

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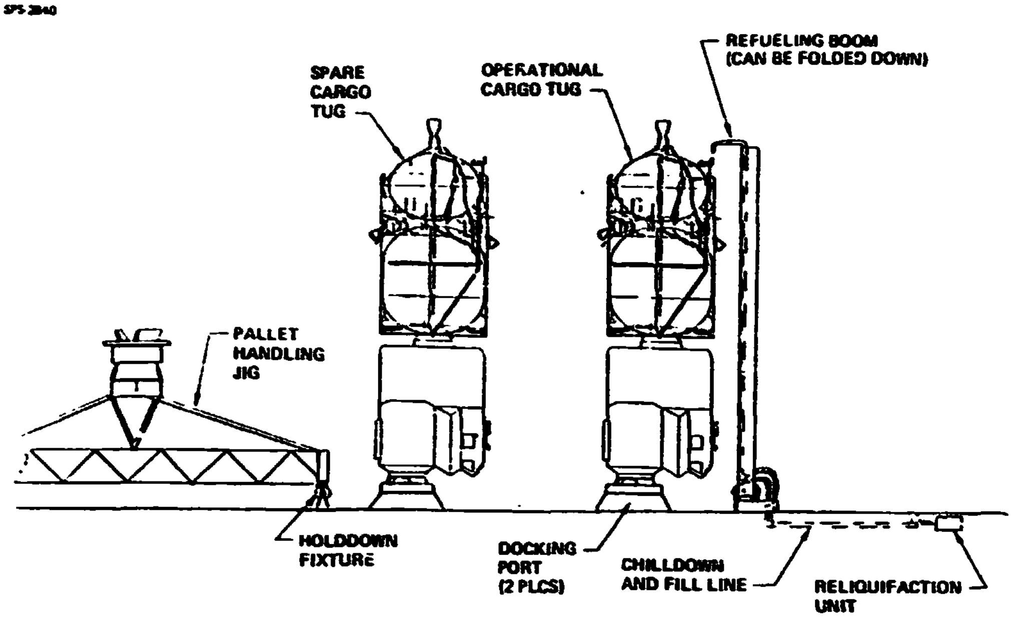

Figure E— Cargo Tug Docking and Propellant Loading Provisions

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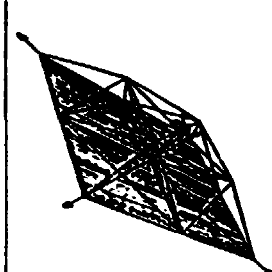
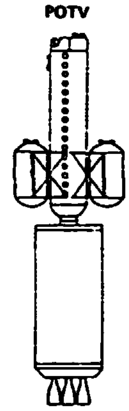
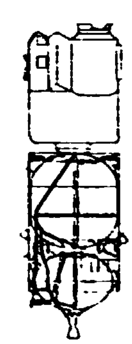
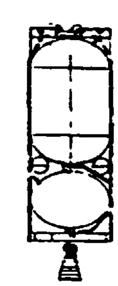
	EOTV	POTV	CARGO TUG	SPS MAINT SUPPORT VEHICLES
VEHICLE [1]				
NO. OF VEHICLES IN FLEET	• 23	• 2 (1 + 1 SPARE)	• 2 AT LEO BASE • 2 AT GEO BASE	• 5 (4 [illegible] SPARE)
WHERE MAINTAINED	• SOLAR ARRAY ANNEALED AT GEO BASE • EVERYTHING ELSE MAINTAINED AT LEO BASE	• LEO BASE	• LEO BASE • GEO BASE	• GEO BASE
MAINT FREQUENCY	• AT LEO BASE EVERY TRIP • AT GEO BASE EVERY TRIP	• AFTER EVERY ROUNDTRIP	• AFTER 15-20 FLTS	• AFTER 9[illegible] DAYS TOUR OF DUTY

[1] THE HLLV AND PLV ORBITERS ARE MAINTAINED ON EARTH-NO IN-SPACE MAINTENANCE IS PLANNED

Figure F— Space Vehicles and In-Space Maintenance Locations

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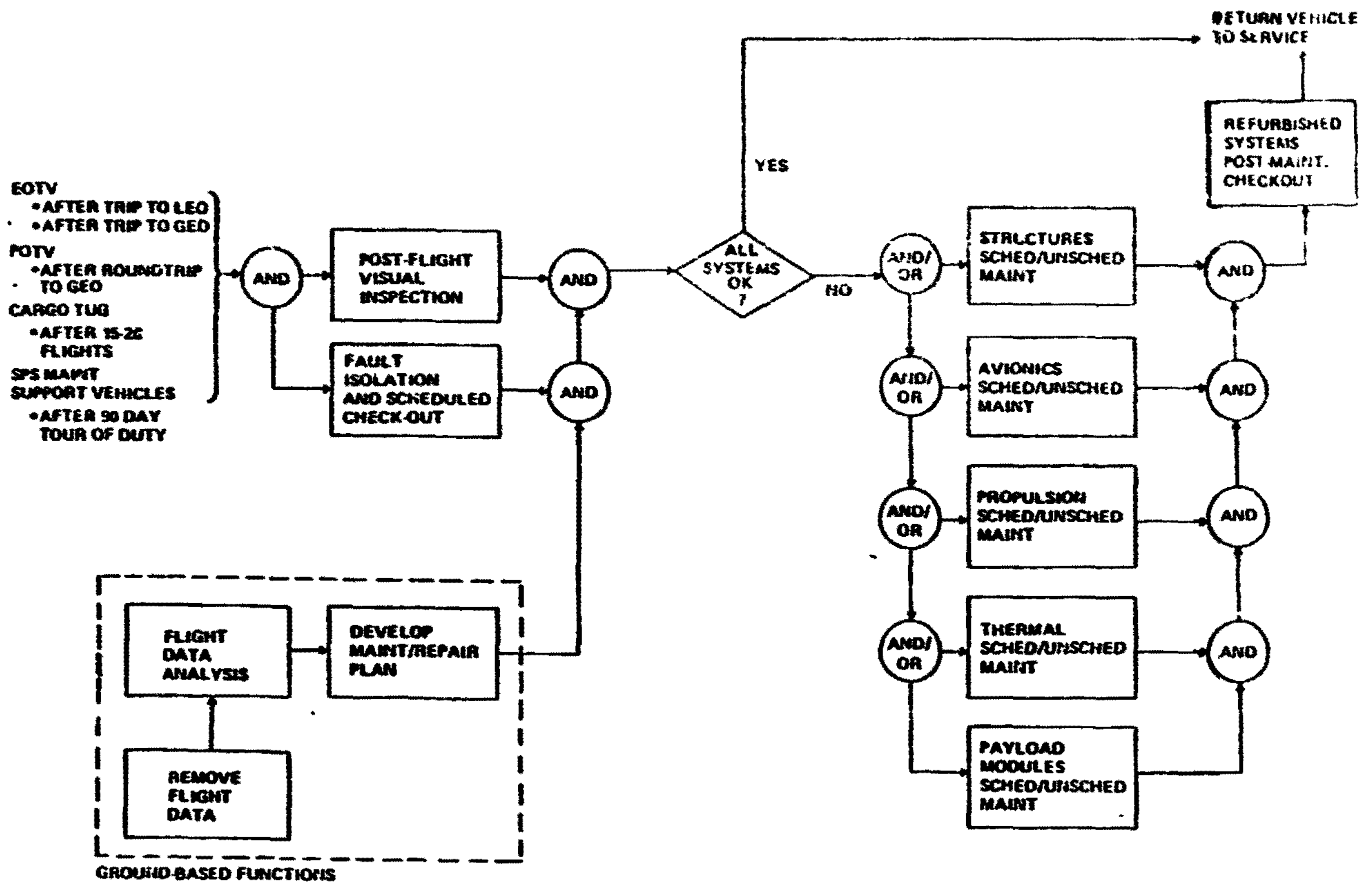

Figure G— Space Vehicle In-Space Maintenance Functional Flow

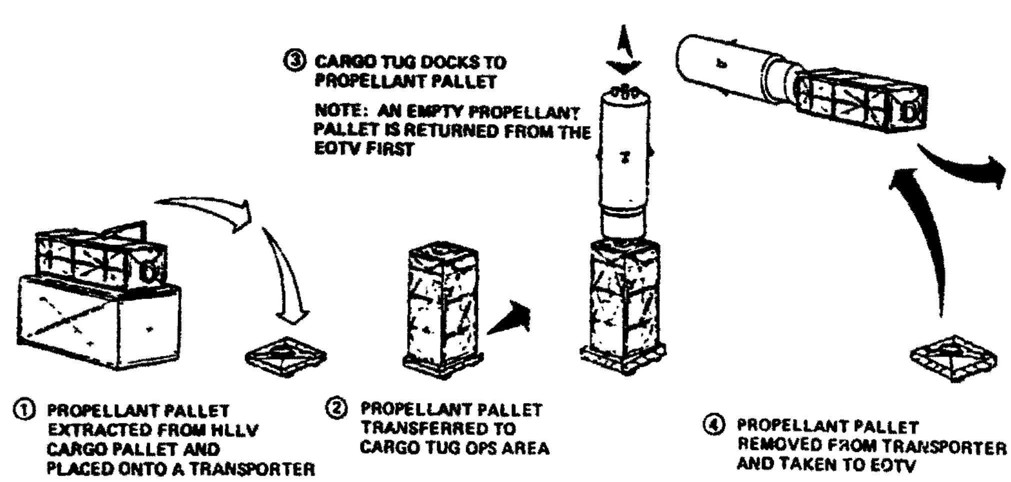

Figure H— EOTV Propellant Pallet Handling Operations at the LEO Base

Figure G shows the general maintenance functional flow. After the specified number of flights, the vehicles receive a visual inspection and fault isolation checkout. The preprocessed flight data is telemetered back to Earth and analyzed. From these inputs, it will be possible to determine whether or not the vehicle can be immediately returned to service. If there is some maintenance required, a detailed maintenance plan is prepared by the Transport Vehicle Maintenance Group in the Transportation Vehicle Command and Control Center on Earth and this plan is then transmitted to the orbital base.

Vehicle maintenance crews stationed at each of the bases will perform the necessary maintenance. If the required maintenance jobs require more manpower, maintenance technicians and mechanics can be borrowed from other maintenance crews at the base (e.g., from the base systems maintenance crew). If the problem is very complex, specialists will be sent to the base from Earth. With the exception of the EOTV, the vehicle stages could be slipped back to Earth for major refurbishment if it becomes unfeasible to repair it in-space.

The vehicle maintenance support equipment has been identified in WBS 1.2.2.1.6.4. This set of equipment would be required at each base. In addition to this equipment, at the LEO Base 2 flying cherrypickers and 4 thruster refurbishment machines are required.

With the exception of the EOTV, maintenance will be performed on the vehicles at their launch and docking pads so no dedicated working area is required. Adequate working area must be provided on the launching and docking area for the maintenance operations. Components that can be removed for refurbishment will be taken to the Maintenance Module located at each base.

Vehicle Refueling Operations - The only vehicles to be refueled at the LEO Base are the cargo tugs and EOTV's.

The EOTV must be resupplied with propellant while at the LEO Base. A total of 469 MT of argon, 39.4 MT of LO_2, and 6.6 MT of LH_2 must be resupplied. It was ground ruled that each of the propellants be packaged in 2 tanks to provide redundancy. The concept calls for placing the 3 loaded propellant tanks into a pallet that would be carried within a HLLV cargo pallet. The propellant pallet would be extracted from the cargo pallet and placed onto a cargo transporter. Figure H illustrates how this pallet is picked up by the cargo tug and flown to the EOTV. Note that an empty propellant pallet is returned from the EOTV first. Figure I illustrates how the propellant pallet is installed on the EOTV cargo platform. It takes 2 roundtrips to changeout the propellant pallets.

The Cargo Tug propellant is also delivered to LEO by HLLV's using propellant pallets. Figure E shows the propellant delivery concept.

Vehicle Launching Operations - The HLLV and PLV are launched away from the LEO Base using a reverse of the docking operation, shown in Figure C. The POTV and Cargo Tug back away from the docking fixture using on-board retro-thrusters and/or by a "push-away" by the docking fixture.

Cargo Handling/Distribution Operations - The functional flow of the cargo handling/distribution operations at the LEO Base are shown in Figure J. These operations are depicted in Figure K.

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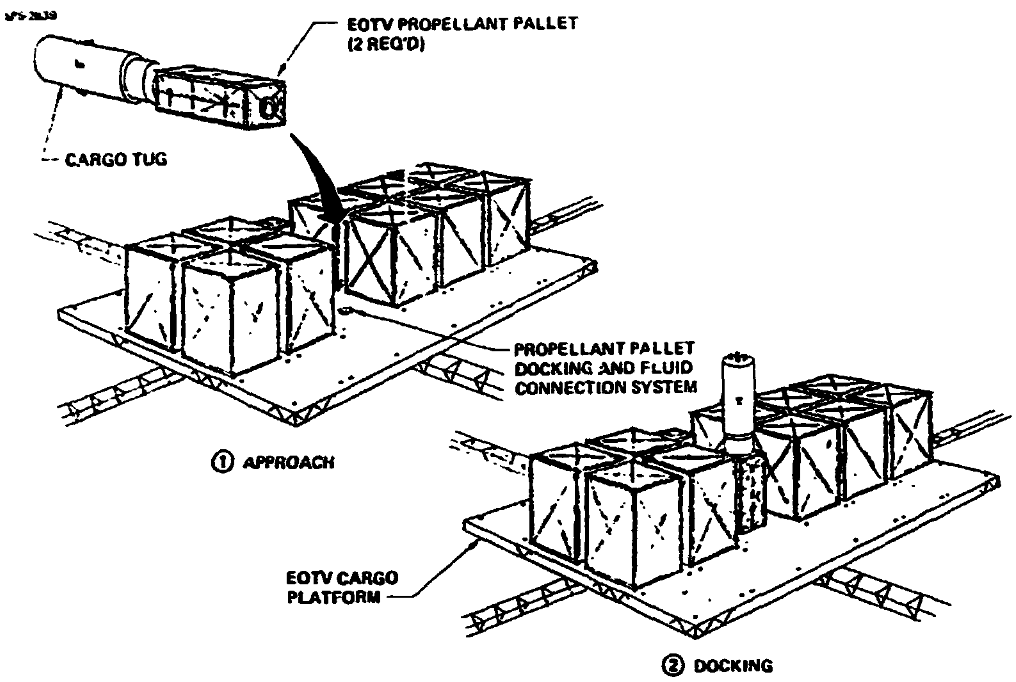

Figure I— EOTV Propellant Pallet Docking Operations at the EOTV

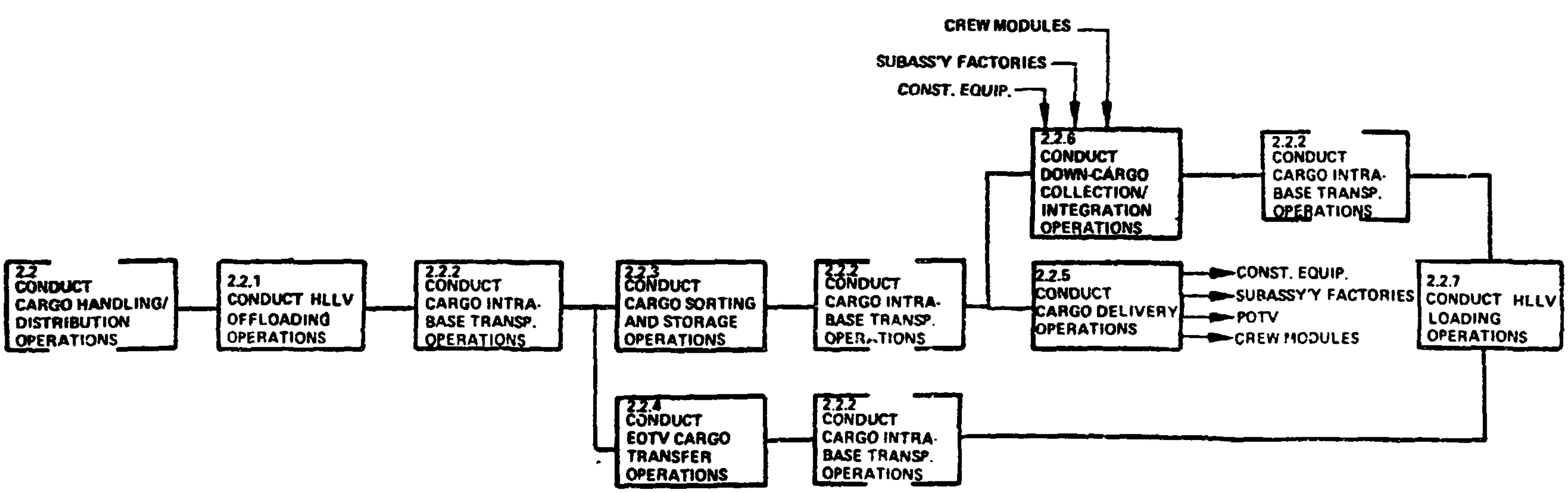

Figure J— Cargo Handling/Distribution Operations Functional Flow

The HLLV is offloaded/reloaded by the pallet handling machine (described in WBS 1.2.2.4.3.1) and loaded onto cargo transporters (WBS 1.2.2.1.3.2). If the cargo within the pallet is to be used at the LEO Base, it is transported to the cargo sorting/storage area for processing (see WBS 1.2.2.1.3.3 and -.4). The components are then delivered to construction equipment, subassembly factories, the POTV's, or to the crew modules.

If the pallets are destined for GEO, the cargo handling operations are as described below.

Figure L illustrates the overall EOTV cargo transportation systems and operations.

At the LEO Base, an Electric Orbital Transfer Vehicle (EOTV) that has just returned from GEO is placed into a station keeping position approximately 1 km away from the base. A cargo tug flies over to the EOTV and picks up an empty cargo pallet and returns it to the LEO Base. (These empty pallets will eventually be returned to Earth on an HLLV.) A loaded cargo pallet is picked up at the base and transported to the EOTV by the cargo tug. This shuttling back and forth with empty and loaded cargo pallets continues until 10-20 cargo pallets are loaded onto the EOTV.

After the cargo pallets are loaded, the cargo tug picks up empty EOTV propellant pallets and returns them to the base. Two loaded propellant pallets will have been delivered to the LEO Base within HLLV cargo pallets. These 2 loaded propellant pallets are installed on the EOTV.

Figure M shows the timeline for the EOTV operations conducted at the LEO Base.

Figure N shows the integrated EOTV flight schedule. A total of 28 EOTV flights are required during a one year period in order to deliver the satellite components necessary to construct two 5gw satellites per year. This requires that an EOTV be launched to GEO every 13 days. A total of 22 vehicles are required to maintain an average of 28 deliveries per year when taking into account EOTV performance due to solar array degradation. One additional vehicle is added to the fleet as a spare giving a total of 23 vehicles.

Crew/Crew Supplies Intrabase Transportation Operations

The subfunctions of this operational category are shown in Figure O.

Intra-Base Crew Transportation - The crews travel between habitable facilities/equipment/vehicles via either 10-man or 24-man crew bosses (WBS 1.2.2.1.3.6.2). These vehicles are driven by an on-board driver. They are equipped with a hatch on one end that interfaces directly with a crew habitat airlock port.

The other end of the crew bus is equipped with a manipulator/transfer capsule. This is used to transfer 1 or 2 crew members to construction equipment control cabs that cannot interface with the main crew bus access hatch.

PLV Crew Transfer Operations - The PLV passengers are transferred to the crew busses via a crew transfer tunnel system (WBS 1.2.2.1.3.6.1) located at each PLV docking system.

POTV Crew Transfer Operations - Figure 4 shows how the POTV passengers are transferred between the POTV and crew bus via a crew transfer tunnel attached to the crew bus.

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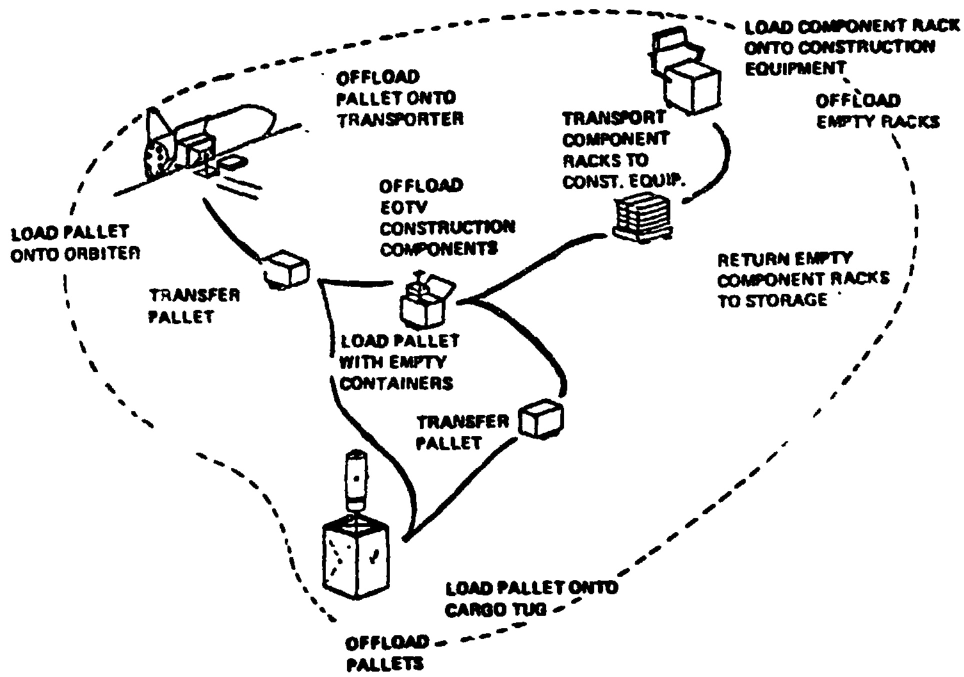

Figure K– Cargo Handling OPS

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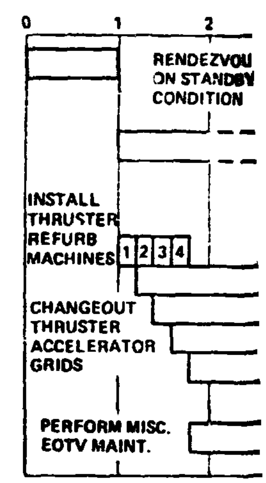

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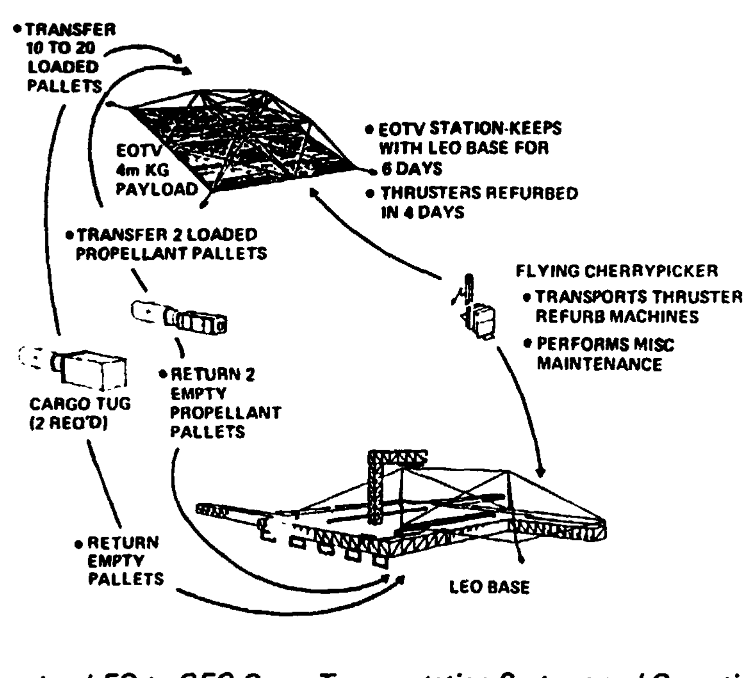

Figure L– LEO-to-GEO Cargo Transportation Systems and Operations

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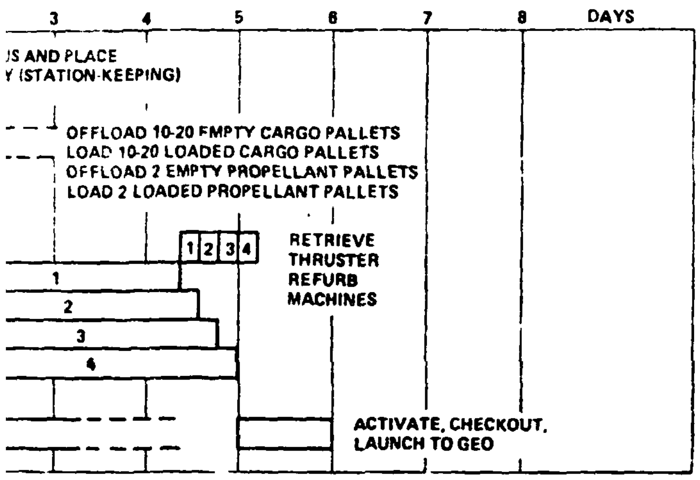

Figure M— EOTV Operations at LEO

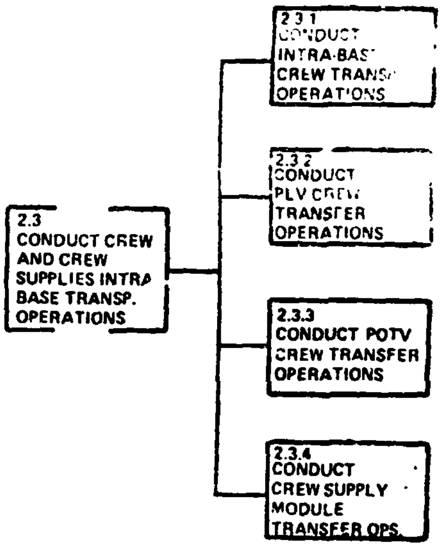

Figure O— Crew and Crew Supplies Intrabase Transportation Operations

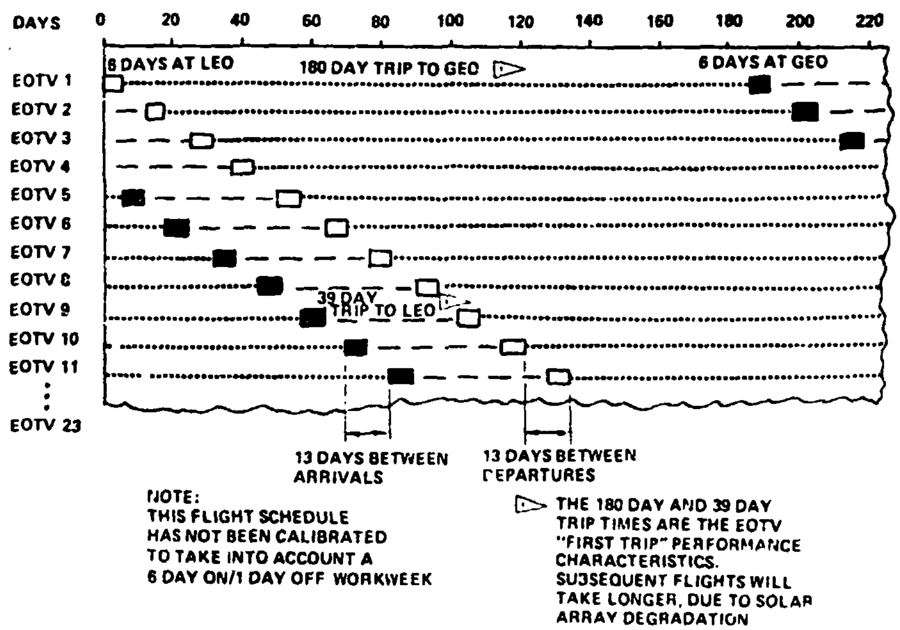

Figure N— EOTV Flight Schedule

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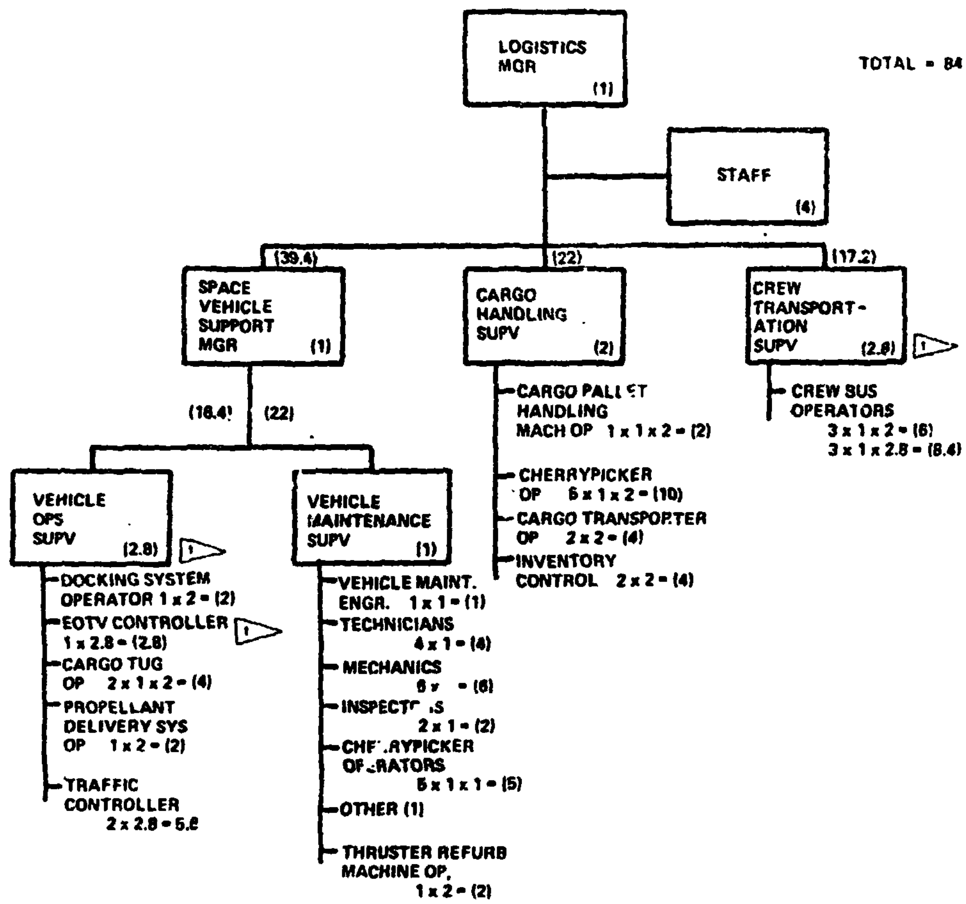

Figure P— Logistics Operations Crew Size and Organization

Crew Supply Module Transfer Operations - The crew supply modules are transported to the LEO Base as an element within a cargo pallet. The crew supply module is processed as described in a previous section. When it is delivered to the POTV, it is removed from the transporter and moved to its attachment fixture on the POTV via a cherrypicker (see Figure D).

Crew Requirements

The logistics operations crew and crew organization are shown in Figure P. A total of 84 people are required for these operations.

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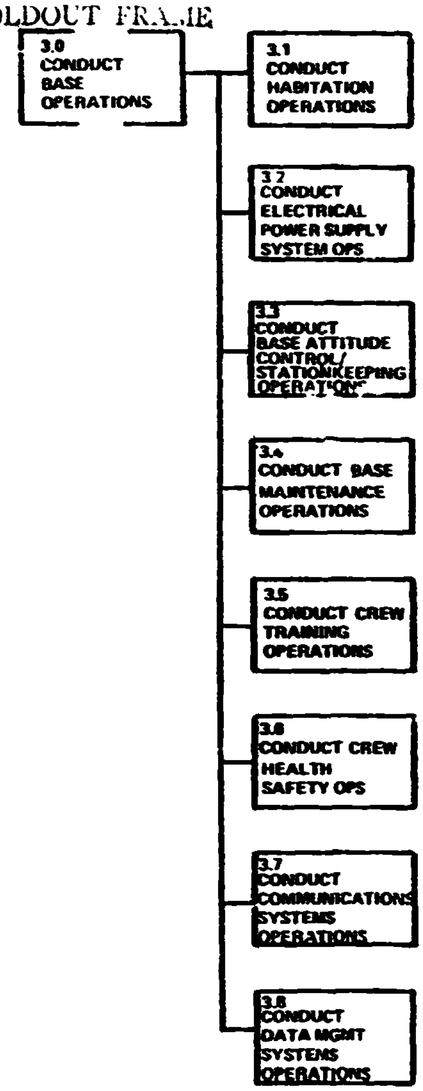

Figure A: Base Operations

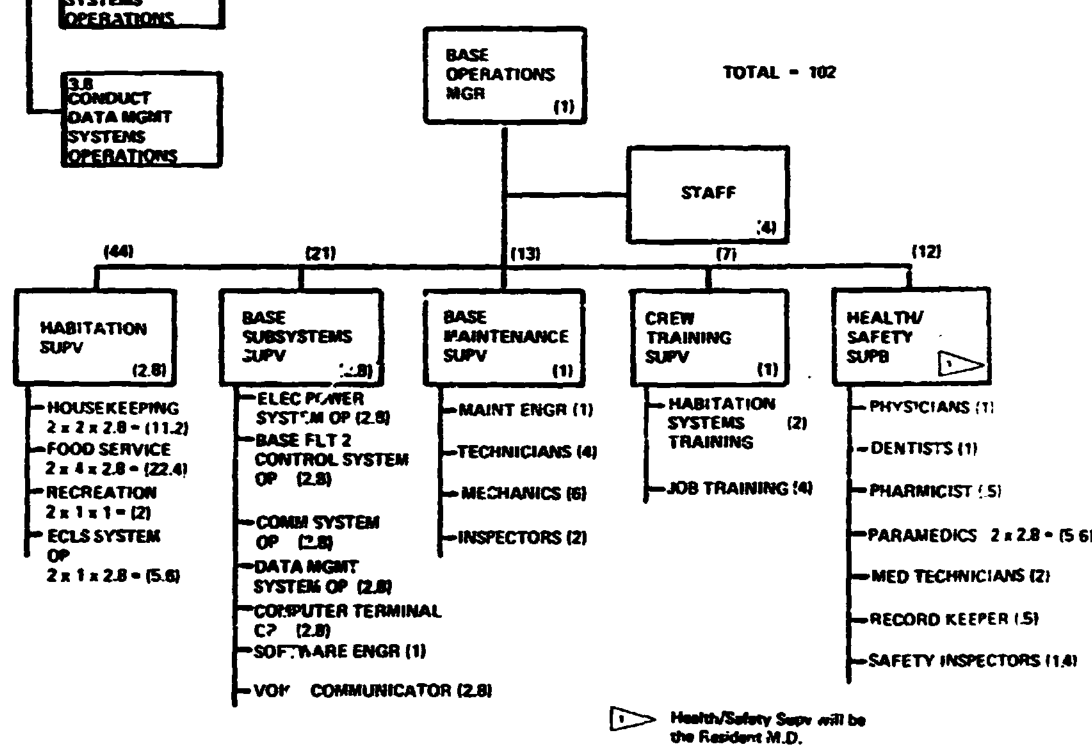

Figure B: Base Operations Crew Size and Organization

1.0 WBS DICTIONARY

This element includes the operations that are not direct EOTV construction or logistics operations. Included are descriptions of the operations, the personnel requirements and consumables requirements.

2.0 DESCRIPTION

The 8 sub-element operations are shown in Figure A. These operations and their sub-elements are described below.

Habitation Operations - The habitation operations include the operation of the environmental control/life support and food service systems, and conduction of the housekeeping and recreation provisions. These operations are conducted 24 hrs/day, 7 days/week at each crew habitat, including transient crew quarters when occupied.

Electrical Power Supply System Operations - The base electrical power supply system (WBS 1.2.2.1.8.1) is controlled/monitored 7 days week, 24 hrs per day.

Base Attitude Control/Stationkeeping System Operations - The LEO base flight control system (WBS 1.2.2.1.8.2) is controlled/monitored 7 days per week, 24 hours per day.

Base Maintenance Operations - These maintenance operations include maintenance of everything at the LEO base except for space vehicles (maintenance for these were included in WBS 1.2.2.3.2). Most elements are maintained in place. Components that can be refurbished will be taken to the maintenance module for processing. Maintenance will be scheduled during equipment idle times. Major maintenance requiring extended downtime will require spare equipment or redundant systems to be brought on-line.

Crew Training Operations - The LEO base will be used extensively as a zero-g training base for all of the GEO base as well as LEO base crewmembers. This training will include training for construction tasks, habitation tasks, operations tasks, and maintenance tasks. The training operations have not been defined in any detail.

Crew Health and Safety Operations - These operations will include the operation of the following: clinics, surgical facilities, X-ray equipment, dental facilities, medical laboratory, pharmacy, paramedic equipment, health monitoring systems, environmental safety hazard monitoring equipment, etc.

Communication Systems Operations - The voice, video, and data communication systems will be operated 24 hours per day, 7 days per week.

Data Management System Operations - The LEO base computer system will be operated 24 hours per day, 7 days per week so that base flight control and critical subsystems can be continuously monitored and controlled. Other data management system users will impose intermittent, scheduled demands.

Crew Requirements

The crew size and organization required to perform the base operations are shown in Figure B.

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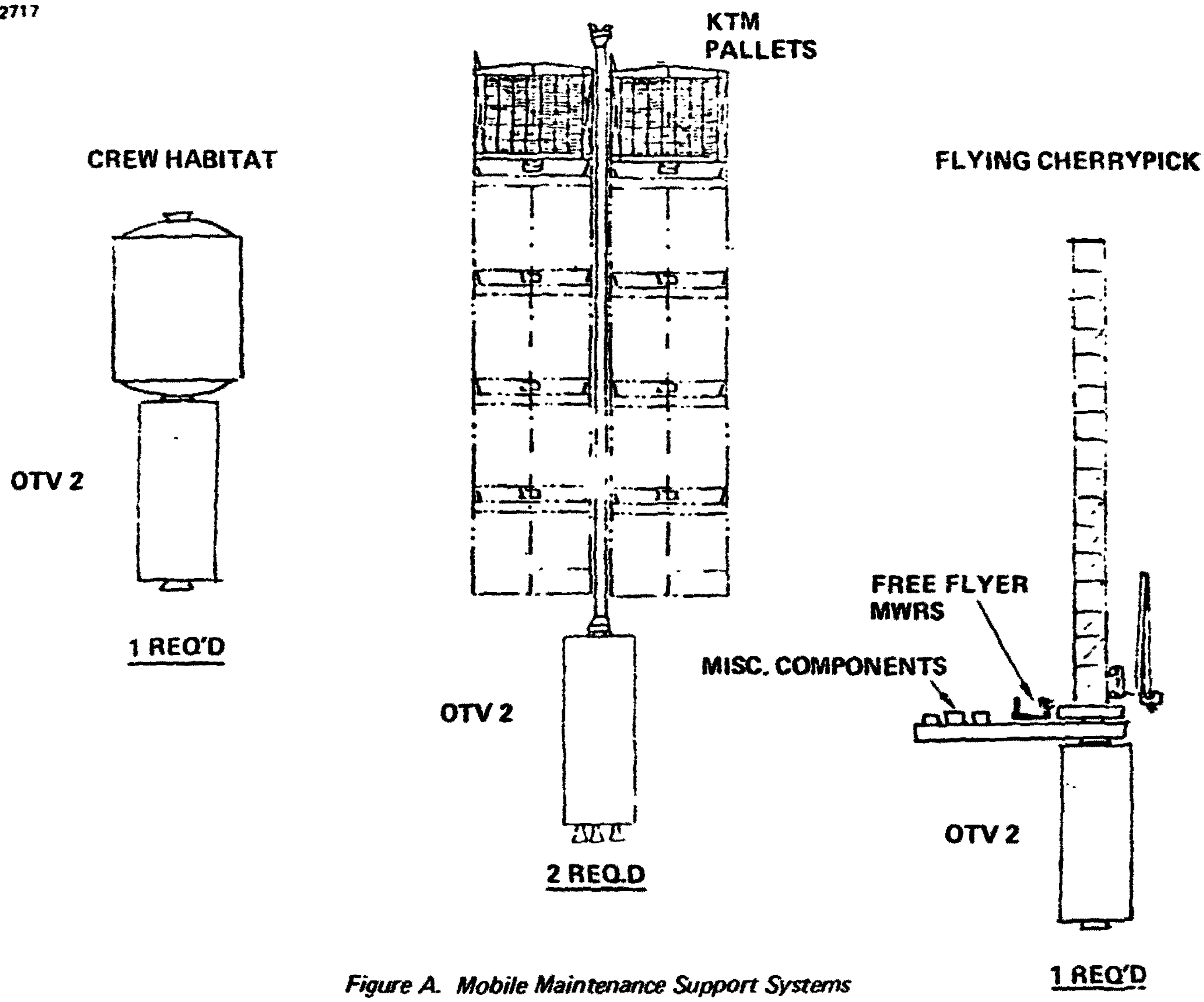

Figure A. Mobile Maintenance Support Systems

1.0 WBS DICTIONARY

This element includes the mobile maintenance systems that are flown between the GEO Base and the operational satellites. Included are the mobile work support systems, crew support systems, and the maintenance operations at the satellite. Other SPS maintenance-related elements and operations are described in the following WBS descriptions:

WBS 1.1.1.6	Energy Conversion System Maintenance Systems
WBS 1.1.2.6	Power Transmission System Maintenance Systems
WBS 1.1.6.5	Interface System Maintenance Systems
WBS 1.2.1.1.7	GEO Base SPS Maintenance Support Facilities
WBS 1.2.1.3	SPS Maintenance Support Operations
WBS 1.3.6	Interorbit Transfer Vehicle (IOTV)

2.0 DESCRIPTION

The mobile maintenance work support and crew support elements are shown in Figure A. The crew habitat is described in WBS 1.2.3.2. The KTM pallets, flying cherrypicker, and free-flyer MRWS are described in WBS 1.2.3.1. The OTV is described in WBS 1.3.6. The mobile maintenance systems will be based at the GEO Base between maintenance sorties. These system elements will shuttle between satellites and the GEO Base. The maintenance operations are described in WBS 1.2.3.3.

3.0 DESIGN BASIS

The mobile maintenance systems and operations were defined for a 20-SPS's-in-orbit scenario. The original maintenance systems and operations concepts are found in the Part III Final Briefing, March 1978, Boeing Doc. No. D180-24071-3. These concepts were updated and amplified in the analysis presented in section 13 of the Operations and Systems Synthesis Document, D180-25461-3.

4.0/5.0 MASS AND COST

Refer to Table A for comprehensive mass and cost summary. Refer to subelement descriptions for mass and cost basis.

TABLE A

WBS 1.2.3 MOBILE MAINTENANCE SYSTEM

COMPREHENSIVE MASS COST SUMMARY

WBS No.	Element	Mass, MT	DDT&E Cost, $ Millions	Unit Cost, $ Millions
1.2.3				
1.2.3.1	Work Support System	269	TBD	64.6
1.2.3.2	Crew Support Syst.	253	TBD	362
Wrap-Around Factors				
	Spares	TBD		
	Inst. Assy, C/O			
	SE&I			
	Proj. Mgmt			
	Systems Test			
	GSE			
	Software			
	Logistics			
	Liaison			
Annual				
	Resupply	103.8 MT/Yr		58
	Salaries & Training			60.5
				$118.5 M/Yr

(The TBD applies, by brace, to all wrap-around factors Spares through Liaison.)

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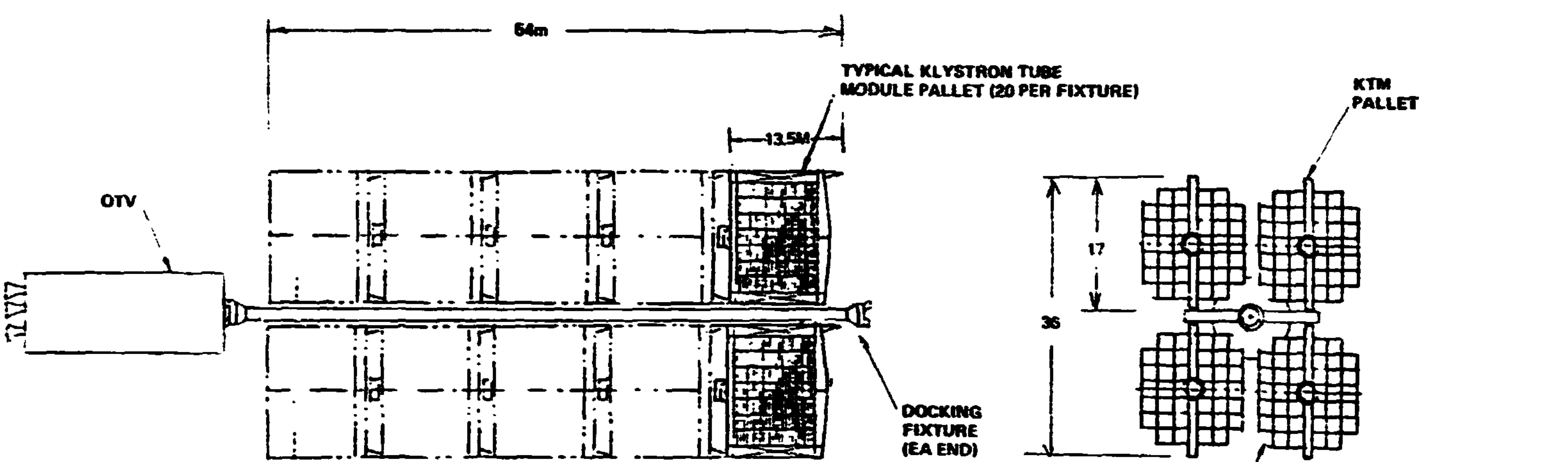

KTM PALLET FIXTURE

TRANSPORTS ENOUGH KTM'S
TO SERVICE 10 SATELLITES

KLYSTRON TUBE
MODULE RACKS (38 RACKS/KTM PALLET)
(25 KTM'S PER RACK)

950 KTM/PALLET

1.0 WBS DICTIONARY

This element includes the klystron tube module pallet fixture assembly, flying cherrypicker, and free-flyer mobile remote work station used by the mobile maintenance crew. The orbital transfer vehicle used to transport these elements is described in WBS 1.3.6.

2.0 DESCRIPTION

WBS 1.2.3.1.1—Klystron Tube Module (KTM) Pallet Fixture Assembly—Figure A shows the KTM pallet concept. These pallets are used to transport KTM's between the satellites and the GEO Base.

The KTM pallet is composed of 3 main elements: WBS 1.2.3.1.1.1—The KTM pallet fixture, WBS 1.2.3.1.1.2—the klystron tube module pallets, and WBS 1.2.3.1.1.3—the klystron tube module racks. There are 38 KTM racks per pallet. Each KTM rack can be loaded with 25 KTM's (WBS 1.1.2.2.1). There will be 20 of the pallets per OTV. This combination provides for transporting 1900 KTM's to and from each of 10 satellites (the projected number of failed KTM's per 6 months).

The KTM pallets fixture can be docked to other similar units, to the OTV, and to the cargo transporters located on the satellite's antenna. The KTM racks can be detached from the pallet/docking fixture, now carried by the cargo transporter, by a cherrypicker. These racks can then be attached to the satellite-mounted maintenance cherrypickers. These maintenance cherrypickers can then remove and store KTM's in the KTM racks.

A total of 2 pallet fixtures are required (1 at a SPS + 1 at GEO Base being offloaded/reloaded).

A minimum of 800 KTM racks will be required (approximately 3 month's of defective KTM's—20,000 units—will be in storage.)

