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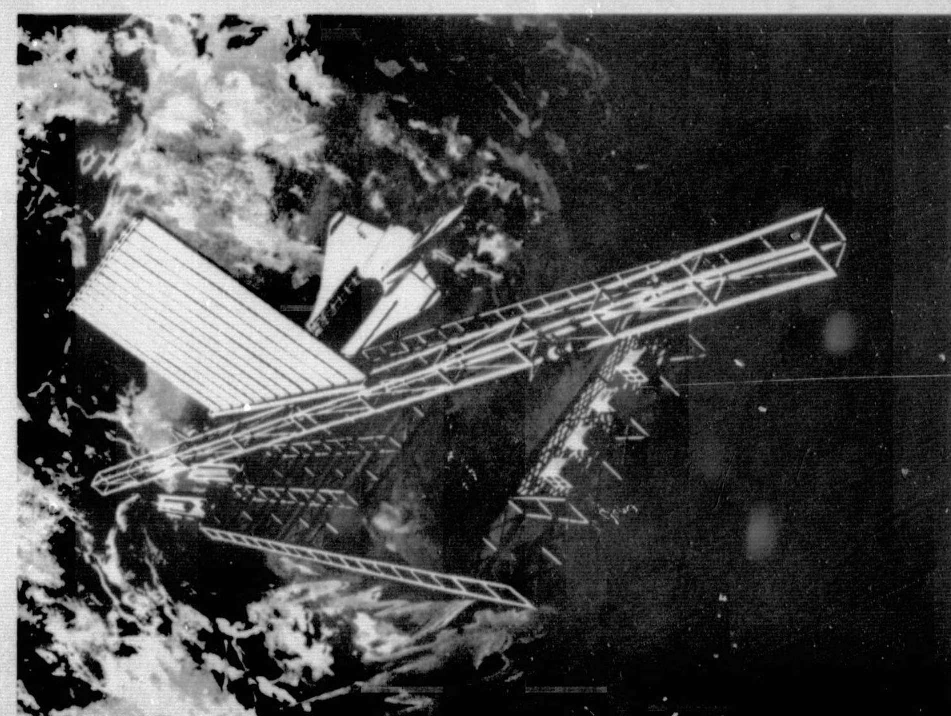
ORBITAL CONSTRUCTION DEMONSTRATION STUDY

VOLUME II
TECHNICAL

FINAL REPORT

(CONTRACT NAS 9-14916)



GRUMMAN

ORBITAL CONSTRUCTION DEMONSTRATION STUDY

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TECHNICAL

FINAL REPORT

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Prepared for

LYNDON B. JOHNSON SPACE CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HOUSTON, TEXAS 77058

By

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

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Section 1

INTRODUCTION AND SUMMARY

The exploration and utilization of space has witnessed a continuous growth in spacecraft size and weight. Many applications are now envisioned which require ultra-large space structures for implementation. The Space Transportation System (STS) is capable of putting large masses into orbit, but these future spacecraft geometries are not compatible with the launch vehicle payload bay size. It is clear that an orbital construction system will be required if we are to have ultra-large structures in space.

Conceptual studies and preliminary designs have been conducted in recent years to define potential mission requirements, structural concepts, and operations for spacecraft utilizing ultra-large structures. As a result, sufficient information exists to define a development program for demonstrating and evaluating orbital construction techniques needed to implement these ambitious programs. The initial phase of this study identified construction technologies needing orbital demonstration and defined demonstration articles that would solve these problems.

The key outputs of this study are conceptual design and program plan for an Orbital Construction Demonstration Article (OCDA), Figure 1-1, that can be used for evaluating and performing practical large structural assembly operations. A flight plan for initial placement, continued utility as a construction base and technology facility is presented as a basis for an entirely new Shuttle payload line-item having great future potential benefit for space applications. If the construction concepts proven during the program initiated in this study result in assembly of power generating plants in orbit, or other similar expansion of man's usage of space, the return to the nation would be enormous.

The OCDA would be a three-axis stabilized platform in low-earth orbit with many structural nodals for mounting large construction and fabrication equipments. These equipments would be used to explore methods for constructing the large structures for future missions. Actual creation of the OCDA in orbit would provide valuable experience toward this goal. The OCDA would be supported at regular intervals by the Shuttle. Construction activities and consumables resupply are performed during Shuttle visit periods. A 250 kW solar array provides sufficient power to support the Shuttle while attached to the

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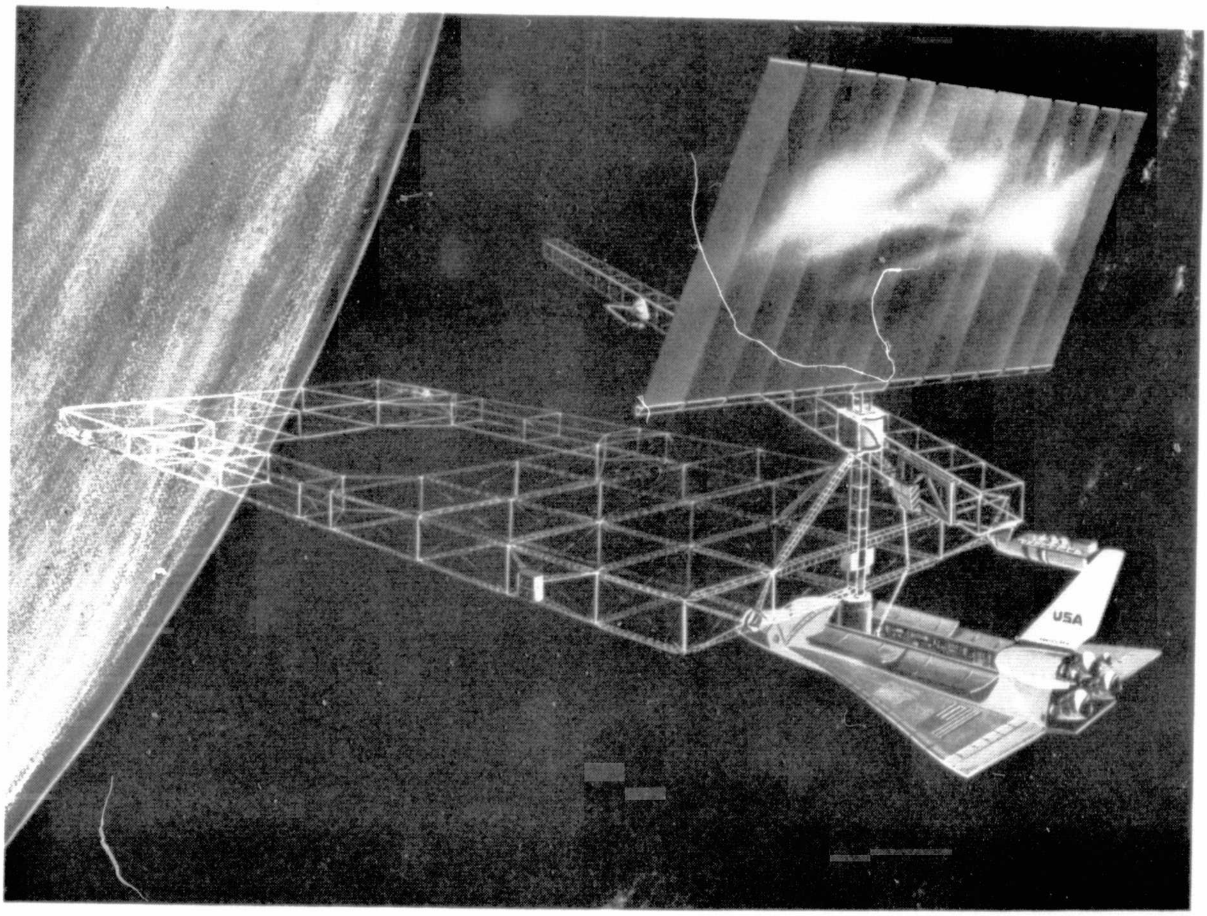


Figure 1-1 Baseline Orbital Construction Demonstration Article

OCDA and to run ambitious construction work at the same time. Wide band communications with a Telemetry and Data Relay Satellite (TDRS) compatible high gain antenna can be used between Shuttle revisits to perform remote controlled, tv assisted construction activities.