WBS 1.2.3.1.2—The Flying Cherrypicker—The maintenance access concepts all use a machine that has been dubbed "the flying cherrypicker." Figure B illustrates the concept. The primary reason that this machine concept was created was that the predicted failure rates of the components to be serviced was much too low to warrant dedicated maintenance cherrypickers located permanently on the satellite. Also, due to the complexities of the various locations in which cherrypickers would be required, it was not feasible to create an integrated track network that would allow a track-mounted cherrypicker to get to all of the locations. Hence, a flying cherrypicker and a set of track-mounted carriages were created.

The flying cherrypicker carries along a power supply which would be connected to the carriage after docking. The platform on the flying cherrypicker is used to transport the replacement components, the components that were removed from the satellite, and the maintenance tools. A docking port for a free-flyer (to be described below) is also provided on the platform. This provides a location for transporting the free-flyer on the inter-satellite flights.

The reach envelope of the flying cherrypicker was derived by consideration of the various maintenance jobs that it would be used for.

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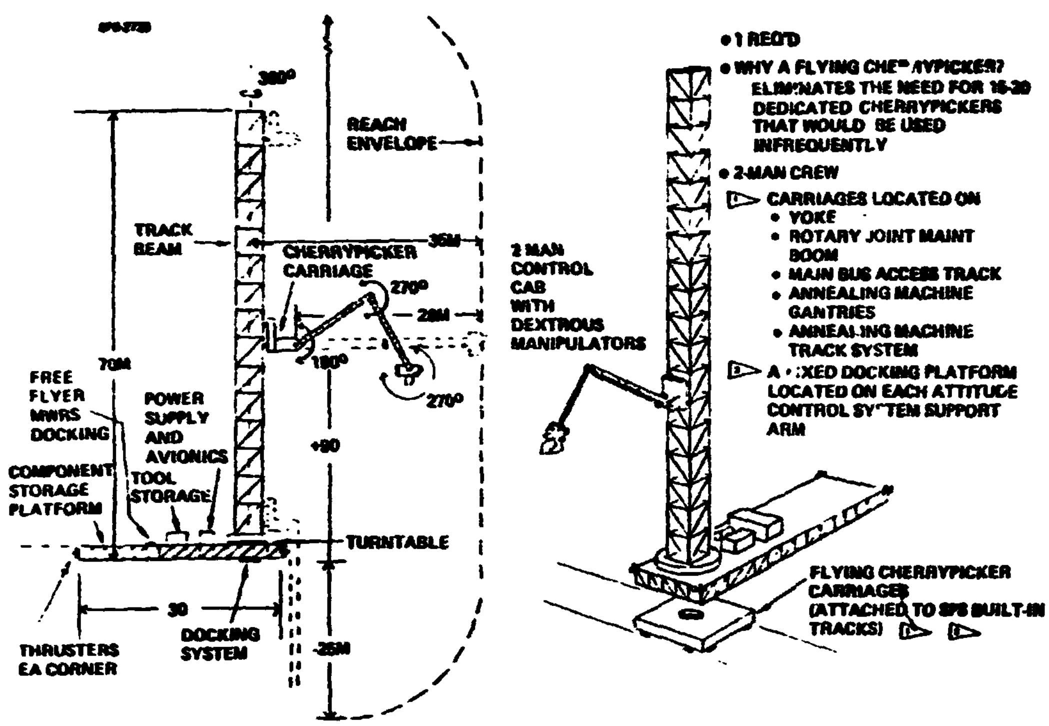

Figure B. Flying Cherrypicker

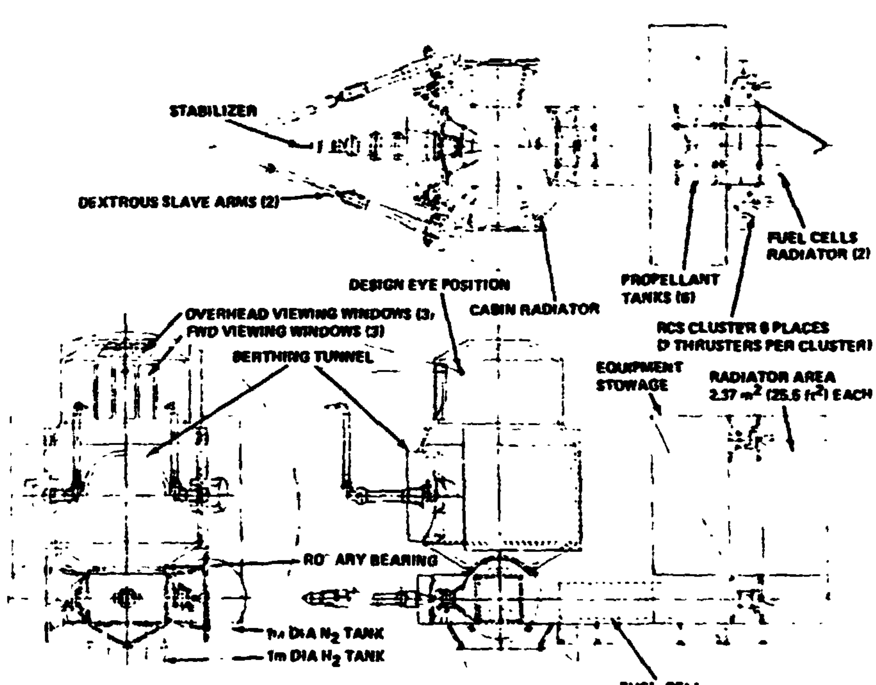

Figure C. Free Flyer MRWS

Examination of the failure rate data shows that there would be about 12 components to be serviced by the flying cherrypicker during a bi-annual maintenance visit (2 cell string blocking diodes, 2 to 3 antenna switchgear, a DC-DC converter, a disconnect switch, and a DC-DC converter thermal control system). During the 52.5 hours of available work time there would be sufficient time available for one flying cherrypicker to perform the changeout of these devices.

WBS 1.2.3.1.3—Free-Flyer Maintenance Vehicle—During the analysis of the maintenance operations required for the various components, requirements for a free-flyer maintenance vehicle were established. This vehicle would be used for the following tasks: (1) used to make a fly-over of the entire satellite to spot solar array tensioning device and catenary failures; (2) used to assist the flying cherrypicker in main power bus repairs; and (3) used to perform maintenance tasks at locations inaccessible to the flying cherrypicker, e.g., the power busses running between the solar array and the attitude control system.

The free-flyer mobile remote work station defined by Grumman in Contract NAS9-15507 is a suitable candidate for this requirement, see Figure C. One of these would be required.

3.0 DESIGN BASIS

The Klystron Tube Module Pallet Assembly (WBS 1.2.3.1.1) was configured taking into account the KTM handling operations, the maintenance mission schedule, and the optimal size of the OTV.

The Flying Cherrypicker (WBS 1.2.3.1.2) design basis is defined in Section 13 of the Operations and Systems Synthesis report (D180-25461-3).

The rationale for the Free-Flyer Maintenance Vehicle (WBS 1.2.3.1.3) is defined in the same report.

4.0 MASS AND MASS BASIS

WBS	Item	Qty	Mass,MT	Basis
1.2.3.1.1	KTM Palley Assembly	2	261	10% of payload
1.2.3.1.2	Flying Cherrypicker	1	5	See Table C in WBS 1.2.2.1.6
1.2.3.1.3	Free-Flyer	1	3	Scaled from 1-Man MWRS

5.0 COST AND COST BASIS

WBS	Item	Qty	Production Cost,$M	Basis	DDT&E Cost
1.2.3.1.1	KTM Palley Assembly	2	10	Guess	
1.2.3.1.2	Flying Cherrypicker	1	35.6	See Table C in WBS 1.2.2.1.6	
1.2.3.1.3	Free-Flyer	1	19	Scaled from 30M CP	
		TOTAL	$64.6		

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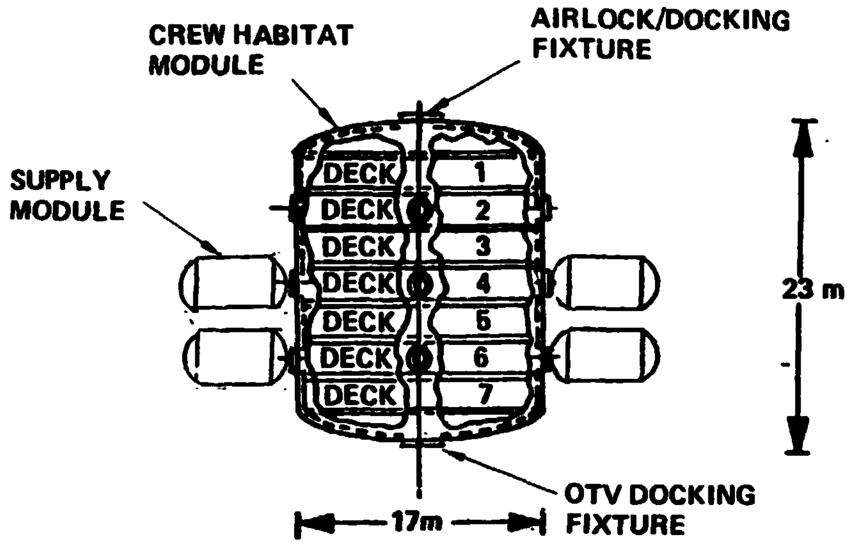
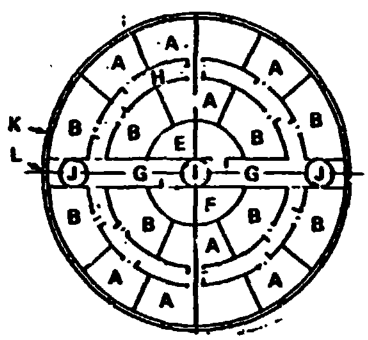
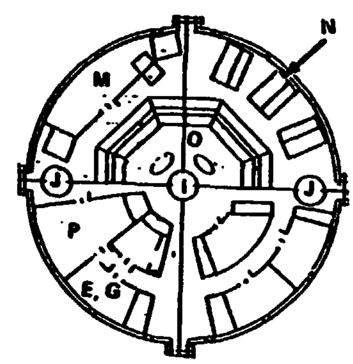


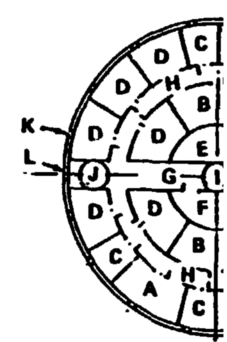
Figure A. Crew Support Systems



DECK 1
CREW QUARTERS



DECK 2
CONTROL CENTER/SUBSYSTEMS



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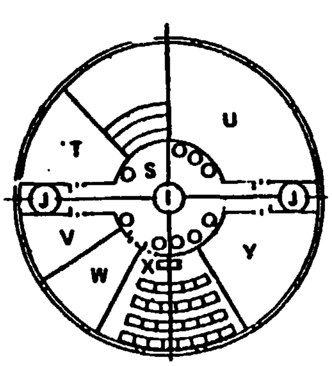
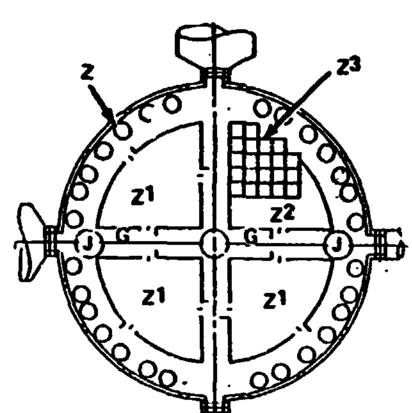
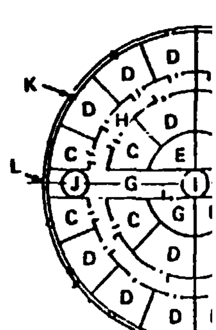


DECK 5
RECREATION/PHYSICAL
FITNESS/SERVICES



DECK 6
EXPENDABLES/SUBSYSTEMS



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1.0 WBS DICTIONARY

This element includes the facilities and equipment required for the life support and well being of the mobile maintenance crew members. Included are the crew habitat and the resupply modules.

2.0 DESCRIPTION

The mobile maintenance crew support systems are shown in Figure A.

WBS 1.2.3.2.1—Crew Habitat Module—This crew habitat module is identical to that described in WBS 1.2.1.2.1. One of these habitats is required.

WBS 1.2.3.2.2—Crew Supply Module—This supply module is identical to those used at the LEO and GEO Bases.

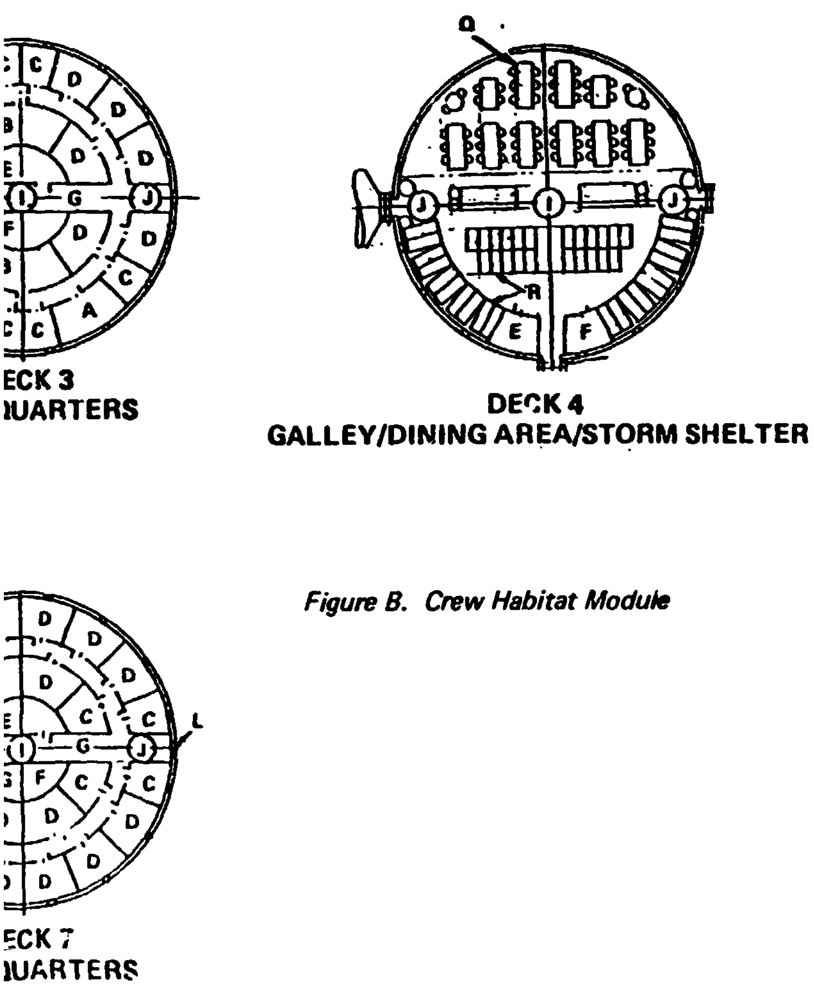

Figure B. Crew Habitat Module

HABIT AREAS:

A. ONE-PERSON STATEROOM
B. TWO-PERSON STATEROOM
C. ONE-PERSON CREW QUARTER
D. TWO-PERSON CREW QUARTER
E. WASTE MANAGEMENT
F. PERSONAL HYGIENE
G. CENTRAL PASSAGEWAY
H. TORUS AISLEWAY
I. THRU-DECK ACCESS
J. INTERDECK ACCESS
K. CABIN WINDOWS
L. VIEW WINDOWS
M. EMU/EVA PREP ROOM
N. COMPUTER RACKS
O. CONTROL CENTER
P. CONFERENCE ROOM
Q. DINING AREA (60 PERSONS)
R. FOOD STORAGE
S. LOUNGE
T. LAUNDRY/SUPPLIES
U. RECREATION/GYMN
V. BARBER SHOP/POST OFFICE
W. LIBRARY/STUDY
X. THEATER/CHAPEL
Y. SICK BAY/DENTIST
Z. EXPENDABLES
Z1. SUBSYSTEMS
Z2. COMPACTED WASTE

3.0 DESIGN BASIS

The crew module provides living quarters for the 83 crewmembers and also provides additional in-door work area for maintenance of small parts. This module will be provided with enough supplies for 83 people for 90 days + 10% contingency.

4.0 MASS AND MASS BASIS

WBS	Item	Qty	Mass	Basis
1.2.3.2.1	Crew Module	1	243.1 Mt	See WBS 1.2.1.2.1
1.2.3.2.2	Crew Supply Module	TBD	TBD	

5.0 COST AND COST BASIS

WBS	Item	Qty	Production Cost	DDT&E	Basis
1.2.3.2.1	Crew Module	1	$347M	TBD	See WBS 1.2.1.2.1
1.2.3.2.2	Crew Supply Module	TBD	TBD		

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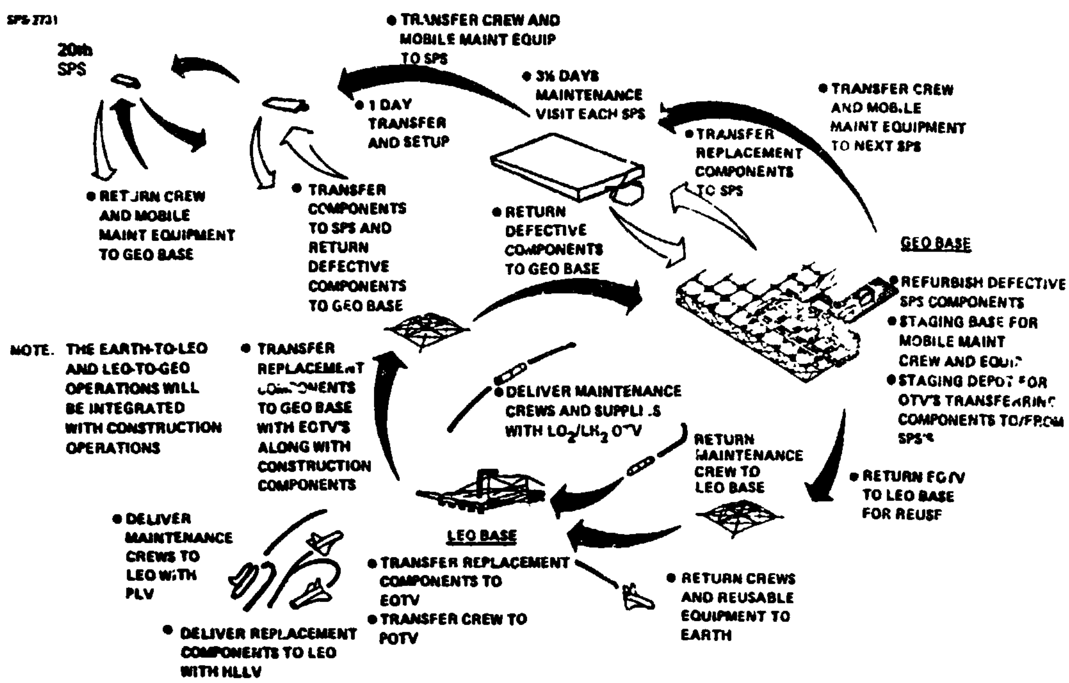

Figure A. Integrated SPS Maintenance Operations

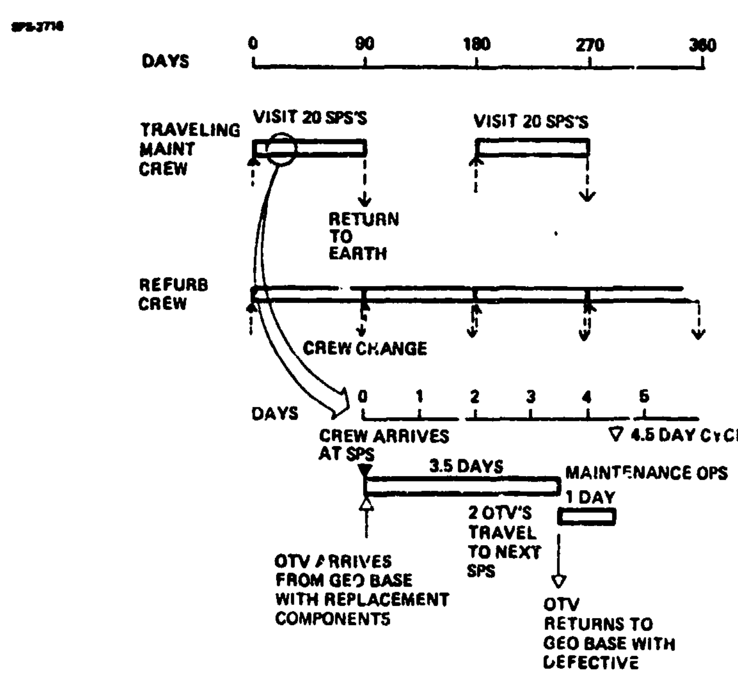

Figure B. SPS Maintenance Timeline

1.0 WBS DICTIONARY

This element includes the at-satellite maintenance operations. Included are descriptions of the sub-operations, personnel requirements, and consummables requirements.

2.0 DESCRIPTION

The integrated SPS maintenance operations concept is depicted in Figure A. The top-level timeline, shown in Figure B, shows that there are two types of operations: 1) maintenance operations at the satellite, and 2) refurbishment of defective components at the GEO base (the refurbishment operations are described in WBS 1.2.1.3).

The at-satellite maintenance occurs over a 90 day period when each satellite is visited by a mobile maintenance crew and equipment for a 3.5 day staytime. Twenty operational 5 GW SPS's are assumed in the mission model. At the end of the 90 day period, the traveling maintenance crews are returned to Earth. They return to orbit after 90 days on Earth and then repeat the maintenance visit routine. Hence, each satellite is visited twice a year for maintenance. The refurbishment operations are conducted continuously with a crew changeout every 90 days.

Mobile Maintenance Operations—A crew of 83 people are loaded at the GEO base into a mobile crew habitat and are transported to the operational SPS's using an OTV. Traveling with the crew is a flying cherrypicker, and an OTV loaded with replacement parts.

The crew habitat docks to a docking port on the satellite's antenna, see Figure C. The satellite will have been deactivated from the ground just prior to the arrival of the crew. The mission control center on the ground will have accumulated a detailed listing of most of the faulty satellite components. A detailed operating plan will have been concocted to plot the maintenance crew's activities while at the satellite so that a minimum of wasted motion is incurred. Upon arrival, a two-man free-flyer vehicle will be dispatched to make a flyover of the satellite to detect non-annunciated failures, e.g., solar array tensioning device failures.

The replacement component cargo OTV docks to a transporter located on the antenna and drops off a pallet of KTM's. It will then fly to another antenna-attached transporter to drop off another load of KTM's. There are two places to do this.

The maintenance crews are taken from their crew habitat to maintenance gantries located on the antenna using a crew bus that is stationed on the antenna. There are 22 maintenance gantries on the antenna, see Figure D. The KTM pallet transporter is moved about to locations where racks of KTM's can be offloaded onto the maintenance gantries.

The maintenance gantries move to predesignated locations where the cherrypicker then removes defective KTM's and replaces them with good ones as shown in Figures E and F.

Meanwhile, the flying cherrypicker is manned, the replacement components loaded onto it, and then it flies to docking carriages located in various locations on the

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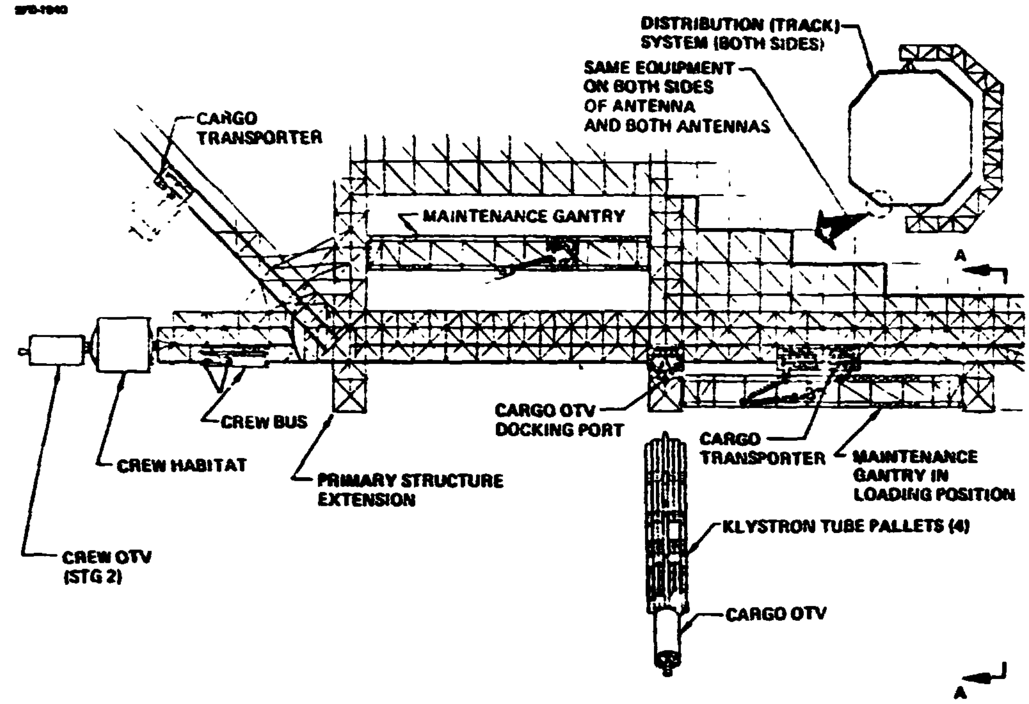

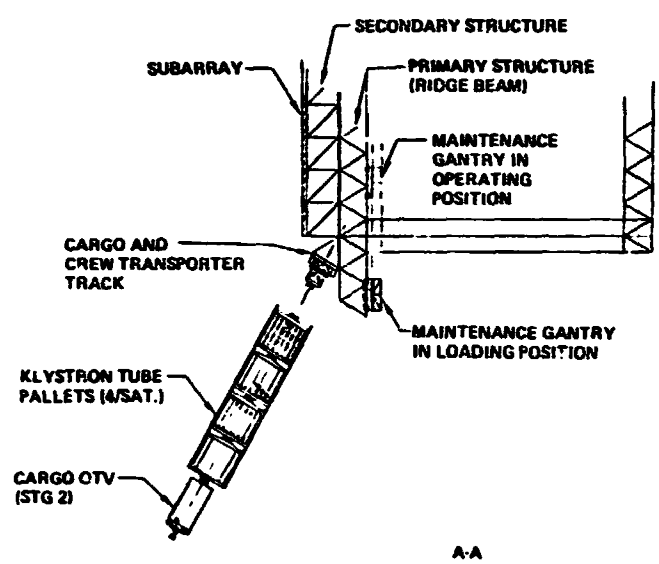

Figure C. Antenna Maintenance Systems

satellite. Figures G, H, and I show some typical locations. The cherrypicker removes defective components and replaces them with good ones.

These operations continue for two shifts a day for 3½ days. The crew habitat and flying cherrypicker then moves on to the next satellite where they will be met with an OTV loaded with replacement parts. The defective components are returned to the GEO base where they will be refurbished.

After 20 satellites have been visited, 90 days are up and the crew returns to the GEO base for return to Earth.

Personnel Requirements—The mobile maintenance crew is composed of 83 people, Figure J shows the crew jobs and organization.

4.0 MASS AND MASS BASIS

Resupply Item	Annual Resupply W/10% Cont.	Rationale	Reference
o Crew Supplies	(39)	All elements	Scaled from values
o Food	29.3	computed for	derived for
o Housekeeping & Other Items	9.8	$(83 \text{ men} \times 90 \frac{\text{Days}}{\text{Trip}}$	GEO Base Crew,
		$\times 2 \frac{\text{Trips}}{\text{Yr}}) + 10\%$	
o Crew Module Supplies	(17.8)		See WBS 1.2.1.3
o ECLS O_2, N_2, & H_2O	9.3		
o ECLS Life Limited Parts	7.5		
o Other Subsystem Parts	1.0		
o Work Facility Supplies	(47)		
o Equipment Parts	3	Guess	
o Cargo Hdlg/Dist. Parts	3	Guess	
o Crew Bus (0_2, N_2)	1	Scaled from GEO Base crew Busses	
o Remote Work Sta. (0_2, N_2, & Parts)	40	Scaled from GEO Base crew Busses	
TOTAL	103.8 MT		

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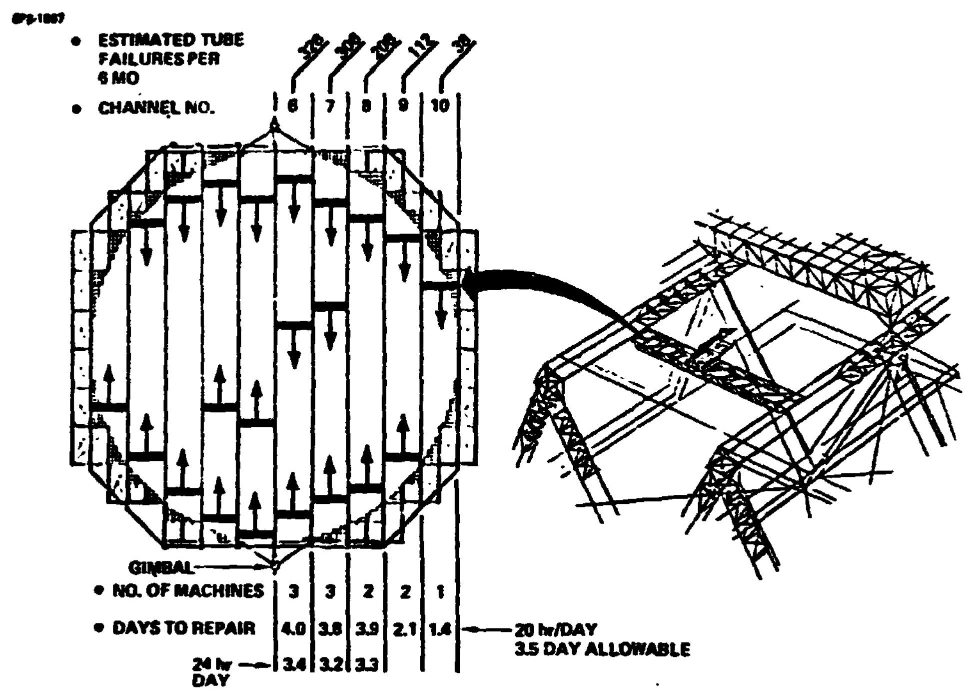

Figure D. Antenna Maintenance System Installation

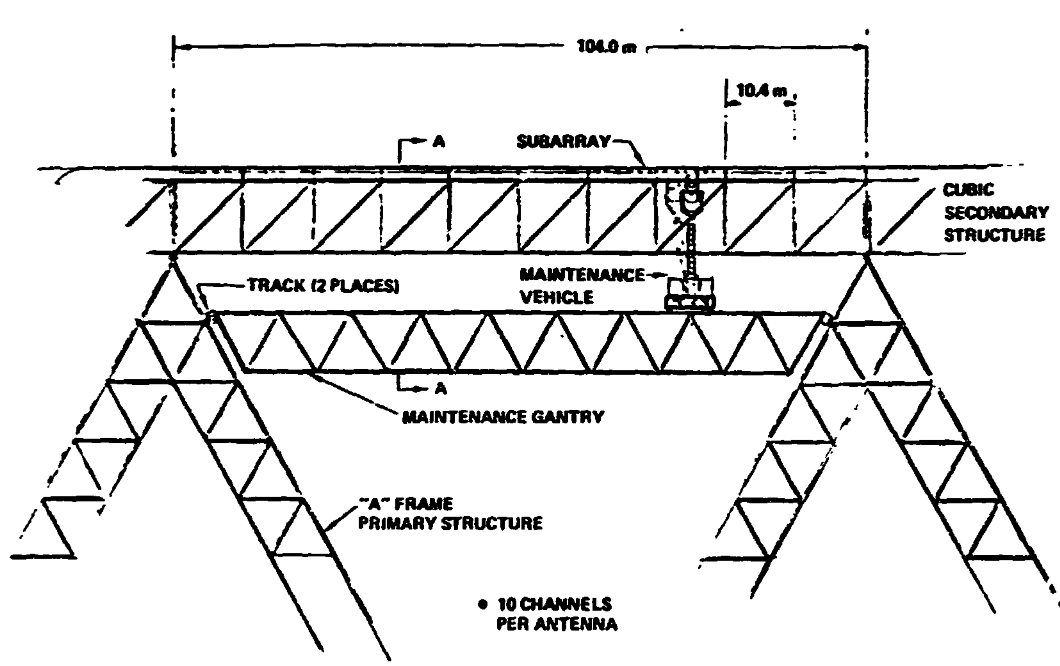

Figure E. Vertical Access for Tube Maintenance

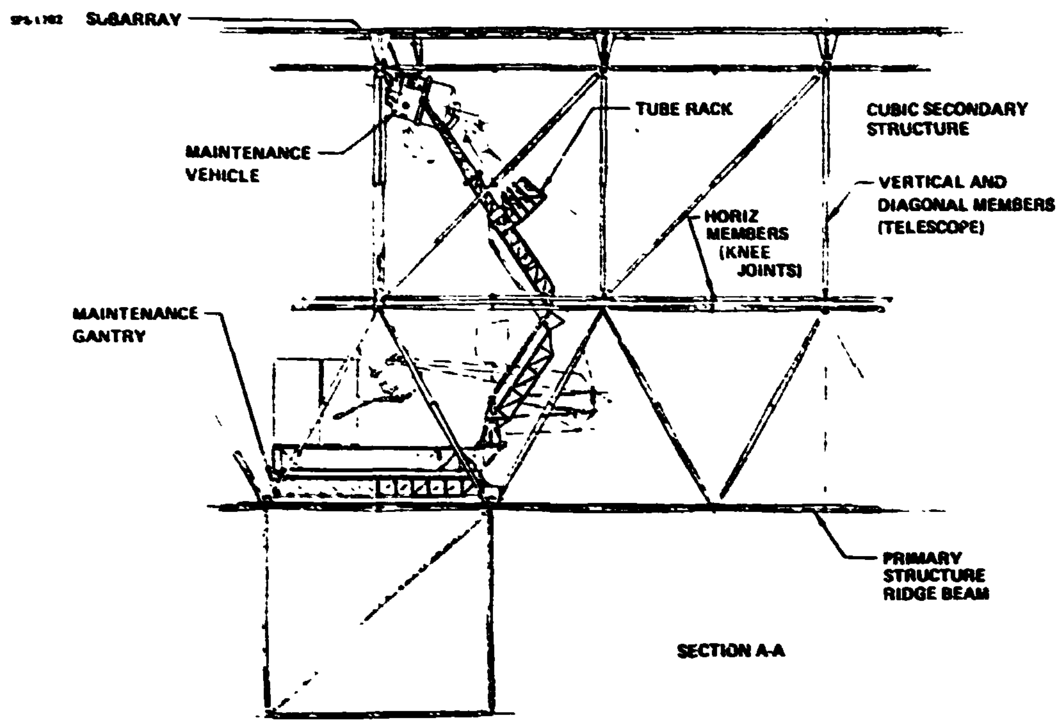

Figure F. Vertical Access Maintenance Vehicle

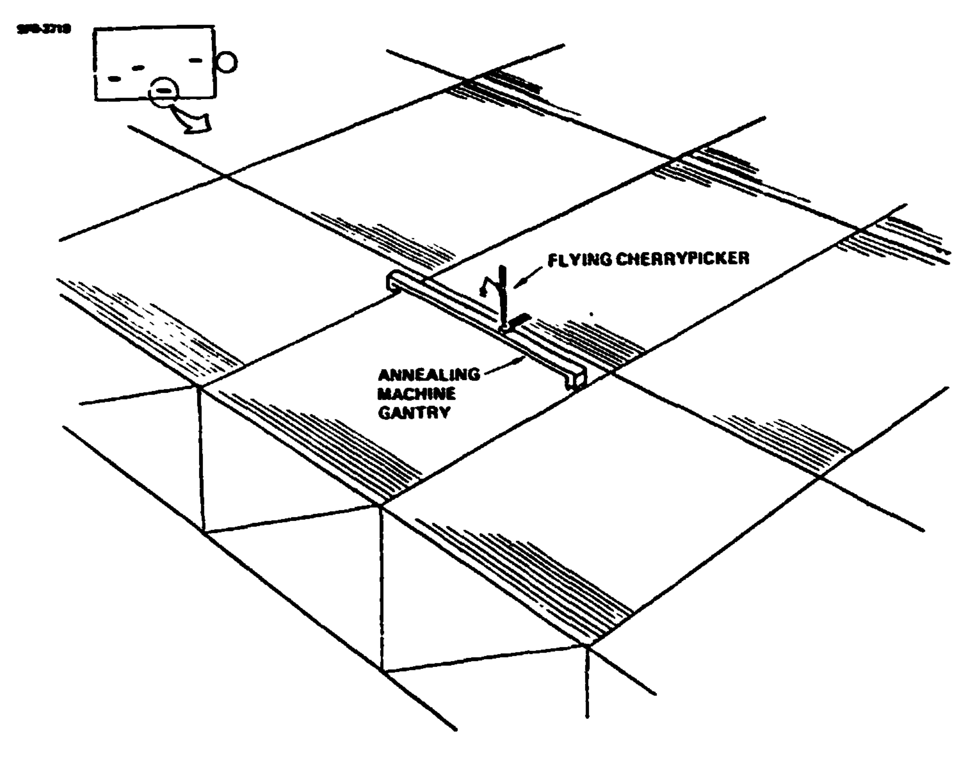

Figure G. Solar Array Top Surf.ce Maintenance Access Systems

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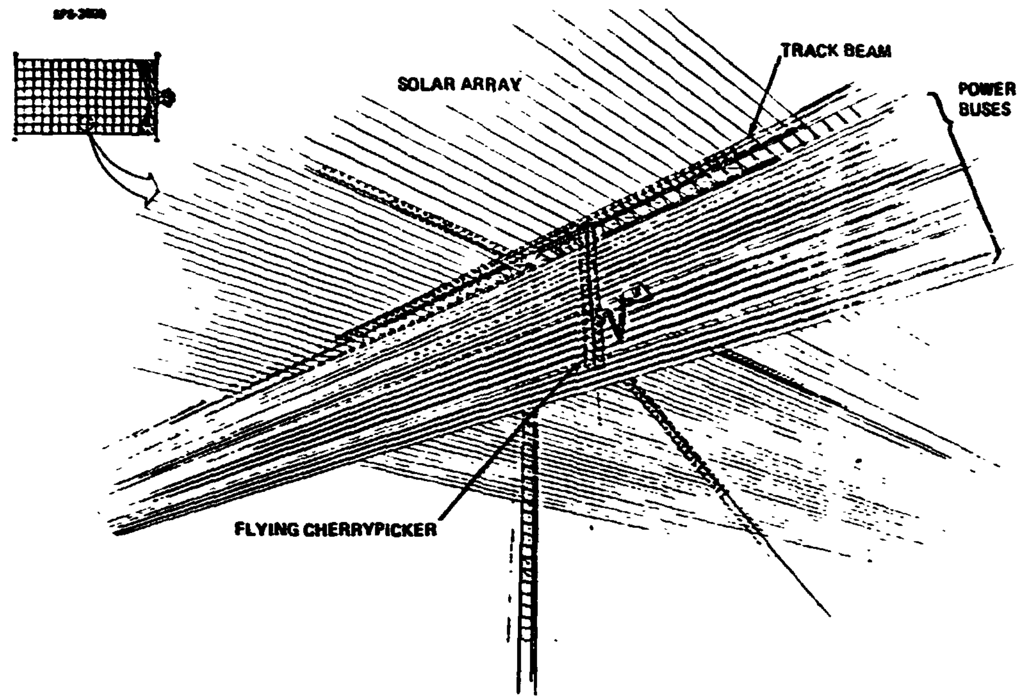

Figure H. Main Bus Maintenance Access System

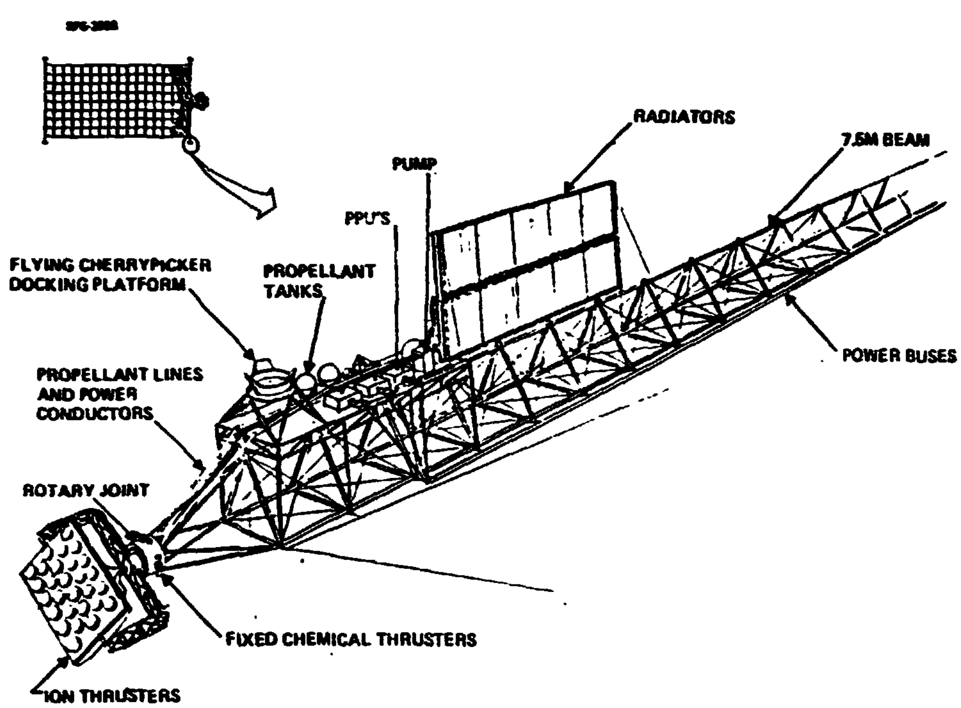

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Figure I. SPS Attitude Control System

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WBS 1.2.3.3 OPERATIONS (Continued)

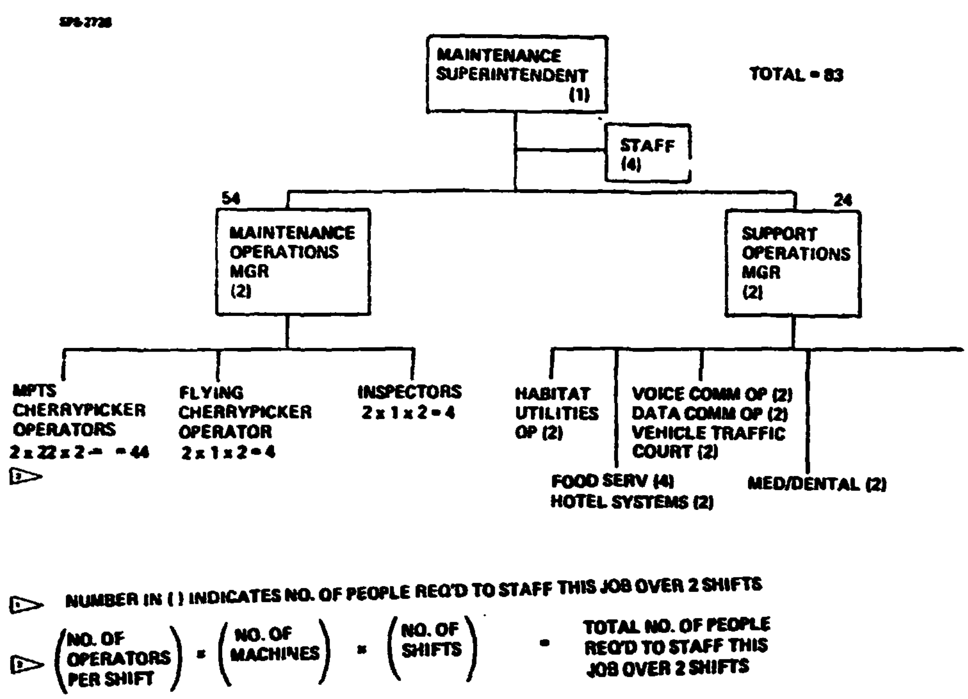

Figure J. Mobile Maintenance Crew

5.0 COST AND COST BASIS

	Operation	Men/Yr	Rational	Annual Cost $M	Rationale
o	Orbital Crew	83	1 crew of 83 makes 2 trips per year	10.7	$129K/Man-Yr
o	Ground Crew	830	10 x orbital crew	41.5	$50K/Man-Yr
o	Training			8.3	20% Salaries
			Total	$60.5	

o <u>RESUPPLY ITEMS</u>

Item	Annual Cost $M/Yr	Rationale	Reference
o Crew Supplies			
o Food	.13	\$4.54/KG x 29.3 MT/YR	Estimate
o Housekeeping & Other Items	.02	\$2.22/KG x 9.8 MT/YR	Estimate
o Crew Module Supplies			
o ECLS N_2, H_2O	neg	N_2: \$.05/KG x 3.07 MT/YR	Use same factors as used for LEO Base Ops.
	neg	H_2O: \$.01/KG x MT/YR	
o ELLS Life Limited Parts	11.9	\$1580/KG x 7.5 MT/YR	
o Other Subsystem Parts	1.6	\$1580/KG x 1 MT/YR	
o Work Facility Supplies			
o Equipment Parts	6.6	\$2190/KG x 3 MT/YR	Use same factors as used for LEO Base Ops.
o Cargo Handling Equipment	6.2	\$2072/KG x 3 MT/YR	
o Crew Buses (H_2O, N_2)	neg	H_2O: \$0.1/KG x .3 MT/YR	
on satellites	neg	N_2: \$.05/KG x .7 MT/YR	
o Remote Work Stations	neg	H_2O: \$.01/KG x 5.6 MT/YR	
on Satellite (H_2O, N_2, Parts)	neg	N_2: \$.05/KG x 14.4 MT/YR	
	31.6	Pacts: \$1580/KG x 20 MT/YR	
TOTAL ANNUAL COST	\$58 M/YR		

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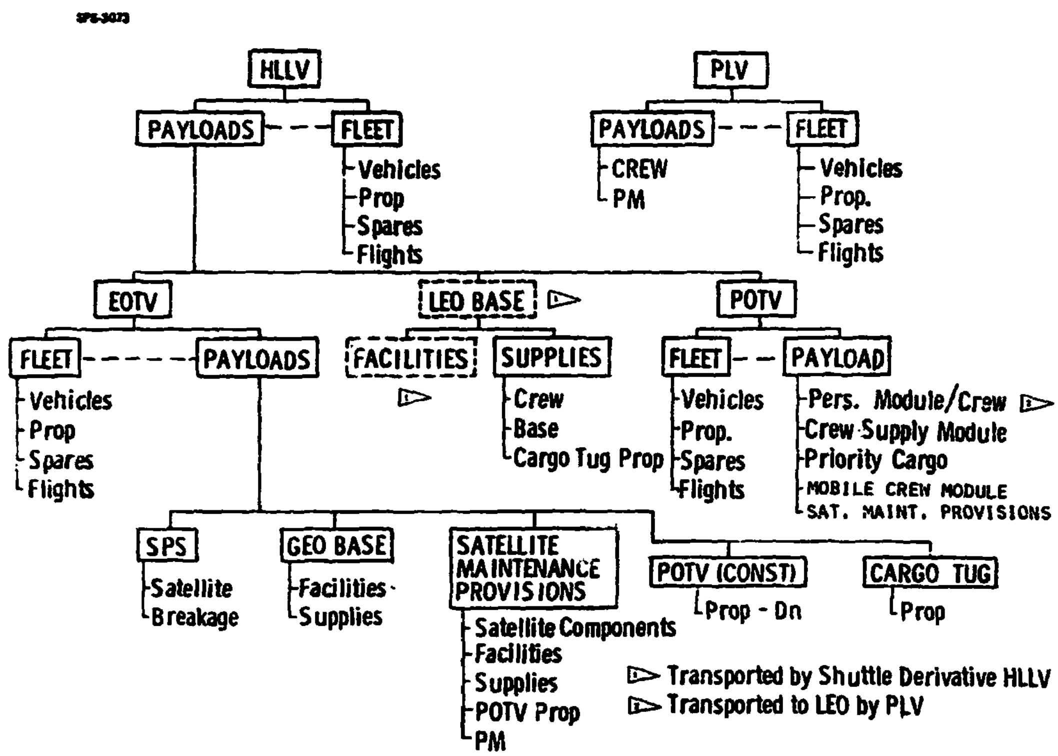

Figure 1.3-1 Space Transportation Traceability

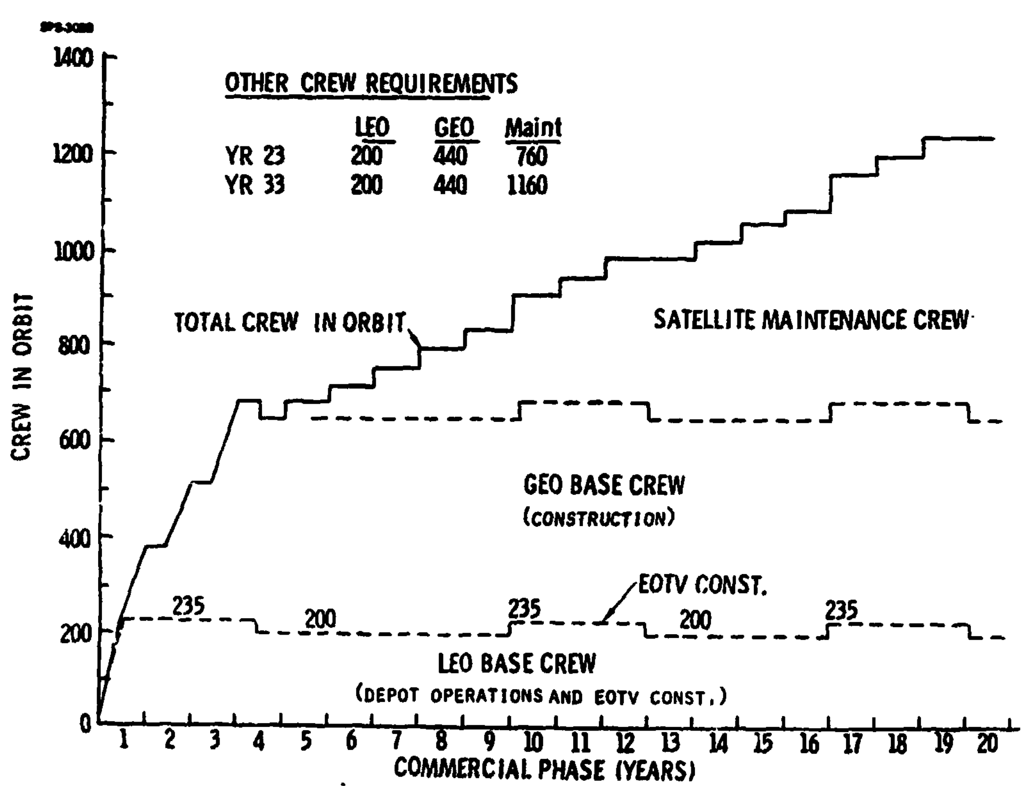

Figure 1.3-2 – Crew in Orbit

WBS 1.3 SPACE TRANSPORTATION

This WBS section will discuss the overall transportation scenario and be followed by system descriptions, mass and cost characteristics associated with each transportation element.