The study guidelines and major assumptions used in performing the analyses are:

- The system must be Shuttle compatible
- Initial OCDA placement must utilize two to six Shuttle flights
- Assume a 1981 technology base
- IOC 1984.

In addition to these groundrules, it was also felt that the OCDA should constitute a logical programmatic step between the capability afforded by individual Shuttle missions and the capabilities of a permanent manned facility.

1.1 GENERAL APPROACH

The Orbital Construction Demonstration Study (OCDS) objective was to define a near-term program that flight demonstrates technologies for the construction and operation of future large structures and associated subsystems to a point where hard program decisions regarding these future missions can be made in the mid 1980s. The demonstration program that evolved from this study meets the objective of compatibility with STS elements and, in fact, can enhance the shuttle potential.

The tasks performed over the initial nine-month study are outlined in Figure 1-2. The first task selected was representative of future missions for the purpose of studying issues associated with the construction and operation of typical large structures. The requirements that need flight demonstration for proof-of-concept were embodied into a conceptual OCDA design. Mission plans, program costs and schedules of this demonstration program were products of the study. Supporting analysis concentrated on the technical issues of placing a construction article into orbit in the early to mid 1980s and investigated demonstration article potential to perform continued experiments and tasks key to an active space program.

Figure 1-3 presents the major considerations that led to requirements for the Orbital Construction Demonstration Program. The first element was the technology and demonstration requirements for future missions. This element dictated that the ultimate operational spacecraft be studied and issues identified. The structural approach, namely the basic building block structure, the joints and the potential for ease of construction had to be evaluated in terms of applicability to both future and near-term missions.

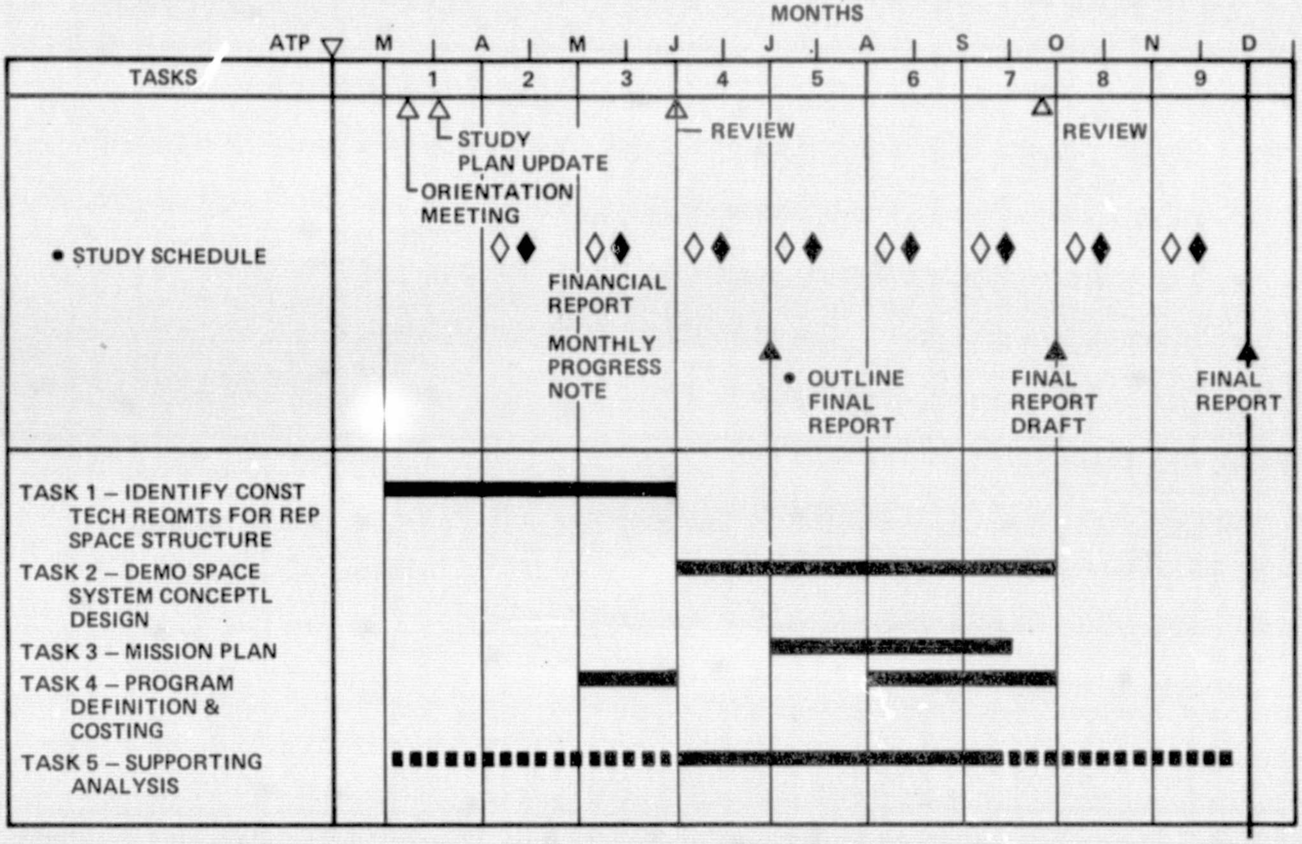


Figure 1-2 Orbital Construction Demonstration Study Schedule

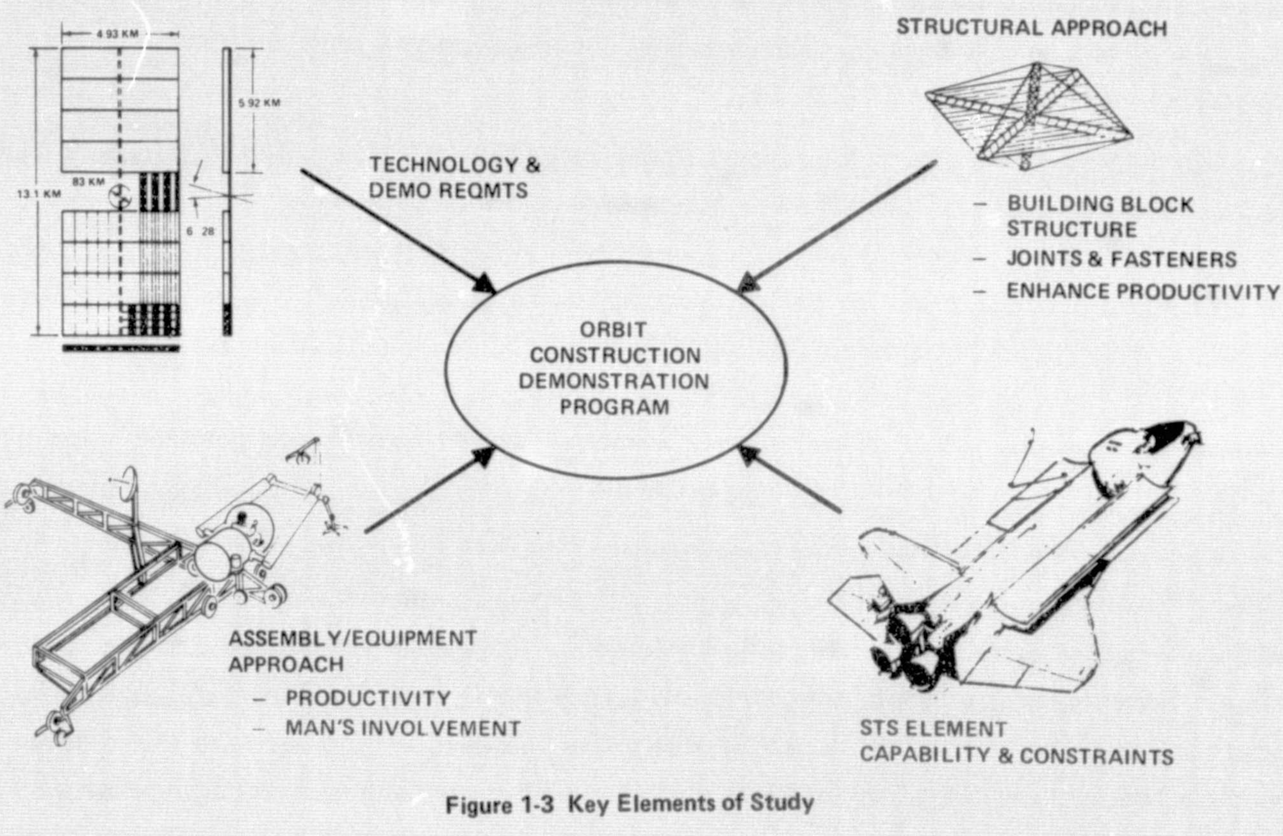


Figure 1-3 Key Elements of Study

The assembly equipments and construction base concept for the future missions were evaluated to specify requirements for assembly approaches used for the demonstration itself. Finally, an assessment was made to verify that OCDA construction operations was shuttle compatible.

The initial nine-month Orbital Construction Demonstration Study, NAS 9-14916, provided a baseline concept for developing and verifying space construction technologies. The Orbital Construction Demonstration Article (OCDA) selected was a small, general purpose, Shuttle-supported construction base that will enable more amibitious construction technology efforts to be undertaken than those which can be achieved through a program of single sortie flights. The basic study defined the OCDA and estimated that 40% of the construction technology objectives can be met with the construction of the OCDA.

The purpose of the add-on study was to define the follow-on uses of the OCDA, and to determine the impact these OCDA construction-related activites have on the basic OCDA design.

The products of this add-on study effort were integrated program plans and costs for on-orbit construction technology development. A major study output was requirements definition for the basic OCDA design. These products were produced through the six tasks shown in Figure 1-3a. The first task identified candidate follow-on activity scenarios that fill-in the missing construction technologies not achieved in the initial deployment of the OCDA itself. Five to ten missions were selected on the basis that all objectives are embodied within the framework of the basic OCDA and follow-on activities.

Task B provided concept designs and definitions for the selected mission scenarios. Mass properties, configuration layout, power requirements, etc., were established. Task C provided the operation sequence for the deployment and conduct of the mission, including plans for test. Task D established program plans and cost. Once the construction activities were defined, the impact these follow-on missions have on the basic OCDA design were identified. Task F established OCDA requirements based on the basic definition established during the initial nine-month study, and on the needs to accommodate the selected follow-on construction activities.

1.2 STUDY PRODUCTS OF INITIAL NINE-MONTH EFFORT

The initial nine-month effort resulted in the definition, mission plan, and program description for an OCDA that can be placed in orbit in the early to mid 1980s. Initial placement of the article requires construction in orbit and therefore establishes preliminary feasibility of this complex function.

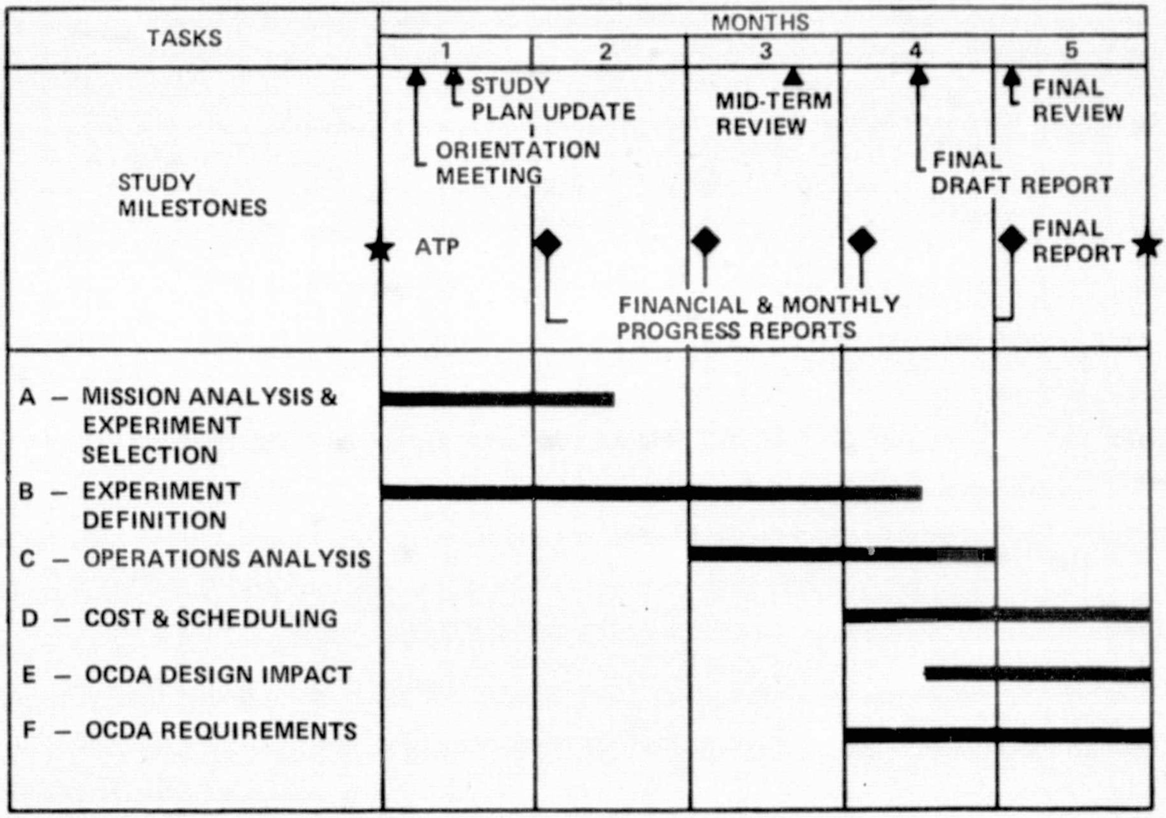


Figure 1-3A OCDA Study Add-On Schedule

The OCDA, shown in Figure 1-4, has four major elements: core module, platform, rotating boom and solar array.