TRANSPORTATION SCENARIO OVERVIEW

The transportation scenario describes the overall flight activity associated with SPS Transportation. The overall goal is to provide "traceability" with the specific objectives being as follows:

a. Identify the payloads to be transported by each transportation element.

b. Identify the schedule associated with the transportation.

c. Identify the number of flights flown by each by transportation element. This output directly contributes to establishing cost per flight.

d. Provide visibility to distinguish between transportation associated with construction of satellites and that related to maintenance.

The data developed covers the first 13 years of the commercial program and the 23rd and 33rd years. Up through the first 13 years is sufficient to include construction of the second fleet of EOTV's and the maintenance of 20 satellites in orbit. The 23rd and 33rd years are since they correspond to 40 and 60 satellites respectively being in orbit which allows the impact of the additional maintenance activity to be assessed. It should also be noted that once satellite construction begins, the rate is always two 5 GWe (ground output) satellites per year.

Should there be the need to know the number of flights for a year not analyzed, a straight line extrapolation between the analyzed years can be used while realizing that some interim years will have higher values because of construction of another EOTV fleet.

The remainder of the transportation scenario includes discussion concerning the following:

- Traceability Approach
- Payloads
- Vehicle Characteristics
- Program Schedule
- Transportation Analysis
- Transportation Cost Summary

Traceability Approach

The method or approach used in establishing traceability is shown in Figure 1.3-1. Each transportation element (HLLV, POTV, EOTV, PLV) has two divisions. One division identifies the "payloads" to be transported by the element. The other division "fleet" identifies the number of flights, propellant and number of vehicles. It should be noted that the POTV, EOTV and HLLV are interrelated while the PLV is completely independent. The transportation analysis section of the scenario will quantify the payload and fleet characteristics of each transportation element.

Payloads

Payloads associated with the transportation can be categorized as either crew or cargo (includes components, supplies, facilities and orbit-to-orbit transportation elements).

Crew - The crew complement in orbit as a function of time (commercial phase) is shown in Figure 1.3-2. The first several years reflect a gradual buildup to achieve operational status. Once achieved, the LEO Base nominally has 200 except when EOTVs are to be constructed (235), the GEO Base construction crew is 440 and satellite maintenance is shown as increasing by 40 per year. The total maintenance requirement for each 20-year increment is 380. The total crew in orbit when 20 satellites are installed is 1000, when 40 satellites (yr 23) are present a crew of 1400 is required while 60 satellites (yr 33) in orbit in conjunction with construction two satellites requires 1800 people.

Cargo - The cargo payloads to be transported are shown in Table 1.3-1. It should be noted that the payload mass constitutes one time expenditure or annual requirements. Total annual requirements are discussed later. The majority of the items are self-explanatory but several require some explanation for more clarity.

Crew facility supplies relate to the spares, atmosphere gases and water expendables associated with all the large crew modules (crew quarters, operations module and maintenance module). Direct crew supplies including food and crew accommodation items are accounted separately. Work facility supplies cover the same items as listed for the crew modules but in this case they are associated with small manned systems such as the cherrypickers (MRWS), crew buses, etc., in addition to base type spares and expendables such as flight control propellant. A breakdown of the crew and work facility supplies for the LEO and GEO bases are presented in Tables 1.3-2 and 1.3-3 respectively.

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

In the area of SPS maintenance, the supplies include spares (new parts) as well as flight control propellant. A breakdown of the satellite maintenance supplies brought to the GEO base and then to the satellites is presented in Table 1.3-4 and 1.3-5 respectively. Crew and work facilities is the mass required for each 20 satellites which covers three crew modules and one maintenance module at the GEO base and one mobile crew module that goes out to the satellite. A breakdown of the maintenance facilities and supplies is presented in Table 1.3-6 and 1.3-7.

Cargo tug propellant relates to that required to move payloads between the LEO base and EOTV.

Crew supplies include food and crew accommodation items constituting 0.9 MT/manyear including packaging. The supply module contribution is 0.8 MT/manyear.

Vehicle Characteristics

A summary of the key characteristics of each transportation element is shown in Table 1.3-8. Details can be found in the following WBS sections:

TABLE 1.3-1 PAYLOAD CHARACTERISTICS
(All Weights in Metric Tons)

		Reference
SPS		
Satellite	50,984	WBS 1.1
Allowance for Breakage (2%)	1,020	Guess
Total per Satellite	52,004	
LEO Base		
Base	1,603	WBS 1.2.2
Crew Facilities Supplies/Yr	313	Table 1.3-2
Work Facilities Supplies/Yr	87	Table 1.3-2
GEO Base		
Base	6,656	WBS 1.2.1
Crew Facilities Supplies/Yr	568	Table 1.3-3
Work Facilities Supplies/Yr	683	Table 1.3-3
EOTV		WBS 1.3.2
Vehicle	1,462	
Propeilant/Flight	515	
Refurbishment/Flight	40	
POTV-CREW ROTATION/SUPPLY		WBS 1.3.4
Vehicle (Stage)	14	
Propellant/Flight (Up/Dn)	200/185	
Refurbishment/Flight	0.1	
Personnel Module	59	WBS 1.3.5
SPS MAINTENANCE		
SPS Supplies/Satellite/Yr (to GEO Base)	236	Table 1.3-4
Crew & Work Facilities/20 Satellites	1,154	Table 1.3-6
Crew & Work Supplies/Yr/20 Satellites	206	Table 1.3-7
POTV Maintenance Sortie Prop/Satellite/Yr	25	WBS 1.3.4
Maintenance Sortie Satellite Supplies/Yr	410	Table 1.3-5
CARGO TUG		
Vehicle	2.4	
Propellant/EOTV Flight	37	
CREW SUPPLIES/MAN YEAR (Incl. supply module contribution of 0.8 MT)	1.7	

TABLE 1.3-2 LEO BASE CREW/WORK FACILITY SUPPLIES

	Qty	Annual Mass (MT) 1
Crew Facilities		(313)
Crew Quarters	3	185
Work Modules	3	128
Work Facilities		(87)
MRWS	16	38
Crew Buses	6	19
Const Equip		4
Misc		11
Flight Cont Prop		15

1 Includes ECLS atm supplies and spares, spares for other subsystems and packaging.

TABLE 1.3-3 GEO BASE CREW/WORK FACILITY SUPPLIES

	Qty	Annual Mass (MT) 1
Crew Facilities		(568)
Crew Quarters	6	406
Work Modules	4	162
Work Facilities		(683)
MRWS	52	146
Crew Buses	5	15
Const Equip		10
Misc		12
Flight Cont Prop		500

1 Includes ECLS atm supplies and spares, spares for other subsystems and packaging.

TABLE 1.3-4 SPS MAINTENANCE SUPPLIES TO GEO BASE

Item	Annual Mass (MT) Per Satellite
Hardware	(169)
Klystron Tube Components	103
DC/DC Switchgear Comp.	30
Misc Components	20
Pallet	16
Propellant	(66)
Argon and Tanks	61
LO_2/LH_2 and Tanks	5
TOTAL	236

TABLE 1.3-5 MAINTENANCE SORTIE SATELLITE SUPPLIES

Item	Annual Mass (MT) Per Satellite
Hardware	(344)
Klystron Tube Modules	278
DC/DC Switchgear Comp.	30
Miscellaneous	20
Pallet	16
Propellant	(66)
Argon and Tanks	61
LO_2/LH_2 and Tanks	5
TOTAL	410

TABLE 1.3-6 MAINTENANCE CREW/WORK FACILITIES FOR 20 SATELLITES

	Qty	Mass (MT) Ea	Total
Base Crew Quarters 1	3	243	729
Base Maint Module	1	182	182
Mobile Crew Module	1	243	243
Total			1154

1 One added per 7 to TAL Satellites in orbit

TABLE 1.3-7 MAINTENANCE CREW/WORK SUPPLIES FOR 20 SATELLITES

	Qty	Mass Per Year (MT) 1 Ea	Total
Base Crew Module	3	38	114
Base Maint. Module	1	54	54
Mobile Crew Module	1	38	38
Total			206
Other Items that were overlooked			
Satellite MRWS	22/Sat	.05	22
Crew Buses on Sat	2/Sat	.06	2
Total			24

1 Includes ECLS atm supplies and spares, spares for other subsystems and packaging

TABLE 1.3-8 TRANSPORTATION VEHICLE CHARACTERISTICS
(All Mass Metric Tons)

	HLLV	EOTV	PLV	POTV
Gross Payload	424	4000	89	90
Net Payload	360	3600 [1]	80 people	80 people 16 MT Cargo
Design Life (Flights)	300	10	300	50
Turnaround Time (days)				
Booster	4	-	4	-
Orbiter	5.3	-	10	-
Stage	-	235	-	-
Dry Weight (Vehicle)	1170	1462	394	14
Propellant/Flight				
LO_2	7102	36	1605	171
LH_2	320	0	78	29
LCH_4	1709	-	424	-
Argon	-	470	-	-
RP-1	85	-	26	-

1 Actual Cargo (components or propellant)

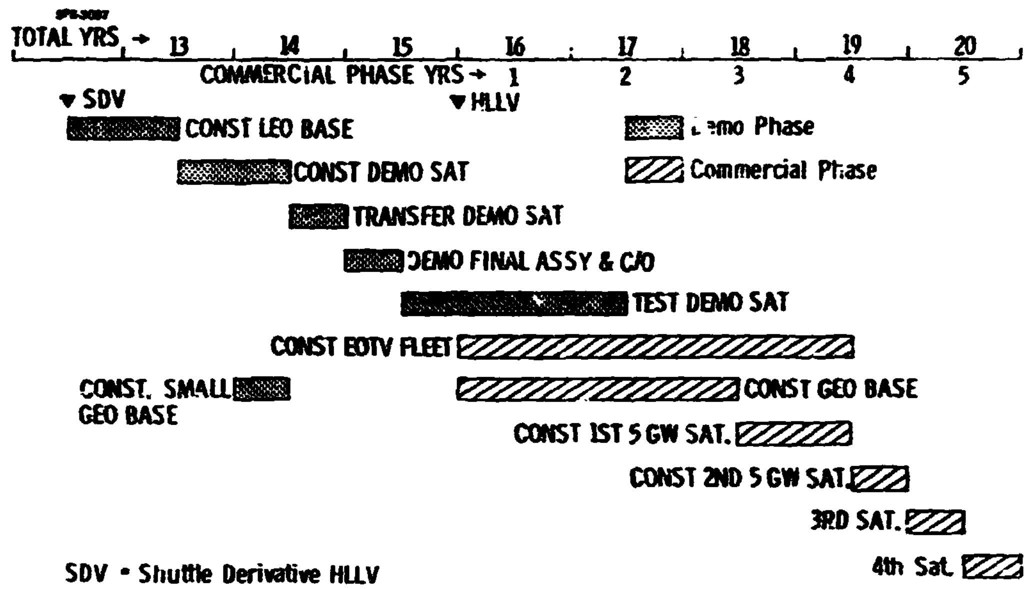

Figure 1.3-3 – SPS Demonstration and Commercialization Schedule

WBS 1.3.1 HLLV
WBS 1.3.2 EOTV
WBS 1.3.3 PLV
WBS 1.3.4 POTV

Program Schedule

The scenario analysis deals only with the commercial phase of the program. The program schedule for the initial portion of the commercial phase is shown in Figure 1.3-3. The schedule also indicates the key tasks associated with the commercial phase. Placement of commercial phase hardware is initiated after 6 months of operation of the Demo Satellite. At that time the construction of the EOTV fleet is begun using the LEO Base. Construction of the full size GEO construction base is also initiated at this time with the components delivered from LEO to GEO using the first production EOTV. Construction of the first 5 GW satellite begins about 2½ years into the commercial phase and due to being the first, one year is allocated. Subsequent satellites are produced every 6 months. Although not shown, maintenance is performed two times a year on each satellite. As indicated earlier, a total of 60 satellites are constructed over a 33 year time period.

TRANSPORTATION SCENARIO ANALYSIS

The payloads to be transported by each system and the system's fleet characteristics are presented. The POTV, EOTV (sometimes referred to as COTV) and HLLV are discussed first and in the indicated order since each successive element contributes to the payload of the next (see Traceability Chart, Figure 1.3-1). The PLV is discussed last and is not directly related to the other elements.

POTV Analysis

The POTV is used to transport crews and direct crew supplies between the LEO and GEO bases. The vehicle has been sized to deliver 90 MT from LEO to GEO and return 80 MT to LEO. Refueling of the POTV at GEO is required for its return to LEO. Propellant for return is delivered to the GEO base by the EOTV. A detailed description of the POTV can be found in WBS 1.3.4.

POTV Payloads - The annual payloads and flights associated with the POTV as well as contribution to the HLLV payloads is shown in Table 1.3-9. The principal factor in establishing the number of flights is that of crew rotation. The crew size indicates the average number of people stationed at GEO at any one time, including the division between those associated with satellite construction and satellite maintenance. The basis for this data was previously shown and discussed in Figure 1.3-2. Since crew stay time in orbit is limited to 90 days per tour of duty the total number of people which must be transported to GEO in a year is four times the average crew size. This value is identified as man-trips. The number of flights is then determined by dividing the man-trips by the 80 passengers transported per POTV flight.

The annual payload associated with the POTV is obtained by multiplying the number of flights by the previously identified 90 MT per flight. The breakdown of the POTV 90 MT payload is as follows:

TABLE 1.3-9 POTV PAYLOADS TO GEO

YR	SAT	CREW SIZE		MANTRIPS		FLIGHTS		PAYLOAD CONTRIB. TO: POTV(MT)	HLLV(MT)	
	QTY	CONST	MAINT	CONST	MAINT	CONST	MAINT	CONST+MAINT	CONST	MAINT
1		45	-	180	-	4(Min)	-	360	167	-
2		140	-	640	-	8	-	720	232	-
3		280	-	1120	-	14	-	1260	406	-
4	2	440	40 [1]	1760	160	22	2 [1]	2160	638	58
5	4	440	40	1760	160	22	2	2160	638	58
6	6	440	80	1760	320	22	4	2340	638	58
7	8	440	120	1760	480	22	6	2520	638	174
8	10	440	160	1760	640	22	8	2700	638	232
9	12	440	200	1760	800	22	20	2880	638	290
10	14	440	240	1760	960	22	12	3060	638	348
11	16	440	280	1760	1120	22	14	3240	638	406
12	18	440	320	1760	1440	22	18	3420	638	522
13	20	440	360	1760	1440	22	18	3600	638	522
23	40	440	720	1760	2880	22	36	5220	638	1044
33	60	440	1160	1760	4640	22	58	7200	638	1682

1 No direct maintenance out relates to activating maintenance equipment.

	MT
Orbital Personnel Module (Dry)	51
Crew (80 + 6)	8.6
Supplies (0.9 MT/M Yr)	13.1
Supply Module (0.8 MT/M Yr)	12.3
Priority Cargo	3.5
Structural Frame	1.5
TOTAL	90

The down payload per flight is the same as the up payload except the supply value is 3 MT of waste products for a total of 80 MT.

The POTV per flight payload contribution to the HLLV payload does not include the following:

- o OPM Dry and Struct. Frame (52.5 MT) Required only once per 500 flights or when more than 52 flights per year occur (excluding spares)
- o Crew (8.6 MT)

The resulting contribution to HLLV payloads is 28.9 MT per POTV flight.

POTV Fleet - POTV fleet characteristics are shown in Table 1.3-10. The primary output of this data is the fleet mass which contributes to the HLLV payload.

The number of flights associated with the POTV are again repeated with additional resolution in terms of the maintenance sorties to be flown by a stage similar to that of the POTV. This stage, however, is permanently based at the GEO base. Maintenance sorties are those flights between the GEO base and the satellites in which satellites servicing provisions are transported as well as the servicing crew. Further description of the maintenance operations can be found in Volume III, D180-25461-3, Section 13. The vehicles required are based on round trip and servicing time of 7 days except for the sortie vehicle quantity which is based on one vehicle per four sorties.

The time period when new vehicles are required is based on 50 flights design life. It should be noted, however, that the quantities are only approximate (do not include equivalent units for refurb and replenishment). The actual estimated total is presented in the cost per flight analysis of the POTV under WBS 1.3.4.

Propellant quantities for the construction and maintenance crew rotation are based on the total for the up and down trips. It should be noted, however, that the EOTV transports the down propellant to the GEO base. Sortie propellant is determined by the number of satellites visited with an average of 25 MT/satellite assumed.

A vehicle mass is indicated at those points in the program where new vehicles are required due to life limits. The fleet mass is the sum of the propellant and vehicle mass as relating to construction and maintenance activities.

TABLE 1.3-10 POTV FLEET

YR	SAT	FLIGHTS			VEHICLE REQ'D			NEW VEHICLES		VEHICLE MASS(MT)	
						MAINTENANCE					
	QTY	CONST	MAINT	SORTIE	CONST	REFURB	SORTIE	CONST	MAINT	CONST	MAINT
1	-	4	-	-	1	-	-	1	-	14	-
2	-	8	-	-	1	-	-		-	-	-
3	-	14	-	-	1	-	-	-	-	-	-
4	2	22	2 [1]	-	1	2	-	-	-	-	-
5	4	22	2	4	1	2	1	1	1	14	14
6	6	22	4	4	1	2	1	1	1	14	14
7	8	22	6	4	1	2	1	-	-	-	-
8	10	22	8	4	1	2	1	-	-	-	-
9	12	22	10	4	1	2	1	1	1	14	14
10	14	22	12	4	1	2	1	-	-	-	-
11	16	22	14	4	1	2	1	1	-	14	-
12	18	22	16	4	1	2	1	-	-	-	-
13	20	22	18	8	1	3	2	1	2	14	28
23	40	22	36	12	1	1	3	1	3	14	42
33	60	22	58	12	1	2	3	1	3	14	42

1 To activate maintenance equipment

2 POTV Turnaround sufficient for both const. and refurbs

TABLE 1.3-10 POTV FLEET (Continued)

YR	SAT	FLIGHTS			PROPELLANT(MT)			FLEET MASS(MT)	
						TOTAL			TOTAL MAINTENANCE
	QTY	CONST	MAINT	SORTIE	CONST	MAINT	SORTIE	CONST	REBURB AND SORTIE
1	-	4	-	-	1540	-	-	1544	-
2	-	8	-	-	3080	-	-	3080	-
3	-	14	-	-	5390	-	-	5390	-
4	2	22	2	-	8470	770	-	8470	770
5	4	22	2	4	8470	770	50	8484	834
6	6	22	4	4	8470	1540	100	8470	1640
7	8	22	6	4	8470	2310	150	8484	834
8	10	22	8	4	8470	3080	200	8470	3280
9	12	22	10	4	8470	3850	250	8484	4114
10	14	22	12	4	8470	4620	300	8470	4920
11	16	22	14	4	8470	5390	350	8484	5754
12	18	22	16	4	8470	6160	400	8470	6560
13	20	22	18	8	8470	6930	450	8484	7408
23	40	22	36	12	8470	13860	950	8484	14852
33	60	22	58	12	8470	22330	1450	8484	23808

1 For 2 less satellites than indicated since they operate 6 months before maintenance.

EOTV Analysis

The EOTV is used to transport all cargo to GEO except crews and direct crew supplies which are transported by the POTV. A description of this vehicle can be found in WBS 1.3.2.

EOTV Payloads - EOTV payloads that relate to satellite construction are shown in Table 1.3-11. The mass of these payloads were previously discussed in conjunction with Table 1.3-1. The mass indicated for the SPS payloads reflect one-half of the first satellite to be constructed in Year 3, the remainder of the first satellite as well as the second satellite in Year 4 and then two satellites per year thereafter. The tug propellant is a function of the number of EOTV flights and consequently is estimated after the number of EOTV flights is established and then reflected back as EOTV payload. Although some of the payloads to be transported by the tug are for maintenance, the value is small and consequently all the value is book kept under construction. As previously discussed, the EOTV delivers POTV down propellant to GEO. The value indicated is only for the flights associated with construction crews. (The total payload per year to be transported by the EOTV and eventually transported by the HLLV is indicated. The HLLV value is lower by the amount equal to the POTV down propellant. This POTV down propellant is not included since it is being "book kept" or charged against the POTV contribution to HLLV payloads - see Traceability Chart.)

EOTV payloads associated with satellite maintenance are shown in Table 1.3-12. Again, the basic values for the payload were shown in Table 1.3-1. The POTV down propellant indicated is that required by the maintenance crews. The crew/work values were previously expressed in Table 1.3-1 as a function of 20 satellites in orbit. The equipment and supplies required however are actually a function of the number of personnel present at a given point in time. The initial facility value at Year 4 reflects the need of one crew module at the GEO base, one maintenance module at the base and one mobile crew module. During Year 7, another base crew module is required due to crew size requirements and the same occurs in Year 10. In Year 13, another crew module is required as well as a maintenance module since more than 20 satellites are in orbit. The supply mass is based on the addition of 40 people per year.

The payload contributed to the EOTV is the sum of payloads for satellite maintenance. The contribution to HLLV is less by the amount of the POTV down propellant since this is charged to the POTV.

EOTV Fleet - The fleet characteristics associated with the EOTV are shown in Figure 1.3-13. Using a net delivery capability of 3600 MT per EOTV flight, the number of flights is established. (Fractions of flights are indicated although in reality the fraction would be eliminated by using more propellant per flight for fixed trip time.) The vehicles required are based on a 235 day turnaround (flight + refurb) for two successive flights of a given EOTV. This results in 1.5 flights per year per EOTV and with the total flights, the number of vehicles can be determined.

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

TABLE 1.3-11 EOTV PAYLOADS TO GEO FOR CONSTRUCTION

YEAR	SAT QTY	SPS	GEO BASE	GEO BASE SUPPLIES	TUG PROP	POTV DOWN PROP	TOTAL PAYLOAD CONTRIBUTED TO: EOTV	HLLV
1		-	3328	127	48	740	4243	3503
2		-	3328	455	63	1480	5326	3846
3		26002		796	296	2590	29684	27094
4	2	78006		1251	851	4070	84178	80108
5	4	104008		1251	1147	4070	110476	106406
6	6	104008		1251	1151	4070	110480	106410
7	8	104008		1251	1161	4070	110490	10620
8	10	104008		1251	1170	4070	110499	106429
9	12	104008		1251	1180	4070	110509	106439
10	14	104008		1251	1195	4070	110524	106454
11	16	104008		1251	1199	4070	110528	106458
12	18	104008		1251	1210	4070	110539	106468
13	20	104008		1251	1224	4070	110553	106481
23	40	104008		1251	1300	4070	110629	106559
33	60	104008		1251	1406	4070	110735	106665

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

ALL MASS IN METRIC TONS

TABLE 1.3-12 EOTV PAYLOADS TO GEO

		SATELLITE MAINTENANCE					
	SAT	SAT	POTV	CREW/WORK		PAYLOAD CONTRIBUTED TO:	
YR	QTY	COMPONENTS	PROP	FACIL	SUPPLIES	EOTV	HLLV
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	2	118	420	668	130	1336	916
5	4	708	840	-	130	1678	838
6	6	1180	1260	-	130	2570	1310
7	8	1652	1680	287	168	3787	2107
8	10	2124	2100	-	168	4392	2292
9	12	2596	2520	-	168	5284	2764
10	14	3068	2940	287	206	6501	3561
11	16	3540	3360	-	206	7106	3746
12	18	4012	3780	-	206	7998	4218
13	20	4484	4200	425	336	9445	5245
23	40	9204	7610	425	504	17743	10133
33	60	13924	12180	425	1008	27537	15357

2 For 1 less SAT. than indicated due to schedule of coming on-line.

1 Not incl EOTV contribution to HLLV P/L since all POTV prop is charged to POTV Fleet, the indicated values are only the down prop.

TABLE 1.3-13 EOTV FLEET

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

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

2 Includes vehicles for turnaround plus 2 for trip time degradation plus one spare.

LEO Base Payloads

The annual supplies for the LEO base are presented in Table 1.3-14. Crew size is based on data in Figure 1.3-2. Crew supplies are the food and crew accommodations plus supply module based on 1.7 MT/MYr.

HLLV Analysis

The HLLV is used to transport all payloads from Earth to the LEO base accept the crews. A description of this vehicle can be found in WBS 1.3.1.

HLLV Payloads - The annual payloads to be transported to LEO by the HLLV are indicated in Table 1.3-15. This data amounts to a summary of the payload contributions to the HLLV from the POTV, EOTV and LEO base discussions.

HLLV Fleet - The fleet characteristics of the HLLV are shown in Table 1.3-16. The payload values are the sum of all the payloads to be transported by the HLLV. The number of flights is determined by dividing the payloads by 360 MT net capability for the HLLV. The number of vehicles required only reflects those necessary for turnaround (plus one spare) and are based on 4 days for the booster (90 flights/year) and 5.3 days (70 flights/year) for the orbiter. The total number of vehicles required must also include the equivalent units for refurb and replenishment. The total can be found in the cost per flight analysis of the HLLV in WBS 1.3.1. The propellant quantity indicated is the amount required for the number of flights to be flown by the HLLV.

PLV Analysis

The Personnel Launch Vehicle (PLV) is used to transport all crews to the LEO base. A description of this vehicle can be found in WBS 1.3.3.

PLV Payloads and Fleet - The payloads and fleet characteristics associated with the PLV are presented in Table 1.3-17. The indicated crew size is based on the data previously shown in Figure 1.3-2. The number of man-trips is based on crew duty cycles 90 days thus requiring four changes per year. The number of flights is based on 80 passengers per flight. The vehicles required are those necessary for turnaround (plus one spare) and result in 90 flights per year for the booster and 36 flights per year for the orbiter. The external tank required for the PLV is expendable thus requiring one per flight. The total number of vehicles required must include those equivalent units associated with refurb and replenishment. The totals can be found in the cost per flight analysis of the PLV in WBS 1.3.3.

Propellant values include that associated with ET and reflect the number of flights per year.

TRANSPORTATION SUMMARY

A summary of SPS transportation is presented in terms of number of flights, number of vehicles and recurring cost. The data is presented for years corresponding to there being 2, 20, 40 and 60 satellites in orbit and, in all cases, two 5 GWe satellites are being constructed per year.

Number of Flights - The number of flights for the POTV, EOTV, HLLV and PLV are summarized in Figures 1.3-4, 1.3-5, 1.3-6 and 1.3-5 respectively.

TABLE 1.3-14. LEO BASE PAYLOADS

(All mass in metric tons)

Yr.	Avg. Crew	Crew Supplies + Module	Crew Facility Supplies	Work Facility Supplies	Total
1	150	255	250	50	555
2	235	400	313	87	800
3	235	400	313	87	800
4	200	340	313	87	740
5	200	340	313	87	740
6	200	340	313	87	740
7	200	340	313	87	740
8	200	340	313	87	740
9	200	340	313	87	740
10	235	400	313	87	800
11	235	400	313	87	800
12	235	400	313	87	800
13	200	340	313	87	740
23	200	340	313	87	740
33	200	340	313	87	740

TABLE 1.3-15. HLLV PAYLOADS TO LEO

(All mass in metric tons)

Yr	Sat. Qty.	LEO Base and Supplies	EOTV Fleet		EOTV Payloads		POTV Fleet		POTV Payload	
			Const	Maint	Const	Maint	Const	Maint	Const	Maint
1	-	555	9280	-	3503	-	1554	-	167	-
2	-	800	9450	-	3846	-	3080	-	232	-
3	-	800	13405	-	27094	-	5390	-	406	-
4	2	740	17607	226	80108	916	8470	770	638	58
5	4	740	18807	1744	106406	838	8484	834	638	58
6	6	740	17345	396	106410	1310	8470	1640	638	116
7	8	740	17345	622	106420	2107	8484	2460	638	174
8	10	740	17345	678	106429	2292	8470	3280	638	232
9	12	740	17345	847	106439	2764	8484	4114	638	290
10	14	800	29041	1017	106454	3561	8470	4920	638	348
11	16	800	29041	1130	106458	3746	8484	5754	638	406
12	18	800	27579	4167	106468	4218	8470	6569	638	464
13	20	740	17345	1469	106481	5245	8484	7408	638	522
23	40	740	17345	2769	106559	10133	8484	14852	638	1044
33	60	740	17345	4294	106665	15357	4584	23808	638	1682

TABLE 1.3-16. HLLV FLEET

(All mass in metric tons)

	Payload		Flights			Vehicle Req'd		Propellant (1000's MT)			
Yr	Const	Maint	Const	Maint	Total	Stg 1	Stg 2	LCH_4	LO_2	LH_2	RP-1
1	15059	-	42	-	42	2	2	75	312	14	3
2	17408	-	49	-	49	2	2	88	365	17	4
3	47095	-	131	-	131	3	3	235	977	45	11
4	107563	70	299	3	302	4	5	542	2252	104	26
5	135075	3474	375	10	385	5	6	691	2871	133	33
6	133603	3462	371	10	381	5	6	684	2841	131	33
7	133627	5363	371	15	386	5	6	692	2878	133	34
8	133622	6482	371	18	389	5	6	698	2901	134	34
9	133646	8015	371	22	393	5	6	705	2930	136	34
10	145403	9846	404	27	431	6	7	773	3214	149	37
11	145421	11036	404	31	435	6	7	780	3244	150	38
12	143395	15409	400	43	443	6	7	795	3303	153	39
13	133688	14664	371	41	412	6	7	739	3073	142	36
23	133766	28798	372	80	452	6	7	811	3371	156	39
33	133872	45141	372	125	497	7	8	892	3706	171	43

TABLE 1.3-17. PLV PAYLOADS AND FLEET

(All mass in metric tons)

Yr	Crew Size		Mantrips		Flights		Vehicles Req'd		Propellant (1000's MT)		
	Const	Maint	Const	Maint	Const	Maint	Boosters	Orbiters	LCH_4	LO_2	LH_2
1	225	-	900	-	11	-	2	2	5	19	1
2	400	-	1600	-	20	-	2	2	9	34	1.6
3	560	-	2240	-	28	-	2	2	12	47	2.3
4	650	40	2600	160	33	2	2	2	16	59	2.9
5	640	40	2560	160	32	2	2	2	15	57	2.8
6	640	80	2560	320	32	4	2	2	16	61	2.9
7	640	120	2560	480	32	6	2	3	17	64	3.1
8	640	160	2560	640	32	8	2	3	18	67	3.3
9	640	200	2560	800	32	10	2	3	19	70	3.4
10	675	240	2700	960	34	12	2	3	20	78	3.8
11	675	280	2700	1120	34	14	2	3	21	81	3.9
12	675	320	2700	1280	34	16	2	3	22	84	4.1
13	640	360	2560	1440	32	18	2	3	22	84	4.1
23	640	760	2560	3040	32	38	2	3	31	118	5.7
33	640	1160	2560	4640	32	58	3	4	40	152	7.4

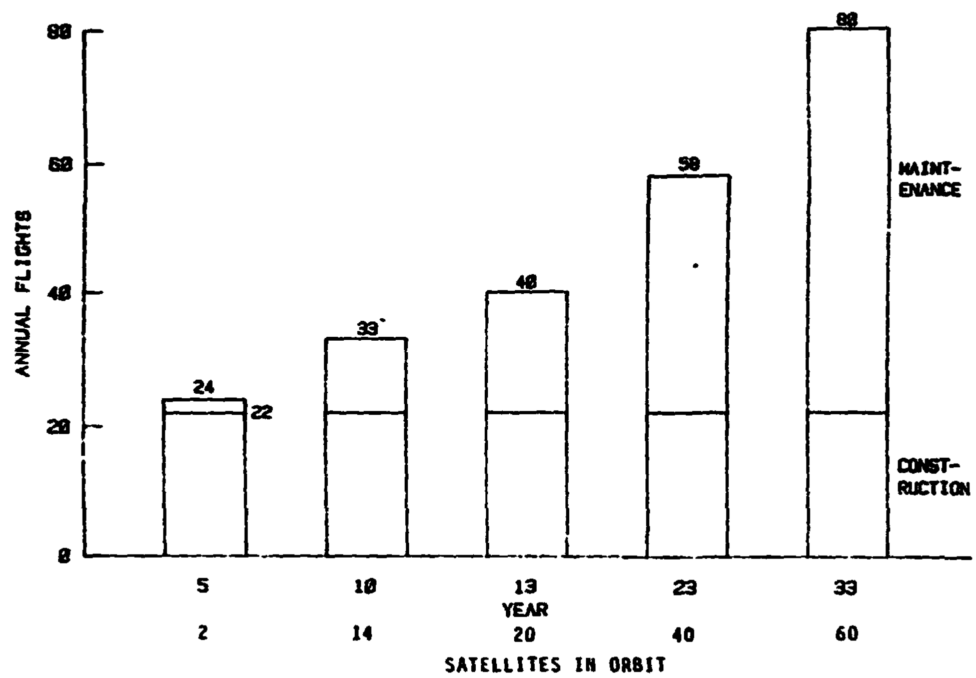

Figure 1.3-4 – POTV Flights

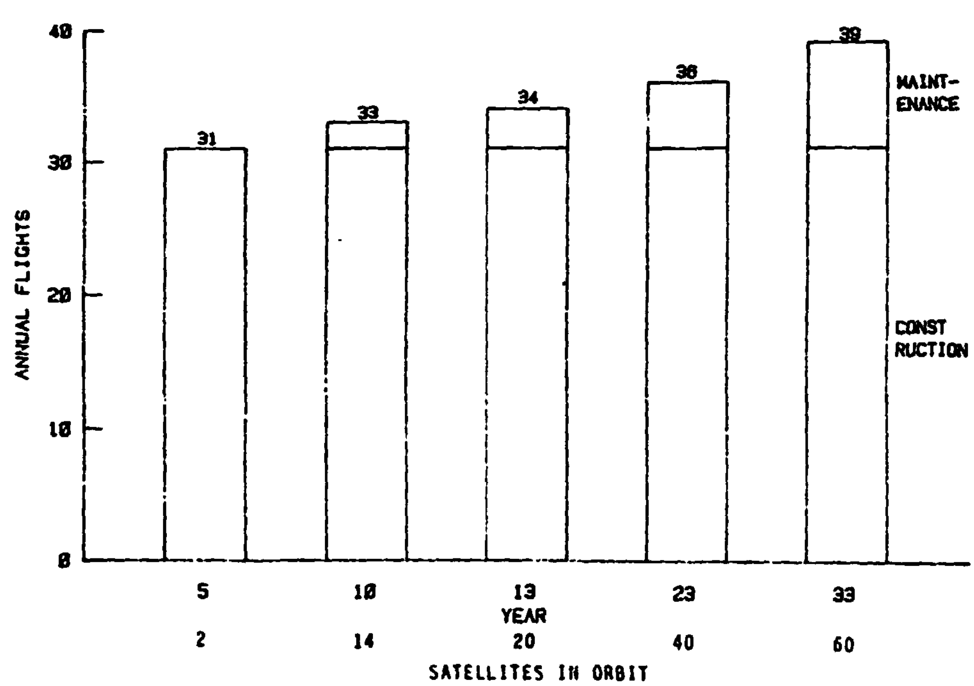

Figure 1.3-5 – EOTV Flights

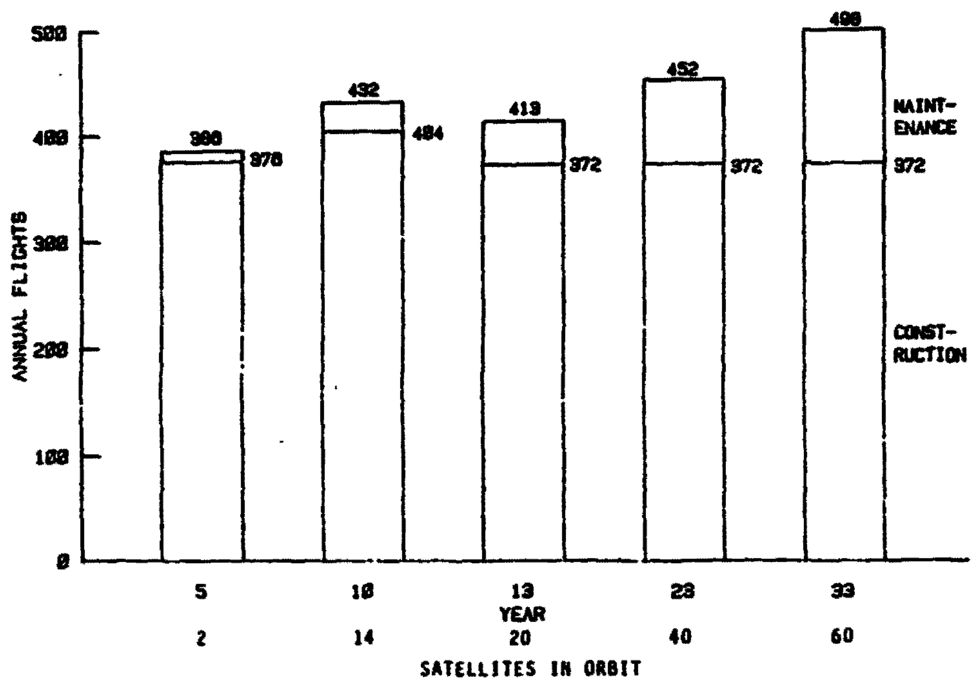

Figure 1.3-6 – HLLV Flights

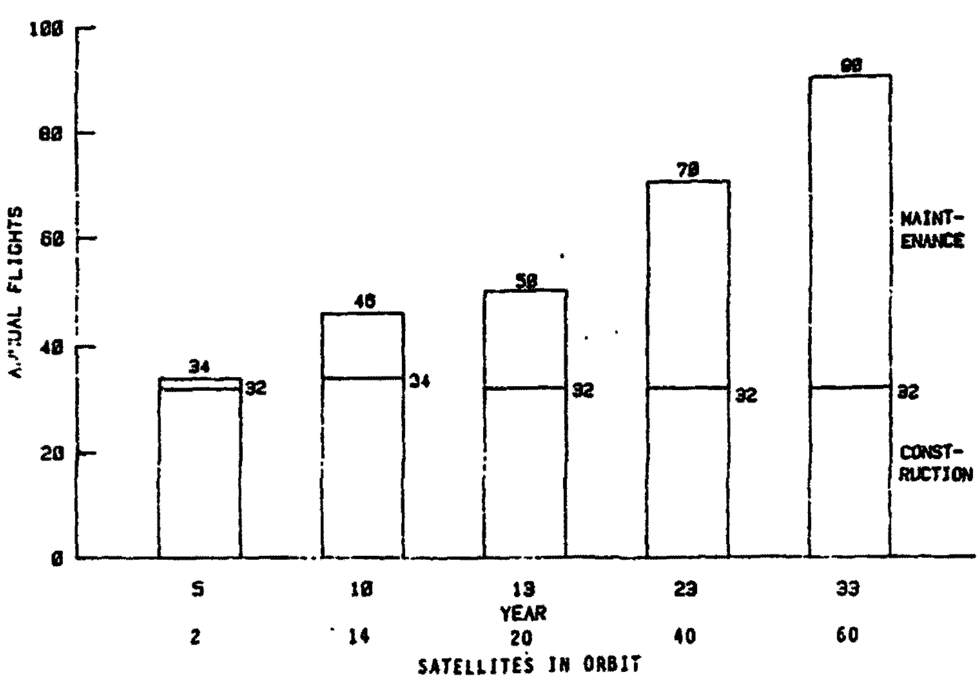

Figure 1.3-7 – PLV Flights

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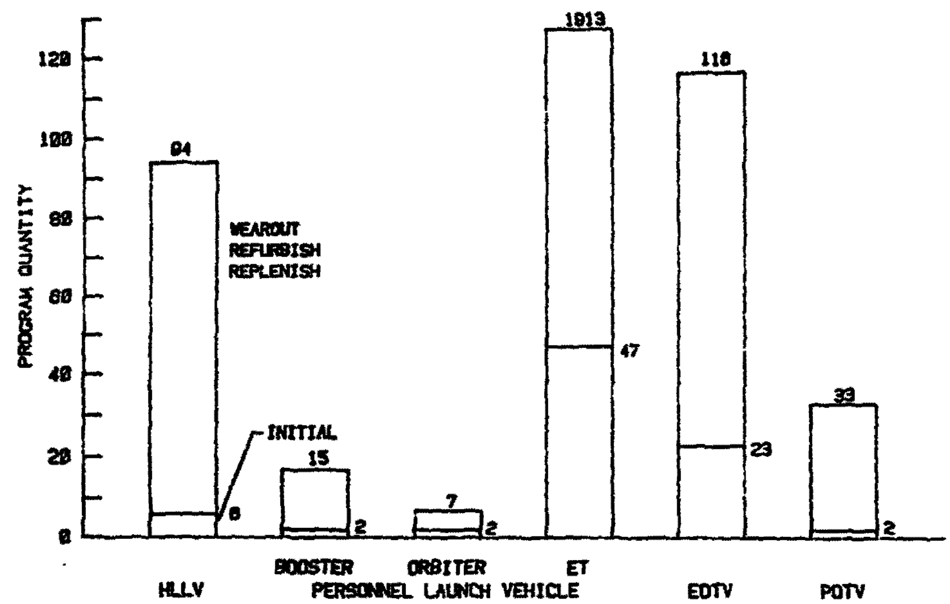

Figure 1.3-8 – Transportation Vehicle Quantities

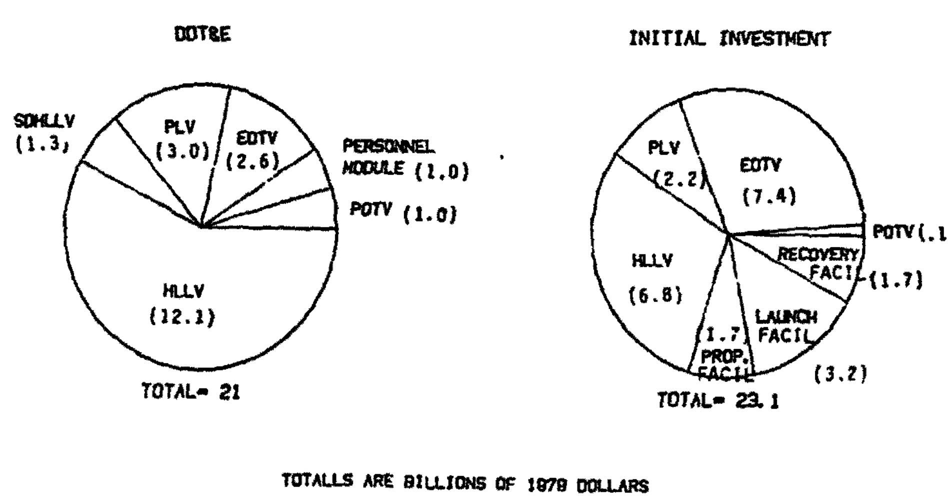

Figure 1.3-9 – Transportation Nonrecurring Cost

Number of Vehicles - The total number of vehicles required in the 60 satellite (33 year) program is presented in Figure 1.3-8.

Cost - Detail cost data is presented for each transportation system in the WBS description. A summary is presented in Figure 1.3-9 through 1.3-10.

The $21 billion DDT&E and $23 ' billion initial investment cost for the transportation system is presented in Figure 1.3-9. The initial investment data relates to the number of vehicles necessary to satisfy the flight turnaround requirements and the facilities necessary to support the flights.

The cost per flight for each transportation element is presented in Figure 1.3-10. The recurring transportation cost is shown in Figure 1.3-11 and indicates annual cost ranging from $6.4 billion to $8.8 billion. The split in recurring cost between construction and satellite maintenance activity is presented in Figure 1.3-12 and indicates maintenance constitutes approximately 3% of the transportation cost with two satellites in orbit and 30% when 60 satellites are in orbit.