The core module contains the article's subsystems, including attitude control, power regulation and control, and communications and data handling. A Shuttle compatible docking mechanism is included, as well as the rotary joint interface with the solar array and rotating boom.

The work platform is configured with twenty 8-m square by 4-m deep cubes or bays. Each bay provides nodal pickup points to support fixtures compatible with a Shuttle pallet of experiments and equipments. A large 24-m x 32-m open area is provided for demonstrating procedures for mounting solar blankets, thin film mirror surfaces, wire mesh and other broad area component installations.

A 108-m rotating boom outfitted with Shuttle manipulators and an equipment traveller (materials logistics module) is used to transport equipments and materials to the assigned work platform station. The boom is instrumental in the initial construction of the OCDA and is used in follow-on experiments in the construction of hardware outside the confines of the platform itself.

The 250 kW solar array is composed of 13 modified Solar Electric Propulsion Stage (SEPS) wraparound silicon cell deployable blankets. This power level was selected to provide 14 kW average power for OCDA housekeeping, 20 kW average power to support Shuttle and 110 kW average power for follow-on construction activities.

The OCDA mass is 37,093 kg including a six-month supply of consumables and a 20% contingency (Figure 1-5). The electrical power system, which utilizes a NASA multi-mission spacecraft EPS module enhanced by additional batteries and regulators, is the heaviest element of the core section primarily due to wire weight needed to route power from the solar array to the rotating boom and platform. The platform (8327 kg) is the heaviest system element with the structure and power distribution system conductors making up 80% of the mass. The rotating boom mass (6869 kg) is influenced most by the conductors (4394 kg) needed to perform follow-on mission activities in the field of microwave testing. The solar array's 13 SEPS solar blankets, support structure, routing wire, etc., constitutes 23% of the spacecraft dry mass.

The OCDA is constructed from an Orbiter base in three flights (Figure 1-6). The first flight deploys the core module as a single unit and adds to it, one section of the solar array and the trailing section of the rotating boom. The second flight is used to construct

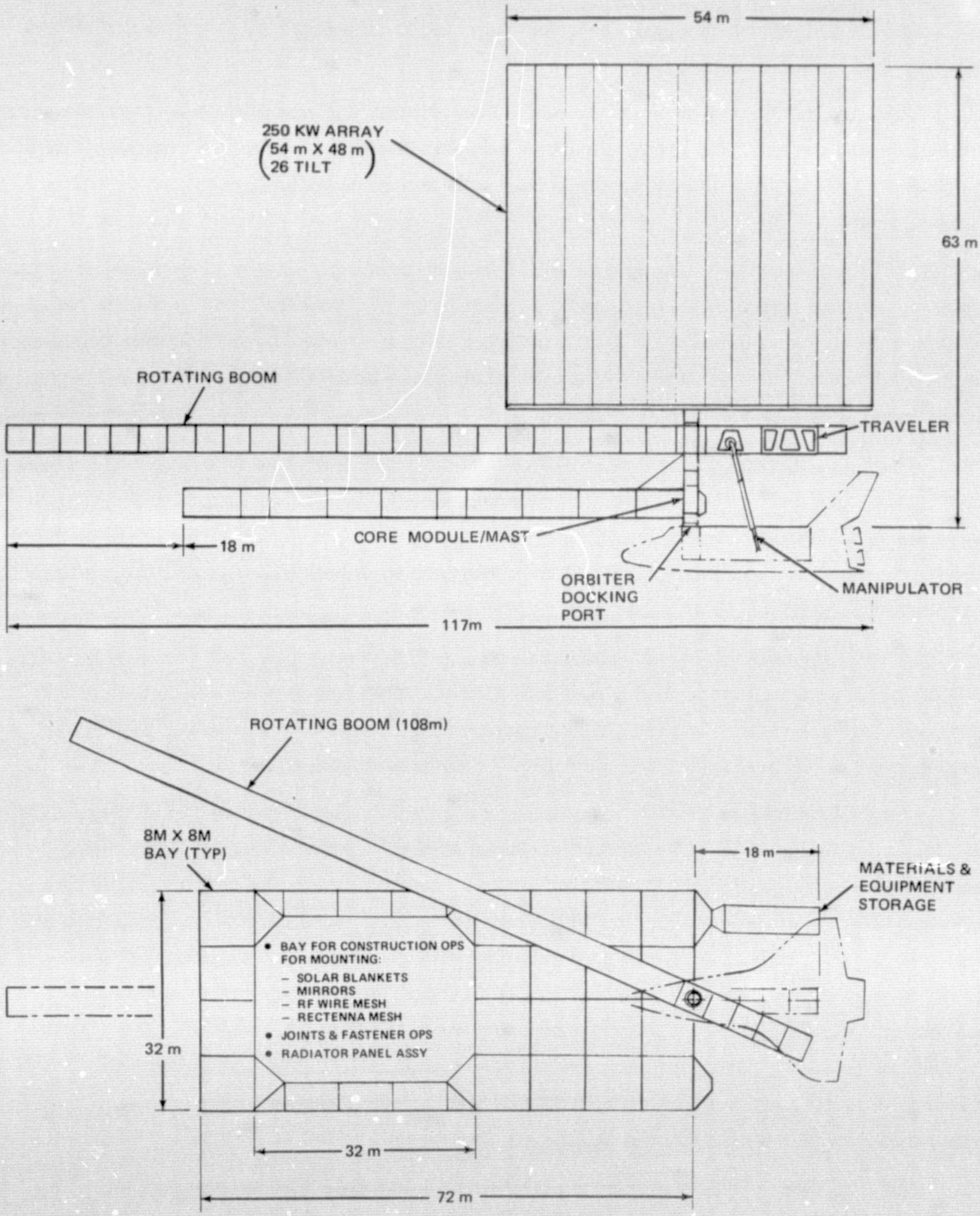


Figure 1-4 General Purpose Demonstration/Test Facility for Construction Technology

		LBM		Kg
• CORE MODULE/MAST	(7669)		(3477)	
– STRUCTURE		316		143
– DOCKING MODULE (PASSIVE)		320		145
– COMM & DATA HANDLING		270		122
– ELECT POWER		3519 ①		1596
– ACS MODULE & REACTION WHEELS		1144		519
– SOLAR ARRAY/ROTATING BOOM DRIVE UNIT		2100		952
• PLATFORM	(18,361)		(8327)	
– STRUCTURE		7421		3365
– PWR DISTRIBUTION		7194 ②		3263
– PROPULSION ORBIT KEEP MODULE (2)		436		198
– ORBIT KEEP MODULE SUPT STRUCT		265		120
– LOGISTIC DOCKING PORT (2)		640		290
– PROPULSION, ATTITUDE CONTROL MODULE (2)		1907		865
– ATTITUDE CONT MODULE SUPT STRUCT		375		170
- COMM-ANTENNA'S (KU-BAND & S-BAND)		123		56
• ROTATING BOOM	(15146)		(6869)	
– STRUCTURE		4349		1972
– MANIPULATION & CARRIAGE		966		438
– TRAVELLER		143		65
– POWER DISTRIBUTION		9688		4394
• SOLAR ARRAY	(12,304)		(5458)	
– STRUCTURE		593		269
– SOLAR BLANKET & DEPLOY MECH.		9634		4369
– POWER DISRTIBUTION		1746		792
– ACS, SUN SENSORS (2)		28		13
– TILT MECHANISM		33		15
TOTAL		53210		24131
20% CONTINGENCY		10642		4827
		63852		28958
CONSUMABLES		17938 ③		8135
		81790		37093

① INCLUDES 583 lbM POWER MODULE
② INCLUDES 1818 lbM ORBIT KEEP BATTERIES & 452 lbM POWER REGULATION
③ INCLUDES 6 MONTH SUPPLY OF ACS HYDRAZINE (16,700 lbM)
6 MONTH SUPPLY OF ACS He (86 lbM)
6 MONTH SUPPLY OF ORB KEEP ARGON (1152 lbM)

Figure 1-5 Mass Summary

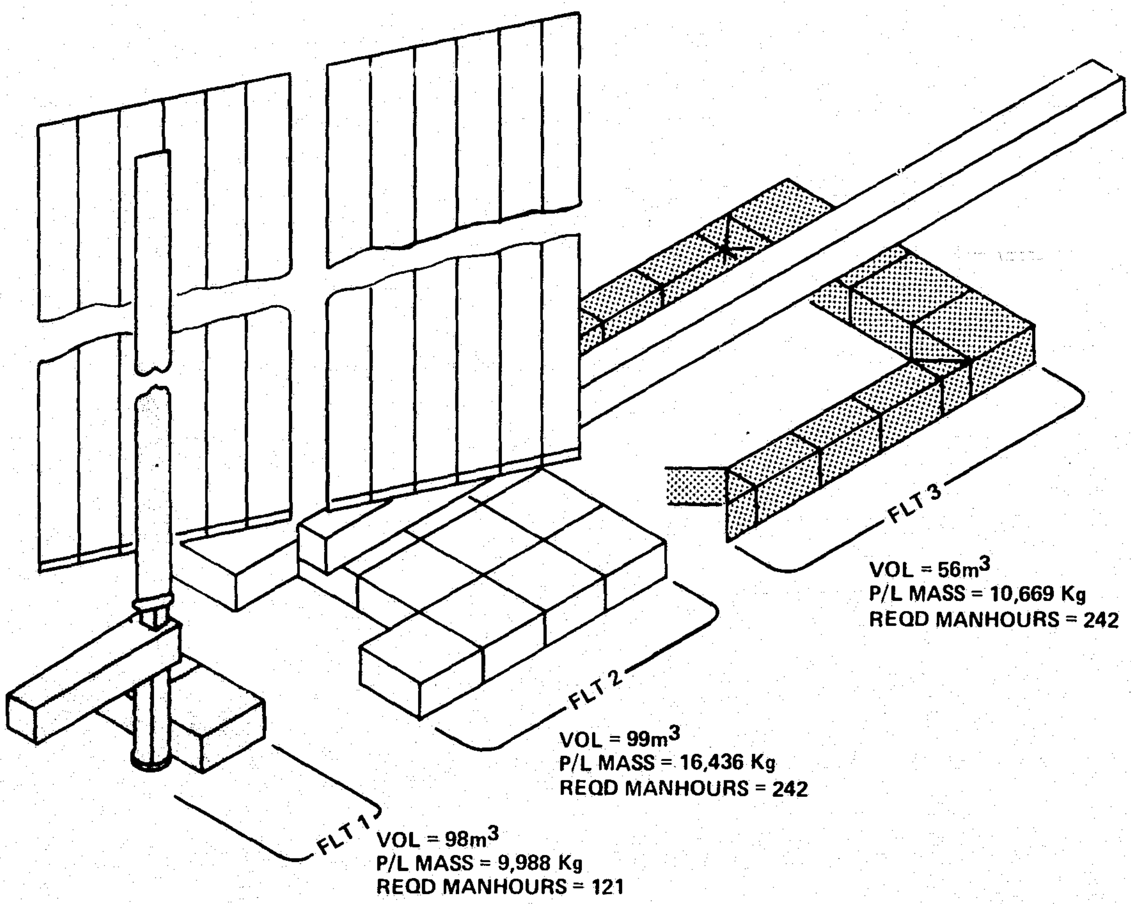


Figure 1-6 OCDA Assembly Approach (Man Assisted by Machine)

the inner 32-m x 32-m area of platform, the remainder of the 108-m long boom and the remainder of the sola. array. The third flight is used to complete the platform structure and to install the power distribution system.

The cost of the OCDA program is estimated at approximately $400 million including the cost of three Shuttle flights and supporting ground operations. The major cost contributors, as shown in Figure 1-7, are the mechanisms, power distribution systems and structure for the rotating boom (included rotary joint cost). The solar array costs are within near-term technology potential with modifications in the automated blanket fabrication equipment.

The program schedule shown in Figure 1-8 has been used for planning. The initial orbital placement starts in early 1984, preceded by a 3 1/2 year design and development phase (C/D). A three-month period (early 1984) has been allocated for the three Shuttle flights required for OCDA construction. Construction of the OCDA itself was judged to meet 40% of the construction demonstration objectives. To enhance meeting the goals of the program, a 1 1/2 year period commencing in mid 1984 following the initial placement, was allocated to construction/structural technologies. During this period, the OCDA is used as a facility to test structural fabrication, control system installation, etc., on a small scale, but still larger than can effectively be handled on a single Shuttle sortie.

1.3 ADD-ON STUDY PRODUCTS

The basic nine-month study concentrated on conceptual design and definition of the initial demonstration article. The objective of the five-month add-on study was to establish utility of the orbital construction demonstration facility by defining a family of activities which demonstrate space fabrication and construction techniques.

The initial placement of the OCDA was envisioned to be performed with the assistance of man in the construction process. The restrictions of room, power and flexibility imposed by operating from the Orbiter payload bay is relieved once the OCDA is operation. The platform rotating boom and abundant power enables the planner to schedule ambitious space fabrication and assembly missions.