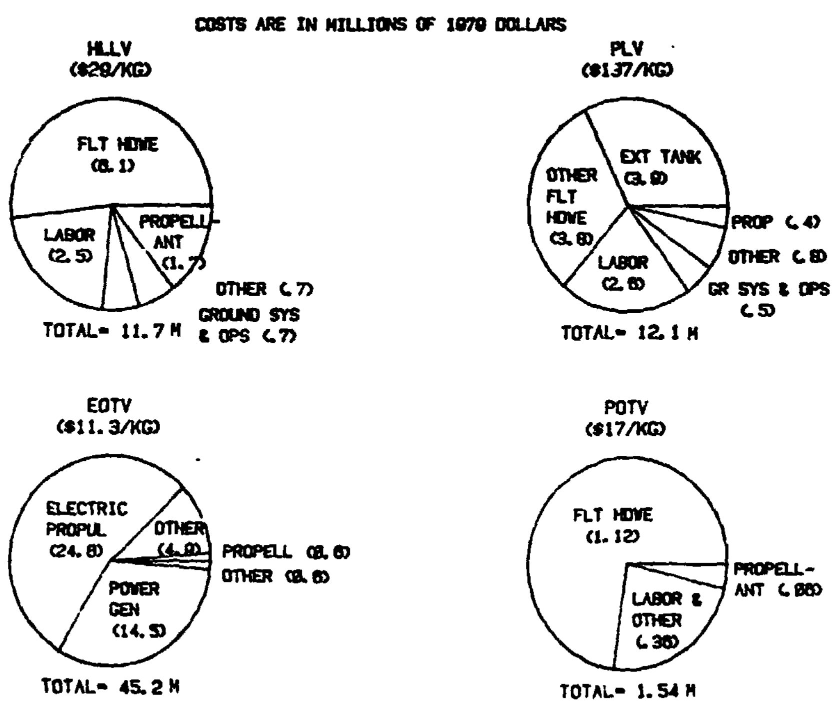

Figure 1.3-10 – Cost Per Flight

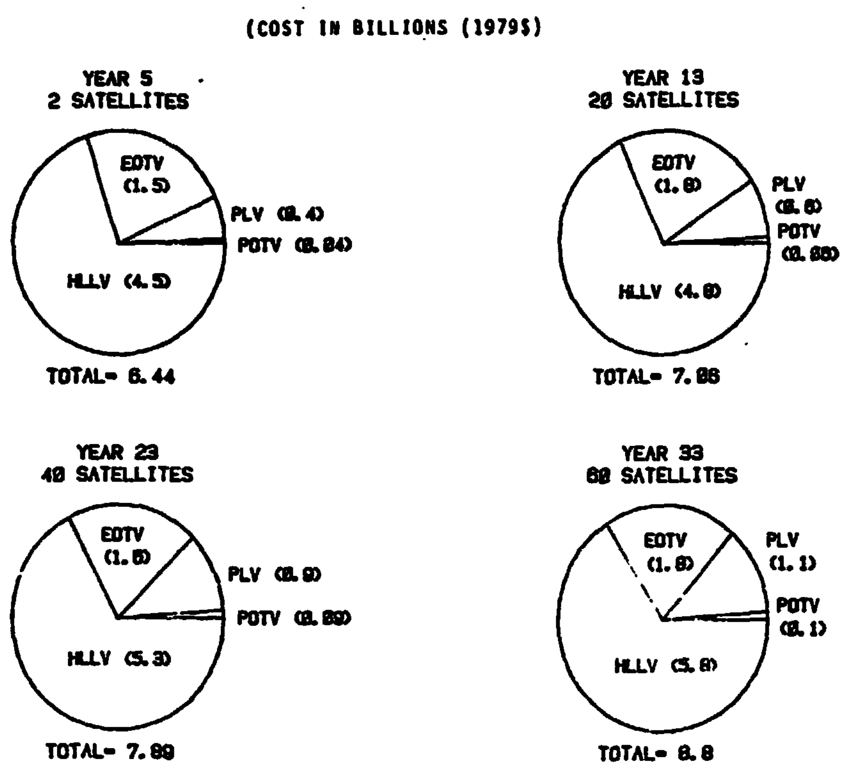

Figure 1.3-11 — Transportation Recurring Cost

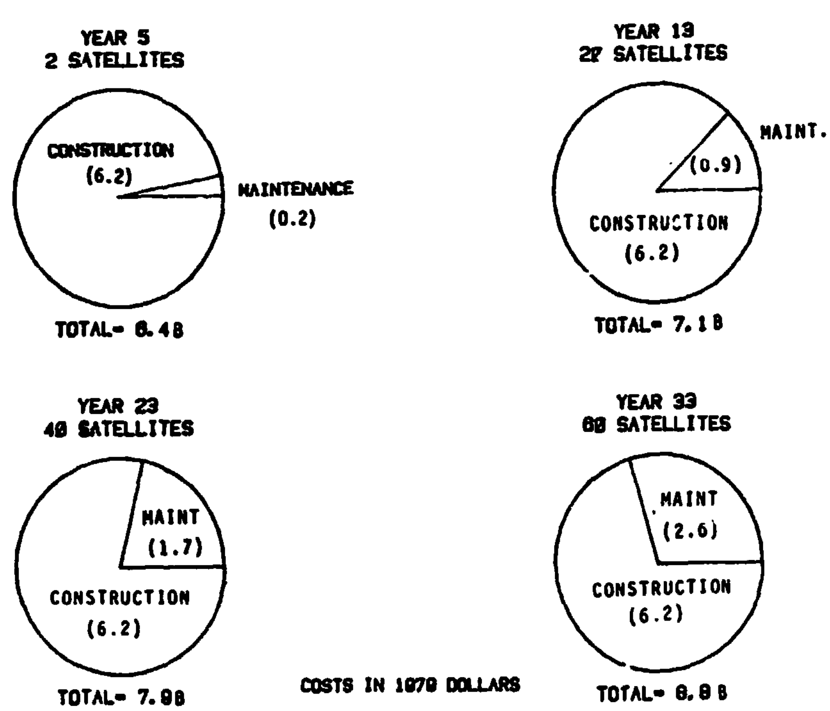

Figure 1.3-12 — Transportation Recurring Cost

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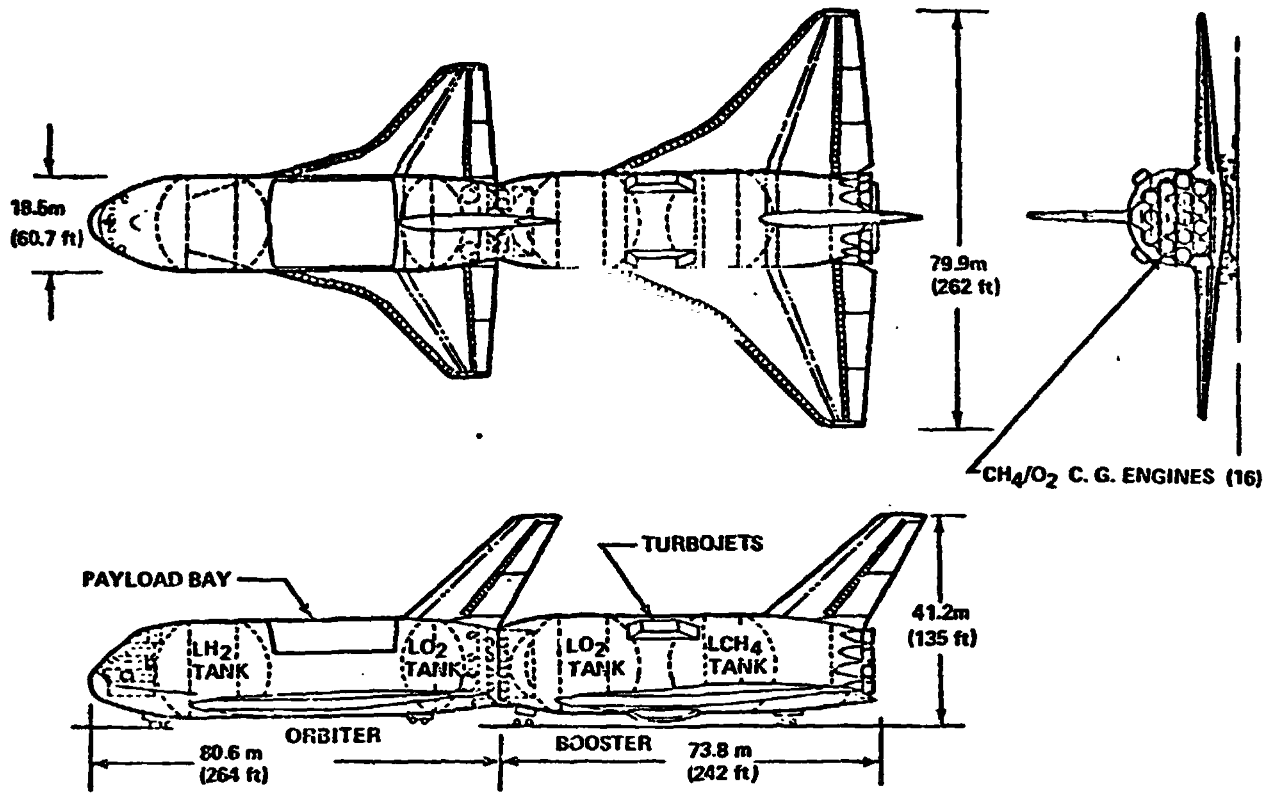

Figure 1.3.1-1 Two-Stage Winged SPS Launch Vehicle (Fully Reusable Cargo Carrier)

SPS-1952

Table 1.3.1-1 Two-Stage Winged Vehicle Design Characteristics

	ORBITER		BOOSTER
GLOW		10,978,400	
BLOW	—		7,813,700
BOOSTER FUEL (LCH_4)	—		1,708,900
BOOSTER OXIDIZER (LO_2)	—		5,126,700
BOOSTER INERTS	—		978,100
OLOW–LESS PAYLOAD	2,740,700		—
ORBITIER FUEL (LH_2)	329,400 }*		—
ORIBITER OXIDIZER (LO_2)	1,976,200 }*		—
ORBITER INERTS	435,100		—
ASCENT PAYLOAD	424,000		—
RETURN PAYLOAD ~ 15%	63,600		—
MASS FRACTION	0.841		0.876
ENTRY WEIGHT–NO PAYLOAD	395,200		836,600
–WITH RETURN P/L	456,000		—
START CRUISE WEIGHT–NO P/L	—		832,900
–WITH RETURN P/L	—		—
LANDING WEIGHT–NO PAYLOAD	391,800		845,700
–WITH RETURN P/L	452,600		—

(ALL MASS DATA IN kg)

*MAINSTAGE + FLIGHT PERFORMANCE RESERVE

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1.0 WBS DICTIONARY

The Heavy Lift Launch Vehicle (HLLV) is used to transport all SPS flight hardware and supplies to low earth orbit during the commercial phase of the program.

2.0 DESCRIPTION

The HLLV is a two-stage winged fully reusable vehicle. The launch configuration and integrated performance/design characteristics are shown in Figure 1.3.1-1 and Table 1.3.1-1 respectively. The series burn concept uses 16 LCH_4/LO_2 engines on the booster and 14 standard SSME's on the orbiter. The LCH_4/LO_2 booster engines employ a gas generator cycle and provide a vacuum thrust of 9.79×10^6 newtons each. The SSME's on the orbiter provide a vacuum thrust of 2.09×10^6 (100% power level). The nominal 100% power level for the SSME's was selected based on engine life considerations which indicated about a 3 factor reduction in life if the 109% power level is used. An airbreather propulsion system has been provided on the booster for flyback capability to simplify the booster operational mode. The reference wing area for both stages is:

S_W (Orbiter) = $1446 m^2$ ($15{,}560 ft^2$)

S_W (Robiter) = $2330 m^2$ ($25{,}080 ft^2$)

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

The payload capability of the HLLV is based on a "3g" maximum acceleration thrust profile with launch from KSC to a 477 km/31 deg inclination orbit. The payload characteristics are as follows:

Gross Payload	424 MT
Provisions for Payload Installation	24 MT
Provisions for Payload Rack and Containers (Packaging)	40 MT
Net Payload	360 MT

The turnaround time (launch to launch) of the booster is 97 hours and the orbiter 127 hours.

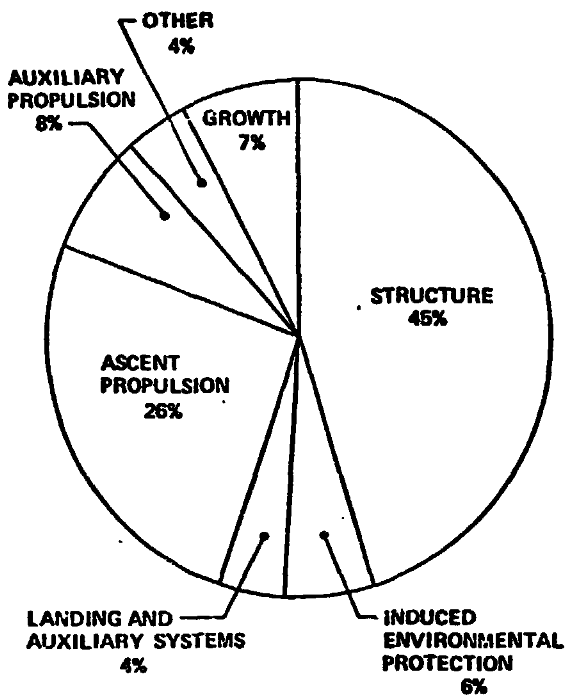
A more detailed description of the vehicle and it performance can be found in D180-25037-3 (pp 255-267) while further definition of the operations is on pp 272-277.

3.0 DESIGN BASIS

Both two stage winged and two stage ballistic vehicles were investigated. The ballistic concept employed ocean recovery of both stages. The comparison of these vehicles was done early in the SPS study when the overall scenario included construction of satellites at GEO, producing 40 GWe of ground power per year and transportation between LEO and GEO provided by LO_2/LH_2 OTV's resulting in 1600 HLLV flight per year. The winged concept had a lower gross liftoff weight (9566

Table 1.3.1-2 – Booster Mass Statement

SPS-1956

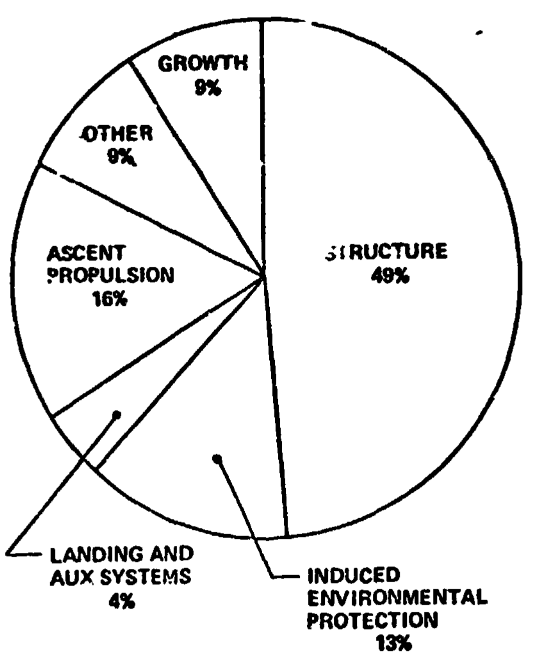


DRY MASS BREAKDOWN

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

SPS-1955

Table 1.3.1-3 – Orbiter Mass Statement



DRY MASS BREAKDOWN

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

MT vs 10,472 MT) but higher DDT&E ($9.1B vs $7.1B) and higher cost per flight ($8.5 vs $8.3B). The winged concept was selected as the reference HLLV, however, since recovery of the stages in a manner similar to an aircraft was judged to be less risky than water recovery and a more extensive analysis of the cost per flight and turnaround with water recovery would result in the winged system being comparable in cost. In addition, the winged vehicle does provide the opportunity to also use it for personnel transportation and thus eliminate the need for the more costly PLV (dollars/kg).

Further description of these two vehicles at the time of comparison can be found in D180-22876-5, pp 219-224.

4.0 MASS

The dry and inert mass of the booster and orbiter are shown in Table 1.3.1-2 and 1.3.1-3 respectively.

5.0 COST

A cost summary of the HLLV for the various phases is presented in Section 5.1 with details presented in 5.2.

5.1 COST SUMMARY

	Millions (1979 $)
Research	TBD
Engineering Verification	TBD
Demonstration	TBD
Shuttle Derived HLLV	
Commercialization	
DDTE	$12,880 M
Initial Investment	$ 6,893 M
Cost/Flight	$ 11.7 M

5.2 COST DETAILS

Research	TBD
Engineering Verification	TBD
Demonstration	TBD
Commercialization	

- o DDTE and TFU

  Details for the booster and orbiter are shown in Table 1.3.1-4. The system test portion of the DDTE includes test labor as well as an equivalent of 2.5 ground test and 2.0 flight test units. The DDTE and TFU cost were developed using the Boeing PCM.

TABLE 1.3.1-4 HLLV DDTE & TFU COST (COST IN MILLIONS)

	DDTE			TFU		
HLLV (1977$)			(11040)			(1748)
Booster			(6367)			(983)
Prog Integ & Mgt		161			44	
Vehicle		1953			725	
Structure	550			169		
Thermal Prot Sys	15			6		
Landing & Aux Sys	193			110		
Main Propul.	803			199		
Aux. Propul.	235			107		
Prime Power	14			31		
Elec Conv & Dist	26			20		
Hyd Conv & Dist.	49			28		
Surf. Controls	16			29		
Avionics	49			25		
Envir Cont	3			1		
Assy & Checkout		–			61	
SE & I		75				
Software Engr		27				
GSE		315			153	
GSE S/S		306				
Tooling		397				
System Test		3294				
Orbiter (See Next Page)			(4673)			(765)

TABLE 1.3.1-4 HLLV DDTE & TFU COST (COST IN MILLIONS) (Continued)

	DDTE			TFU		
Orbiter			(4673)			(765)
Prog Integ & Mgt		133			33	
Vehicle		1114			567	
Structure	325			104		
Thermal Prot Sys	164			65		
Landing & Aux Sys	92			56		
Main Propul	41			182		
Aux Propul	280			24		
Prime Power	9			19		
Elec Conv	29			22		
Hyd Conv	21			11		
Surf Cont	12			21		
Avionics	100			50		
Envir Cont	36			11		
Pero Provisions	5			2		
Assy & checkout		–			46	
Tooling		273			–	
System Test		2569			–	
SE & I		65			–	
Software		24			–	
GSE		258			119	
GSE S/S		237			–	

- o Initial investment

  The initial investment costs shown in Table 1.3.1-5 cover all flight hardware necessary to satisfy a 400 flight per year requirement and the tooling and GSE necessary to produce and handle the vehicles. The costs do not cover ground support facilities. Although the costs are described as initial investment, the values are based on the average cost of units that result from the total program.

- o Cost per Flight

  The cost per flight of $11.7 M is summarized in Table 1.3.1-6. Further detail on each of the major elements is presented in Tables 1.3.1-7 through 1.3.1-11.

Key factors and assumptions associated with the cost per flight are as follows:

- o An average of 400 flights per year during each of the 33 years of the program (until 60 satellites are in orbit).
- o 360 days per year are used for launching.
- o Tooling and GSE contributions are based on sustaining engineering and spares requirements
- o Flight hardware

Element	Uses	Refurb	Replenish
Airframe	300	30% of Unit Cost for 100 flights	0.18% per flight
Rocket Engines	Indefinite	30% of Unit Cost per 50 flights	0.5% per flight
A/B Engines	Indefinite	15% of Unit Cost per 500 flights	0.1% per flight

TABLE 1.3.1-5 HLLV INITIAL INVESTMENT

Vehicle	Units	Avg Cost	Initial Invest	
Stg 1				
Airframe	6	258	1548	2507
Rocket Engines	96	6.1	585	
A/B Engines	72	5.2	374	
Stg 2				
Airframe	7	223	1561	2246
Rocket Engines	98	6.6	647	
OMS Engines	28	1.35	38	
			Sub Total	4753
Tooling				506
GSE				813
			Total (1977$)	$ 6072 M
			Total (1979$)	$ 6893 M

TABLE 1.3.1-6 HLLV COST PER FLIGHT SUMMARY

Program Support (T 1.3.1-11)		0.397
Flight Hardware (T 1.3.1-7)		5.279
Stage 1	2.775	
Stage 2	2.504	
Ground Systems & Ops		0.628
Ground Ops (T 1.3.1-8)	0.188	
Ground Sys Maint (T 1.3.1-8)	0.243	
GSE Hardware (T 1.3.1-9)	0.135	
Other (T 1.3.1-11)	0.062	
Tooling (T 1.3.1-9)		0.235
Propellant (T 1.3.1-10)		1.523
Manpower (T 1.3.1-11)		2.138
Direct	1.165	
Indirect	0.973	

Total (1977 $) 10.2 M

Total (1979 $) 11.7 M

TABLES 1.3.1-7 HLLV FLIGHT HARDWARE COST

Flight Hardware Elements	Equivalent Units					TFU $M	LEARNING	AVG COST $M	TOTAL FLT HRDW COST $M [1]	COST/FLIGHT $M [1] (132000 Flts)
	INITIAL BUY (FOR TURNAROUND)	Δ BUY FOR PROG LIFE	REFURB	REPLENISHMENT	TOTAL UNITS					
Stage 1									(36635)	(2.775)
Airframe & Subsys	6	38	26	24	94	586	85	258	21689	1.643
Rocket Engines	96	N/A	1238	1056	2390	16.8	90	6.1	13933	1.055
A/B Engines	72	N/A	37	158	267	10.5	90	5.2	1013	0.077
Stage 2									(33067)	(2.504)
Airframe	7	37	26	24	94	507	85	223	19409	1.470
Rocket Engines	98	N/A	1080	924	2102	17.5	90	6.64	12886	0.976
OMS Engines	28	N/A	308	264	600	3	90	1.35	772	0.058

[1] Excludes cost of initial buy since this is included in initial investment

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TABLE 1.3.1-8 GROUND OPERATIONS AND SYSTEM MAINTENANCE

WBS	FACILITY	TOTAL ANNUAL MAN-HOURS OPERATIONS	TOTAL ANNUAL MAN-HOURS MAINTENANCE
1.3.7	Ground Support Facilities	(5,174,832) [3]	(7,676,714) [4]
1.3.7.1	Launch Facilities		
1.3.7.1.1	HLLV Launch Facilities	476,800	862,500
1.3.7.1.2	PLV Launch Facilities	79,196	133,616
1.3.7.2	Recovery Facilities		
1.3.7.2.1	Landing Site [5]	145,920	218,880
1.3.7.2.2	HLLV Orbiter and Payload Processing Facility	906,400	1,359,600
1.3.7.2.3	HLLV Booster Processing Facility	492,800	739,200
1.3.7.2.4	Engine Maintenance Facility	[1]	[1]
1.3.7.2.5	Hypergolic Maintenance Facility	[1]	[1]
1.3.7.2.6	Passenger Offloading Facility	2,240	3,360
1.3.7.2.7	PLV Booster Processing Facility	67,520	101,280
1.3.7.2.8	PLV Orbiter Processing Facility	75,656	1,134,984
1.3.7.2.9	Vertical Assembly Building	35,840	36,854
1.3.7.2.10	Mobile Launcher Platform	[2]	[2]
1.3.7.3	Fuel Facilities [5]	727,080	823,440
1.3.7.4	Logistic Support [5]	1,314,000	1,971,000

TABLE 1.3.1-8 GROUND OPERATIONS AND SYSTEM MAINTENANCE (Continued)

WBS	FACILITY	TOTAL ANNUAL MAN-HOURS OPERATIONS	TOTAL ANNUAL MAN-HOURS MAINTENANCE
1.3.7.5	Operations [5]	851,280	292,000

[1] Included in 1.3.7.2.2 and 1.3.7.2.3
[2] Included in 1.3.7.1.2
[3] Total Annual Operations Man-Hours = 2,587 Man-Years
[4] Total Annual Maintenance Man-Hours = 3,838 Man-Years

	Operations	Maintenance
HLLV Related Man-Hours	4,710,500	6,075,700
HLLV Related Cost	0.188B	0.243B ($40/MHr)
PLV Related Man-Hours	464,300	1,601,000
PLV Related Cost	0.018B	0.064B ($40/MHr)

[5] HLLV and PLV Man-Hours each assume a portion of these items

TABLE 1.3.1-9 HLLV TOOLING AND GSE COST

	PRODUCT. LINES (UNITS)	TFU $M [3]	LEARNING	AVG COST $M	PRODUCT COST $M	SUSTAIN COST $M [4]	COST/FLT $M [5]
Tooling	[1]				(1240)	(3100)	(0.235)
Stage 1	2	397	85	367	734	1835	0.139
Stage 2	2	273	85	253	506	1265	0.096
GSE	[2]				(711)	(1778)	(0.135)
Stage 1	3	153	85	133	399	998	
Stage 2	3	119	85	104	312	780	

[1] → 94 Stage 1's
94 Stage 2's
25 years for production
0.5 year per stg

[2] → Assumes no more than 3 units of each stg in final assembly and C/O at one time

[3] → See TFU Details

[4] → Covers Spares and Engr
10% of Product. cost for each year of 24 year production cycle

[5] → Sustaining ÷ 13200 flts

TABLE 1.3.1-10 HLLV PROPELLANT COST

A

	Loaded Mass (KG)	Burden Factor	Prop. Cost ($/KG)	Cost/Flight ($)
Stage 1				
LO_2	5,126,700	1.05	0.037	199,172
RP-1	85,000	1.02	0.21	18,207
LCH_4	1,708,900	1.05	0.39	699,794
Stage 2				
LO_2	1,976,200	1.05	0.037	76,775
LH_2	329,400	1.05	1.53	529,181
			TOTAL (1977$)	$ 1,523,129
			(1979$)	= 1,751,600
				= 1.751M

TABLE 1.3.1-11 HLLV MISC COST

Items Covered

Program Support

Other Ground Sys and Ops

Direct Manpower

Indirect Manpower

Cost Basis

Scaled to the cost developed in the Shuttle Derivative Vehicle Study (NAS8-32395) which in turn was scaled to cost for the Space Shuttle

The key factors are the number of flights and learning factor of 88%.

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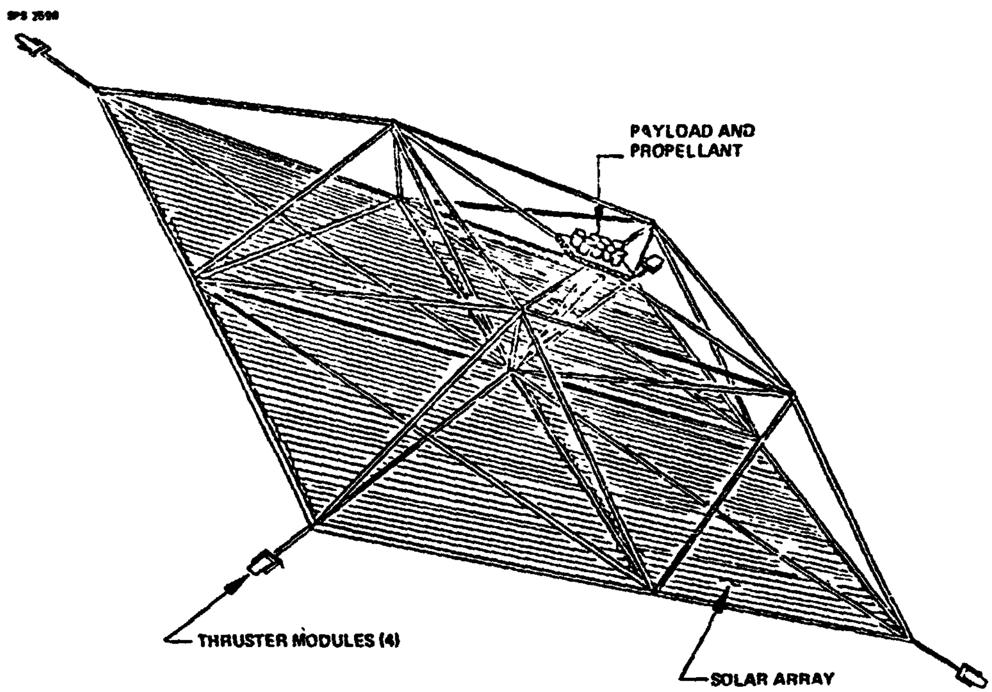
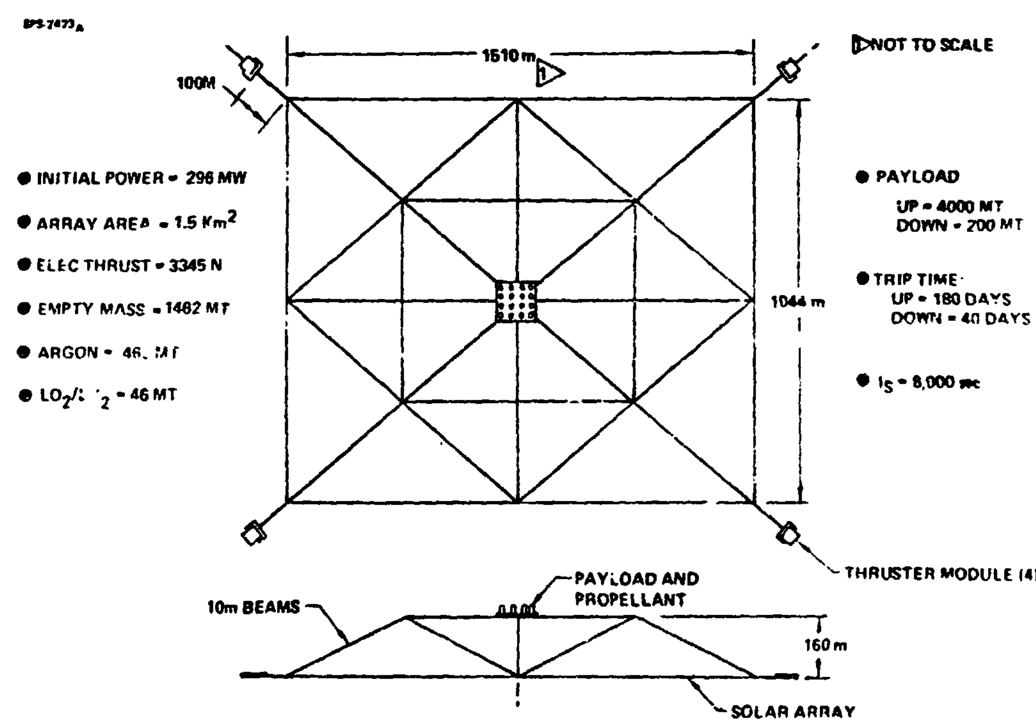




1.0 WBS DICTIONARY

The cargo Orbit Transfer Vehicle is used to transport satellite components and selected crew and base supplies from the LEO staging depot to the GEO construction base. This vehicle uses electric propulsion and is hereafter referred to as the electric orbit transfer vehicle (EOTV). A total of 21 vehicles are required for construction of two 5 GWE satellites in one year.

2.0 DESCRIPTION

The selected EOTV configuration for cargo transportation is shown in Figure 1.3.2-1. The vehicle is sized to deliver 4000 metric tons and return 200 metric tons with an uptrip time of 180 days and down time of 40 days, with a specific impulse of 8,000 seconds.

The vehicle structure consists of graphite thermoplastic material formed on-orbit. Electric power is provided by four separate solar arrays. The solar array blankets have essentially the same make-up as for the satellite which includes a 3 mil cover, 2 mil silicon cell and 2 mil substrate. The only significant difference is that a 5 x 10 cm cell is used rather than 6.48 x 7.44 cm in order to optimize the overall configuration. The arrays are configured to generate 2685 volts. Sheet busses collect power in each bay. Propulsion is provided by 120 cm diameter ion thrusters using argon propellant. Solid state processors are used to condition the power prior to use by the thrusters. Thermal control of the processors is accomplished using active radiators. Additional detail can be found in D180-25037-3, pp 278-256.

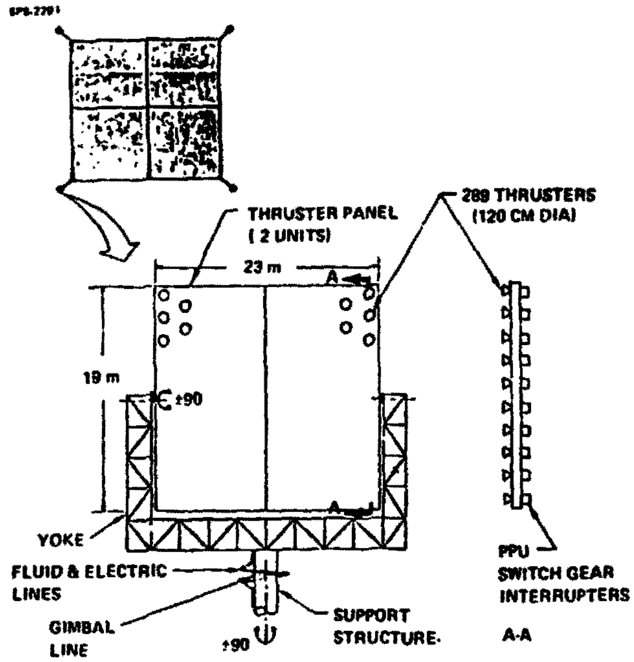
3.0 DESIGN BASIS

The payload capability of the vehicle was somewhat arbitrarily selected although it is judged that little effect would occur in terms of cost for rather significant variations in delivery capability. The selected value is made up of 10 HLLV deliveries. This value is judged to be a reasonable compromise considering smaller vehicles would result in a larger quantity of vehicles while more payload capability would make a larger vehicle which affects the LEO base size and vehicle flight control. The down payload to up payload ratio (5%) is judged sufficient to return the component containers, payload racks and waste products. The selected Isp and trip time is the result of extensive cost optimization studies involving a wide range of both Isp and trip times. This data is presented in Boeing document D180-25037-2, pp 373-376. Vehicles using silicon solar cells were found to be more cost effective than those using GaAs when a silicon cell satellite is used (also see D180-25037-2, pp 376-384). Processing of power prior to use by the thruster was found necessary due to the wide swings in both power and voltage of the array as a result of the radiation degradation that occurs during the transfer through the VanAllen belts (also see D180-25037-2, pp 393).

4.0 MASS AND MASS BASIS

The total dry mass of the vehicle is 1462 MT while the total propellant is approximately 500 MT. The breakdown is shown in Table 1.3.2-1. The estimates indicated are based on a mass estimating submodel described in D180-25037-2, pp 359-361. This model takes the propellant quantities and power requirements and through the use of various specific masses and mass fractions calculates the mass for all major system elements. A detail mass breakdown can be found in D180-25037-3, pp 287.

1 FOLDOUT FRAME



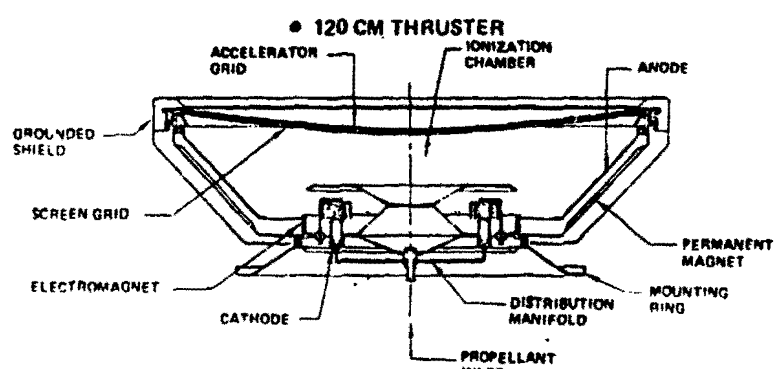


Table 1.3.2-1. EOTV Mass Summary

ITEM	o EMPTY MASS (MT)		o STARTBURN MASS (MT)	
Power Gen. and Distribution	(951)		Payload	4000
Solar Array	780		Empty	1462
Structure	122		Propellant	
Distribution	42		Argon	469
Energy Storage	7		LO_2LH_2	46
Electric Propulsion	(496)			5977
Thrusters	79			
Power Conditioning	219			
Thermal Cont.	88			
Struct/Mech	61			
Propellant Feed	49			
Auxiliary Systems	(15)			
TOTAL	1462			

5.0 COST

A cost summary of the EOTV for the various program phases is presented in Section 5.1. Details are presented in Section 5.2.

5.1 COST SUMMARY

	Millions (1979 $)
o Research	TBD
o Engineering Verification (component testing)	TBD
o Demonstration	
o Vehicle DDTE	2584
o Propulsion hardware for demo satellite transfer	TBD
o TFU	2444
o Commercialization	
o Average Unit	327
o Investment	
Construction (21 vehicles)	6858
For maintenance (per 20 satellite . . . 8 vehicles)	2612
o Production--cost/flight	68.2

5.2 COST DETAILS

Research

TBD

Engineering Verification

TBD

Demonstration

- o DDTE and TFU

The Boeing Parametric Cost Model was used to develop the vehicle DDTE and TFU estimates. A breakdown is shown in Table 1.3.2-2. Key elements of the DDTE include a tooling estimate based on a vehicle production rate up to 5 per year and ground and flight test hardware each equivalent to 0.3 of the TFU.

TFU costs reflect learning when multiple units of a given element are required to achieve the initial EOTV. The key elements in this category include thrusters, power conditioning and solar array. Additional DDTE and TFU cost detail can be found in the Cost Notebook.

- o Initial Investment

  TBD

WBS 1.3.2 CARGO ORBIT TRANSFER VEHICLE (cont'd)

		DDTE		TFU
o Flight Hardware		(119.9)		(1715)
o Power Gen. & Distribution	(10.9)		(924)	
Solar Array	0.4		878	
Structure	5.8		39	
Distribution	0.6		5	
Energy Storage	4.1		2	
o Electric Propulsion	(89.1)		(777)	
Thrusters	8.3		168	
Power Conditioning	23.4		528	
Thermal Control	7.2		51	
Structure/Mech	22.5		21	
Propellant System	27.7		9	
o Avionics	(19.9)		(14)	
Data Management	12.6		8	
Communication	7.3		6	
o Assembly & Checkout				(96)
o Tooling		(858.5)		–
o Systems Test		(1164.1)		–
o Labor	(77.9)			
o Ground Test	(543.1)			
o Flight Test	(543.1)			
o System Engr. & Integration		(12.0)		–
o Software Engr.		(18.3)		–
o Ground Support Equipment		(23.1)		228
o Sustaining Engineering				12
o Program Integ. & Management		(51.3)		75
TOTAL (1977 $)		$2247		$2126
TOTAL (1979 $)		$2584		$2444

Commercialization

- Average Cost

Average unit costs were developed using the TFU cost in conjunction with the annual production rate of the components for the entire EOTV fleet. The annual production rate assumed was equivalent to four EOTV's. This quantity of EOTV's results in components such as thrusters and solar cells having sufficient production rates that mature industry costing can be used (cost equals two times material cost). Power conditioning components such as processors, switchgear and interrupters have production rates sufficient to merit learning values of 70%. Other EOTV components have lower production rates and have been costed at 85% learning.

A breakdown of the average unit cost is shown in Table 1.3.2-3. Additional detail concerning costing of each component can be found in the Cost Notebook.

Table 1.3.2-3 EOTV Average Unit Cost

		Cost in Millions
o Flight Unit		(247)
o Power Gen. & Distrib.	(99.7)	
Solar Array	79.6	
Structure	12.1	
Distribution	1.6	
Energy Storage	6.4	
o Electric Propulsion	(141)	
Thrusters	15.4	
Power Cond.	87.2	
Thermal Control	22.1	
Struct/Mech	11.3	
Propellant Sys.	5.0	
o Avionics	(6.5)	
o Programmatic		(36.6)
TOTAL (1977 $)		283.6
TOTAL (1979 $)		327

Commercialization (cont.)

- Cost Per Flight

  A summary of the $70M cost per EOTV flight is shown in Table 1.3.2-4. Details are shown in Table 1.3.2-5. It should be noted that the indicated costs are lower than the value presented in D180-25037-3, pp 291, since amortization, contributions from construction base, trip time delay (interest cost) and payload launch are included elsewhere in the cost analysis.

Table 1.3.2-4. EOTV COST PER FLIGHT

Flight Hardware		$32.5 M
Refurb		11.3
Refueling		15.0
Program Support & Misc.		0.5
	(1977$)	$59.3 M
	(1979$)	$68.2 M

Tooling and GSE have been included in the LEO base cost

TABLE 1.3.2-5 COST PER FLIGHT DETAILS

Flight Hardware (1977$)

- o Average Unit Cost = $ 284 M
- o Launch Cost

  1462 MT/EOTV
  360 MT/Launch
  4.06 Launches @ $10.2 M = 41.4 M
- o Total Cost - $ 325.4 M
- o Cost Per Flight @ 10 Flights/EOTV = 32.5 M

Refurbishment

- o Primarily relates to thruster grids and Cathodes
- o Thruster Spares

  Equal 50% Avg. Cost (.5)(15.4) - 7.2 M
- o Launch of Thruster Spares

  Mass = 50% initial mass
  = (.5)(80 MT) = 40 MT
  Launches = .111 @ 10.2 M/Launch 1.1 M
- o Misc. Spares and Launch 3.0 M
  - . Estimate
  - . 1% of Unit Cost less Thrusters = $2.7 M
  - . Launch = 0.3 M
- o Total Refurb/Light 11.3 M

Refueling

- o Propellant Cost =

Item	Mass	Burden Factor	$/kg	Cost ($M)
Argon	470 MT	1.05	1.00	.493
LO_2	36 MT	1.05	.037	.001
LH_2	9 MT	1.05	1.53	.014
				$ .508 M

- o Launch Cost
  - . 515 MT
  - . 360 MT/Launch
  - . 1.43 launches @ 10.2 M = $14.5 M
- o Total Refueling/Flight = $15 M

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SPS-2098

VEHICLE CHARACTERISTICS:

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

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

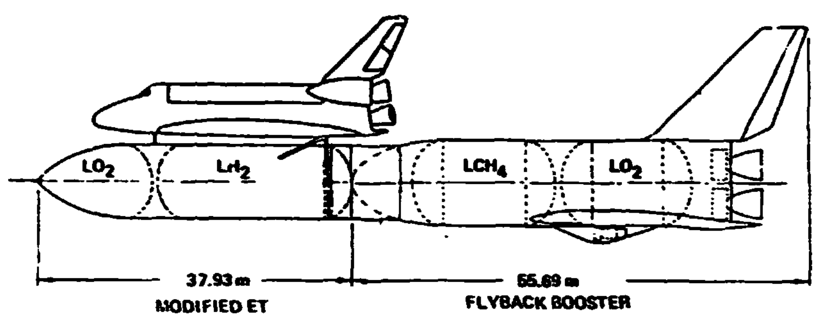

Figure 1.3.3-1 – Shuttle Derived PLV

1.0 WBS DICTIONARY

The Personnel Launch Vehicle is used to transport cargo and personnel to low earth orbit during the demonstration phase of the program and only personnel during the commercial phase.

2.0 DESCRIPTION

The PLV is derived from the current space shuttle system. The vehicle consists of a winged liquid propellant fly-back booster than employs four O_2/CH_4 engines similar to the HLLV booster, a resized, smaller version of the space shuttle external tank and the space shuttle orbiter. The payload capability to the LEO base in a 477 km/31 degree orbit is approximately 89 MT. The configuration, vehicle characteristics and engine characteristics are shown in Figure 1.3.3-1.

3.0 DESIGN BASIS

Studies conducted early in the SPS contract analyzed a PLV employing a ballistic recoverable booster, modified ET and orbiter. However, once a decision was made to use a two stage winged HLLV it appeared reasonable to develop a PLV that also employed a winged booster in order to provide an evolutionary path. The reference configuration described above is the result.

4.0 MASS

The mass statement for the flyback booster is shown in Table 1.3.3-1. The mass statement for the ET which has a propellant load of 547 MT (rather than 703 MT when used with the space shuttle) is shown in Table 1.3.1-2.

TABLE 1.3.3-1 FLYBACK BOOSTER MASS SUMMARY

ELEMENT		KG
Wing		31,940
Tail		4,930
Body		68,490
Induced Environ. Protection		9,050
Landing and Aux. Systems		9,710
Propulsion—Ascent		51,320
Propulsion—RCS		960
Propulsion—Flyback		13,800
Prime Power		1,190
Elec. Conv. and Distribution		960
Hyd. Conv. and Distribution		4,230
Surface Controls		2,020
Avionics		1,450
Environmental Control		210
Growth Allowance		16,200
Dry Mass		(216,460)
Residuals and Reserves		12,700
Landing Mass		(229,160)
Flyback Fuel		26,260
Inflight Losses	3,900	
Inert Mass		(259,320)

TABLE 1.3.3-2 ET MASS SUMMARY

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

5.0 COST

A cost summary of the PLV for the various phases is presented in Section 5.1 with details presented in 5.2.

5.1 COST SUMMARY

	Millions (1979$)
Research	TBD
Engineering Verification	TBD
Demonstration	
DDTE	$ 3,008
Initial Investment	TBD
Cost Per Flight	TBD
Commercialization	
DDTE	0
Initial Investment	$2,297 M
Cost Per Flight	$12.33 M

5.2 COST DETAILS

	(1979$)
Research	TBD
Engineering Verification	TBD
Demonstration	
o DDTE and TFU	$ 3,008 M

Since the PLV is used initially to support the demon satellite its DDTE is included in this phase. Detail DDTE and TFU costs were not developed for the flyback PLV. The method used to obtain the cost is as follows:

- o Detail cost were developed for the ballistic PLV.
- o Detail costs were also developed for flyback and ballistic HLLV's.
- o The cost ratio of the booster stage of the flyback HLLV to ballistic HLLV was applied to the ballistic PLV to get the flyback booster cost.

The DDTE and TFU cost of the major elements of PLV are shown in Table 1.3.3-3.

TABLE 1.3.3-3 PLV DDTE AND TFU COST

	DDTE	TFU
Booster	2,479	207
External Tank	60	15
Orbiter	0	
Prog. Mgt. and Integ.	77	18
(1977$)	$ 2,616 M	$ 140 M
(1979$)	$ 3,008 M	$ 276 M

o Initial Investment TBD

Commercialization

o DDTE

None, charged to Demonstration Phase

o Initial Investment

The initial investment cost, shown in Table 1.3.3-4, covers all flight hardware including expendable external tanks necessary to complete the construction of the GEO construction base as well as the vehicle tooling and GSE to satisfy the initial requirements of the commercial phase.

TABLE 1.3.3-4 PLV INITIAL INVESTMENT

ELEMENT	UNITS	AVG COST (M)	TOTAL COST (M)
Booster Airframe	2	115	130
Booster Engines	8	4.8	38
Orbiters	2	550	1100
External Tanks (thru GEO Base const)	47	3.2	150
Tooling	1	300	300
GSE	2	22	44
		Total (1977$)	$1860 M
		Total (1979$)	$2139 M

o Cost per Flight

The PLV cost per flight of $12.33 M is summarized in Table 1.3.3-5 Additional detail is provided in Tables 1.3.3-6 and 1.3.3-7.

The method used to determine the PLV cost per flight was generally the same as used for the HLLV. The indicated costs are based on a total of 2,579 flights during the 33 years required to place 60 satellites. The average number of flights per year for SPS program 58. An additional 20 flights per year has also been assumed for non SPS activity and is included in the total number of flights indicated above.