The approach taken during the add-on study was to select representative OCDA follow-on program scenarios that embodied the demonstration objective identified in the basic nine-month study and spanned a range of activity complexity and cost. Emphasis was placed on advancing technologies for photovoltaic Solar Power Satellite and large antenna. Demonstration objectives pertaining to developing solar thermal power satellites

ELEMENT	COST, $M DDT&E	COST, $M 1ST UNIT
CORE MODULE/MAST	(13.11)	(18.85)
• STRUCTURE	3.04	.76
• DOCKING RING	0	1.47
• COMM/DATA HDL	.82	2.70
• ELECTRICAL POWER	5.82	8.40
• ACS	3.42	5.53
PLATFORM	(50.62)	(20.74)
• STRUCT/MECH	37.92	9.48
• POWER DISTRIBUTION	3.55	2.21
• PROPULSION	4.14	1.08
• ACS	5.00	5.00
• COMM ANT (WB COMM)	0	.03
• DOCK RINGS (2)	0	2.94
ROTATING BOOM/MANIP	(41.36)	(17.42)
• STRUCT/MECH	22.64	5.66
• PWR DISTRIBUTION	5.97	3.72
• MANIP/CARRIAGE	0	3.46
• TRAVELLER	4.51	.78
• ROTARY JOINT	8.25	3.80
SOLAR ARRAY	(23.04)	(79.34)
• STRUCT/MECH	.69	1.52
• SOLAR BLKTS/DEPL MECH	18.81	76.69
• PWR DISTRIBUTION	3.54	1.13
TOTAL SUBSYSTEMS	(128.13)	(136.35)
PROGRAM MANAGEMENT	15.36	11.97
SYSTEM ENGR & INTEGRATION	12.68	12.35
GSE	12.81	.90
SUBTOTAL	330.55	
SHUTTLE COSTS	58.5	
TOTAL	389.05*	

* Initial Spares Excluded

Figure 1-7 Basic OCDA Costs

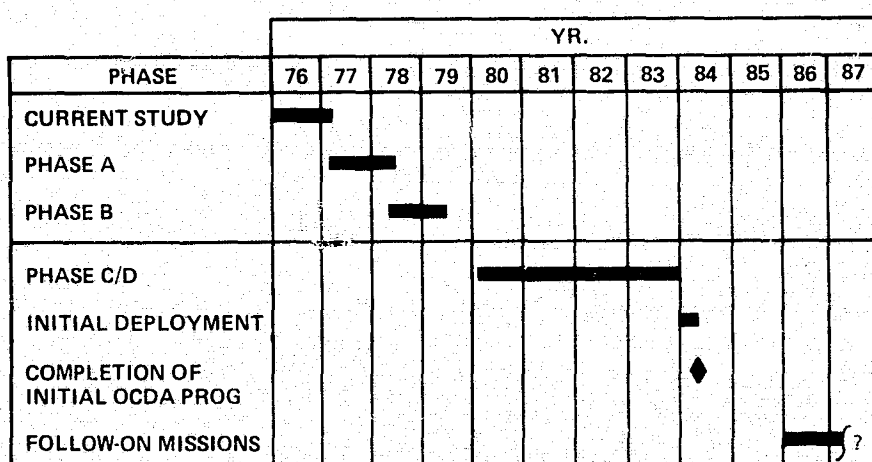


Figure 1-8 OCDA Program Planning Schedule

were not addressed because they are being adequately covered in Boeing's Solar Power Satellite System Definition Study at JSC.

The following program scenarios were addressed:

- Program Scenario 1 - Construction of a 2 MW photovoltaic SPS pilot plant
- Program Scenario 2 - SPS technology advancement through element testing at the OCDA (OCDA is the pilot plant)
- Program Scenario 3 - Large antenna prototype construction.

The schedules for the three programs are shown in Figure 1-9. The major difference between Program Scenarios 1 and 2 is that Program 1 uses the OCDA platform to construct an independent 2 MW SPS pilot plant while Program 2 utilizes the OCDA as the pilot plant. Program 3 emphasizes the use of the OCDA to construct a large 100-m diameter radiometer and a 61-m diameter multi-beam communications antenna.

The cost and mission suitability (% demonstration objectives met) are summarized on Figure 1-10 for the three program scenarios discussed above. The demonstration objectives identified in the initial nine-month study were used as the basis of comparing mission suitability. It was estimated that Program 1 meets a higher percentage of SPS related objectives than Program 2 mainly because the size of the 2 MW pilot plant constructed in Program 1 provides a basis for higher confidence in construction technologies needed for the ultimate Solar Power Satellite. Program 1, however, is 32% higher in total program cost (including OCDA costs) than Program 2 and 54% higher than Program 3. Program 3 meets a high percentage of demonstration objectives related to antenna construction but does not significantly advance technologies for all future large structures and is found to be as high in program cost as Program 2 for advancing SPS technology.

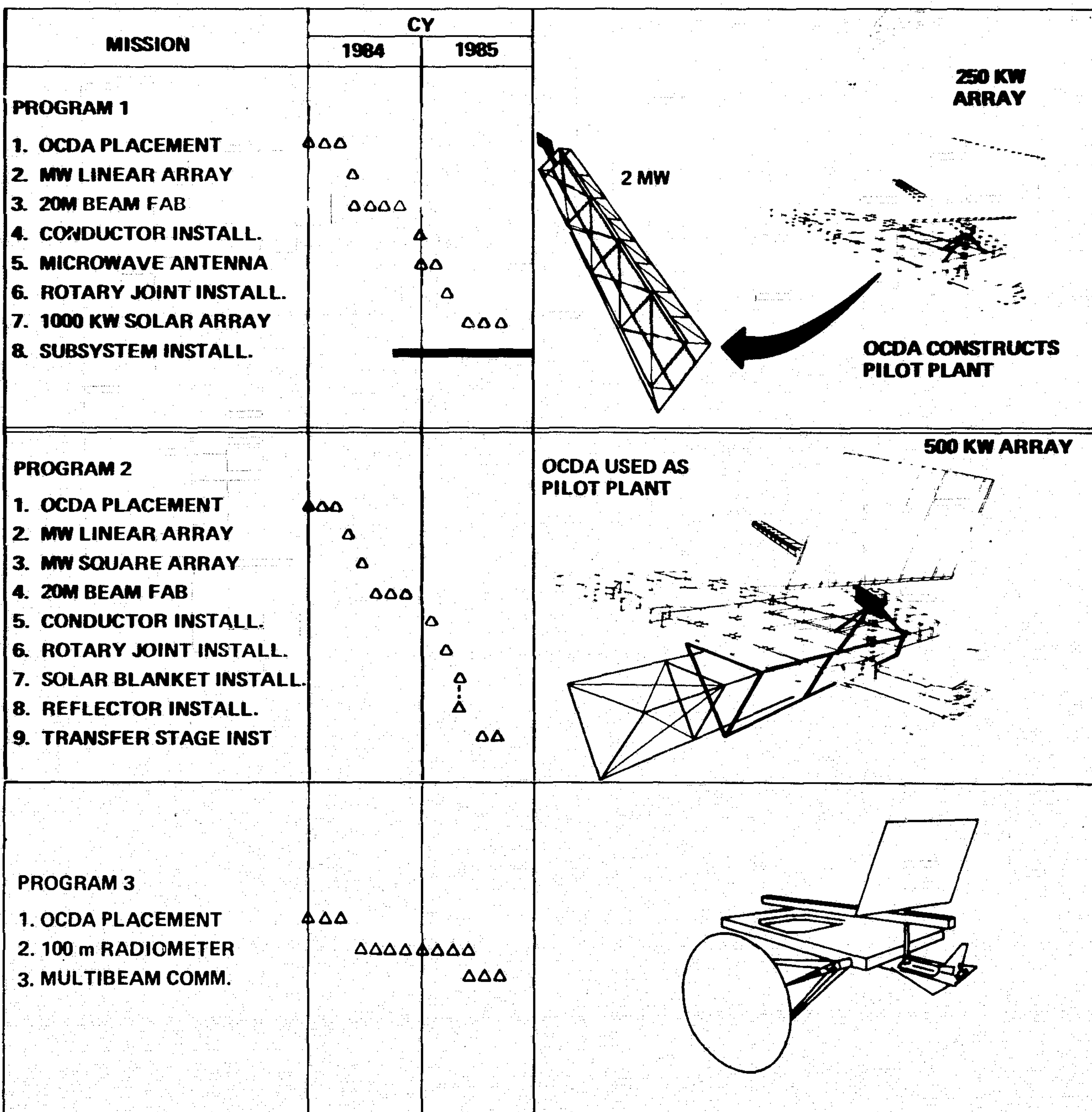


Figure 1-9 Program Scenario Options Studied to Date

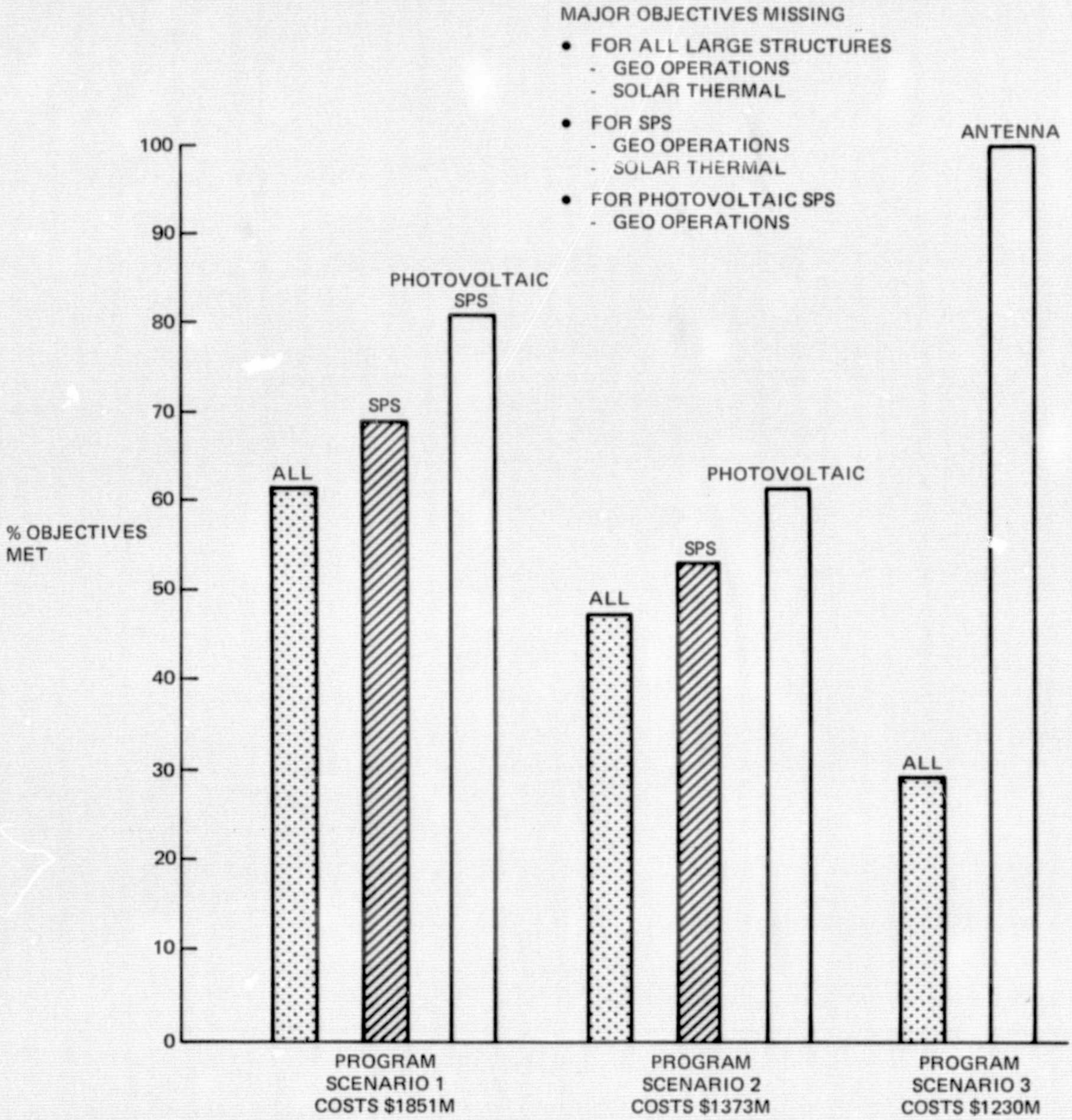


Figure 1-10 Percent Objectives Met

Section 2

REQUIREMENTS FOR CONSTRUCTION DEMONSTRATION

The Orbital Construction Demonstration Study effort was directed toward definition of the requirements that future Spacecraft utilizing ultra-large structures impose on near-term construction technology. The approach used during the first task (see Figure 1-2) was to identify and describe potential large structures by reviewing future missions. A few representative missions were then selected for the purpose of delineating construction issues. The issues were studied to determine a near-term orbital demonstration program that would provide sufficient confidence in the state of technology to start development of these future missions. Those issues requiring orbit demonstration were embodied into several programs of varying cost and complexity and a program selected that met a high percentage of demonstration objectives, had reasonable cost, and offered potential for continued usage as a construction technology test facility.

The point of departure for selection of representative future missions was a data base provided by such documents as the "Outlook for Space" and The Aeroscope Corporation's "Study of the Commonality of Space Vehicle Applications to Future National Needs" (ATR-5 (7365)-2). To ensure that the sample of representative future missions was reasonably balanced, space programs were divided into seven general classifications for study, namely:

- Communications
- Navigation
- Earth Observation
- Energy Systems
  - Generation
  - Transmission
  - Power Relay
- Radio Astronomy
- Illumination
- Space Colonization

In all, 40 future missions were reviewed. This number was reduced to 10 candidates, Figure 2-1, by eliminating those concepts that did not require space construction for deployment or to achieve required structural accuracy. The exception to this criteria was in the field of navigation and space colonization where the concepts were not sufficiently defined or considered too far in the future to benefit from a near-term demonstration program. A further reduction in candidate representative missions was made by eliminating systems whose requirements are embodied by other systems. This step eliminated the