TABLE 1.3.3-5 PLV COST/FLIGHT

Program Support (Table 1.3.1-7)			(0.623)
Flight Hardware (Table 1.3.3-6)			(6.814)
Orbiter Production		1.95	
Orbiter Spares		0.30	
SSME Spares		0.236	
Booster Airframe		0.758	
Booster Engines		0.205	
Crew Related GFE		0.165	
Expendable ET		3.20	
Tooling (Table 1.3.3-7)			(0.116)
Ground Ops/Sys (Table 1.3.3-7)			(0.517)
Ground Ops		0.018	
Ground Sys. Maint.		0.064	
GSE		0.345	
Other		0.090	
Propellant (Table 1.3.3-7)			(0.356)
Manpower (Table 1.3.3-7)			(2.3)
Direct		1.8	
Indirect		1.5	
Total	(1977$)		$10.725 M
Total	(1979$)		$12.33 M

TABLE 1.3.3-6 PLV FLIGHT HARDWARE

ELEMENTS	EQUIVALENT UNITS					TFU ($M)	LEARNING	AVERAGE COSTS ($M)	TOTAL COST $M (1)	COST/FLT ($M) (1)
	INITIAL BUY	Δ BUY FOR LIFE	REFURB	REPLENISH	TOTAL UNITS					
Orbiter	2	6	-	-	8	-	-	550	5040	1.95
Booster Airframe	2	7	5	5	19	183	85	115	1955	.758
Booster Engines	8	N/A	58	52	118	10	90	4.8	528	0.205
External Tank	47	2532	-	-	2579	15.5	85	3.2	8253	3.2
Orbiter Spares	Scaled to STS considering number of flights and = 90									0.30
SSME Spares										0.236
Crew Related GFE										0.165

(1) Excludes initial investment

TABLE 1.3.3-7 PLV OTHER COST/FLIGHT ELEMENTS

Tooling - Booster

Sustaining only
1 production line ($300 M)
2 Vehicles/yr rate
10 yr production line sustaining
= 10% of prod. cost for each of 10 years

GSE

Scaled to STS since same yearly flight rate

Propellant	MT	Burden Factor	$/kg	Total $
LO_2	1605	1.05	.037	$ 62,350
LCH_4	424	1.02	.39	168,866
LH_2	78	1.05	1.53	125,307
				$356,523
				$ 0.356 M

Other Elements

Prog Support Other Ground Cost Direct Manpower Indirect Manpower	Scaled to Shuttle Derivative study M manner similar to HLLV

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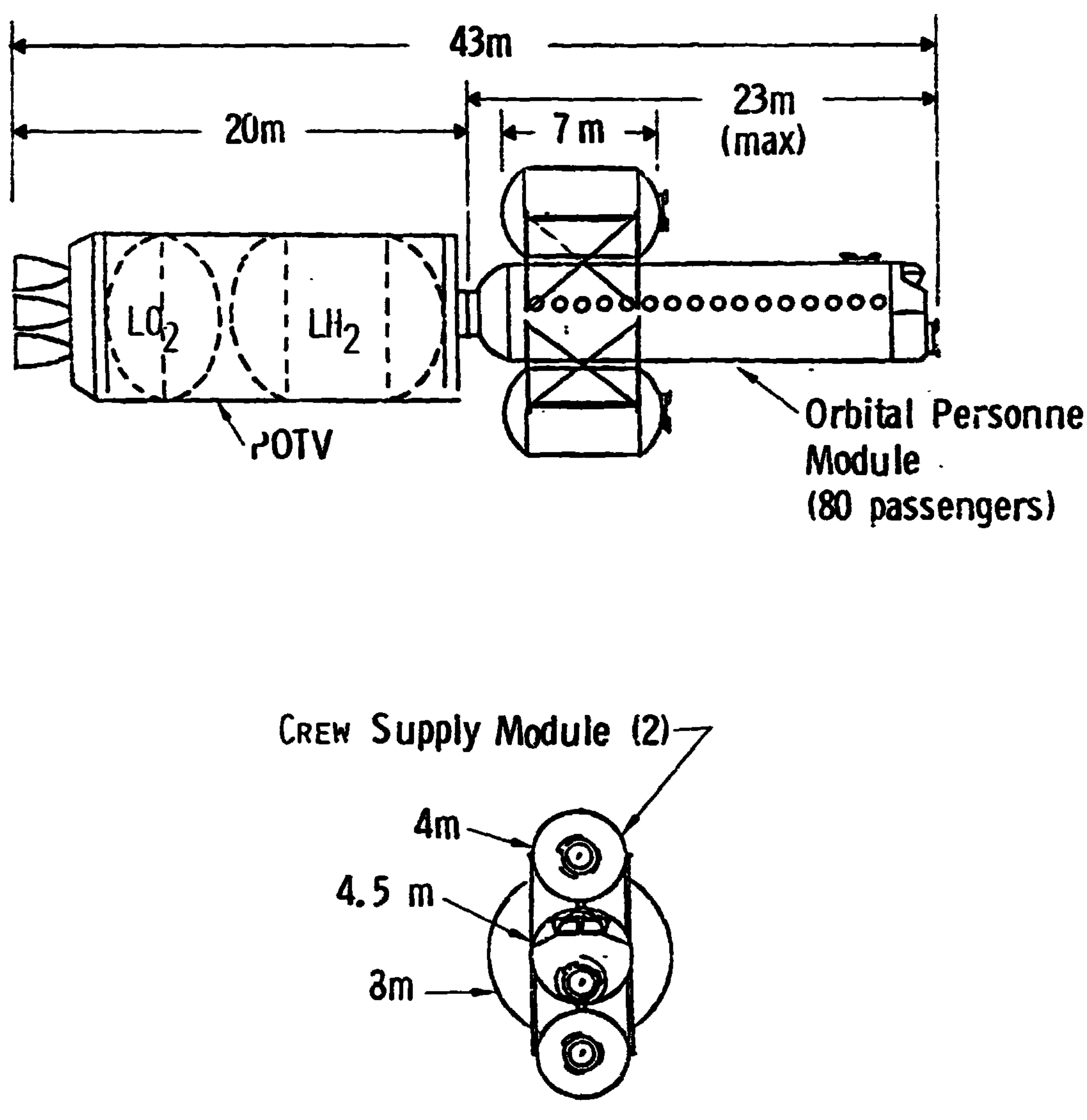

Figure A – Orbital Crew Rotation/Resupply Configuration

WBS 1.3.4 PERSONNEL ORBITAL TRANSFER VEHICLE

1.0 WBS DICTIONARY

The Personnel Orbit Transfer Vehice (POTV) is defined as the transportation system that will be used to transfer personnel and crew supplies between the LEO base and GEO base. The POTV will also be used to transport crews and cargo between the GEO base and the satellites when maintenance is required. The integrated flight configuration for a crew rotation/resupply mission is shown in Figure A.

2.0 DESCRIPTION

The POTV is a single stage LO_2/LH_2 vehicle which in the normal mode has the capability of transporting 90 MT of payload between LEO and GEO. Return of the vehicle and payload requires refueling at GEO. The POTV can be flown in a roundtrip mode without refueling if necessary but with a reduction in payload capability. An inboard profile of the POTV is shown in Figure B.

Main propellant containers are welded aluminum with integral stiffening as required to carry flight loads. Intertank, forward and aft skirts, and thrust structures employ graphite/epoxy composites. An Apollo/Soyuz type docking system is provided at the front end of the stage for docking with payloads and orbital bases.

Five ASE type engines (staged combustion) are used for main propulsion. A thrust level per engine of 88 KN (88,000 lb_f) is assumed along with an extension expansion area ratio of 400 and a specific impulse of 470 sec.

Auxiliary propulsion is used for attitude control and low delta V maneuvers during coast periods and for terminal docking maneuvers. An independent $L0_2/LH_2$ system is used and provides an Isp of 375 seconds averaged over pulsing and steady state operating modes.

Primary electric power is provided by fuel cells based on shuttle technology, tailored to the OTV requirement. Reactants are stored in vacuum-jacketed pressure vessels. Ni-Cad batteries are employed for peaking and smoothing. 28 BDC power is rough.

Avionics functions include onboard autonomous guidance and navigation, data management, and S-band telemetry and command communications. Navigation employs Earth horizon, star and Sun sensors with an advanced high performance inertial measurement system. Cross-strapped LSI computers provide required computational capability including data management, control and configuration control. The command and telemetry system employs remote-addressable data busing and its own multiplexing.

Main propellant tanks are insulated by aluminized mylar multilayer insulations contained within a purge bag. Environmental control of the avionics systems is accomplished using semi-active louvered radiators and cold plates. Active fluid loops and radiators are required for the fuel cell systems. Superalloy metal base heat shields are employed to protect the base areas from recirculating engine plume gas. Further information on the subsystems can be found in D180-25037-3, pp. 298-2-9.

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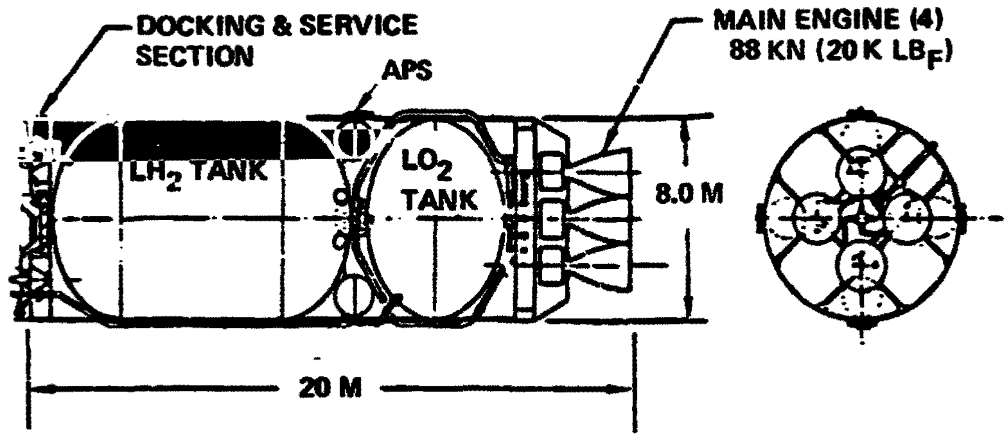

Figure B –

The nominal transfer time beginning with separation from the LEO base and docking at the GEO base is approximately 11 hours. Orbit phasing requirements could add an additional 12 hours.

3.0 DESIGN BASIS

Previous POTV designs have used a two stage vehicle that provides round-trip capability without refueling at GEO. The present single stage vehicle requiring refueling at GEO was selected to reduce the total POTV propellant per flight since the highly efficient EOTV could be used to deliver the POTV return propellant to GEO. The POTV savings per flight is approximately 265 MT with the net savings including EOTV penalty of 175 MT per POTV flight.

The 90 MT payload capability was the result of sizing the vehicle to be delivered by the shuttle Derivative HLLV (without propellant). This capability is sufficient to deliver up to 80 GEO workman and food and crew accommodations for 6600 man days.

4.0 MASS AND MASS BASIS

The total dry mass is 13420 Kg while the main impulse propellant is 200,000 Kg. The breakdown is shown below. The estimate is based on mass parametrics developed in the Future Space Transportation Study NAS9-14323 Document D180-20243-3.

<u>POTV MASS (kg)</u>

Structure & Mechanisms	6900	Unusable LO_2/LH_2	1130
Main Propulsion	2500	Unusable & Reserve	
		APS Prop	500
APS	500		
Avionics	300	Fuel Cell Reactant	150
		Boil-off	100
Electric Power	450		
Thermal Control	1030	Burnout	
Contingency (15%)	1750	Main Impulse Prop	200000
		APS	1200
Dry	13430	Stage Startburn	216510

5.0 COST

A cost summary of the various phases is presented in Section 5.2 with details presented in 5.2.

5.1 COST SUMMARY

	Millions (1979 $)
Research	TBD
Engineering Verification	TBD
Demonstration	
o DDTE	$1,012 M
o TFU	100 M
o Investment (2 vehicles)	101 M
Commercialization	
o Investment (2 vehicles)	$ 129 M
o Cost per Flight	1.54 M

5.2 COST DETAILS

Research — TBD

Engineering Verification — TBD

Demonstration

o DDTE & TFU

The DDTE and TFU costs are shown in Table 1.3.4.1. The system test value is based on an equivalent of 1½ ground units and 1 flight test unit. These costs have been determined using detail mass statements and the Boeing PCM.

o Investment

The investment cost of $101 M is based on requiring two vehicles to support the Demo satellite program and an average cost per vehicle based on the total number of units required including the commercialization phase of the program.

Commercialization

o Investment

The initial investment cost of $129 M is based on the need of two vehicles, tooling and GSE. The cost breakdown is shown in Table 1.3.4-2.

o Cost per Flight

The cost per flight is $1.54 M and is summarized in Table 1.3.4-3. Details of the cost per flight are shown in Table 1.3.4-4.

TABLE 1.3.4-1 POTV DDTE AND TFU COST

		DDTE		TFU
POTV		(1012)		(100)
Vehicle		509		53
Structure	39		15	
Thermal Control	23		1	
Avionics	45		8	
Elec. Pwr. Sys.	16		4	
Main Propul	381		19 [1]	
Aux Propul	5		6	
Assembly and Checkout	-			6
SI and I		22		
Software Engr.		26		
GSE		48		21
System Test		198		
Tooling		14		7
Cost of Mass Contingency		102		6
Logistics		9		
Liaison		4		2
Initial Spares		10		
Program Mgt.		70		5

[1] Engines are $15 M

TABLE 1.3.4-2 POTV INITIAL INVESTMENT

Vehicle		101
Airframe and subsys.	86	
Rocket Engines	15	
Tooling		7
GSE		21
	Total	$129 M

Table 1.3.4-3. POTV COST PER FLIGHT

Flight Hardware (T1.3.4-4)		1.123
Airframe & Subsystem	0.889	
Rocket Engines	0.234	
Tooling		0.004
GSE		0.013
Propellant		0.063
Misc		0.340
Program Support		
Manpower-Direct & Indirect		
TOTAL (1979$)		$1.54 M

TABLE 1.3.4-4. COST PER FLIGHT DETAILS

Flight Hardware Cost

	Airframe & Subsys	Rocket Engines
Equivalent Units	2	10
Initial Buy		
Δ Buy for Life	28	155
1500 flts in 33 yrs - Initial 50 flts/veh		
Refurb	N/A	40
	(Expendable after 50 flights)	(30%/unit cost/50 flts)
Replenish	3	39 (.5%/flt)
Total Units	33	244
TFU ($ M)	75	3
Learning	85	90
Avg Cost ($ M)	43	1.5
Total Hardware Cost ($ M) ▷1	1333	351
Cost/Flight ($ M) ▷1	0.889	0.234
Initial investment	86	15

▷1 Excludes cost of initial units since they are part of initial investment.

TABLE 1.3.4-4. COST PER FLIGHT DETAILS (Continued)

Tooling

33 vehicles in 33 years

1 production line

4 vehicles produced/year

Assume line operates 10 years

Production hardware cost = $6.9 M

Sustaining cost = $6.9 M

10% of production hardware during 10 years of production

Cost/Flight = 0.004

6.9 ÷ 1500

GSE

1 set of equipment

Production cost = $21 M

Sustaining cost = $21 M

10% of production cost for 10 years

Cost/Flight = $0.013 M

$21 M ÷ 1500

TABLE 1.3.4-4. COST PER FLIGHT DETAILS (Continued)

Propellant

Prop	Mass Kg	Burden Factor	$/Key	Total Lost
LO_2	170,000	1.05	0.037	6604
LH_2	30,000	1.05	1.53	48,195
		(1977 $)		$54,800
		(1979 $)		$63,020
				$0.063M

Miscellaneous

Program Support

Direct Manpoer

Indirect Manpower

Used 30% of the other cost/flight elements—same as was used in HLLV

Space Operations and System Maintenance

Equivalent to HLLV ground operations and ground system maintenance

These costs have been charged to the LEO base.

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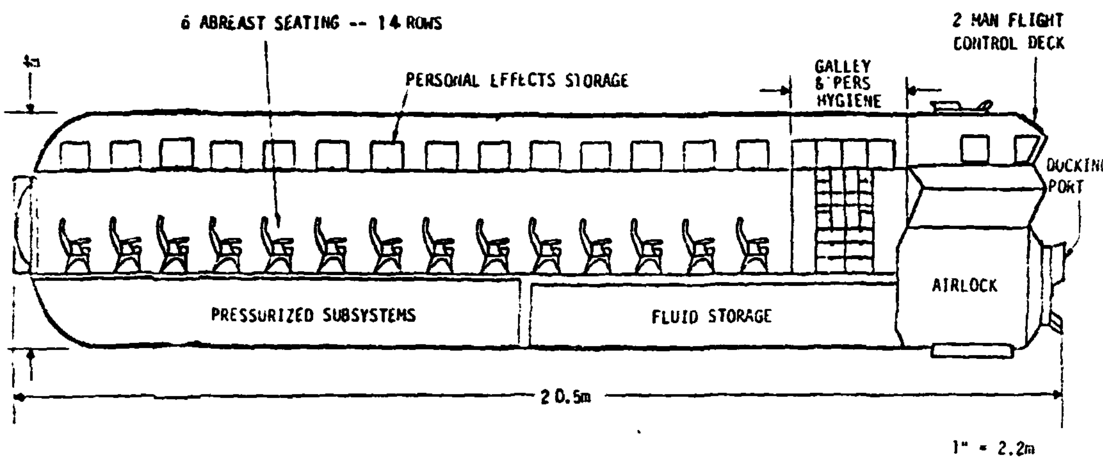

6 ABREAST SEATING -- 14 ROWS
PERSONAL EFFECTS STORAGE
GALLEY & PERS HYGIENE
2 MAN FLIGHT CONTROL DECK
DOCKING PORT
AIRLOCK
PRESSURIZED SUBSYSTEMS
FLUID STORAGE
20.5m
1" = 2.2m

1.0 WBS DICTIONARY

The Orbit Personnel Module (OPM) is used to accommodate crews during the transfer between the LEO and GEO bases. The Launch Personnel Module (LPM) accommodates crews during transit between Earth and the LEO Base. The OPM differs from the LPM in terms of the mission duration and associated needs as well as the environmental protection requirements.

2.0 DESCRIPTION

The configuration for the OPM is shown in Figure A. This design has the flight control deck integrated with the passenger crew cabin. The OPM has been sized to transport 78 orbital workman in a single deck, 6-abreast arrangement in addition to a flight crew (pilots, flight engineer, flight attendants).

The structural shell is aluminum with an inside layer of tantalum to improve radiation protection characteristics. An average electrical power requirement of 15 kw has been estimated for the OPM. Advanced LO_2/LH_2 fuel cells are the primary power source with batteries for peaking and emergency. The environmental control/life support system is a scaled down version of the system used in the crew modules at the LEO and GEO bases. This closed loop system was selected due to the large crew size and frequent use. The system employs a sabatier reactor for CO_2 reduction, water recovery and electrolysis for oxygen production. Thermal control consists of water loops inside the cabin and freon loops for the space radiator.

Crew accommodations include pressure suit garmets for all on-bard personnel, several EVA suits for emergencies, food storage and preparation, furnishings such as seats and mobility aids and limited recreation provisions. The information system includes data processing, displays and controls to operate the POTV as well as OPM, supplemental G&N equipment to that incorporated on the POTV and communications equipment. Crew consumables are leased on a nominal transfer of 1-day for both delivery and return flights and an additional day provided for emergency.

3.0 DESIGN BASIS

The major issue considered thus far in the design of the OPM is that of defining the crew capacity. The principle considerations in selecting the crew capacity of the OPM are the payload capability of the POTV and the payload envelope of the launch vehicle which will initially deliver the OPM to orbit. As previously described, the POTV was sized for refueling at GEO and delivery to LEO by the shuttle derivative HLLV. These conditions resulted in a paylod capability that allowed delivery of approximately 80 people. Using crew rotation cycles of 90 days results in POTV flights approximately every 15 days. Previous analysis had a flight every 30 days but the more frequent flight arrangement is judged to provide more flexibility for the case of deliverying a small amount of priority cargo.

4.0 MASS AND MASS BASIS

The hardware mass of the OPM including growth is 43685 Kg with the total flight weight including crew is 53285 Kg.

A mass summary and detail hardware breakdown is presented below.

OPM MASS SUMMARY

Hardware		(349.50)
Structure	12,560	
Electrical Power	710	
Envir Cent/Life Support	18,300	
Crew Accommodations	2,980	
Avionics System	400	
Consumables		(1,450)
EPS - LO_2/LH_2	400	
Afm Supply - LO_2/LN_2	150	
Water - Crew	585	
Food & Pkg	315	
Fluids		(1,060)
Thermal Cont (H_2O & Freon)		
Payload		(7,090)
Crew & Pers Effects		
	Sub Total PM	44,500 Kg
Growth (Contingency) - 25% on Hardware		8,735
	PM Grand Total	53,285 Kg

WBS 1.3.5 ORBITAL PERSONNEL MODULE (cont'd)

SUMMARY MASS STATEMENT
OPM TOTAL

Structure		(12,560)
Shell	8,760	
Other	3,505	
Thermal Prot	295	
Electrical Power		(710)
Fuel cells	220	
Tanks	370	
Distribution	120	
Reactant (See Consumable)		
Batteries		
ECLS		(18,300)
AFM &	7.4	
Water Mgt	1.9	
Waste Mgt	3.2	
Therm Cont	5.8	
H_2O + Freon Loops		
Crew Accommodations		
Pers Equip	1,770	
General & Emergency	395	
Furnishings	530	
Recreation	70	
Food Mgt	215	
Avionics System		(400)
G&N	50	
Data Process	100	
Display/Control	150	
Ext. Comm.	50	
Int. Comm.	150	
TOTAL HARDWARE w/o GROWTH		34,950 Kg

5.0 COST

A cost summary of the OPM for the various phases is presented in Section 5.1. Details are presented in 5.2.

5.1 Cost Summary

	Millions (1979 Dollars)
Research	TBD
Engineering Verification	TBD
Demonstration	TBD
Commercialization	
DDTE	1,092
TFU	222
Avg. Unit Cost	190

5.2 Details-Commercialization

DDTE

The Boeing Parametric Cost Model (PCM) was used to develop this data. Ground and flight test hardware is equivalent to 2-1/2 operational units. A breakdown is shown below.

TFU

The Boeing PCM was also used to develop the TFU cost. A cost breakdown is also provided.

Avg. Unit Cost

This cost is based on 4 units during the first 15 years with a learning factor of 0.9.

OPM COST

	DDTE	TFU
H1 Structure	(278)	(139)
H2 Elec Power	68	17
H3 ECLS	66	17
H4 Crew Accomm	8	8
H5 Avionics	110	67
ASSEMBLE AND C/O	(0)	(21)

WBS 1.3.5 ORBITAL PERSONNEL MODULE (cont'd)

SUPPORT COST	(298)	(15)
System Engineering & Integration	25	--
Software Engineering	35	--
Systems Ground Test Conduct	133	--
SE Design	66	--
SE Mfg	39	15
Tooling & STE	--	--
Systems Flight Test Conduct	--	--
OTHER COST	(516)	(68)
GRND/FLT Test Hardware	320	
Logistics and Data	17	
Liaison/Sustain Engr	13	6
Spares	32	42
Program Management	134	20
TOTAL ($M)	1092	222

/

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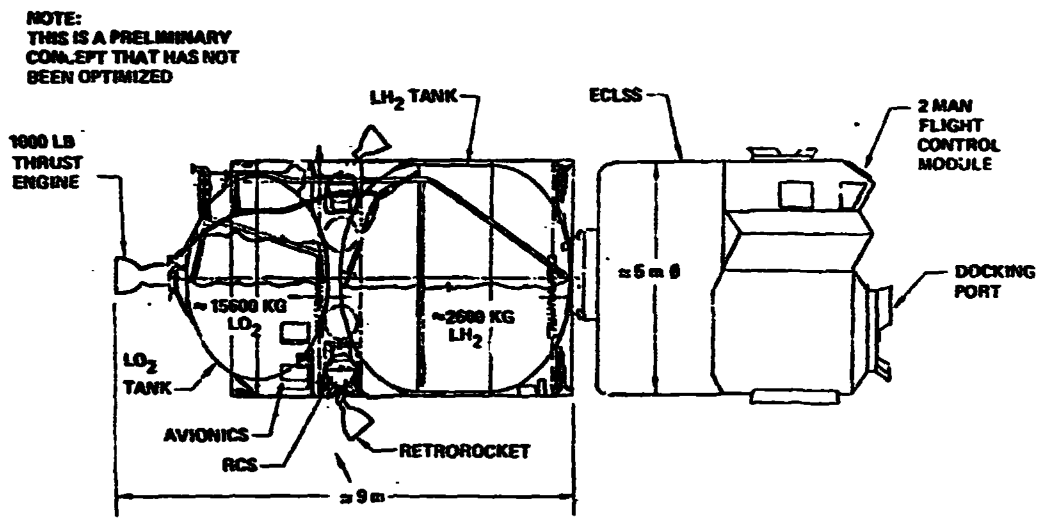


REFERENCE: BOEING AEROSPACE COMPANY
OTV PROPOSAL, APRIL 1979

1.0 WBS DICTIONARY

The cargo tug is used at both the LEO Base and the GEO Base to transfer cargo and propellant pallets between the bases and the EOTV's.

2.0 DESCRIPTION

The cargo tug consist of a single stage LO_2/LH_2 OTV that is normally used with a 2 man flight control module. Two of these tugs are required at each base. Also see WBS 1.2.2.3.2 for operational use of the system and WBS 1.2.2.1.5 and WBS 1.2.2.1.6 for its support systems.

3.0 DESIGN BASIS

This preliminary concept is based on meeting the following requirements:

1. 2-man flight control module.
2. Docking fixture on the control module (mates with the pallet handling fixture, WBS 1.2.2.1.3.1.3), the EOTV propellant pallet, and to a docking port at the bases)
3. Electrical connector incorporated into the docking fixture that provides an interface with the crew controls and displays used for the following systems:
   a. Cargo pallet handling fixture gimbal
   b. Cargo pallet handling fixture attachment mechanisims
   c. Laser guidance system
   d. EOTV pallet holdown mechanisms
   e. Propellant tank fluid coupling mating mechanism
4. Must have 6 DOF capability.
5. Vehicle sizing criteria
   - 400,000 Kg payload (Max)
   - 1-3 Km trips (one way)
   - Refuel after 12 round trips
   - Transit time 5 to 30 minutes
6. Refueled from a propellant transfer system colocted with the docking port on the LEO and GEO bases.

4.0/5.0 MASS AND COST

This vehicle has not been weighed or costed.

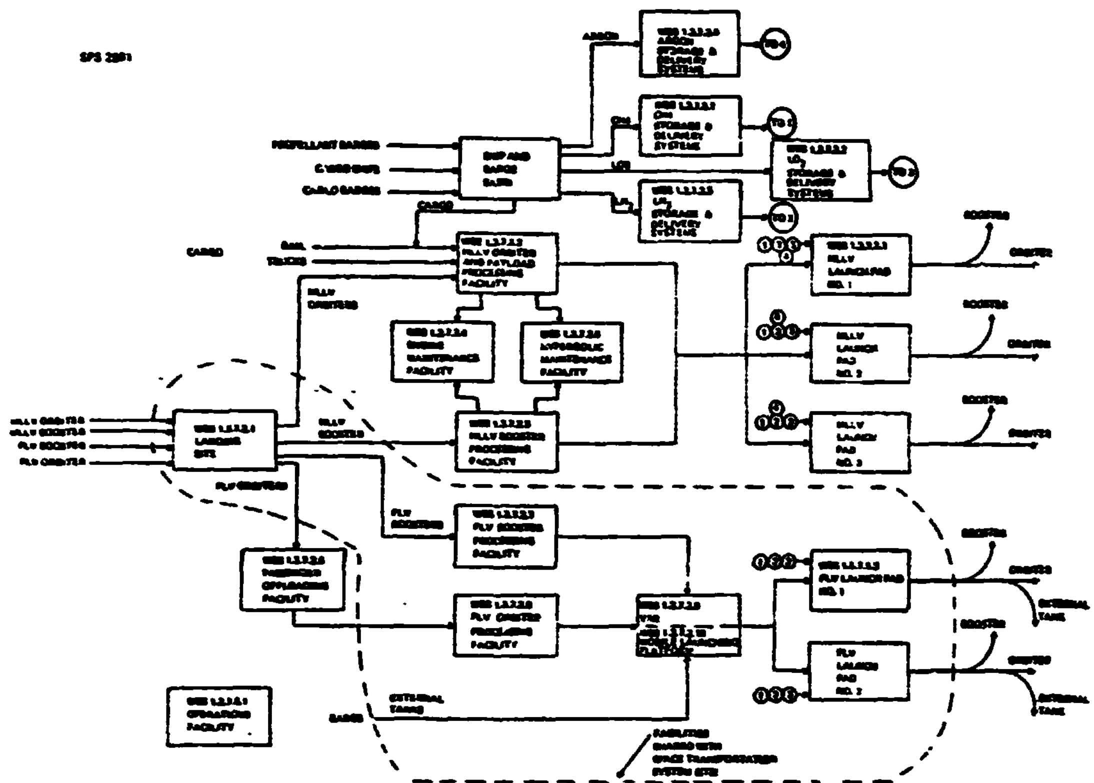


Figure A. Ground Support Facilities

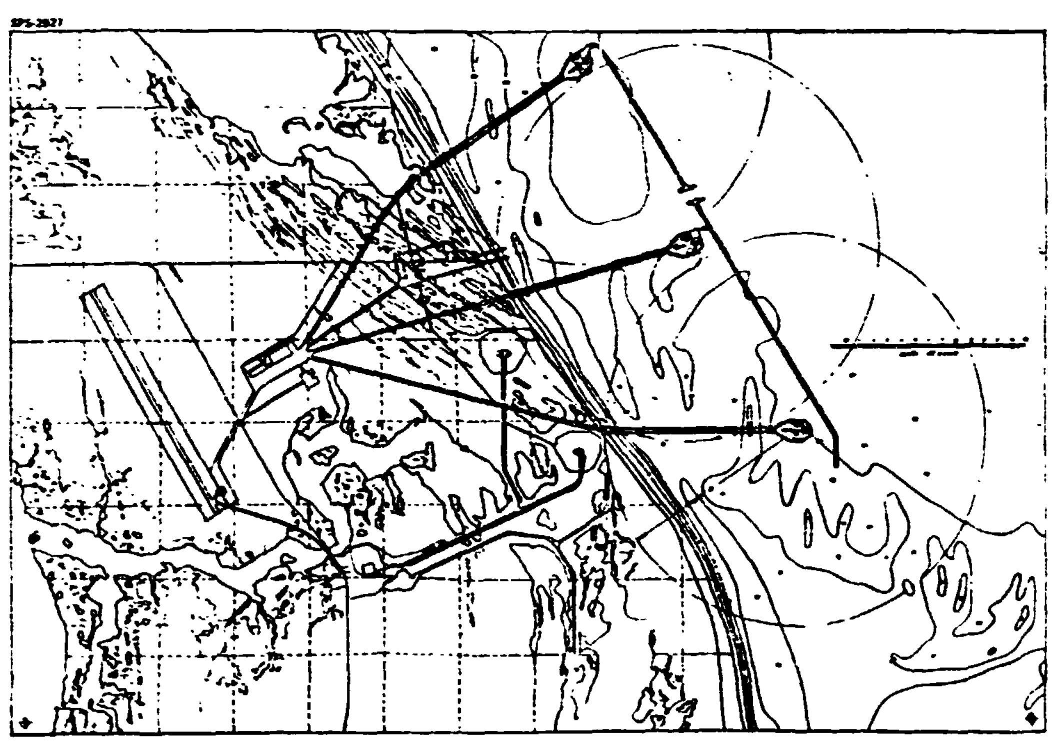


Figure B. Overlay of HLLV Pads on KSC Map

1.0 WBS DICTIONARY

This element includes all land, buildings, roads, shops, etc. required to support the cargo handling, launching, recovering, refurbishment and operations of the space transportation system.

2.0 ELEMENT DESCRIPTION

Figure A shows the various ground support facilities that have been identified and their functional interfaces. Each of these elements are described in following subsections.

The reference launch and recovery site is the Kennedy Space Center. Maps of the SPS space transportation ground support facilities at this location are shown in Figures B, C, and D.

The landing site is common to both the HLLV and PLV ground support operations.

The HLLV facilities will be new.

The PLV facilities will be shared with the Space Transportation System (STS) Shuttle-Growth vehicle ground facilities.

3.0 DESIGN BASIS

The launch and recovery site facilities, systems, and operations are based on the requirements imposed by the 2-stage winged HLLV (WBS 1.3.1) and the POTV (WBS 1.3.4). The specific requirements are discussed in detail in Section 6 of the operations and systems synthesis document(D180-25461-3). The Kennedy Space Center was selected as the location only to serve as a reference case.

4.0 MASS

Not applicable.

5.0 COST

The total cost for the ground support facilities is given in Table A. The rationale is found in the cost sections for the sub-elements.

WBS 1.3.7 GROUND SUPPORT FACILITIES (CONT'D)

SPS-2026

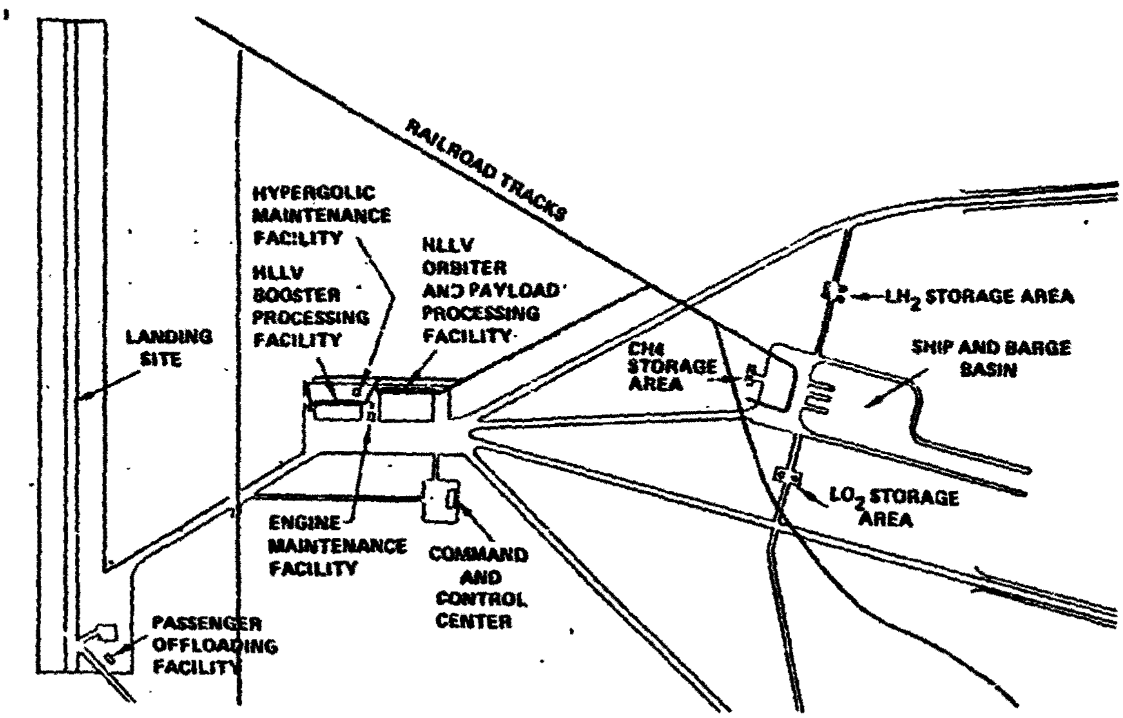


Figure C. SPS Ground Support Facilities

SPS-2029

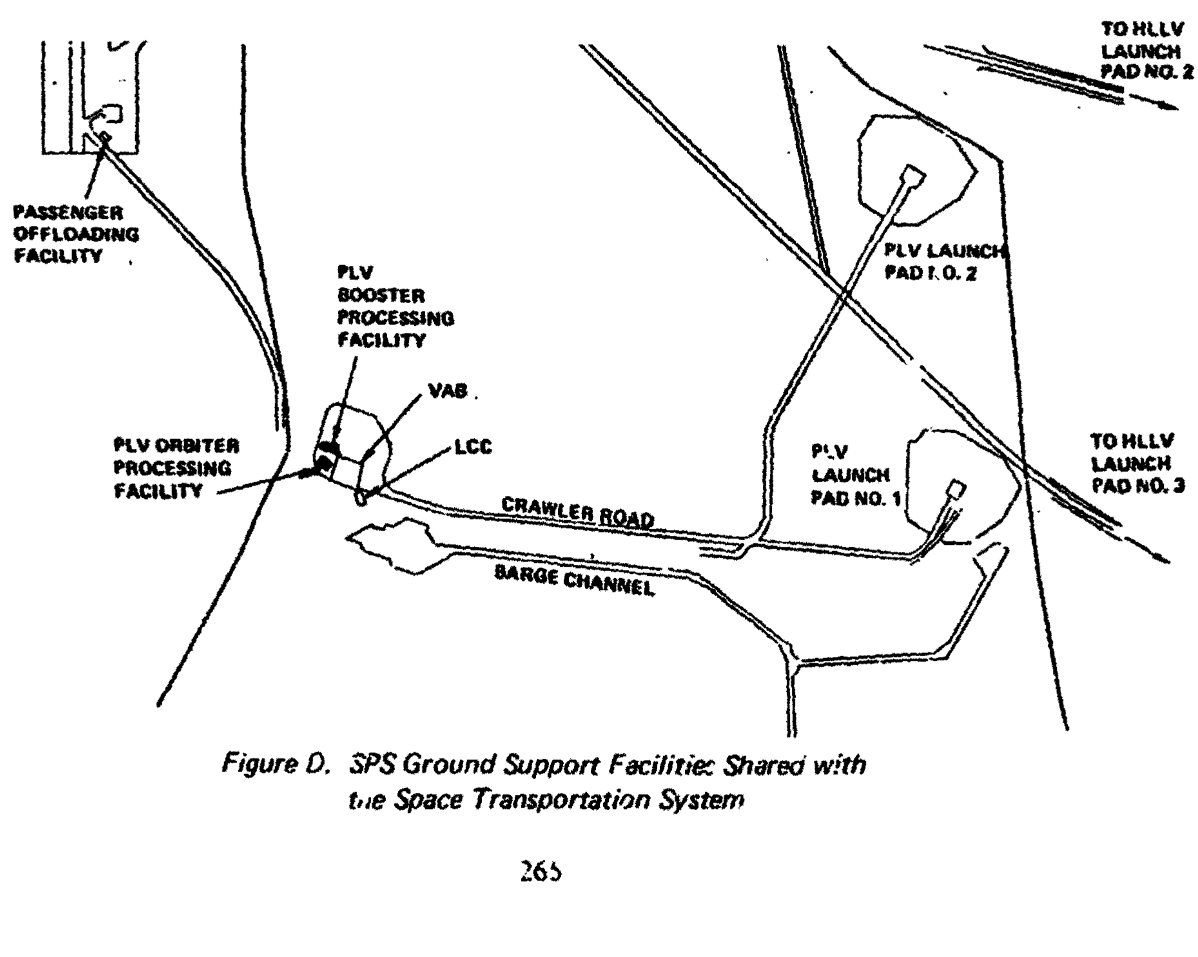


Figure D. SPS Ground Support Facilities Shared with the Space Transportation System

TABLE B
WBS 1.3.7. GROUND SUPPORT FACILITIES COST SUMMARY

WBS	FACILITIES	COST	
1.3.7.1	Launch Facilities		($3,222 M)
1.3.7.1.1	HLLV Launch Facilities	3,222 M	
1.3.7.1.2	PLV Launch Facilities	-	
1.3.7.2	Recovery Facilities		($1769.83+TBD)
1.3.7.2.1	Landing Site	20.53 M	
1.3.7.2.2	HLLV Orbiter and Payload Processing Facility	1114. M	
1.3.7.2.3	HLLV Booster Processing Facility	445.5 M	
1.3.7.2.4	Engine Maintenance Facility	120.8 M	
1.3.7.2.5	Hypergolic Maintenance Facility	65.0 M	
1.3.7.2.6	Passenger Offloading Facility	4.0 M	
1.3.7.2.7	PLV Booster Processing Facility	TBD	
1.3.7.2.8	PLV Orbiter Processing Facility	TBD	
1.3.7.2.9	Vertical Assembly Building	TBD	
1.3.7.2.10	Mobile Launcher Platform	TBD	
1.3.7.3	Fuel Facilities	TBD	(TBD)
1.3.7.4	Logistic Support	40.1 M	(40.1 M)
1.3.7.5	Operations	78.3 M	(78.3 M)
		TOTAL	$ 5.11B+TBD
	Crew Salaries (5,174,832 + 4,548,290) ($40/Man hr)	TOTAL	$ .39B

1.0 WBS DICTIONARY

This element includes the design and construction of the actual launch facility and its associated equipment.

2.0 ELEMENT DESCRIPTION

This element includes both the HLLV and the PLV launch facilities and systems. Each of these are discussed in following sections.

1.C WBS Dictionary

This element includes the HLLV launcher/erector and its associated subsystems.

2.0 ELEMENT DESCRIPTION

The reference HLLV launcher/erector concept is illustrated in Figure 17. Three HLLV launch facilities are required.

4.0 MASS

Not applicable.

5.0 COST

Refer to Table A.

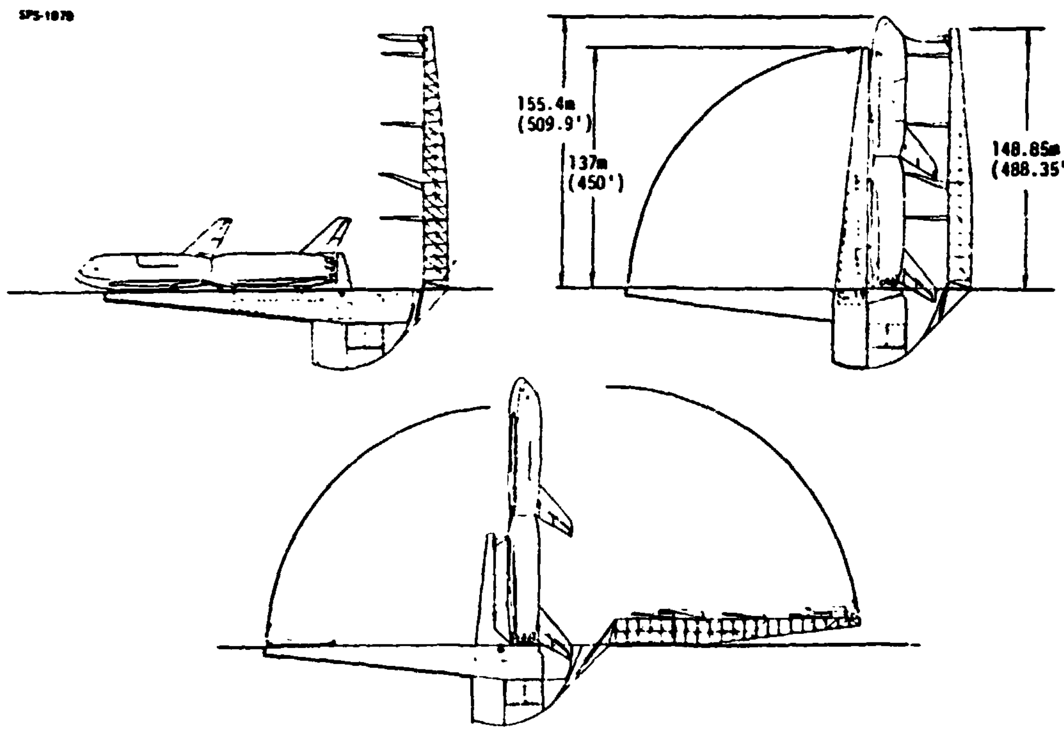


Figure 17. Launcher/Erector Concept

TABLE A
WBS 1.3.7.1.1 HLLV LAUNCH FACILITIES

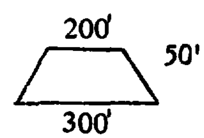
Item No.	Facilities/Equipment	Qty	Unit Cost	Total Cost
1	Causeways & Taxiway			$ 1,727M
2	Breakwater			$ 673M
3	Launch Pad	3	$ 112M	$ 336M
4	Equipment/Utilities/Etc.	3	$ 162M	$ 486M
				($ 3,222M)

Ground Rules, Assumptions, and Rationale

1.0 Causeways and Taxiways - The length of the taxiways and causeways were scaled from Figure 14.

Pad		Taxiway Length	Causeway Length
1		10,000 ft	14,000 ft
2		15,000 ft	11,000 ft
3		21,000 ft	12,000 ft
	Total	46,000 ft	37,000 ft

Causeway X-Section



Area = $12{,}500 ft^2$

Volume = $(37{,}000\ ft)(12{,}500 ft^2) = 462.5 \times 10^6 ft^3$

For the jetties we used the costs from "STS Ground Support System Study Extension" report for the Ocean Beach site (Table 8-1). For 4,950', cost estimate was $\$2.6 \times 10^6$ or \$530/L.F. in 1971 dollars. Adjusting for 1977 dollars, the unit cost estimate per linear foot is 530 x 1.48 = \$785/L.F.

We obtained a rough estimate for a rubble-mound breakwater in place of $\$100/yd^3$ from local operation.

TABLE A (Con't)

Groundrules, Assumptions, and Rationale - Con't

Causeways cost = $(\$100/yd^3)\left(\frac{462.5 \times 10^6 ft3}{27 ft^3/yd^3}\right)$ = \$1.7B

Paving of Causeways and Taxiways

46,000 ft + 37,000 ft 83,000 lineal ft

x 200 ft wide

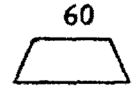
$16.6 \times 10^6\ ft^2$ of paving

@ \$1.64/ft^2

\$27,224,00

Total cost of causeways + paving = \$1.727 B Item 1

2.0 Breakwater - The length of the breakwater scaled from Figure 14 is 33,000 ft.

Breakwater X-Section 60  50 100 $A = 5{,}500\ ft^2$

Volume = 33,000 x 5,000 = 181,500,000 ft^3

$= 6.72 \times 10^6\ yd^3$

Cost = $(6.72 \times 10^6\ yd^3)(\$100/yd^3) = \$673 \times 10^6$ Item 2

TABLE A - Con't

Groundrules, Assumptions, and Rationale - Con't

3.0 Launch Pad - Each pad has an estimated area of 602,800 ft^2 and is 50 ft deep.

Volume = 1.12 x 10^6 yd^3

Cost @ $100/y	$112,000,000	Item 3
	X 3 pads	
	$336,000,000 for pads	

4.0 Equipment/Utilities/Etc.

Service area, utilities, propellant installations, instrumentation, fixed boom cranes,	est.	$50 M	
Vehicle erector		$112M	
		$162M each pad	Item 4

1.0 WBS DICTIONARY

This element includes the PLV launch pad and its associated subsystems. The Mobile Launcher Platform is not included.

2.0 ELEMENT DESCRIPTION

The referencer PLV launch pads are considered to be those that would be built for a Shuttle-growth vehicle. The KSC pads 39A and 39B are the candidate locations for these facilities. The Shuttle-growth launch pad configuration has not been defined.

The major PLV-specific provision that will have to be included at these launch pads will be a means for boarding the 75 passengers into the Passenger Module that will be located within the Shuttle cargo bay.

3.0 ELEMENT COST

For now, it will be assumed that the cost of the PLV launch features will be absorbed by the Shuttle-growth vehicle program.

WBS 1.3.7.2 RECOVERY FACILITIES

1.0 WBS DICTIONARY

This element includes the design and construction of the recovery facilities.

2.0 ELEMENT DESCRIPTION

There are eleven sub-elements that have been identified:

WBS 1.3.7.2.1	Landing Site
WBS 1.3.7.2.2	HLLV Orbiter and Payload Processing Facility
WBS 1.3.7.2.3	HLLV Booster Processing Facility
WBS 1.3.7.2.4	Engine Maintenance Facility
WBS 1.3.7.2.5	Hypergolic Maintenance Facility
WBS 1.3.7.2.6	Passenger Offloading Facility
WBS 1.3.7.2.7	PLV Booster Processing Facility
WBS 1.3.7.2.8	PLV Orbiter Processing Facility
WBS 1.3.7.2.9	External Tank Processing Facility
WBS 1.3.7.2.10	Vertical Assembly Building
WBS 1.3.7.2.11	Mobile Launcher Platform

These sub-elements are described in following description sheets.

1.0 WBS DICTIONARY

This element includes the design and construction of the landing strip, the control tower and other landing site facilities.

2.0 ELEMENT DESCRIPTION

The landing strip provided for the STS will have to be widened from 300 feet to 600 feet to adapt to the HLLV booster and orbiter landing and taxi requirements.

The control tower, navigational aides, fire/rescue facilities, and ground support equipment required for the STS will be used for the HLLV vehicle landing support operations.

5.0 ELEMENT COST

The only cost to be considered here is the cost of widening the runway to 600 feet. The original landing field cost $17,700,000 (1974). Applying a 1.16 cost escalation, the additional runway modifications will cost $20.53M.

WBS 1.3.7.2.2 HLLV ORBITER AND PAYLOAD PROCESSING FACILITY

1.0 WBS DICTIONARY

This element includes the design and construction of the HLLV orbiter and payload processing facilities.

2.0 ELEMENT DESCRIPTION

The HLLV Orbiter and Payload Processing Facility is shown in Figure A.

5.0 COST

The element cost and rationale is given in Table A.

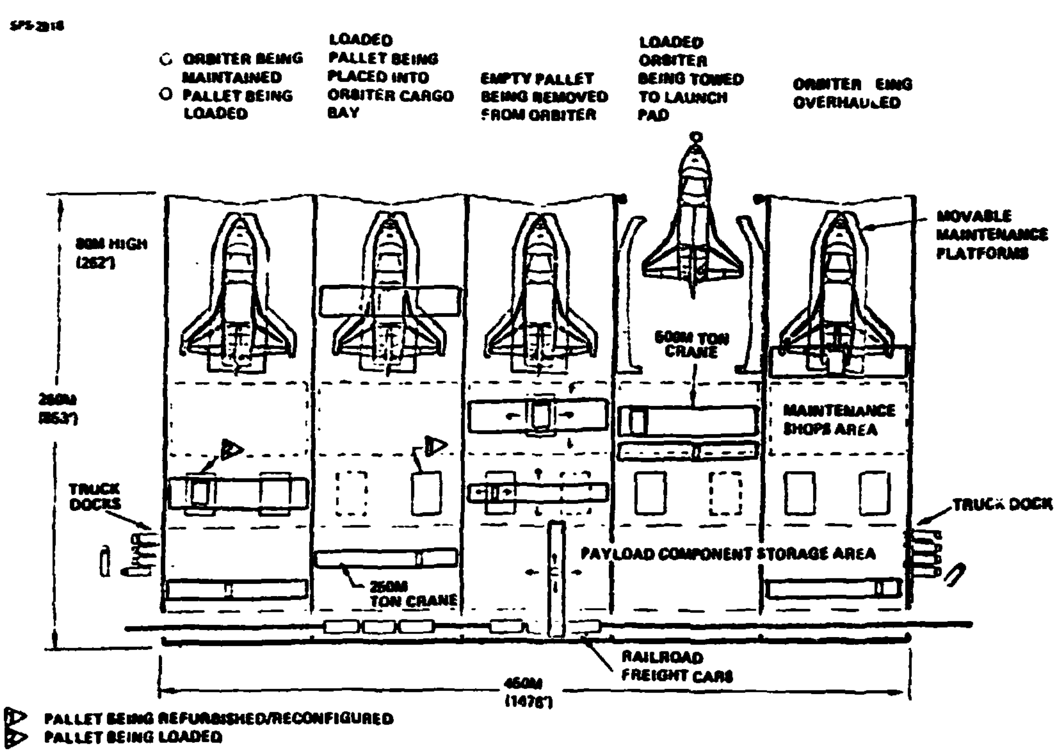


Figure 4. HLLV Orbiter and Payload Processing Facility

TABLE A

WBS 1.3.7.2.2 HLLV ORBITER AND PAYLOAD PROCESSING FACILITIES AND EQUIPMENT COST ESTIMATES

Item No.	Facilities/Equipment	Qty.	Unit Cost	Total Cost
1	Facility			$989,298,000
2	500 Ton Crane	5	$ 15M	$75,000,000
3	250 Ton Crane	6	$ 5M	$30,000,000
4	Communication/Instrumentation Interface Equipment			19,886,000
				($ 1.114B)

Ground Rules, Assumptions, and Rationale:

1. Dimensions of HOPPF scaled from Figure 20. Low Bay 853' x 1476' (use 850' x 1500' for computations).
2. Base cost estimates on existing KSC LC-39 facilities.
3. Maint. test stations located within maint/admin area.
4. Maint. Planning & Control function included in admin. spaces.
5. Cranes to be priced separately.
6. Communications & Instr. Interface Equip. = LPS Remote Station

Continued on following page.

TABLE A (Cont'd)

Ground Rules, Assumptions, and Rationale (Cont'd)

HLLV Orbiter and Payload Processing Facility Requirements		Area (Ft^2)	Height (Ft)	Strength (Tons)
Low Bay	850' x 1500'	342,000	260	500

Rationale Approach

1. Use original cost of LC-39 VAB (Ref NHB 8840.5A-II)
2. Prorate costs high/low bays according to volume.
3. Determine cost/ft^2 for high and low bays.
4. Estimate factor for height/strength req'ts.

KSC Dimensions and Volume Ratio Determination

	Area (Ft^2)	Volume (Ft^3)	Volume Ratio %	ht
Low Bay	117,600	12,282,000	10	105'

High/Low Bay Cost Determination

LC-39 VAB Cost (1966)		- $144,042,000	
Less cost of cranes	1-175T	- 592,000	
	2-250T	- 1,526,742	($763,371 ea)
		$141,923,258	(1966)

Continued on following page

TABLE A (Cont'd)

Ground Rules, Assumptions, and Rationale (Cont'd)

<u>LC-39 VAB</u>

Low Bay Cost/ft^2 = $\frac{141,923,258 \times .1}{117,600}$ = \$120.68/ft^2

<u>Height/Strength Factor Determination</u>

Comparative Data	LC-39 VAB	HOPPF
Low Bay	210'/175T	260'/500T

Estimated H/S Factor	Height	Strength	Overall
Low Bay	1.2	2.85	3.42

Escalation Factor 1966 to 1977 = 1.88

Estimated Cost/ft^2 = original cost x H/S factor x escalation

Low Bay = \$120.68 x 3.42 x 1.88 = \$775.92/ft^2 x 1,275,000 ft^2 = \$989,298,000 Item No. 1

<u>Cranes</u>. A comparison was made first with the existing LC-39 250 Ton cranes in an attempt to establish a baseline to scale up with.

LC-39 High Bay Crane 250 Ton, 150' span, 462' lift.
Cost \$753,000 (1966) escalation factor = 1.88
Current Cost \$753,000 x 1.88 = \$1,415,640 each.

500 Ton Crane, 300' span, 200' lift.
250 Ton Crane, 300' span, 200' lift.

Continued on following page

TABLE A Cont'd)

Ground Rules, Assumptions, and Rationale (Cont'd)

Since the span increase was so great for both cranes, we contacted Harnishseger Corp., Milwaukee, Wisc. (414) 671-4400. Mr. Jim Mock for an estimate. He stated that to his knowledge, a 500 Ton crane of that size has never been built. His estimates were:

500 T - Crane	$15,000,000	Item No. 2
250T - Crane	$ 5,000,000	Item No. 3

<u>Communications & Instrumentation Interface Equip.</u>

Assume: 67 consoles in maint. test stations

Estimated console cost $250,000

$250,000 x 67 = $16,750,000

Assume: OIS cost 20% total

Use cost LC-39 OIS cost as baseline
($8,000,000 - 1965)
(Escalation factor = 1.96)

8,000,000 x 1.96 x .20 = <u>$3,136,000</u>

Estimated Com/Inst. Interface Equip. Cost = 16,750,000 + 3,136,000 = $19,886,000 Item No. 4

WBS 1.3.7.2.3 HLLV BOOSTER PROCESSING FACILITY

1.0 WBS DICTIONARY

This element includes the design and construction of the HLLV Booster Processing Facility and its equipment.

2.0 ELEMENT DESCRIPTION

The HLLV Booster Processing Facility is shown in Figure A.

5.0 ELEMENT COST

The estimated cost for this facility is summarized in Table A.

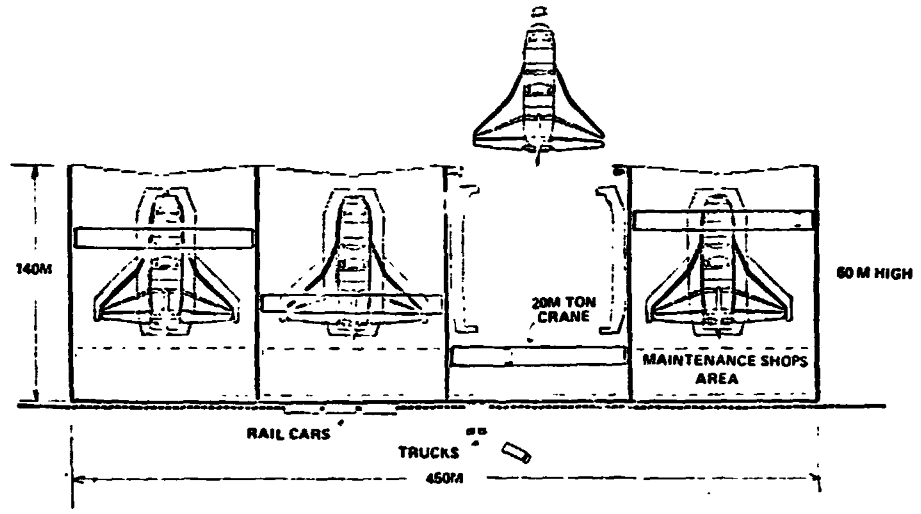


Figure A— HLLV Booster Processing Facility

TABLE A
WBS 1.3.7.2.3 HLLV BOOSTER PROCESSING FACILITY AND EQUIPMENT COST ESTIMATES

Item No.	Facilities/Equipment	Qty.	Unit Cost	Total Cost
1	Facility			$415,628,740
2	20M Ton Crane	4	$2.5M	$ 10,000,000
3	Communications/Instrumentation			$ 19,886,000
				$445,514,000

Ground Rules, Assumptions, and Rationale:

1. Dimensions of HBPF scaled from Figure 24. 460' X 1476' X 196' High (use 460x1475=678,500 ft^2)
2. Base cost estimates on existing KSC LC-39 facilities.
3. Maint. test stations located within maint/admin area.
4. Maint. Planning & Control function included in admin. spaces.

Continued on following page.

TABLE A (Con't)

Ground Rules, Assumptions, and Rationale (Cont'd)

5. Cranes to be priced separately.

6. Communications & Instr. Interface Equip. = LPS Remote Station.

HLLV Orbiter Processing Facility Requirements		Area (Ft^2)	Height (Ft)	Strength (Tons)
Low Bay	460 x 1475	678,500	200	500

Rationale Approach

1. Use original cost of LC-39 VAB (Ref NHB 8840.5A-II)

2. Prorate costs high/low bays according to volume.

3. Determine cost/ft^2 for high and low bays.

4. Estimate factor for height/strength req'ts.

Continued on following page.

TABLE A (Con't)

Ground Rules, Assumptions, and Rationale (Cont'd)

KSC Dimensions and Volume Ratio Determination

	Area (Ft^2)	Volume (Ft^3)	Volume Ratio %	Ht
Low Bay	117,600	12,282,000	10	105'

High/Low Bay Cost Determination

LC-39 VAB Cost (1966) - $144,042,000

Less cost of cranes	1-175T	- 592,000	
	2-250T	- 1,526,742	($763,371 ea)
		$141,923,258	(1966)

LC-39 VAB

Low Bay Cost/ft^2 = $\frac{141,923,258 \times .1}{117,600}$ = \$120.68/ft^2

Height/Strength Factor Determination

Comparative Data	LC-39 VAB	HLLV VAB
Low Bay	210'/175T	200'/500T

Continued on following page.

TABLE A (Cont'd)

Ground Rules, Assumptions, and Rationale (Cont'd)

Estimated H/S Factor	Height	Strength	Overall
Low Bay	.95	2.85	2.7

Escalation Factor 1966 to 1977 = 1.88

Estimated Cost/ft^2 = original cost x H/S factor x escalation

Low Bay = \$120.68 x 2.7 x 1.88 = \$612.57/ft^2 x 678,500 ft^2 = \$415,628,740 Item No. 1

Cranes. A comparison was made first with the existing LC-39 250 Ton cranes in an attempt to establish a baseline to scale upwards.

LC-39 High Bay Crane 250 Ton, 150' span, 462' lift.
Cost \$753,000 (1966) escalation factor = 1.88
Current Cost \$753,000 x 1.88 = \$1,415,640 each.

20 Ton Crane, 360' span, 150' lift. Est. \$2,500,000 each Item No. 2

Continued on following page.

TABLE A (Cont'd)

Ground Rules, Assumptions, and Rationale (Cont'd)

<u>Communications & Instrumentation Interface Equip.</u>

Assume: 67 consoles in maint. test stations

Estimated console cost $250,000

$250,000 x 67 = $16,750,000

Assume: OIS cost 20% total

Use cost LC-39 OIS cost as baseline

($8,000,000 - 1965)

(Escalation factor = 1.96)

8,000,000 x 1.96 x .20 = <u>$3,136,000</u>

Estimated Com/Inst. Interface Equip. Cost = 16,750,000 + 3,146,000 = $19,886,000 Item No. 3

1.0 WBS DICTIONARY

This element includes the design and construction of the engine maintenance facility and its equipment.

2.0 ELEMENT DESCRIPTION

The HLLV booster and orbiter main engines will be overhauled in this facility. There will be separate work areas for each engine type.

This facility has not been sized.

5.0 ELEMENT COST

The estimated cost of this facility is shown in Table A.

TABLE A
WBS 1.3.7.2.4 ENGINE MAINTENANCE FACILITIES AND EQUIPMENT COST ESTIMATES

Item No.	Facilities/Equipment	Qty. Cost	Unit Cost	Total
1	Facilities			$ 20.0M
2	Ground Support Equipment			$100.8M
2A	Orbiter Engines			$ 47.1M
2B	Booster Engines			$ 53.7M
				$120.8M

Ground Rules, Assumptions, and Rationale:

1. Facility Cost - The size of this facility has not been determined. An arbitrary cost of $20M was assigned.

2. HLLV Orbiter Engines GSE - For the reference HLLV orbiter, it was assumed that the engines are similar to the Space Shuttle Main Engine (SSME) and that fourteen engines are required. Therefore, the estimate of the cost of the Ground Support Equipment (GSE) for the HLLV orbiter engines was based on cost data for the SSME GSE required at KSC, which was obtained from SP-FGS-A personnel. The quantities of GSE for the HLLV were estimated on the basis of (1) the quantities required at KSC for Shuttle, (2) three SSME for Shuttle versus fourteen engines on HLLV second stage and (3) 40 launches per year for Shuttle versus 400 launches per year for HLLV. Finally, the total estimated cost of listed GSE was factored by 1.5 to account for probable omitted items. The calculations for the HLLV second stage engines are as follows:

Item of GSE: Shuttle ID No.	Item of GSE: Nomenclature	Shuttle Quantity	Cost/Unit	HLLV Quantity	HLLV Estimated Cost
H70-0901	Engine Handler	3	$ 175K	30	$ 5.25M
H70-0902	Sling	1	40K	10	0.40M
H70-0903	Sling	1	50K	10	0.50M

Continued on following page.

TABLE A (Cont'd)

Ground Rules, Assumptions, and Rationale: (Cont'd)

Item of GSE: Shuttle ID No.	Nomenclature	Shuttle Quantity	Cost/Unit	HLLV Quantity	HLLV Estimated Cost
H70-0904	Sling	1	30K	10	0.30M
H70-0905	Sling Set	1	225K	10	2.25M
H70-0906	Load Fixture	1	185K	10	1.85M
H70-0907	Engine Stand	1	40K	10	0.40M
H70-0528	Engine LRV Removal	1	400K	10	4.00M
H70-0568	Engine Installer	1	500K	10	5.00M
H70-0629	Actuator Support Set	1	15K	10	0.15M
S70-0902	Engine Covers	4	10K	40	0.40M
S70-0903	Internal Protective Pads	7	1K	70	0.07M
S70-0904	Special Tool Set	1	100K	10	1.00M
S70-0905	Special Tool Set	3	62K	30	1.86M
A70-0501	Actuator Locks	1	70K	10	0.70M
A70-0645	Alignment Fixture	1	40K	10	0.40M
C70-0901	Test Set	1	30K	10	0.30M
C70-0902	Test Set	6	40K	60	2.40M
C70-0903	Flow Tester	7	5K	70	0.35M
C70-0904	Flow Tester	4	5K	40	0.20M
C70-0906	Command & Data Simulator	1	225K	10	2.25M
C70-0907	Internal Inspection Equipment	2	40K	20	0.80M
C70-0908	DCU Memory Loader	1	60K	10	0.60M

Total Estimated Cost	$ 31.43M
Times 1.5 factor	1.5
Total Adjusted Estimated Cost	$ 47.145M
	Item 2A

3. HLLV BOOSTER ENGINE GSE - For the reference HLLV Booster, it was assumed that the HLLV first stage engines are similar to the F-1 engine and that sixteen engines are required on the HLLV first stage. Since the F-1 engine and SSME are not significantly different in size or weight and the SSME is only slightly more complex, it was decided that estimated

Continued on following page.

TABLE A (Cont'd)

Ground Rules, Assumptions, and Rationale: (Cont'd)

costs of the HLLV second stage GSE costs. Therefore, the HLLV first stage GSE costs were estimated by using a factor of 1.14 times the HLLV second stage GSE costs (sixteen engines on first stage versus fourteen engines on second stage) as shown below.

1.14 X $47.145M	=	$53.745	Item 2B

1.0 WBS DICTIONARY

This element includes the design and construction of the facilities used to maintain the hypergolic propulsion system and its equipment.

2.0 ELEMENT DESCRIPTION

This facility has not been configured.

5.0 ELEMENT COST

The estimated cost of this facility is $15M with an additional $50M for equipment.

WBS 1.3.7.2.6 PASSENGER OFFLOADING FACILITY

1.0 WBS DICTIONARY

This element includes the design and construction of the PLV Passenger Offloading Facility and its equipment.

2.0 ELEMENT DESCRIPTION

A facility, such as shown in Figure A, will be required adjacent to the landing field. This facility is used to offload the 75 passengers carried within the passenger module in the PLV Orbiter cargo bay.

5.0 ELEMENT COST

The estimated cost of this facility is \$2M plus an additional \$2M for equipment.

SPS-2850

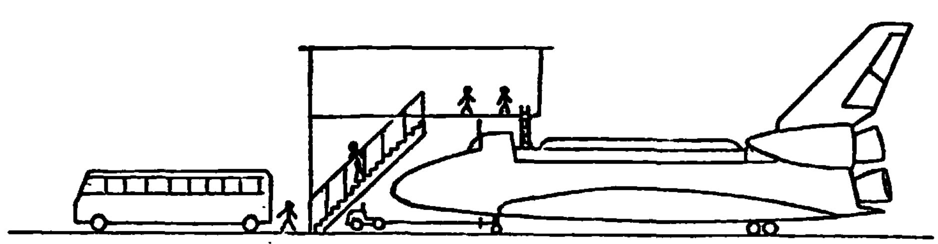


Figure A. Passenger Offloading Facility

1.0 WBS DICTIONARY

This element includes the design and construction of the PLV Booster Processing Facility and its equipment and operations.

2.0 ELEMENT DESCRIPTION

It is assumed that the PLV will be the Shuttle-Growth vehicle. Therefore, the PLV Booster Processing Facility will be the Shuttle-Growth Booster Processing Facility.

The Shuttle-Growth Booster Processing Facility will be sized to accommodate 1) 2 vehicles dedicated to the PLV mission, 2) N vehicles dedicated to other missions, and 3) at least 1 vehicle undergoing major overhaul. It will be assumed that this processing facility will contain 5 bays and will be 340m long, 100m wide, and 50m high. This facility will be equipped with 5 20m ton cranes.

5.0 ELEMENT COST

The cost of the PLV-dedicated portion of this facility and equipment is TBD.

1.0 WBS DICTIONARY

This element includes the design and construction of the space Shuttle Orbiter Processing Facility (OPF) and its equipment that is dedicated to the PLV mission.

2.0 ELEMENT DESCRIPTION

It is assumed that the PLV orbiter will be a Shuttle Orbiter. Therefore, the PLV Orbiter Processing Facility will be the Shuttle Orbiter Processing Facility (OPF).

The OPF will have to be enlarged to accommodate 2 Orbiters dedicated to the PLV mission in addition to those required for other missions.

5.0 ELEMENT COST

The cost of the PLV-dedicated portion of this facility and equipment is TBD.

1.0 WBS DICTIONARY

This element includes the design and construction of the Vertical Assembly Building (VAB) and its equipment dedicated to the PLV mission.

2.0 ELEMENT DESCRIPTION

The PLV will be assembled in the VAB on the Mobile Launcher Platform (WBS 1.3.7.2.10). The Shuttle-growth booster will be towed from its processing facility to the VAB where it will be hoisted to its tail-down orientation and then attached to the MLP. The Orbiter will be towed to the VAB from the OPF and it will be hoisted to its mating position on top of the Booster.

No PLV dedicated modifications to the VAB have been identified.

3.0 ELEMENT COST

The cost of the PLV-dedicated portion of this facility and equipment is TBD.

1.0 WBS DICTIONARY

This element includes the design and construction of the Mobile Launcher Platform (MLP) and its equipment dedicated to the PLV mission.

2.0 ELEMENT DESCRIPTION

It is assumed that the MLP will be modified to accommodate the Shuttle-growth vehicle. No PLV-dedicated changes have been identified.

5.0 ELEMENT COST

The cost of the PLV-dedicated MLP's is TBD.

1.0 WBS DICTIONARY

This element includes fuel production, facilities, storage and handling facilities, transportation, delivery and safety facilities for both the fuel and the oxidizer. Also included are the facilities for fuels used in the various orbital transfer facilities.

2.0 ELEMENT DESCRIPTION

The fuel facilities, storage, handling, transportation, etc., has not been examined in detail. The general concept is identified in the following paragraphs.

Fuel Production Facilities—No on-site fuel production facilities are planned.

Fuel Storage and Handling Facilities—Tank farms and reliquification plants for LO_2, LH_2, and Liquid Argon will be required. A tank farm for LCH_4 will also be required.

Fuel Transportation Systems—The fuel and oxidizers will be delivered to KSC via ship, barge, tank cars, and pipelines.

Fuel Delivery Systems—The various propellants will be delivered to the launch pads via pipelines from the various tank farms. The propellants (Liquid Argon, LO_2, LH_2) to be loaded into the POTV and EOTV Propellant Pallets will be delivered to the HLLV launch pads via pipeline. The propellants will be pumped into the pallets via umbilical fluid lines from the launch servicing tower.

5.0 ELEMENT COST

The cost estimate for these fueling facilities is TBD.

1.0 WBS DICTIONARY

This element includes the land, buildings and handling equipment for the receiving, inspection, storage and packaging of all payloads to be launched except for fuels and oxidizers.

2.0 ELEMENT DESCRIPTION

The SPS and EOTV construction components will be delivered to KSC via truck, rail, and sea. The truck and rail deliveries go directly to the HLLV Orbiter and Payload Processing Facility (WBS 1.3.7.2.2). At this time, no intermediate storage or processing facilities have been identified. Payloads too large for truck or rail delivery (e.g., slipring assembly, antenna subarrays, etc.) will be delivered to KSC via ships or barges. These vessels will be docked at a ship and barge basin to be constructed near the launch pad areas (see Figure C in WBS 1.3.7). Some storage facilities may be located adjacent to the basic. The cargo would be delivered from the ship basin to the HLLV Orbiter and Payload Processing Facility via the railroad system or via surface roads using large wheeled or crawler-type vehicles.

5.0 ELEMENT COST

The cost estimate for these elements is given in Table A.

TABLE A
LOGISTIC SUPPORT FACILITIES AND EQUIPMENT COST ESTIMATES

Item No.	Facilities/Equipment	Qty.	Unit Cost	Total Cost
1	Basin			18.5M
2	500 Ton Crane (Mobile on Rails)			3.0M
3	Off Shore Dredging			15.5M
4	Rails			.8M
5	Facility, Roads, Parking, Lights, etc.			2.3M
			Total	$40.1M

Ground Rules, Assumptions, and Rationale:

1.1 Basin. We have assumed that basin area is at sea level. The basin is located 2,000 feet inland with access by a 700' x 2,000' channel. The channel and basin is dredged to a 45' depth. The perimeter and entrance channel is bulkheaded except where facility foundations provide the bulkheading. For dredging estimates, we have assumed the following basin dimensions:

Main Area	2,000' x 3,000'
Channel	700' x 2,000'

We have assumed a price of $1.00/yd^3 for dredging and $500.00/linear ft. for the interlocking bulkhead. Cost data source is from local dredging operations.

Continued on following page.

TABLE A (cont.)

Ground Rules, Assumptions, and Rationale: (Cont'd)

Dredging

Basin Main Area $= \dfrac{2 \times 10^3 \times 3 \times 10^3 \times 45}{27} = 10 \times 10^6 \text{ yd}^3$

Channel $= \underline{7 \times 10^2 \times 2 \times 10^3 \; 45} = 2.33 \times 10^6 \text{ yd}^3$

Total Basin $12.33 \times 10^6 \text{ yd}^3$

Cost Estimate: \$1.00 x 12.33 x 10^6 = \$12.33M

Bulkheading

Basin: 3,000 + 3,000 + 2,300 = 8,300 L.F.
Port Channel: 2 x 2,000" = 4,000 L.F.
Total 12,300

Cost Estimate: \$500 x 12,300 = \$6.15M

Total: \$18.48M Item 1

1.2 500 Ton Crane (Mobile on Rails)
Cost Data Source: Clyde Iron Co., Newark, De.
Cost: #3M Item 2

Continued on following page

TABLE A (cont.)

Ground Rules, Assumptions, and Rationale: (Cont'd)

1.5 Offshore Dredging

Port Channel $V = \frac{700' \times 2{,}000' \times 45'}{27} = 2.3 \times 10^6 \text{ yd}^3$

Entrance Channel $V = \frac{.5 \times 3 \times 5.28 \times 10^3 \times 10^3 \times 45'}{27} = 13.2 \times 10^6 \text{ yd}^3$

Cost Estimate: $\$1.00 \times 15.5 \times 10^6 = \underline{\$15.5M}$ Item 3

1.6 Rails

Railroad. Figure 15 indicates that a railroad track is provided between the basin and the HLLV facilities. We have estimated 20,000 linear feet of track is required.

Cost Estimate: Unit value $37/L.F. adjusted to 1977 dollars = 37 x 1.08 = $40/L.F.
Cost = 40 x 20,000 = $.8M Item 4

Data Source: Building Construction Cost Data, 34th edition.

1.7 Facility, Roads, Parking, Lights

Roads. We have assumed that 3 miles of 2 lane roads would be required to provide access to the HLLV facilities from the main KSC highway. Price includes base, 1½ BIT. asphalt topping, shoulder, drainage and seed.

Continued on following page

TABLE A (cont.)

Ground Rules, Assumptions, and Rationale: (Cont'd)

Cost Estimate: Unit Value = $\$13.7/yd^2$, adjusted to 1977 dollars 13.7 x 1.08 = $\$14.8/yd^2$

$$\text{Cost} = \frac{3 \times 5280 \times 40 \times 14.8}{9} = \$1.04M$$

Cost data source: "Budget Cost for Construction Systems", dated 4/21/76.

Parking. We have assumed a total parking space requirement for 3,000 cars at all facilities. We used a unit vlaue of $\$14.8/yd^2$ for paving plus $\$1.00/yd^2$ for lighting, barriers, sidewalks, etc.

Cost Estimate: Parking area required at 250 ft^2/car - 3,000 x 250 = 750,000 ft^2

$$\text{Cost} = \frac{750000 \times 15.8}{9} = \$1.3M$$

Totals = $2.3M   Item 5

1.0 WBS DICTIONARY

This element includes all land, buildings and equipment required to support the various crews. It also includes the required control centers and administrative facilities.

2.0 ELEMENT DESCRIPTION

A Launch and Recovery Site Operations Facility (LRSOF) will be required. This facility will house the equipment and personnel required to manage all of the SPS operations at the base.

3.0 ELEMENT COST

The ccst estimate for this facility is given in Table A.

TABLE A
LAUNCH AND RECOVERY SITE OPERATIONS
FACILITIES AND EQUIPMENT COST ESTIMATES

Item No.	Facilities/Equipment	Qty.	Unit Cost	Total Cost
	Building and Facilities			$19.6M
	Three Firing Rooms (Equipped)			
	Launch Processing System (LPS)			45.6M
	Communication Interface Equipment			13.1M
	Administrative Offices		Included in Bldg. & Fac.	
			TOTAL	$78.3M

Ground Rules, Assumptions, and Rationale:

1. The LRSOF building was assumed to be the same size as the existing Apollo/Saturn LCC because (1) three Firing Rooms are specified, (2) a complete LPS system, including the CDS, was assumed to be required, and (3) administrative office space is required. Therefore, the cost of construction of the existing LCC ($10M) was adjusted by the proper escalation factor to project the 1964/65 cost to current cost as shown below:

$10M x 1.96 = $19.6M   Item 1

2. The firing room equipment and Launch Processing System (LPS) were grouped together for costing because (1) most of the firing room equipment is part of LPS (CCMS) and (2) cost figures were available as a total LPS system which were used as a cross-check on the cost computed by individual pieces of equipment. The cost calculation for the LPS is shown below. The quantities of items of LPS equipment in the firing rooms were estimated from the drawings in the HLLV monthly report dated 12/15/76. The cost figures used are today's cost except for the cost of the CDS; the CDS cost is a 1970 cost estimate for an auxiliary base which was adjusted for size and for escalation.

Continued on following page.

TABLE A (cont.)

Ground Rules, Assumptions, and Rationale: (Cont'd)

3. Communication Interface Equipment, which has not already been costed as a part of LPS, was assumed to consist of OIS, OTV, and cable termination facilities. 50% of the OIS and OTV systems were assumed to be in the LCC. 1965 cost figures were available for this equipment and were adjusted by the proper escalation factor as shown below:

	1965 Cost	% in LCC	% of Cost
OIS _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	8.0M	50%	4.0M
OTV _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	5.0M	50%	2.5M
Cable Termination Facility _ _ _	0.2M	100%	0.2M
Total			6.7M

$6.7M x 1.96 = $13.1M   Item 3

4. Sources for the cost data were:

A. Apollo Launch Complex 39 Facilities Handbook, U.S. Army Corps of Engineers, no date (approximately 1968).
B. Cost Study, Two Space Shuttle Launch Sites Versus One, KSC TR-1119, dated September 10, 1971.
C. Space Shuttle Launch Operations Study, KSC TR-1078-1, dated December 1, 1971.
D. Personnel in DL-DED-3 at KSC.

TABLE A (cont.)

Ground Rules, Assumptions, and Rationale: (Cont'd)

Console ________	26 @ $250K	=	$ 6.5M	
CDBFR __________	3 @ 200K	=	.6M	
FEP __________	12 @ 75K	=	.9M	
PDR/SPA ________	1 @ 1.2M	=	1.2M	
Video/Data Assy ____	1 @ 1.3M	=	1.3M	
HIM __________	100 @ 70K	=	7.0M	
In-Place Spares (FEP, CDBFR, PDR/SPA, etc.)				
20% of active equipment (20% x 17.5M)		=	3.5M	
CDS -- (1970 cost of $10.5M)				
Cost times size factor times escalation				
factor ($ 0 5M x 1.5 x 1.56)		=	24.6M	
Total			$45.6M	Item 2

This cost estimate compares favorably with a 1970 cost estimate for the total LPS system, adjusted by the proper escalation factor as shown below:

28.6M x 1.56 = 44.6M

Continued on following page.

1.0 WBS DICTIONARY

This element includes the operations conducted at the launch and recovery site. Included are the HLLV and PLV ground and handling operations. The personnel requirements are also included.

2.0 DESCRIPTION

The Kennedy Space Center (KSC) is the reference location for the SPS System Launch and Recovery Site.

HLLV and PLV boosters and orbiters land at the landing strip. This landing strip is a widened STS orbiter landing strip. The HLLV Boosters and Orbiters and the PLV Boosters are towed from the landing strip directly to their processing facilities. The PLV Orbiter, with a 75-man passenger module in its cargo bay, is towed from the landing area to a Passenger Offloading Facility where the passengers are disembarked. The vehicle is then towed to the PLV Orbiter Processing Facility.

The HLLV Orbiters are taken to the HLLV Orbiter and Payload Processing Facility. In this facility, the Orbiter is maintained and the cargo pallets are loaded in a 70 hour turnaround time. Cargo is delivered to KSC via ship, rail, and truck. This facility has crews working 7 days per week, 3 shifts per day.

The HLLV Boosters are taken to the HLLV Booster Processing Facility where the booster vehicle is maintained. The boosters are turned around in 58 hours. The crews in this facility also work 7 days per week, 3 shifts per day.

The HLLV Boosters and Orbiters are towed to one of 3 HLLV launch pads where the stages are mated horizontally and then erected for launch. The launch pad operations take 34 hours. The launch pad crews work on a 7 day per week, 2 shifts per day schedule. There will be approximately 400 HLLV launches per year.

The PLV Booster (a shuttle-growth fly-back booster) is towed from the landing strip to the PLV Booster Processing Facility. After the booster is maintained, it is taken to the Vertical Assembly Building (VAB) where it is mounted onto a Mobile Launcher Platform (MLP).

After passengers are offloaded, the PLV Orbiter (an STS Orbiter) is towed to the STS Orbiter Processing Facility (OPF).

The PLV Booster, Orbiter, and an expendable upper stage are mated in the VAB on the MLP. The MLP is then moved to Pads 39A or 39B. The 75 passengers are boarded at the launch pad. There will be 56 PLV launches per year.

The command and control of the Launch and Recovery Site are conducted by several groups located in the Launch and Recovery Site Operations Facility.

Table A shows the estimated total annual man-hours required for the SPS ground support operations.

The detailed analysis of the launch and recovery site operations is found in the Operations and Systems Synthesis document(D180-25461-3).

WBS 1.3.7.6 OPERATIONS (Continued)

TABLE A
GROUND SUPPORT FACILITIES TOTAL ANNUAL MAN-HOURS

WBS	FACILITY	TOTAL ANNUAL MAN-HOURS OPERATIONS	TOTAL ANNUAL MAN-HOURS MAINTENANCE
1.3.7	Ground Support Facilities	(5,174,832) [3]	(7,676,714) [4]
1.3.7.1	Launch Facilities		
1.3.7.1.1	HLLV Launch Facilities	476,800	862,500
1.3.7.1.2	PLV Launch Facilities	79,196	133,616
1.3.7.2	Recovery Facilities		
1.3.7.2.1	Landing Site	145,920	218,880
1.3.7.2.2	HLLV Orbiter and Payload Processing Facility	906,400	1,359,600
1.3.7.2.3	HLLV Booster Processing Facility	492,800	739,200
1.3.7.2.4	Engine Maintenance Facility	[1]	[1]
1.3.7.2.5	Hypergolic Maintenance Facility	[1]	[1]
1.3.7.2.6	Passenger Offloading Facility	2,240	3,360
1.3.7.2.7	PLV Booster Processing Facility	67,520	101,280
1.3.7.2.8	PLV Orbiter Processing Facility	75,656	1,134,984
1.3.7.2.9	Vertical Assembly Building	35,840	36,854
1.3.7.2.10	Mobile Launcher Platform	[2]	[2]
1.3.7.3	Fuel Facilities	727,080	823,440
1.3.7.4	Logistic Support	1,314,000	1,971,000
1.3.7.5	Operations	851,280	292,000

[1] Included in 1.3.7.2.2 and 1.3.7.2.3
[2] Included in 1.3.7.1.2
[3] Total Annual Operations Man-Hours = 2,587 Man-Years
[4] Total Annual Maintenance Man-Hours = 3,838 Man-Years

/

FOLDOUT FRAME

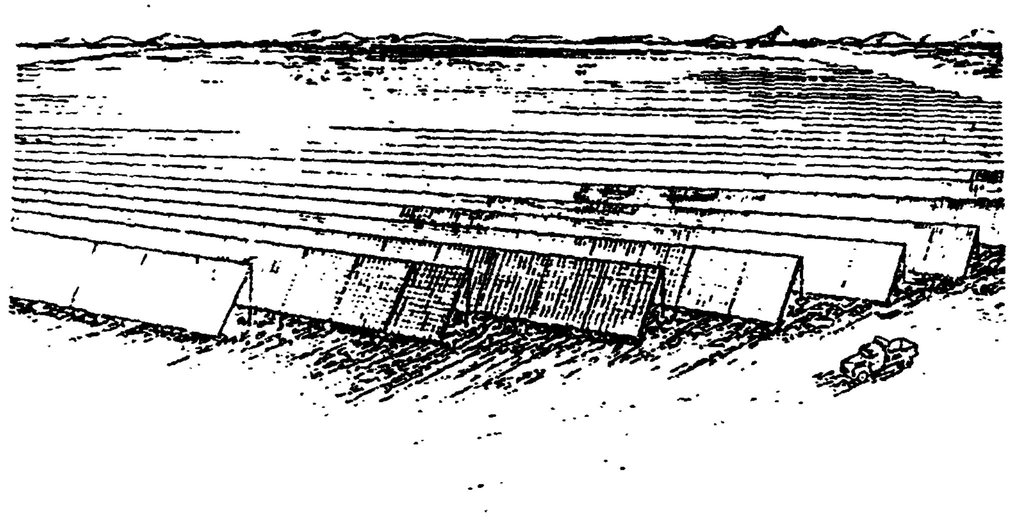


Figure A— Tilted Panel Rectenna Configuration

1.0 WBS DICTIONARY

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

2.0 DESCRIPTION

Each receiving station includes the land area, rectenna (rectifying antenna), grid interface equipment, and control and communications systems. The land sites are 13.1? x 18.7 km (nominal, at 35^{o} latitude) and each rectenna proper is 9.885 x 14 km. The output power of 5000 megawatts is delivered through five 1000-megawatt transformer stations. Several rectenna configuration options were evaluated. The tilted-panel configuration shown in Figure A was retained as preferred concept.

3.0 DESIGN BASIS

The rectenna size was cost-optimized at 75% of the main beam diameter. At this size, the rectenna intercepts 95% of the power in the main beam. A larger rectenna would intercept more power, but the added cost would exceed the value of the power collected, causing the system cost per kwe to increase.

The reference system design is based on the assumption in Table A.

The size of the rectenna land area is latitude-dependent because of the chnage in incoming beam elevation angle. The total area of rectenna panel changes only slightly with latitude—the panels are tilted at a steeper angle and placed farther apart in the north-south direction.

The reference rectenna design was based on 35^{o} latitude. At more northerly latitudes, the design may change due to snow loads. Boeing has developed under IR&D a "greenhouse rectenna" design that is compatible with a snowy environment —the surface of the rectenna is smooth glass and snowpacks will slide off.

Another concern that has been expressed regarding rectennas at higher latitudes is that the incoming power beam will be nearly parallel with the Earth's magnetic field, thus possible exacerbating ionosphere heating. If this turns out to be a consequential concern, it can be mitigated by the simple expedient of a few degrees' longitude offset between the SPS and its rectenna site.

4.0 MASS

Principal materials consumption for one rectenna is estimated as follows, based on the GE construction analysis:

Concrete*	3,715,000 metric tons
Steel	1,689,000 metric tons
Aluminum	170,000 metric tons
Ceramic (probably Al_2O_3)	6,000 metric tons
Plastic	12,000 metric tons
Gallium arsenide (in diodes)	25 metric tons

* Indications are that this is a high estimate.

5.0 COST SUMMARY

Rectenna costs were based on General Electric studies of rectenna construction, power collection, power processing and grid interfacing.

Land was estimated at $2500/acre for acquisition.

A summary follows:

		Cost Million of $
Land	47,800 acres	120
Structures & Installation		346
RF Assemblies & Ground Plane		959
Distribution Busses		308
Command & Control Center		70
Power Processing & Grid Interface		775
		2578

These figures are for one receiving site.

TABLE A. SUMMARY OF ASSUMPTIONS

<u>Space Antenna</u>	
Equivalent diameter:	1000m = 8153.6λ = D
Power distribution:	Gaussian, approximated by 10 constant level rings with -9.5 db edge taper.
Frequency:	2450 MHz
Wavelength:	12.2449 cm
Aperture Gain:	$G_o = \lambda^2 D$ = 88.17 db
Aperture illumination efficiency:	A = 88.25%
Antenna Gain:	$G = \eta_A G_o$ = 87.63 db
3 db beamwidth:	$\frac{72.08}{D} = 8.84 \times 10^{-3}$ deg.
8.8 db beamwidth:	$\frac{119.37^o}{D}$ = .01464 deg.
Number of transmitters:	101552
Transmit power out of antenna module:	67.3 kw
Total transmit power:	P_T = 6.836 Gw
Orbit location:	-100^o long.
Northern tilt of antenna:	5.65 deg.
<u>Ground Antenna</u>	
Location:	-100^o long., 35^o lat. Texas
Elevation angle to spacecraft:	49.4^o
Slant range:	T ≈ 37125 km
Edge taper:	-8.8 db
Receive power density in middle of rectenna:	P_R = 23 mw/cm^2
Nominal N-S dimension:	14 km
Nominal E-W dimension:	9.885 km
Aperture shape:	Nominal elliptical, approximated by N-S and E-W straight lines.
Antenna Panel Area:	76.7 km^2
Beam efficiency between space and rectenna:	95.33%
Beam efficiency sensitivity:	± 1.5%/± 12.11% antenna variation. (Beam efficiency can be increased to approximately 96.77% if antenna area is increased to 95.01 km^2)

1.0 WBS DICTIONARY

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

2.0 DESCRIPTION

The land area requirement was assumed to be equivalent to the SPS power beam footprint on the ground. The size is nominally 13.8 x 18.7 km, elliptical, but varies with latitude. That portion of the land area not used for active rectenna elements may be planted in grass or forest (as is appropriate to the climate) to minimize reflection of the outer fringes of the microwave beam. The beam intensity in this region will be less than 1 mw/cm^2. The entire receiving site will be fenced.

4.0 MASS

Not applicable.

5.0 COST

47,800 acres @ \$2500/acre = \$120,000,000

1.0 WBS DICTIONARY

This element includes all support structure for the active rectenna.

2.0 DESCRIPTION

The structural design selected is illustrated in Figure A, excerpted from the General Electric Rectenna construction study.

3.0 MASS AND COST

Accounted for at higher level - see WBS 1.4.

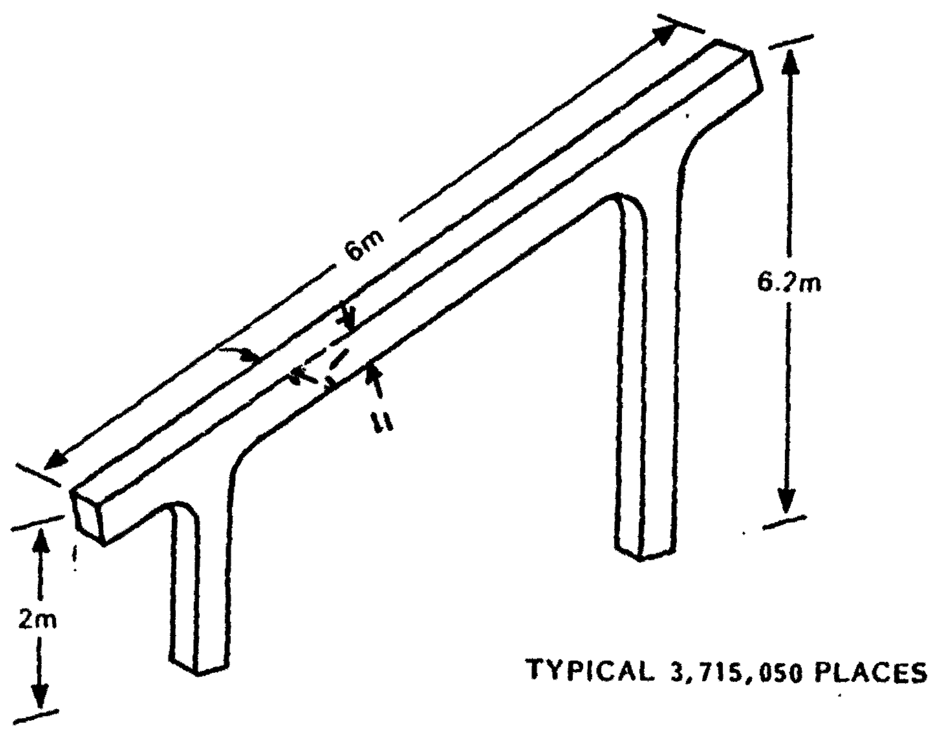


Figure A— Pre–Stressed Concrete in Baseline Structure

1.0 WBS DICTIONARY

This system includes the equipment that converts RF energy to DC electricity and that collects and distributes the DC electricity to the DC/AC convertors.

2.0 DESCRIPTION

This sytem consists of two subelements:

WBS 1.4.3.1 RF-DC Conversion
WBS 1.4.3.2 DC collection and distribution

The system is described at the lower level.

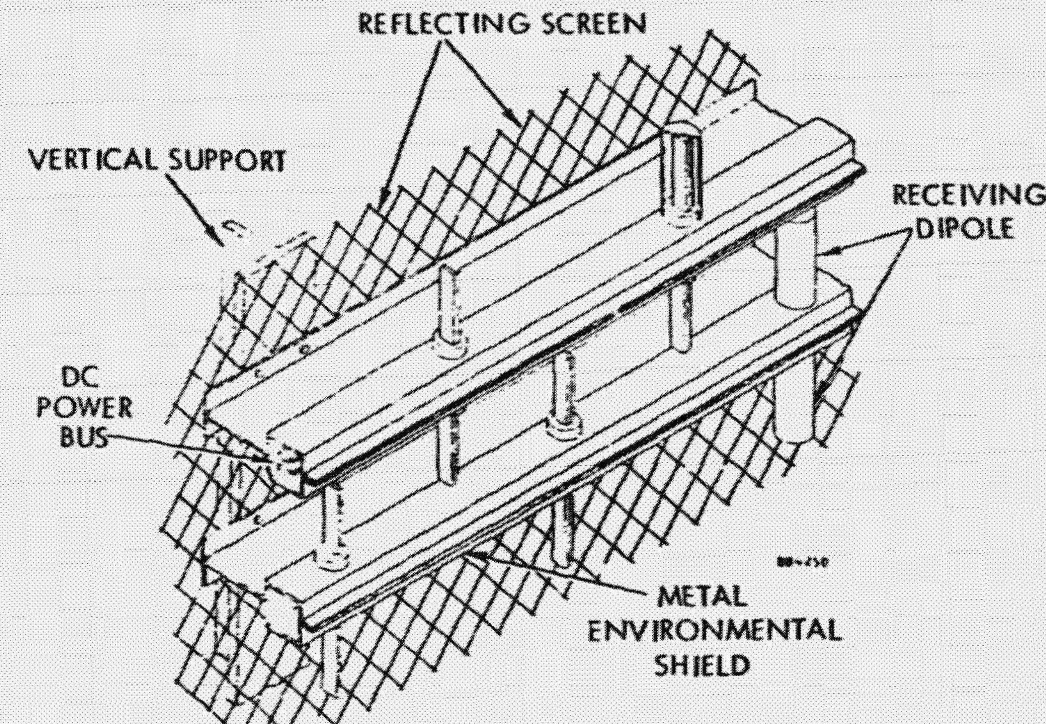


Figure A *Drawing of the two-plane rectenna construction format consisting of a reflecting screen or ground plane and the foreplane which contains dipole antenna, wave filters, diode rectifiers, and bus bars - all protected from the environment by a metal shield.*

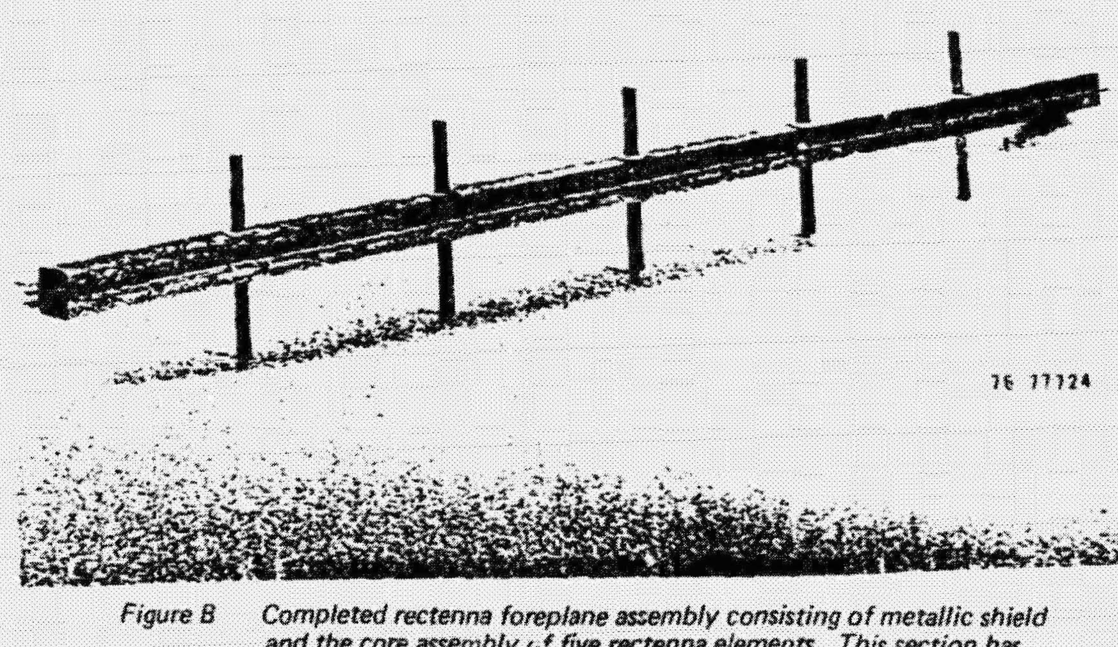


Figure B *Completed rectenna foreplane assembly consisting of metallic shield and the core assembly of five rectenna elements. This section has been substituted for a section of the three level construction in a rectenna and found to perform as well.*

1.0 WBS DICTIONARY

This element includes the hardware elements used to connect microwave energy into DC current.

2.0 DESCRIPTION

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

Ground Planes

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

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

R.F. Assemblies

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

Dipoles

The dipoles are formed of aluminum wire as shown in Figure D. There are approximately 7.654×10^9 dipole assemblies per rectenna.

Circuitry

Refer to Figure C for the electrical circuit of the rectenna panels.

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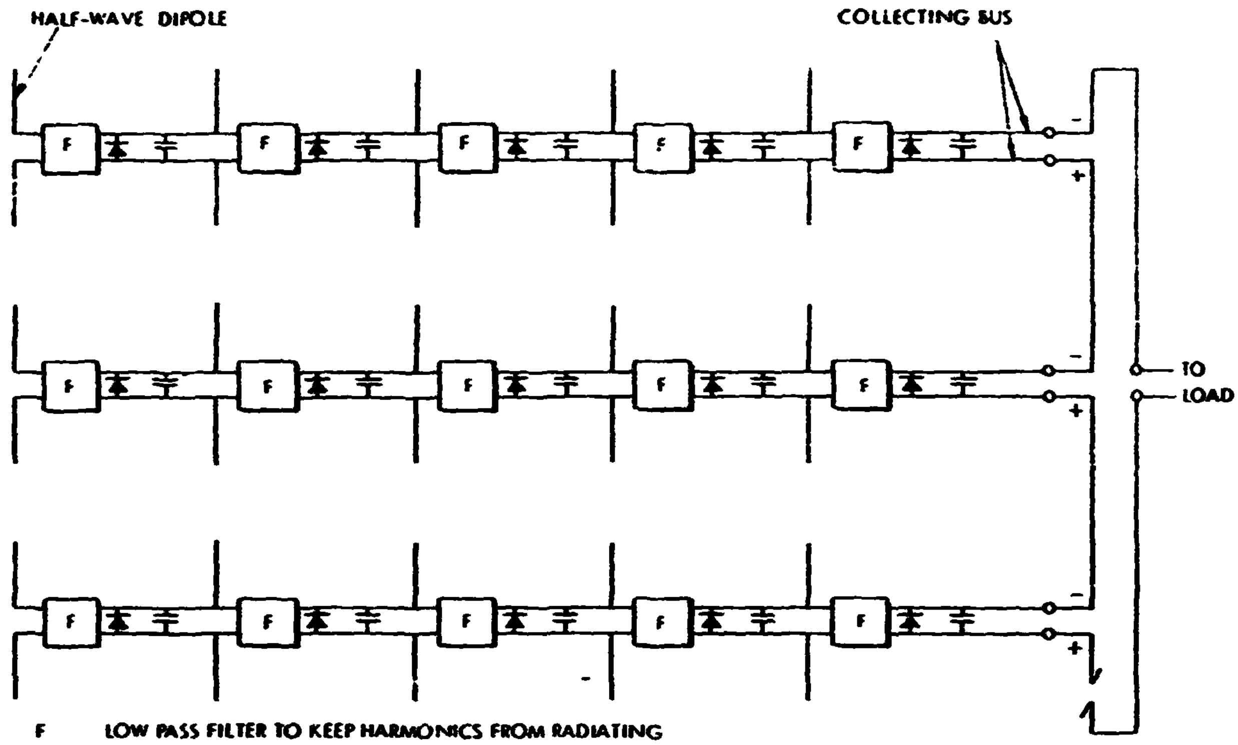

Figure C-1 *Schematic of the foreplane of the two-plane rectenna showing the arrangement of half-wave dipoles, input filters, and Schottkybarrier rectifying diodes. Two-wire transmission lines are used for both microwave circuits and carrying out the DC power collected by the array.*

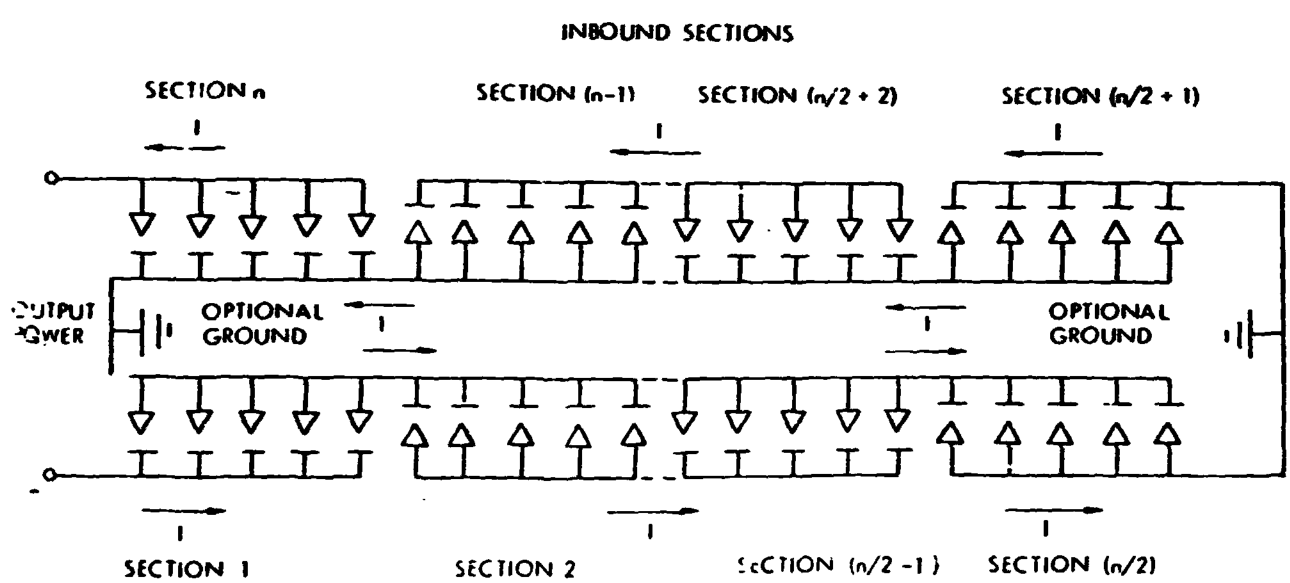

Figure C-2 *Schematic electrical drawing showing how the sections of diodes representing the rectenna elements within a long length of foreplane are connected in parallel and series to build up to the desired output current and voltage levels.*

Shields and Covers

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

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

4.0/5.0 MASS AND COST

Accounted for at higher level - see WBS 1.4.

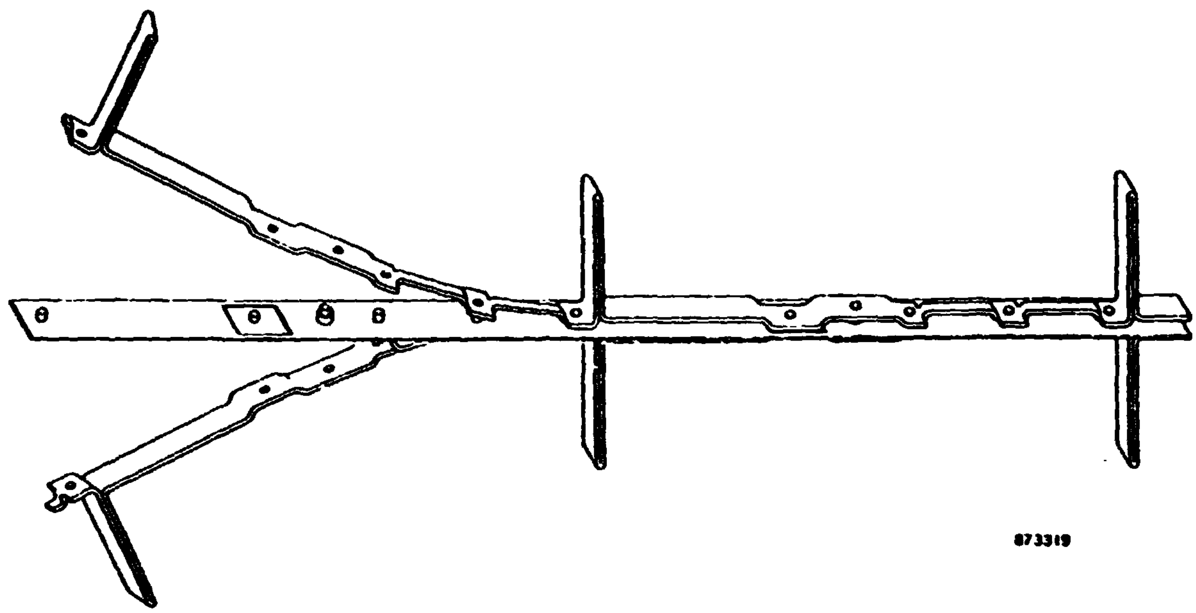

Figure D Proposed method of continuous fabrication of the core assembly of retenna elements. Top and bottom members are continuously formed from two rolls of flat wire to the left of the assembly.

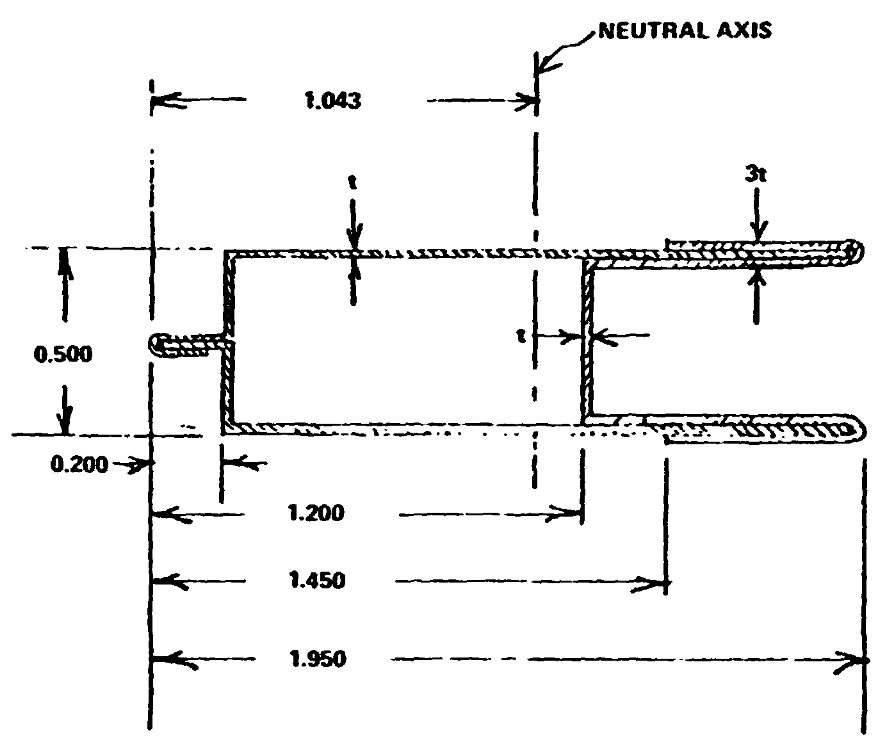

Figure E Proposed design of the shield for the foreplane assembly. Design consists of three parts. The parts are continuously assembled to each other by rolling over flanges left on top and side pieces, after the parts flow around the enclose the core of the foreplane.

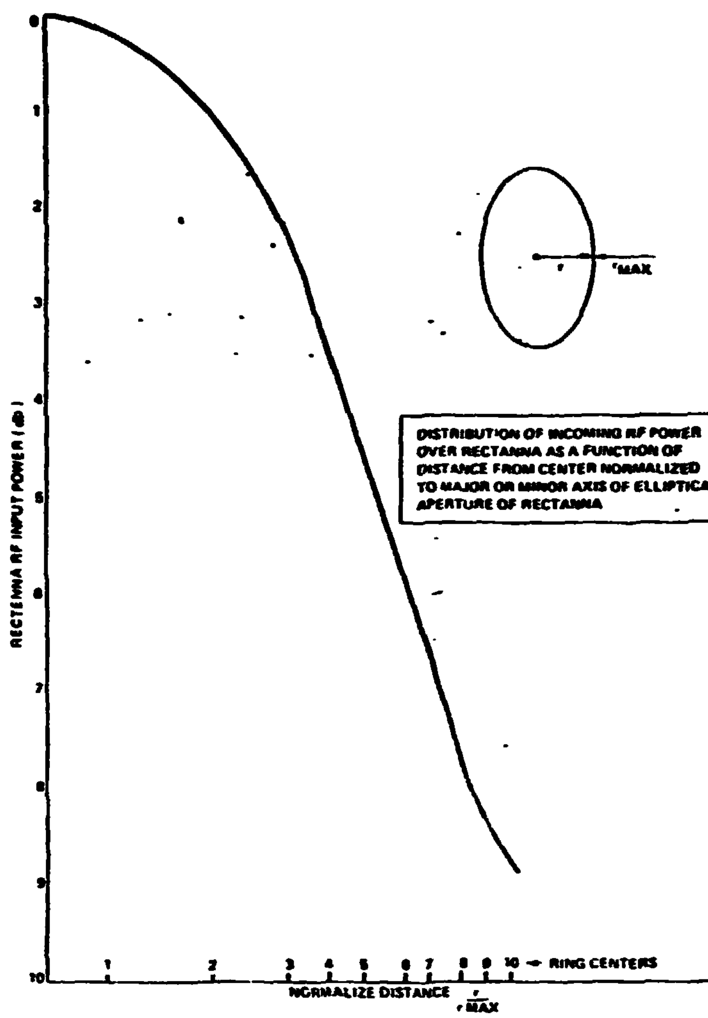

Figure A – Distribution of Incoming RF Power over Rectenna as a Function of Distance from Center Normalized to Major or Minor Axis of Elliptical Aperture of Rectenna

1.0 WBS DICTIONARY

This element includes all conductor and switching equipment necessary to collect the dc power produced by the RF-DC converters and conduct it to the DC/AC converters.

2.0 ELEMENT DESCRIPTION

In order to develop the details of the rectenna power collection network the aperture area is divided into ten approximately elliptically shaped rings as shown in Figure A. The DC power collecting scheme distinguishes the following assemblies:

Dipole
Array
Panel
Unit
Group

These assemblies can be connected in a number of ways. Two particular configurations were analyzed in some detail. In the first, so-called "low voltage" design the network is connected in such a way that the line voltages remain within a nominal ±3.25 kV range.

In the second, so-called "low current" design the network current remain below 300A, but the range of the highest voltage increases to ±23 kV. For safety and reliability reasons the first design was selected as the baseline. However this design results in a rectenna configuration which is 10-20% more expensive than the high voltage design, due to the larger conductor quantities necessary.

Layout and Characteristics of a Low Voltage DC System

Dipole Assembly

It is assumed that the basic receiving element of the rectenna is an electrical dipole in the front of a perfect reflecting element, or ground plane. The dipole assembly also contains a filtering and matching circuit to match the dipole, when it is emplaced in an infinite array of dipoles, to the incoming wave at least with a -20 db reflection coefficient.

Array Assembly

Due to the power density variation over the rectenna aperture a single type of radiating element and a single type of rectifier cannot provide optimum conversion efficiency. Either a number of radiating element types or a number of diode types must be provided. Presently one single type of diode is assumed which is operated with four different types of antenna elements. It is assumed that besides the dipole element already described these antenna elements are formed by using the basic dipoles in arrays containing 2, 4 or 8 dipoles. The corresponding assemblies will be called Type 1, 2, 3 and 4 receiving element or array. The array formation requires 2, 4 and 8 way power combiners, which can be simple printed circuits.

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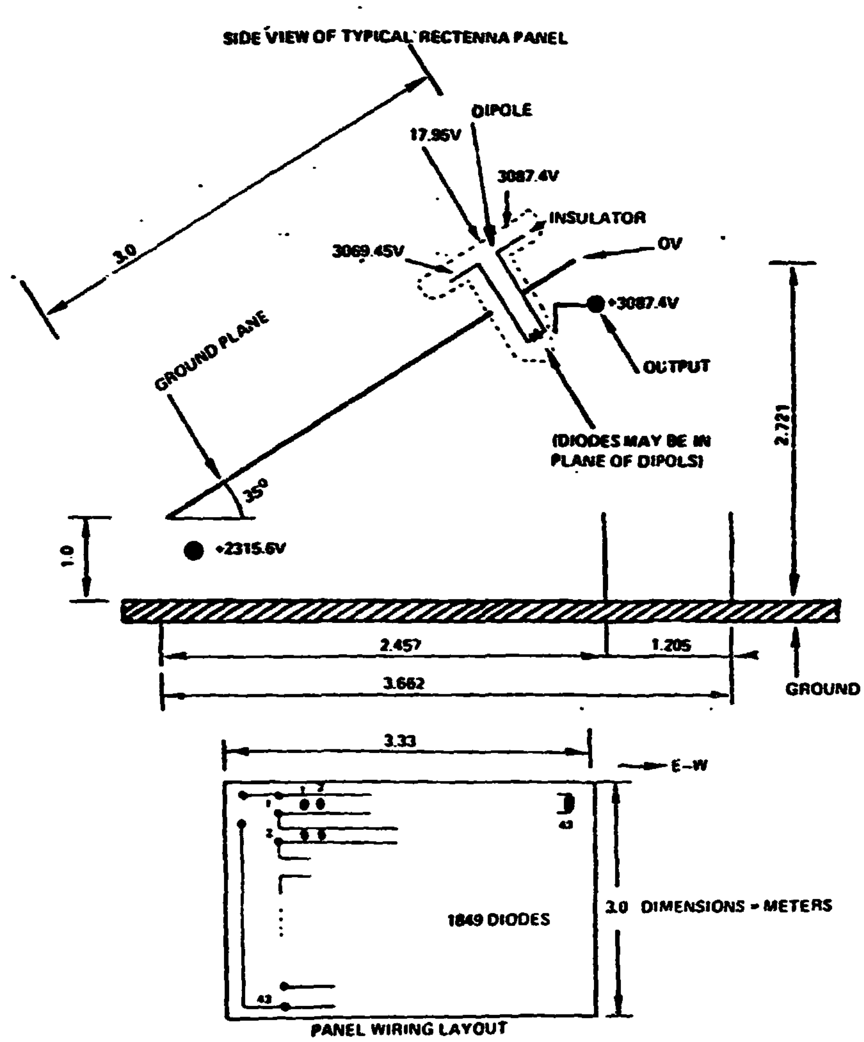

Figure B – Conceptual Layout of Panel in the Middle of Rectenna Containing 1849 Dipoles and Diodes (Dimensions are in m.)

Panel Assembly

From the dipole or array assemblies panels are formed. It is assumed that the panel is the smallest assembly from fabrication point of view. 10 m^2 is selected for the panel area, with a N-S plane dimension of 3 m and E-W plane dimension of 3.33 m. Figure B shows a typical panel assembly in the center of the rectenna. It is assumed that all panel sizes are identical and this requires 7.67 million panels in the rectenna. There are four different type of panels, corresponding to the four different types of receiving arrays. Although the dipoles and diodes are identical for all panels the combining-matching-filtering circuits and the diode wiring represent four types.

Figure C shows the layout of the various types of panels and corresponding arrays.

Unit Assembly

From the panels unit assemblies are formed. The units are combined from panels in such a manner that nominally 1000 panels are in one unit and the N-S dimension of a unit is always 32 x 3.662 = 117.184 m, which means that the number of panel rows in the N-S plane is always 32. This allows a standardization of the unit layouts to a minimum of seven types.

Figure D shows the unit layouts selected for the various rings.

Group Assemblies

The last assembly which is formed at DC is called "group" and brings the power output into the 5 to 10 MW range. In order to keep the voltage levels relatively low the groups are formed from the units by paralleled connections only.

The power from the unit output is brought to the group centers, where the DC to AC inverters are located by a relatively long transmission line and these lines are parallel connected at the group centers only.

Figure E presents the overall circuit diagram of group 1 in ring 1 of the rectenna.

Only one iteration was made for the selection of conductor sizes and the system was not optimized. Relatively small amount of additional conductor weight could take out some losses from the panels (about 4300 T aluminum can reduce panel losses by .48%), however, the increasing conductor size increases the fabrication problems and may rule out the use of printed conductors on the panels.

4.0/5.0 MASS AND COST

These have been summarized at a higher level - see WBS 1.4.

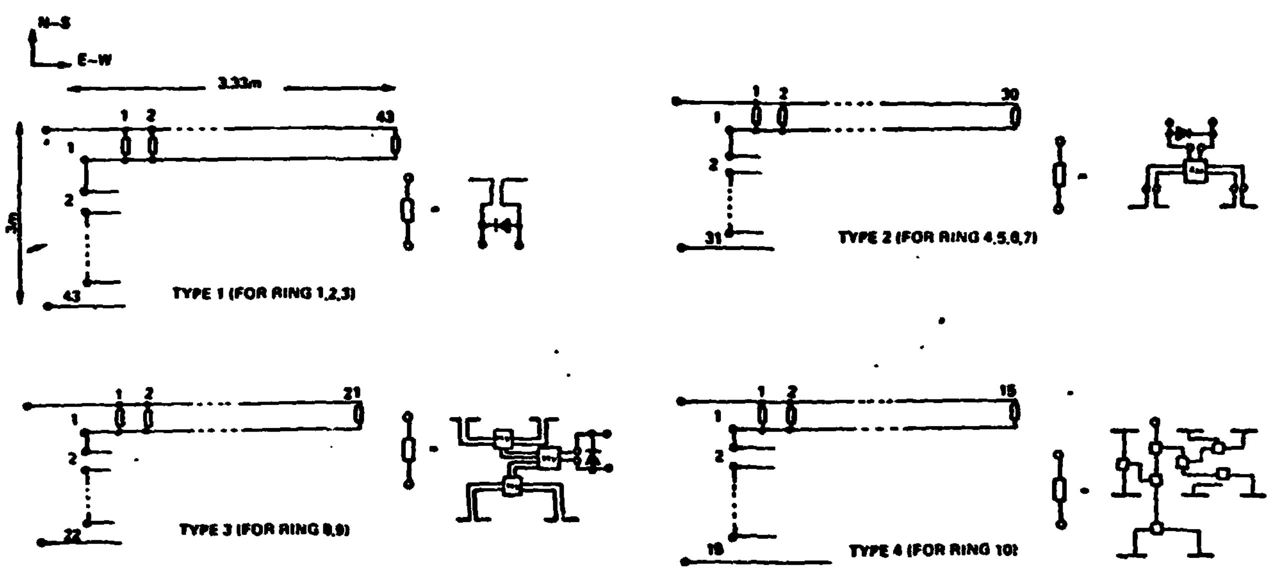

Figure C – Wiring Layout of the Four Different Panel Designs Used in the Rectenna

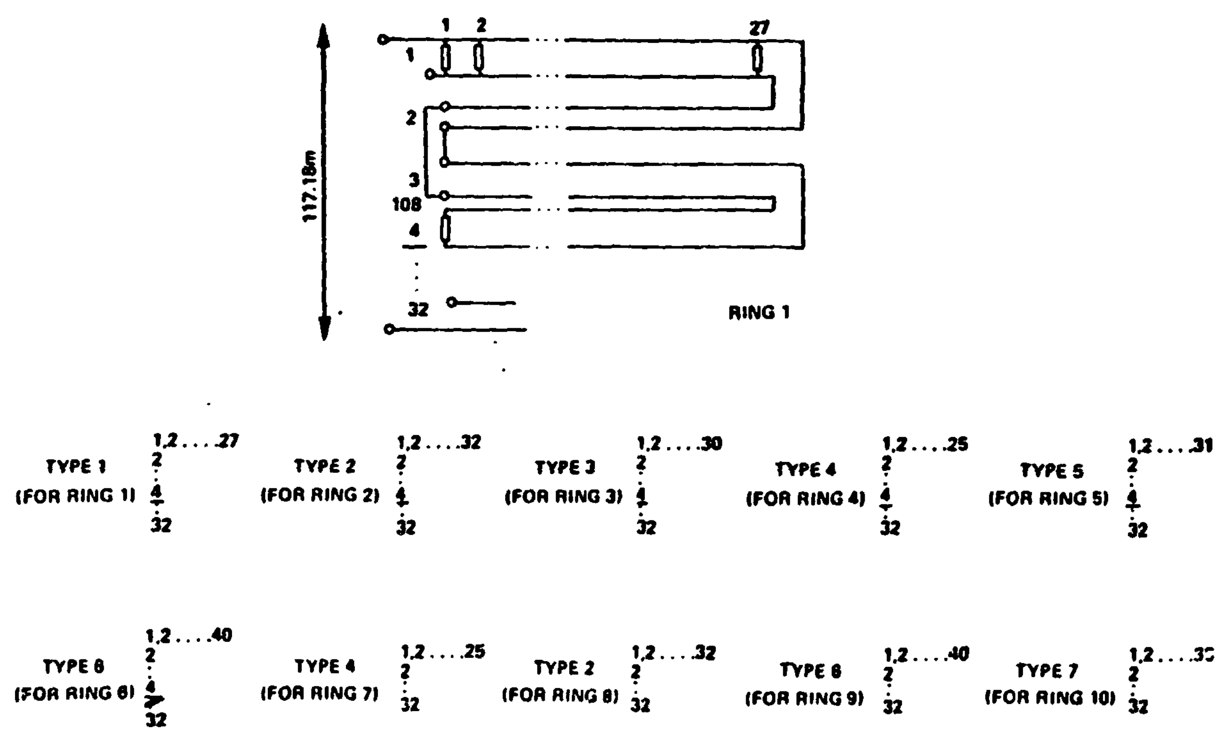

Figure D – Wiring Layout of the Seven Different Unit Designs used in the Rectenna for the Low Voltage Configuration

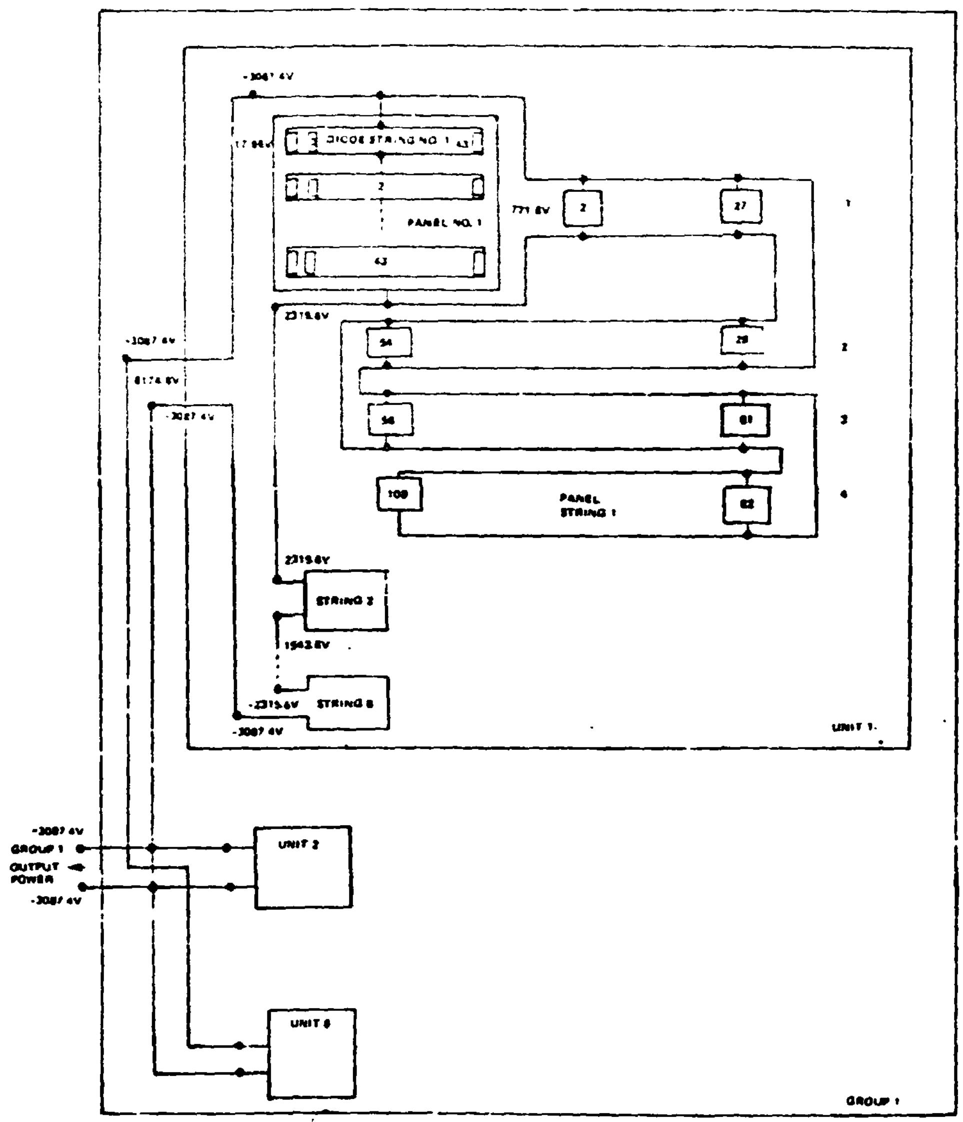

Figure E – Block Diagram of a Typical Group for the Low Voltage Configuration. Example shows a Group within the Inner Ring (Circle) of the Rectenna Aperture

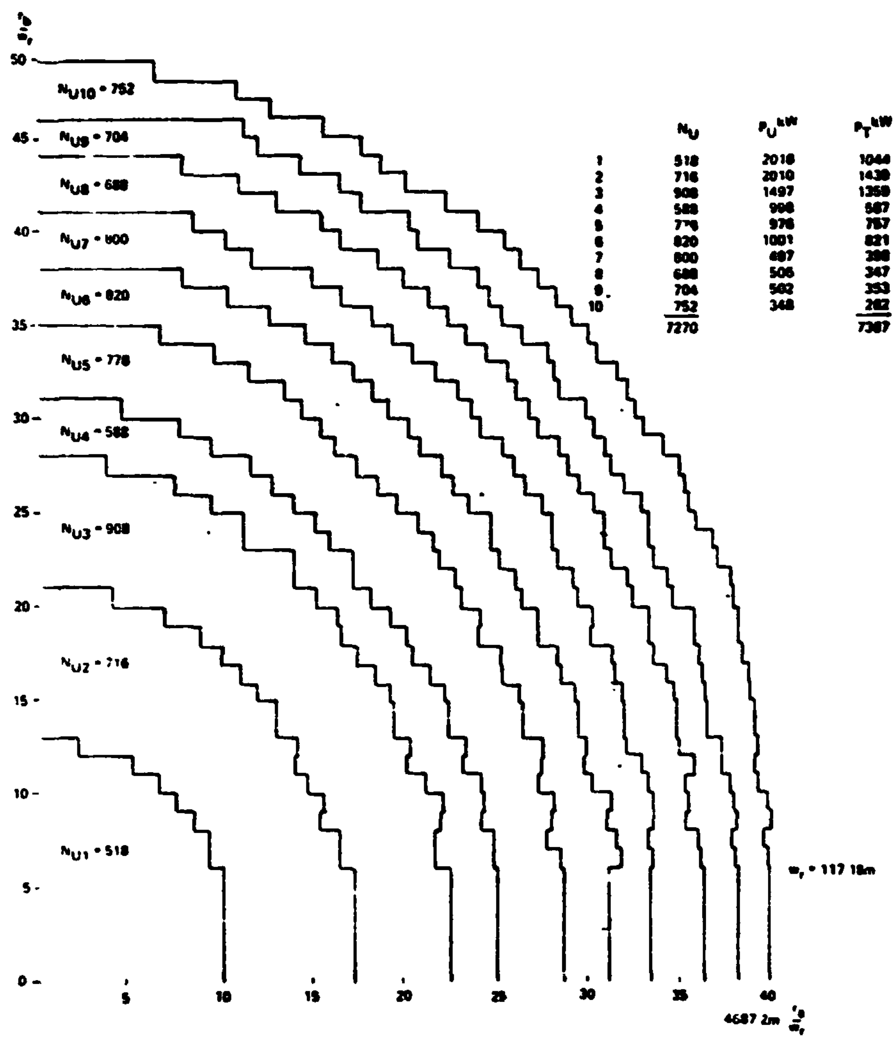

Figure F Geometrical Layout of Unit Boundaries in the Rectenna (Within Each of the Ten Rings of Units Different Unit Power Levels are Used)

1.0 WBS DICTIONARY

This element includes the hardware elements used for the uplink phase control system.

2.0 ELEMENT DESCRIPTION

Phase control of the SPS transmitter is provided by an uplink transmitter at the center of the rectenna. This uplink system employs the spread-spectrum coding technique defined by W.L. Lindsey of Lincon, for JSC under separate contract.

Other control is provided through the communications system described under WBS 1.1.5.

4.0/5.0 MASS AND COST

These have been summarized at a higher level - see WBS 1.4.

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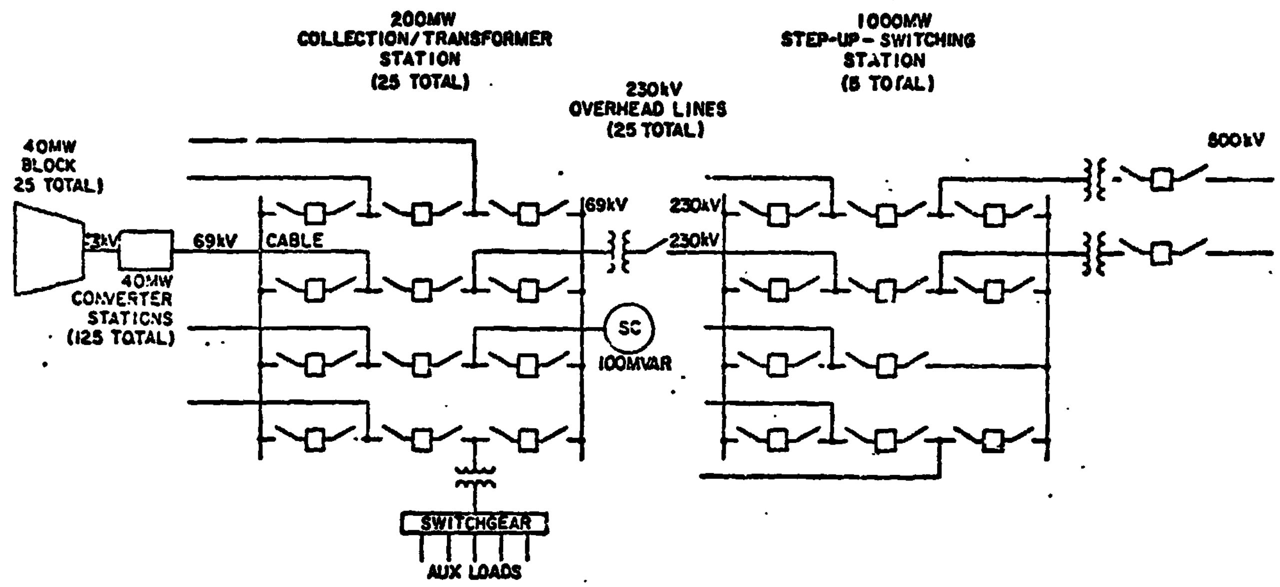

Figure A– Ground Power Collection and Transmission System

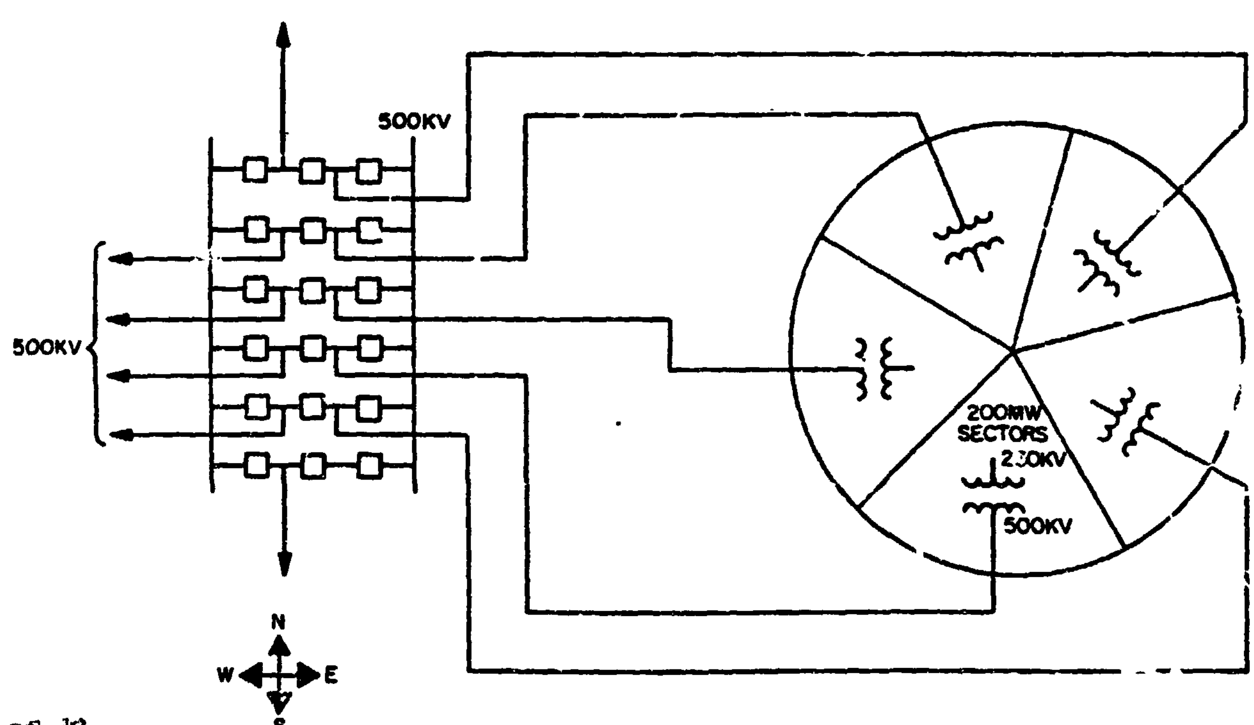

Figure B– Transmission Requirement for Utility Interface

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WBS 1.4.5 AC SYSTEM AND INTERFACE WITH ELECTRIC UTILITY SYSTEMS

1.0 WBS DICTIONARY

This element includes the hardware that is used to convert DC power to AC power and to interface with the AC power grid.

2.0 DESCRIPTION

This selection of the layout for the rectenna AC system between the individual DC/AC converters and the power grid is based upon the bulk power levels of the DC/AC converters as well as on the needs of the bulk power transmission system. The one-line diagram for the rectenna AC system as it was developed for the previous baseline design where the DC output from the dipoles were collected into 40 MV DC/AC converter stations is shown in Figure A. The 40 MW converter station output is transmitted by underground cable to 200 MW transformer stations where the voltage is stepped up to 230 kV, then collected in 1000 MW groups and transformed to 500 kV for interphase with the bulk transmission system. The switchyards are shown arranged as reliable "breaker and a half" schemes where single contingency outages may be sustained without loss of power output capability. The selection of the voltage level for the ultimate bulk power transmission interface with the utility grid as well as the possibility of interconnecting two or more of the 1000 MW switching stations together should be optimized based on detailed information about the connecting utility system. The solution shown in Figure A is one of several possible.

Further consideration of the transmission system and associated high voltage bussing arrangements has resulted in refinements which should provide both greater reliability and economy. While an arrangement as shown in Figure A nicely fits an assumption of symmetrically located load areas surrounding the site, it is more likely that the major portion of the output would be required at a single area geographically. For example, with location of the ground power station in the desert areas of the Southwest, one would expect that the major output would be absorbed on the West Coast.

With this in mind, it is logical to consider fewer transmission circuits from a single substation in a double bus type of arrangement.

Figure B shows the proposed arrangement, using a total of six 500 kV circuits, four of which are assumed direct to a single load area with the remaining two circuits directed to two additional load areas. It is anticipated that any two of the 6 circuits could be removed from service without reduction of the rectenna output. The remaining four circuits, together with the normal utility transmission interconnections should be capable of carrying the 5000 MW output required. In other words, the sytem shown could handle either a line maintenance outage plus sudden fault loss of a second circuit, or sudden loss of two circuits alone. Additional circuits would, of course, provide the ability to handle additional multiple contingency situations.

The breaker and a half arrangement shown can survive a fault in any component without load reduction. The major contingency situations are:

Bus fault	- no loss of circuits
Breaker fault	- one or two circuits lost, depending on breaker location
"stuck" breaker (i.e., failure to trip for line fault)	- one or two circuits lost (including faulted circuit) depending on location of stuck breaker

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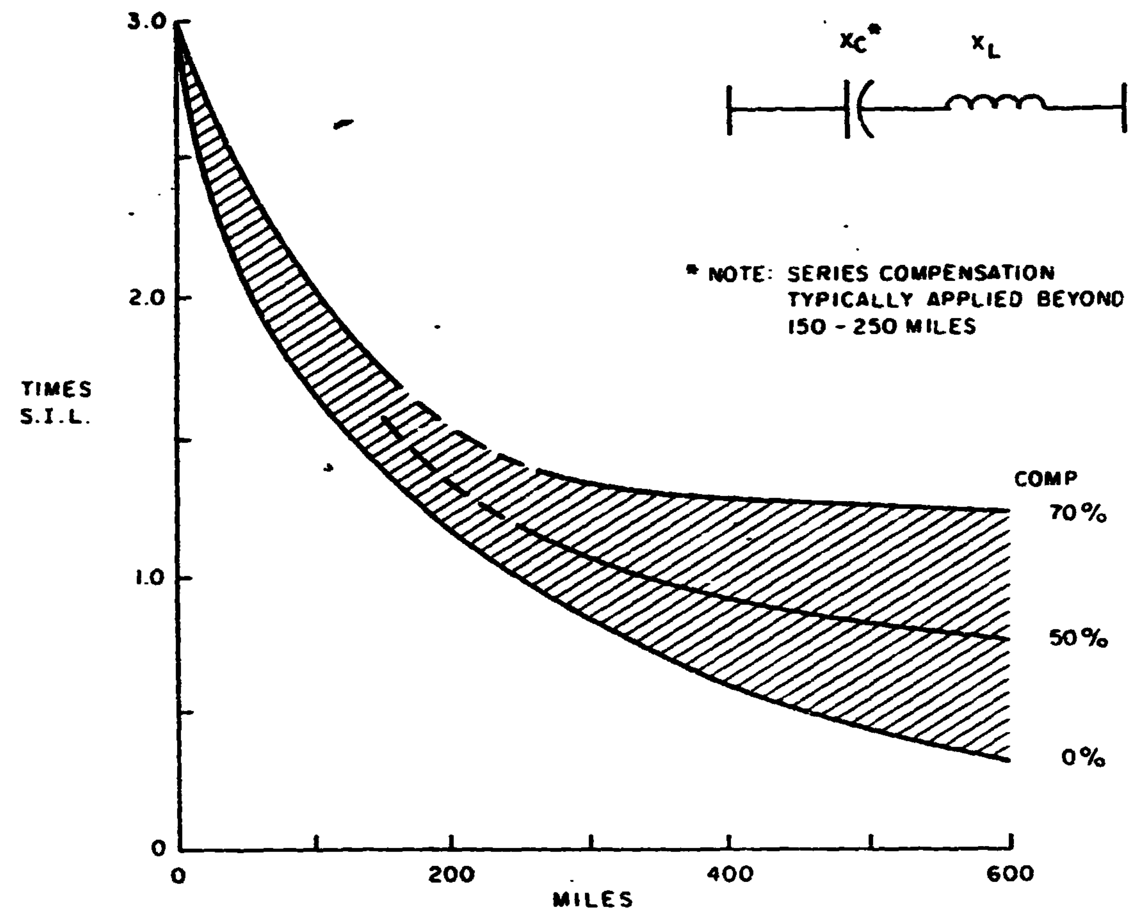

Figure C– Typical Economic line Loadings

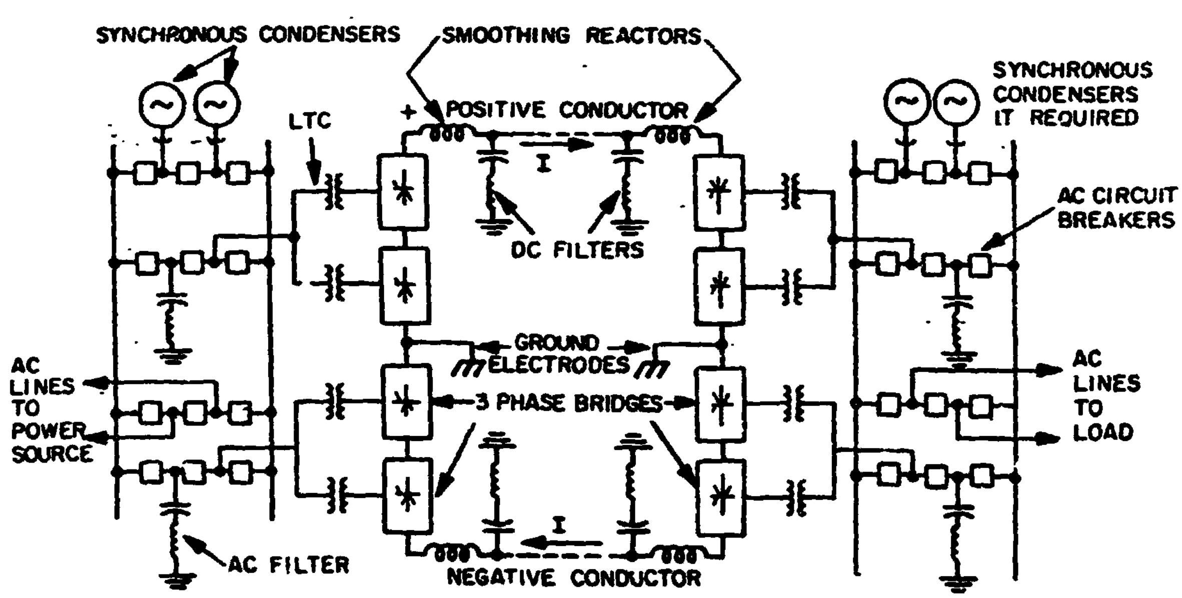

Figure D– Elements of a HVDC Transmission System

The conventional electric utility bulk transmission systems operate AC and the following paragraph will discuss system parameters on AC transmission systems to illustrate the considerations necessary when selecting AC or DC as well as voltage levels for the high voltage transmission system connecting the SPS power plant to the rest of the electric utility system.

For conventional generating stations, depending on the distance to the load center, some series capacitor compensation of the AC transmission lines would normally be expected when considering contingency line loadings. Typical line loadings versus distance and amount of series compensation for AC transmission lines is shown in Figure C.

When considering contingency loadings as discussed above with 2 lines down and 4 lines carrying the full 5000 MW the line loadings would be 1.25 times the surge impedance loading (SIL). The surge impedance loading for various voltage levels are shown in Table A and for 500 kV, the SIL would be about 1000 MW. From Figure C it would appear that a reasonable transmission distance with no series compensatoin for this example would be about 200 miles, which could be increased to 350 or 400 miles with up to 70% series compensation.

To define the specific requirements for a given situation, load flow and system stability sutdies would be required. It is likely, however, that the SPS power system would be far more stable than a conventional power plant of the same rating. This would mean that the transmission distances could be increased for a given line loading without need for series compensation.

When substantial amounts of power are to be transported for distances of 400 miles or more, the consideration of a high-voltage DC (HVDC) as the transmission load is often indicated. The HVDC system is ideally suited for long distance bulk poewr transport since it does not suffer from stability effects and can be used to improve the stability of the AC system to which it is connected. The DC system is asynchronous and can easily transmit power between independent power systems such as those of the Eastern and the Western United States.

There are, however, certain specific requirement to be met. At each of its terminals the DC transmission system absorbs reactive power which must be supplied by static capacitors, rotating machines, like synchronous condensers or from the connected AC network. Reactive volt-amperes equal to approximately 60% of the transmitted active power are required.

TABLE A. Representative Line Surge Impedance Loadings (SIL)

Line Volt	One Conductor	Two Conductor	Three Conductor	Four Conductor
kV	MW	MW	MW	MW
242	146	183	209	---
362	327	410	468	504
550	--	945	1080	1160
800	--	--	2280	2460

The current on the AC side of the terminals contains substantial harmonic components which must be removed, generally by shunt-connected tuned circuits. These filters are also large enough to provide some of the required reactive power.

Lastly, the DC terminal must be connected to an active AC network having a short circuit capacity (in volt-amperes) equal to a minimum of two times the transmitted power. If the AC system does not have the required level of short circuit capacity, which would be the case of the SPS system, synchronous condensers (also called synchronous compensators) are connected adjacent to the terminals. They will regulate the AC system voltage, provide the needed system strength, and provide the reactive power not generated by the filters. For these same reasons synchronous condensers have also been recommended for use with the DC to AC converters within the rectenna system.

When the requirements for filtering, reactive supply, and short circuit capacity are met, the HVDC system is a reliable, efficient, and readily controlled power transmission medium.

A typical HVDC power transmission circuit is shown in Figure D. The synchronous condensers and AC filters are shown connected to the AC switchyard. The DC terminal consists of three phase bridge converters connected in parallel on the AC side and in series on the DC side. Although only two bridges are shown between ground and the DC conductor, it is not uncommon for four such bridges to be applied when the DC voltage exceeds ±400 kV.

The DC system is balanced with respect to ground and is firmly held this way by fully rated ground electrodes. In normal operation there is not current in these ground electrodes, but in an emergency if one conductor or its converters are lost, the other conductor and the ground circuit will continue to transmit half power. Such emergency use can usually be tolerated. The transformers which couple the AC system to the bridges are shown equipped with load tap changes (LTC) which insure that the converter operates at the proper voltage and firing angle regardless of normal smaller variations in the AC system voltage.

Power flow in the DC system is subject to accurate and rapid electronic control. Power is held steady or adjusted according to source or load requirments as desired. In this respect it is ideally suited for the SPS power transmission system.

HVDC technology is advanced and the systems have been well received. A 6300 MW system in Brazil is currently in the proposal stages with full scale operation scheduled for 1985. It would appear that a DC system or a combination of DC and AC system could be applied to the Solar Power Satellite system with few difficulties using today's electric utility system's transmission design practices.

4.0/5.0 MASS AND COST

These are summarized at a higher level - see WBS 1.4.

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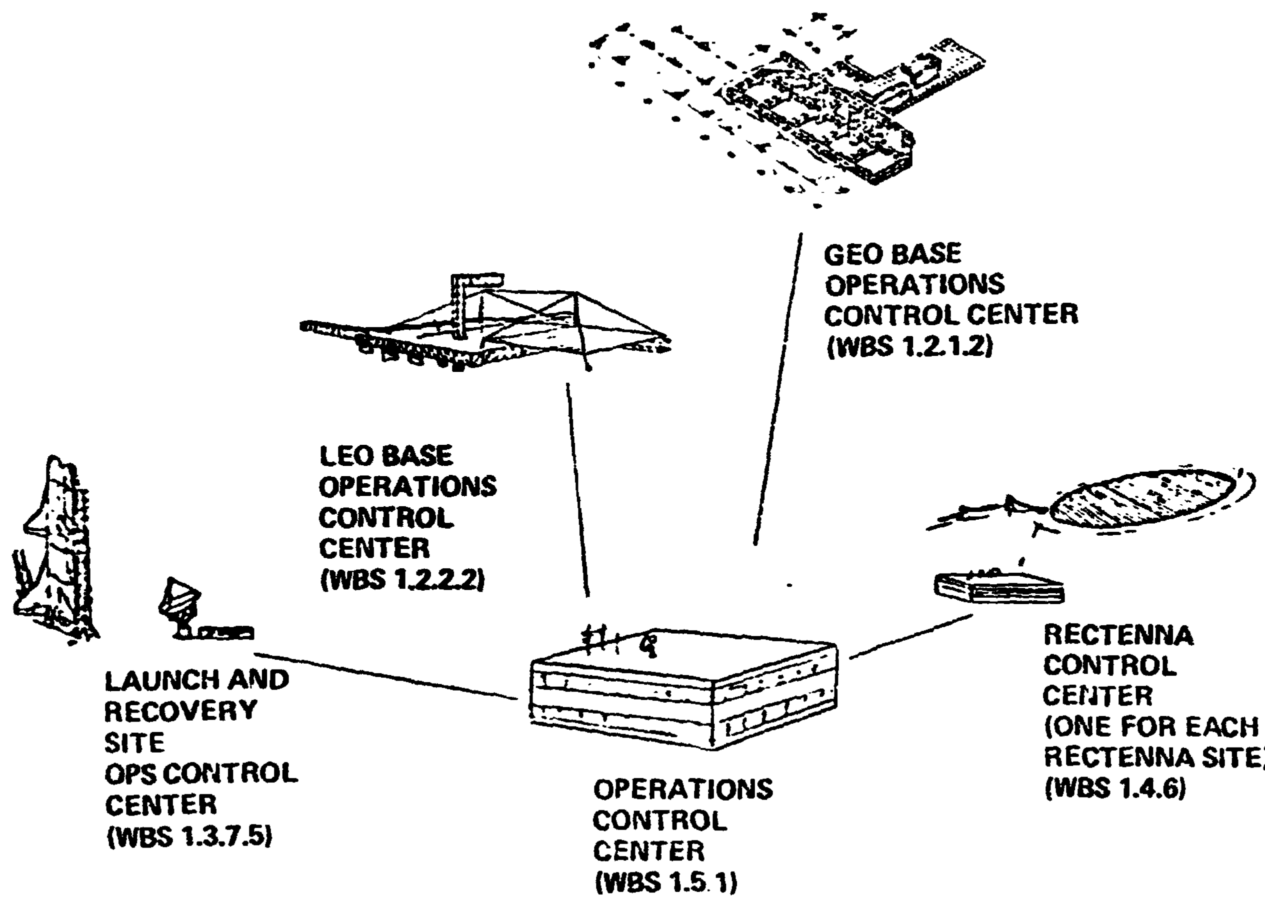

1.0 WBS DICTIONARY

This element consists of the people, facilities and equipment required to coordinate and integrate the operations of the SPS program to assure that the SPS system meets all requirements in a timely manner and that a mechanism exists for the generation of program decisions in real time if on-orbit or other problems so require.

2.0 DESCRIPTION

The facilities involved in the SPS program operation, control are shown in the Figure. For conceptual purposes, the bulk of the operations control functions are shown to be conducted from within a single facility called the Operations Control Center (in reality, there may be several facilities located in various geographical locations). The only operations control facilities that are known to be located remotely from the central Operations Control Center are those shown in the Figure. At this time, there does not appear to be any requirement for a dedicated communication satellite and/or ground tracking system; currently our planned satellites and tracking systems seem to be adequate. A total of 2927 people will be required for the Operations Control Center.

4.0 MASS AND MASS BASIS

Not applicable.

5.0 COST

5.1 COST SUMMARY

An estimate was made of the total number of people required within Integrated Operations. In previous analyses, detailed cost and personnel estimates had been made for a satellite operations facility and a shuttle operations facility. Based on the similarity of facilities, equipment and personnel required, the Integrated Operations costs were computed based on the costs per person from the previous analyses, modified to be applicable to the IO functions.

Research	- 0
Engineering Verification	- 0
Demonstration	- 0
Investment	- $512 million
Production	- $146.3 million/year

5.2 COST DETAILS

Research	- Not required
Engineering Verification	- Not applicable
Demonstration	- Not applicable
Investment	- Refer to WBS 1.5.2
Production	- Refer to WBS 1.5.2

5.3-5.7

Not applicable

7.0 SUITABILITY FOR SERVICE

This WBS item is available for both scheduled and unscheduled ground maintenance and repair. Much experience on equipment of this type is already in existence.

1.0 WBS DICTIONARY

This element includes all the facilities and equipment required for the accommodation of the operations control personnel. Excluded are the control center associated with the Rectennas, see WBS 1.4.6, and with the launch and recovery site, see WBS 1.3.7.5.

2.0 DESCRIPTION

The Operations Control Center is the location of the central organization which coordinates and integrates the operation of the SPS program. The performance of these functions requires technical and administrative office space plus the associated support facilities and equipment (e.g., reproduction facilities, print shop, photographic, technical illustration, etc.); a communications center for communications; relatively extensive computer facilities for automated scheduled maintenance, logistics planning and technical functions; support facilities such as power, air conditioning, etc.

3.0 ELEMENT DESIGN BASIS

The design of this element is very preliminary. It is based on a functional analysis of the activities of Integrated Operations, an estimate of the number of people involved and consideration of the type of facilities and equipment required.

4.0 MASS AND MASS BASIS

Not applicable

5.0 COST

5.1 COST SUMMARY

Cost estimates are based upon detailed cost estimates obtained during previous analyses of a satellite operations center and a shuttle operations center which required similar facilities and equipment. Estimates for facilities are based on the number of square feet of facilities required and the cost per square foot of these facilities. Equipment costs are based on the cost of equipment per person. In both cases the costs are based on the previous analyses and the number of people required is based on an Integrated Operations functional analysis.

Research	- 0
Engineering Verification	- 0
Demonstration	- 0
Investment	$524 million
Production	- 0

5.2 COST DETAIL

<u>Research</u> - Not required
<u>Engineering Verification</u> - Not applicable
<u>Demonstration</u> - Not applicable

	Cost ($M except as noted)	Reference or Source
Investment		
	2996 people x $175K/person = $524 million (includes facilities, furnishing, computers communication systems, etc.)	Previous OMB analyses

Production - Not applicable

5.3 - 5.7

Not applicable

6.0 TECHNOLOGY DESIGN STATUS

Technology required for this WBS item is within the current state of the art.

7.0 SUITABILITY FOR SERVICE

This WBS item is available for both scheduled and unscheduled ground maintenance and repair. Much experience on equipment of this type if already in existence.

FOLDOUT FRAME

	OCC	LCC	LEO BASE	GEO BASE	MMB	SPS'S	RCC	PLV	HLLV	EOTV	POTV	CARGO TUG	MSS-OTV
OPERATIONS CONTROL CENTER (OCC) (WBS 1.5.1)		×	×	×	×	×	×	×	×	×	×		×
LAUNCH CONTROL CENTER (LCC) (WBS 1.3.7.5)			×										
LEO BASE (WBS 1.2.2)				×				×	×	×	×	×	
GEO BASE (WBS 1.2.1)					×					×	×	×	×
MOBILE MAINTENANCE BASE (MMB) (WBS 1.2.3.2)						×							
SOLAR POWER SATELLITES (SPS's) (WBS 1.1)							×						
RECTENNA CONTROL CENTER (RCC) (WBS 1.4.6)													
PERSONNEL LAUNCH VEHICLE (PLV) (WBS 1.3.3)									×		×	×	
HEAVY LIFT LAUNCH VEHICLE (HLLV) (WBS 1.3.1)											×	×	
ELECTRIC ORBIT TRANSFER VEHICLE (EOTV) (WBS 1.3.2)												×	
PERSONNEL ORBIT TRANSFER VEHICLE (POTV) (WBS 1.3.4)												×	
CARGO TUG (WBS 1.3.6)													×
MAINTENANCE SORTIE SUPPLY OTV (MSS-OTV) (WBS 1.3.3)													

Figure A — SPS Communications Matrix

1.0 WBS DICTIONARY

This element includes the ground antennas and relay communications satellites dedicated to the SPS program. Other communication system elements are included in the orbital bases, space vehicles, and ground-based operations control centers.

2.0 DESCRIPTION

A communication system concept has been developed for the SPS operational system. The Surface Transportation System and the Industrial Complex have not been included in this system since it is anticipated that communication between these and other system elements will be by common carrier; hence, not a part of the dedicated SPS system.

The matrix in Figure A indicates those system elements between which communication is required. (For each "x" on the matrix, a fact sheet which defines the requirements for communication between the elements is found in the Operations and Systems Synthesis (D180-25461-3), section 15. These fact sheets also state how the communications will be implemented using the system concept presented herein).

A summary description of the system and its operation is presented in the following paragraphs; the details of each element-to-element communication link are provided on the appropraite fact sheet. The concept consists principally of direct links from the CONUS ground elements to the space elements in geostationary orbit over CONUS; two dedicated relay communication satellites at geostationary altitudes located east and west of the GEO Base such that the line-of-sight communications path from the GEO Base just misses the earth; a communication capability on the GEO Base equivalent to that of the relay satellites; and a series of direct links among the vehicles, bases and relay satellites. Communications will be completely digital, thus providing flexible, efficient interconnection of all the diverse types of communication required. Cost trends in analog and digital hardware make this approach the proper choice for the time frame being considered. The data rates required are well within current technology capabilities.

Figure B illustrates the four main links at CONUS plus the LEO Base link to the communication satellite equipment on the GEO Base (when the LEO Base is over CONUS). Analysis of the individual element to element communications implementations indicates that Link 1 is the most heavily loaded link (400 Mbps) since it carries the OCC to GEO traffic. This includes all traffic from the OCC to non-geostationary orbital elements which must be relayed via GEO to the communication satellites. The traffic on this high data rate, high reliability link consists of a wide range of voice, data and video information.

Ku-band has been selected as the appropriate baseline frequency range for this Link 1. Large parabolic antennas will be used on both ends of this link. Twenty-meter diameter antennas are probably appropriate for the earth terminal antennas, and the GEO antenna will be in the five-to-ten-meter range.

Link 2 is the Ku band command and control link fromthe OCC to each of the SPS's. In order to minimize the number of frequencies and amount of equipment required when the ultimate umber of 60 satellites are deployed, it is planned to monitor each satellite periodically rather than continuously. In the event of an anomaly, a

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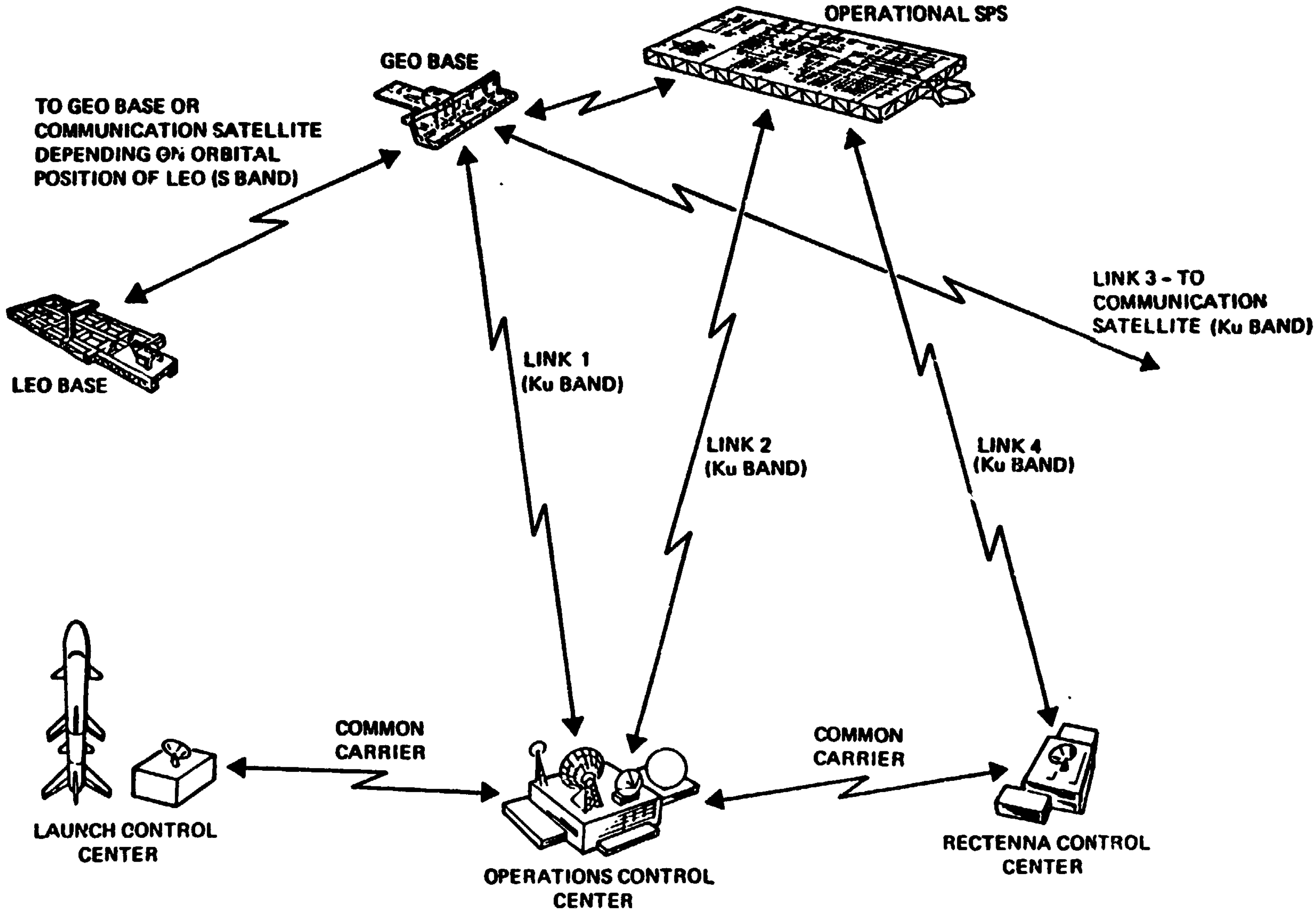

Figure B — SPS Communications at CONUS
SPS Program Operations Control Concept

continuous monitoring and command capability would, of course, be available. It is also planned to utilize toroidal multiple-beam antennas, such as are currently being used in COMSAT terminals, to minimize the number of antennas.

Link 3 is the link from GEO to the relay satellites which carries all traffic from the CONUS to the non-geostationary elements. An RF link in the 60 GHz satellite crosslink band is recommended for this link which requires approximately 200 Mbps of duplex communication over a 40,000 nautical mile crosslink path.

Continuous communication with the system elements in low earth orbit is most economically provided by placing two communication relay satellites in geosynchronous orbit at locations where the line-of-sight communications path from GEO just misses the earth. Two satellites are required to avoid a communications gap of approximately 10% of the orbit in the very lowest orbits. Two satellites also provide additional system reliability. The normal communicationpath to any low-earth-orbit system element will be through GEO and one of the two relay satellites.

Link 4 is the link between the Rectenna Control Centers and the SPS's. The principal purpose of this link is to provide the RCC with information on the available power level of the SPS and a limited capability to control that power. A Ku-band link is used since the Ku capability on the satellite can also be used for Link 2. Also. this link will be pointed in or near the power beam and interference potential is very high.

The other links of the system which are links between vehicles or links between vehicles/bases and the relay satellite, are principally S-band, However, Ku-band has been used in those cases in which data rates or power beam interference considerations make it necessary. Special cases for S-band are the links for those vehicles requiring ranging and docking information. For these cases an S-band communication system similar to that used on the Shuttle payload link, plus a Ku-band radar system, also similar to that used on Shuttle is recommended.

3.0 DESIGN BASIS

The proposed system has the following advantages:

1. Commonality of equipment. Essentially only two types of equipment are used, Ku-band and S-band.

2. The equipment is current state-of-the-art and should be very low weight and inexpensive in the time period of interest.

3. The possibility of interference from the 5GW power beam is minimized by using Ku-band communication to the elements generating or utilizing this beam.

4. Relatively broad-beam, S-band is used to communicate with space vehicles, thus relaxing the pointing and attitude control requirements imposed by communication.

5. The frequencies recommended are within those currently allocated for this type of communication.

6. All links have ample growth potential in the event additional capability is required as the requirements become better defined.

7. The potential of terrestial noise interference is minimized.

The 12/15 Ghz communication satellite bands may be used, but a new allocation might be required for this rather spe ial point-to-point communication service. Much higher frequencies are not desirable, due to excessive rain losses during heavy rain storms. Much lower frequencies do not allow the signals to be restricted to the immediate area of the OCC and GEO, and would therefore utilize more of the valuable frequency/orbit spectrum resource.

All of the individual communication requirements are within the capability of the current Tracking and Data Relay Satellites with minor modifications to some channel bandwidths. The number of communications channels to be supported require a new satellite design, however. Using a laser or 60 Ghz crosslink for data communications to the low orbit system elements. More parabolic antennas will be required than are now on TDRS.

4.0 MASS AND MASS BASIS

Not applicable.

5.0 COST

5.1 COST SUMMARY

Research - 0

Engineering Verification	- $120 M
Demonstration	- 0
Investment	- $189 M
Production	- 0

5.2 COST DETAILS

Research - 0
Not required

Engineering Verification - $120 M
Based on development RDT&E for similar communications satellite systme

Demonstration - 0
Not required

Investment - $189 M
(2 operational satellites + 1 spare) x $63 M each

Production - 0
Not applicable

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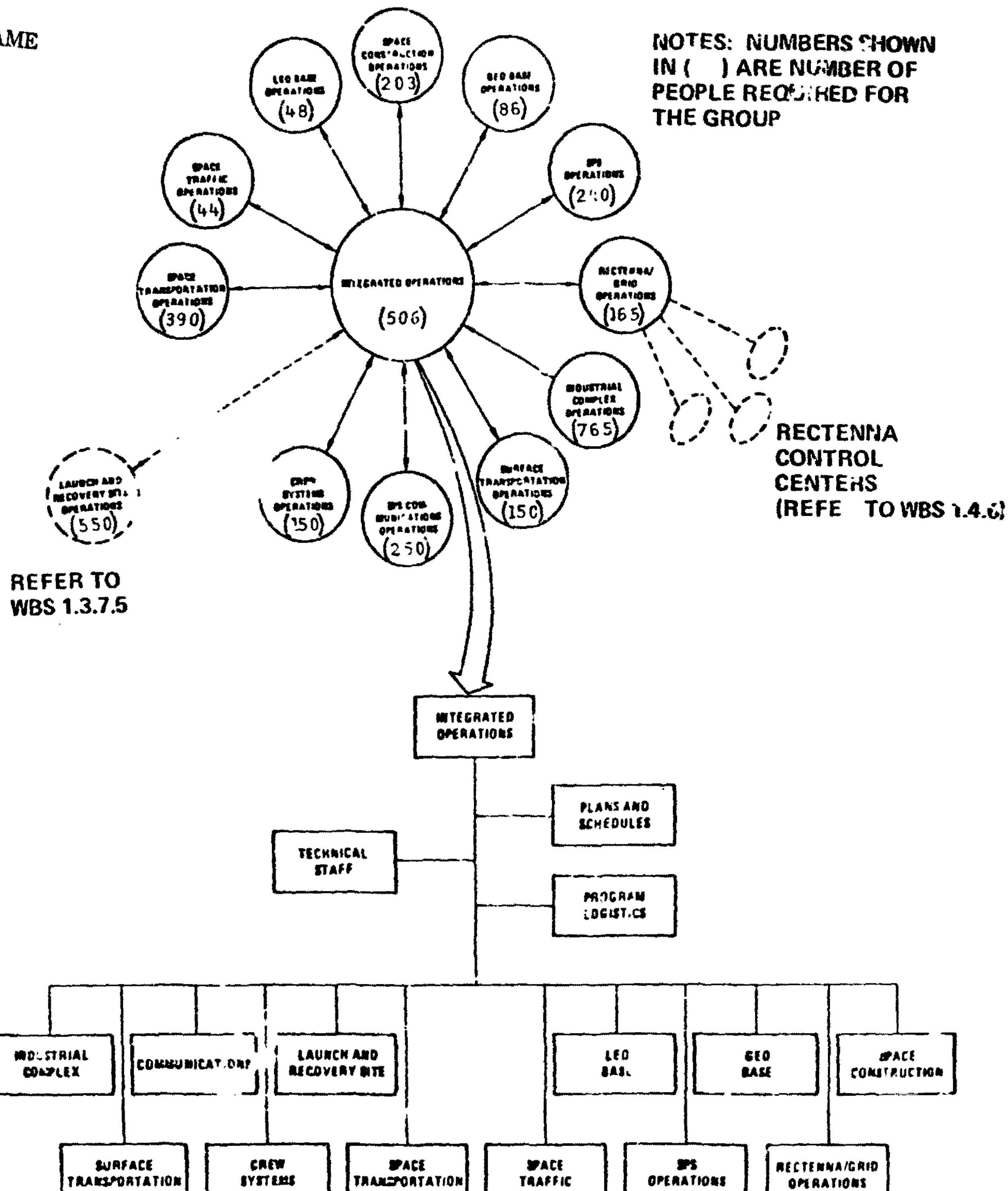

1.0 WBS DICTIONARY

This element includes the personnel required to perform the program coordination and integration functions of Integrated Operations as well as the recurring support costs for these personnel.

2.0 DESCRIPTION

Within the operations Control Center there are located 12 groups of people and their equipment. These groups either 1) directly control system operations (e.g. the communication systems operations, SPS operations and space traffic control operations), 2) act as consultants for various system operations that are directly controlled locally (e.g. space construction, LEO Base, and GEO Base operations), or 3) provide overall program integration control (The Integrated Opreations Group).

The Integrated Operations group (IO) is composed of representatives from each of the 12 operations control and consultant groups. This IO group prepares the master plans and schedules, allocates tasks/responsibilities to local operations, monitors program performance, and directs corrective actions at the system-wide level.

In addition to the operations control group, shown in the figure, there are people and equipment located at both the LEO Base and the GEO Base. These poeple manage the base operations, construction operations, and space vehicle operations. (Refer to WBS 1.2.1.3 and WBS 1.2.2.3). The total number of operations control personnel (not already accounted for elsewhere) is estimated to be 2996 people (estimate based on 20 satellites in orbit).

3.0 ELEMENT DESIGN BASIS

The SPS Operations control concept was developed by analyzing the SPS program to define, at a summary level, the tasks which must be performed to assure proper execution of the program. The program was divided into major sections and a definition of tasks was made for each section. After several iterations it was established that the tasks could be categorized into twelve groups, each of which would be the responsibility of a "local operation". The activity of these twelve groups would be coordinated and integrated by a central group or "Integrated Operations", which is described above. Refer to the Operations and Systems Systhesis document (D180-25461-3) Section 15 for complete details.

4.0 MASS AND MASS BASIS

Not applicable

5.0 COST

5.1 COST SUMMARY

The task analyses used to establish the Operations Control concept were further used to estimate the number of people required to perform these tasks. In order to estimate the costs of operating The Control Center, the results of previous detailed analyses of the costs of a satellite operations center and a shuttle operations center were used. From these analyses of operations with somewhat similar functions and facilities, the cost per person of operating with site were determined. This cost was modified to be compatible with the SPS Operations Control task, then multiplied by the estimated number of people required in Operations Control Center.

Research	- 0	Investment	- 0
Engineering Verification	- 0	Production	- $ 149.83 M/year
Demonstration	- 0		

5.2 COST DETAILS

<u>Research</u> - Not required
<u>Engineering Verification</u> - Not applicable
<u>Demonstration</u> - Not applicable
<u>Investment</u> - Not applicable

	Cost (<u>$M except as noted)</u>	Reference <u>or Source</u>
<u>Production</u>	$50K/person/yr. x 2996 people =$149.8 M/year	<u>Previous OMB</u> Analysis

5.3 - 5.7

Not applicable

6.0 - 7.0

Not applicable

SECTION II

SPS DEVELOPMENT SCENARIO

Purpose

This scenario was established as a basis for estimating research, development, investment, and production costs for solar power satellites.

OVERALL PROGRAM SCOPE AND ASSUMPTIONS

The SPS program was divided into five phases:

(1) Research: This phase will address and resolve issues of environmental effects, socio-economic factors, technical practicality and selection of cost-effective technologies, and will develop a comparative assessment of benefits attendant to SPS relative to other energy options. It will be comprised mainly of ground-based research, but certain flight projects are also required to complete the research.

This scenario treats only SPS hardware and software research and research on support technologies such as space operations. Environmental research will be conducted in parallel with the research described herein. Costs and schedules for environmental research are not reflected in this scenario.

(2) Engineering Verification: This phase will bring the technology results of the research phase to a state of large-scale development readiness. This means that prototype subystems will be developed and tested, as will prototype production and operations processes. The products of this phase will be (a) specification for the demonstration SPS and all its support system; (b) cost estimates for the demonstration and production SPS's and all its support system; (c) cost estimates for the demonstration and production lines; and (d) firm development and risk management plans for the following program phases.

(3) Demonstration: This phase will produce and test a pilot plant SPS that delivers power to a commercial electric power net, in order to demonstrate the operational suitability of SPS's for large-scale baseload power generation.

(4) Investment: This phase will create the industrial and operational infrastructure necessary for installation of SPS generation capacity at the reference rate of 10,000 megawatts (2 SPS's) per year.

(5) Commercialization: For purposes of this scenario analysis, the production run will be sixty 5-gigawatt SPS's produced at a rate of two per year after the first unit, which will be produced as a prototype in one year.

The following assumptions are employed in the construction and analysis of this scenario.

(1) The commercial SPS's are the DOE/NASA silicon photovoltaic reference system. The main features of this system are:

(a) Silicon solar array without sunlight concentration, employing 50-micrometer single crystal silicon solar cells with 75-micrometer glass coversheet and 50-micrometer glass substrate.

(b) Graphite composite solar array and transmitter support structure.

(c) Electronically-steered phased array microwave power transmitter employing a 10-db truncated Gaussian illumination taper on a 1-kilometer aperture. The power beam is focused at the ground receiver by a spread-spectrum retrodirective active phase control system. The power beam baseband is synthesized from the spread-spectrum uplink amplified by 70-KW_{RF} klystron power amplifiers, and radiated by a slotted waveguide antenna.

(2) The SPS's are assembled by a construction base in geosynchronous orbit. SPS components and subsystems are fabricated on Earth, shipped to low orbit by HLLV, and transported to GEO by an electric orbit transfer vehicle (EOTV). Assembly and test of subsystems and components are performed on Earth up to the limits imposed by capabilities of the transportation system.

(3) Space crews are transported to and from low orbit by a modified space Shuttle and between low orbit and geosynchronous orbit by a high-thrust orbit transfer vehicle. Crew duty periods are nominally 91 days, resulting in four crew exchanges per year. The total time spent in space by a crewperson is 95 to 100 days including transportation periods.

(4) Decisions to initiate subsequent program phases are incrementally made as necessary to avoid schedule delays. As an example, if a proto-flight klystron were needed two years into the engineering verification program, its development could be initiated during the research program at such time as a decision between klystrons, magnetrons, solid state, etc., could be made based on research results.

(5) Development costs for potentially multipurpose space systems such as manned OTV's and a reusable Shuttle booster are accounted in this scenario as SPS costs.

Based on this scenario, a total nonrecurring cost for SPS research, engineering verification, demonstration, investment, and the first 5-GW prototype SPS, was estimated as summarized in Table 1. The nonrecurring cost was also time-phased and spread as shown in Figure 1. A preliminary labor estimate was also made and is shown in Figure 2.

Table 1
SPS PROGRAM NON-RECURRING COST

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Research		430	
GBED	Ground-Based Exploratory Development	240	Detailed Estimate Reported in Planning Document
Flight Research	Microwave Propagation and Phase Control Experiment Satellite + Shuttle Sorties	190	(Same)
Engineering Verification		9145	
SPS-Related	Subsystems Devel. & Test	421	Sub-Allocation of SPS DDT&E
EVTA Hardware	Engineering Verification Test Article: 1-Megawatt Array Plus Microwave and Electric Propulsion Experiments	240	Sub-Allocation of SPS Hardware Cost
LEO Development Labs	8-Man Test & Space Support Facility	2700	JSC Estimate
Manned OTV	All-Prolpulsive or aero-braking OTV with 2- to 4-man capability	1430	800 for OTV from OTV studies. 500 guess for manned module DDT&E plus one unit at 80 + 50
Shuttle Flights	LEO Dev. Lab & MOTV Support plus EVTA Launch	1000	40 flights total
Shuttle Booster	Liquid Flyback Booster for Shuttle	3284	DDT&E plus one extra flight unit. Provides shuttle payload increase to support MOTV.
Program Mgmt & Integration	Integration, Coordination, and Management support to tie program elements together.	70	200 people for 5 years

TABLE 1
SPS PROGRAM NON-RECURRING COST - Cont.

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Demonstration Program		26349	
Demonstrator DDT&E	Development of the Demonstrator Subsystems and Integrated Configuration	3134	Sub-allocation of SPS DDT&E
Pilot Production Facilities	Pilot Lines for Arrays, Klystrons, Power Pro-processors, etc.	460	Sub-allocation of SPS Investment
Demonstrator	Hardware for Demonstrator	2922	Sub-allocation of SPS Hardware Cost
Shuttle DDT&E & Fleet	2 Boosters, 2 Orbiters, 25 ET's, Development of Pod-Type HLLV	3403	Boosters: 310; Orbiters: 1265; ET's: 115; Tooling: 173; GSE:50; HLLV DDT&E 1490
Construction DDT&E	Leo Base: 8-meter Habitat & Full Work Support Facility GEO Base: Habitat Delta for Shielding & 10% WSF	3586	Based on 8-meter habitat DDT&E 1135 & Unit 136, scaled from 17-meter habitat
Construction Base Cost	LEO Base: 4 Habitats & Full WSF GEO Base: 1 Habitat & 10% WSF	3421	Scaled from 17-meter habitat
Space Operations	4 Years Operations: Construct Bases & Demonstrator	3200	130 HLLV flights @ 12:1560 24 PLV flights @ 15:360 Crew salaries & resupply based on 100 crew • 1/6 of operational SPS: 1280
POTV DDT&E Plus one extra unit	Personnel OTV with Passenger Module	1986	From DDT&E estimate with MOTV credits: Engine - 355 Avionics - 55 ECLS - 30
EOTV DDT&E	Electric OTV Development Only (supports Demo Article)	2041	From DDT&E estimate with 543 credit for commonality with Demo Article (no flight test unit)
Demonstrator Rectenna	8 x 11 km	2021	Scaled from operational rectenna + $250 M DDT&E
Program Mgmt & Integration		175	500 people for 5 years

Table 1

SPS PROGRAM NON-RECURRING COST - Cont.

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
Investment		66363	
HLLV Development	2-Stage Fully Reusable	12100	From DDT&E estimate with booster engine credit 800
SPS DDT&E	Upgrading Demo Subsystems & Integration of Configuration	2473	Sub-allocation of SPS DDT&E
HLLV Fleet	6 Boosters, 7 Orbiters, Tooling and GSE	6983	From detailed estimate
EOTV Fleet	30 Vehicles	6858	From detailed estimate
Construction DDT&E	Delta DDT&E to Upgrade Bases to Operational Capability	4900	New 17-meter habitat & work module plus GEO Base work support facilities
Construction Base Buildup	Fabricate & Launch Base Systems	14875	GEO Base: Total Unit Cost LEO Base: Crew Support Facilities Space Flight Ops: 3 EOTV, 14 POTV, 94 HLLB, 33 PLV Crew Ops: 1942
Ground-Based SPS Facilities	Production Factories	8924	Per Detailed Estimate
Space Systems Facilities	Launch & Recovery Site Deltas plus Special Factories	8375	Propellant Production: 1765 Launch: 3222 Recovery: 1770 Logistics & Ops Support: 118 Habitat Factory: 800 HLLV Factory: 750
Program Mgmt. & Integration		875	2500 people for 5 years

TABLE 1

SPS PROGRAM NON-RECURRING COST - Cont.

ITEM	DESCRIPTION	COST ($M79)	RATIONALE
First SPS		15040	
SPS Hardware	Flight Hardware Ready to Ship	3999	Detailed estimate less amortization
Space Transportation	All Space Transport, Hardware + Crew	4616	Delta flights due to 1-year construction time EOTV 1.3 POTV 12 HLLV 54 PLV 29
Ground Transportation	Factory to Launch	35	ADL estimate
Packaging Equipment	Launch Packaging	200	5% of SPS Hardware Packaging is Reusable
First Year Full Base Ops	Crew Salaries & Spares & Support	1922	Detailed estimate
Rectenna	9 x 13 km	2578	GE estimate in 79$
Mission Ops		20	TRW Estimate
Sustaining DDT&E	Development Support to Prototype	495	3500 people 2 years
Program Mgmt & Integration		495	3500 people 2 years
Cost Growth		680	17% on SPS Hardware
TOTAL THROUGH #1 SPS		117327	

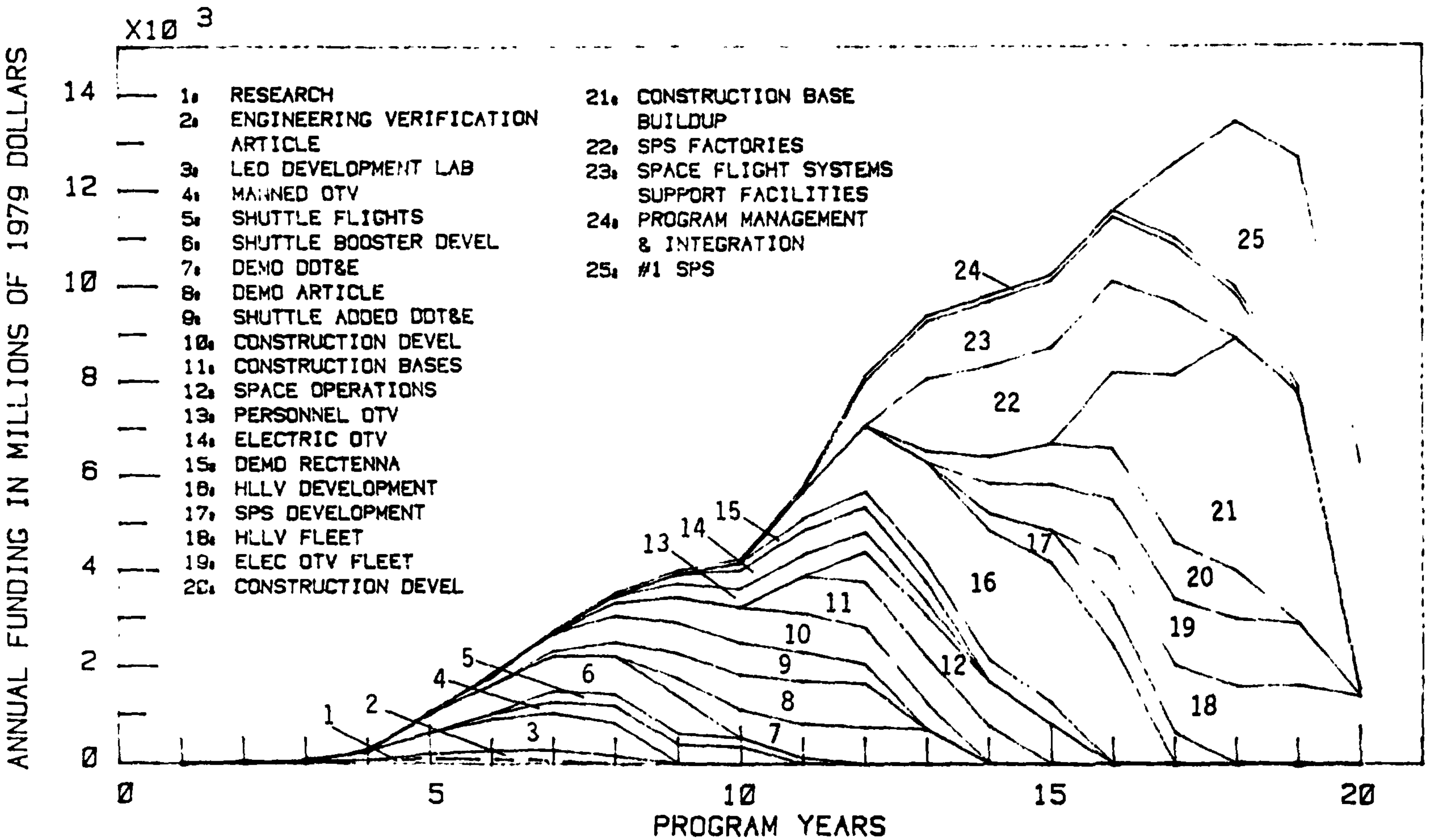

FIGURE 1. SPS TOTAL PROGRAM THRU #1

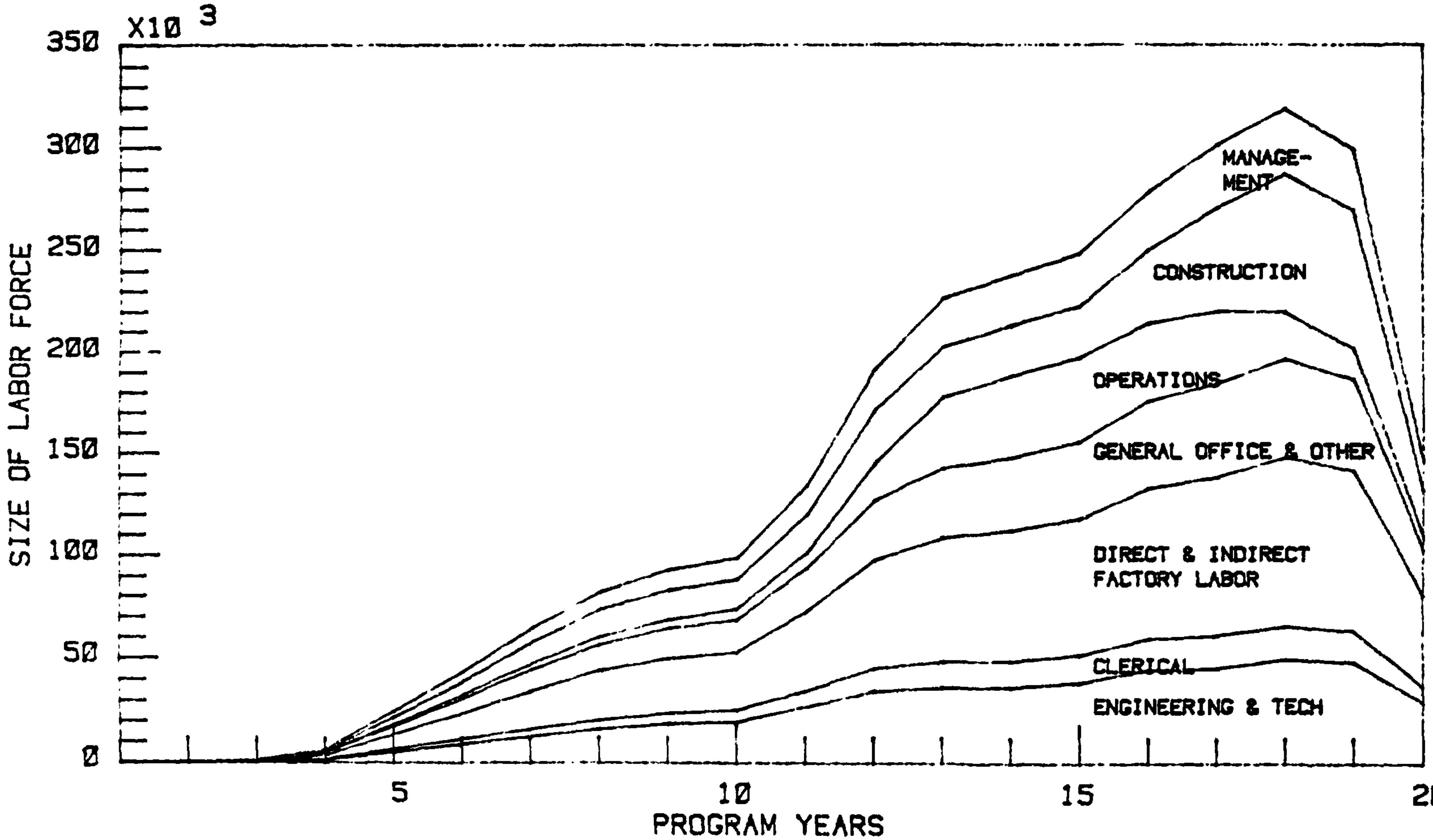

FIGURE 2. SPS DEVELOPMENT LABOR ESTIMATE

D180-25461-2