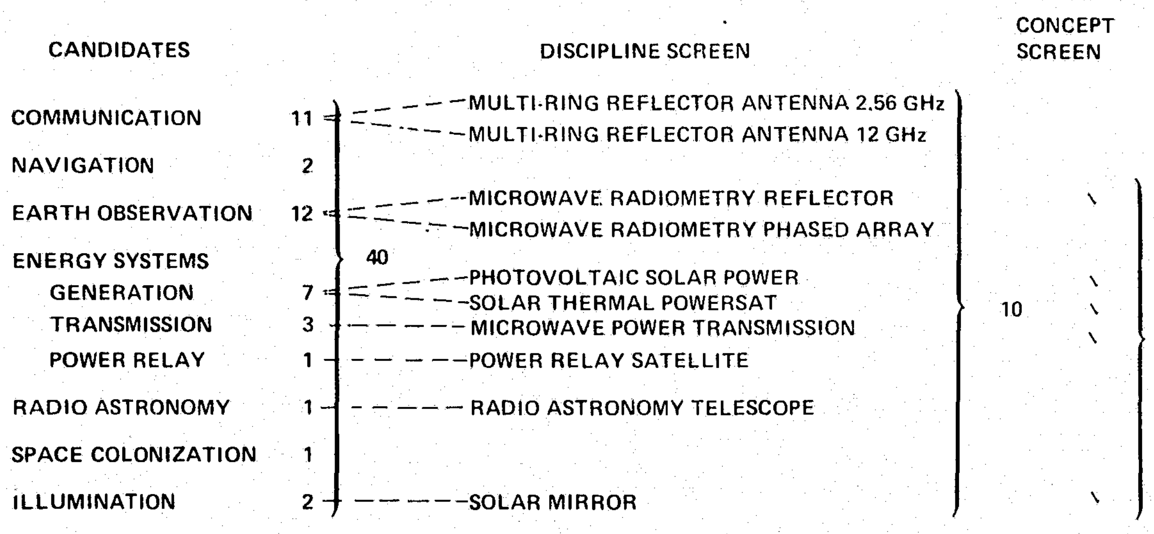


Figure 2-1. Representative Mission Screen

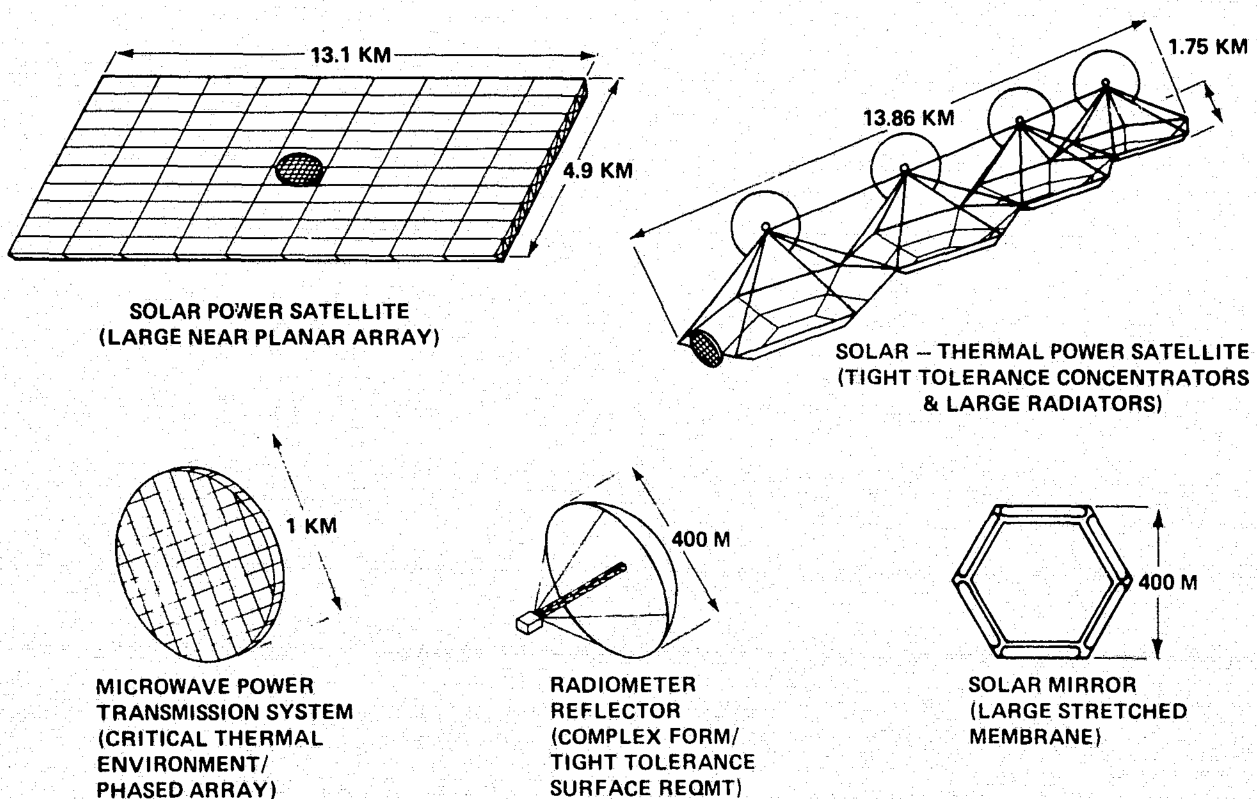


Figure 2-2 Recommended Representative Structures

communications antennas and radio astronomy antennas in that their requirements were embodied in those of the radiometer and power transmission system phased array.

The remaining five representative structures, Figure 2-2, were studied for technology requirements and categorized into 12 problem areas needing orbital construction demonstration and test.

2.1 DEMONSTRATION/TEST OBJECTIVES

Seventy-six demonstration/test objectives were identified for the structures shown in Figure 2-2. Delineation of these objectives can be found in Volume III of this report. The topic for each of these objectives is listed in Figure 2-3 with a numerical weight assigned to each area that indicates the need for an orbital demonstration. Figure 2-4 provides the scale and criteria used to assign the demonstration need weight. The status of technology, hardware availability and ground test potential were considered in assessing the benefits an orbital demonstration would have to the solution of a given construction problem.

A typical factor considered in determining the applicability of ground demonstration to meeting objectives is summarized in Figure 2-5. The large size and light weight of typical space structure complicates ground handling. The beams allowable loads would be exceeded during simple logistics movements of the hardware. Simulation of zero-g for as large a structural element needed in future missions was found to be difficult and potentially costly using existing neutral buoyance facilities.

Analysis and design methods development also need the data space construction demonstrations can provide. The analytical techniques for modelling large flexible structures can be refined as test information from orbital demonstration becomes available. The long-period dynamic response to thermal excitation is a problem identified that needs orbit verification tests of analytic methods. More precise approaches for modelling gravity gradient forces and moments using series expansion techniques could be verified through orbit demonstration.

Assessment of construction productivity of man and machine is needed by the mission planner to accurately schedule the construction of future spacecraft. An orbit demonstration would verify and fine-tune the data accumulated in ground simulation. This is particularly true for the installation of subsystems and associated secondary structure. Methods for handling installation of propulsion units used for attitude control is an example of an assembly procedure development that would benefit from an orbit demonstration program.

PROBLEM AREA	DEMO/TEST OBJECTIVE	DEMO NEED WEIGHT
STRUCTURES	1) BUILDING BLOCK STRUCT FAB AND/OR DEPLOY	6
	2) JOINT ASSEMBLY PROCEDURES	8
	3) MAN/MACHINE/INTERACTION	8
	4) LARGE ELEMENT MATING	9
	5) SECONDARY STRUCTURE INSTALLATION	8
	6) MEASURE PRODUCTIVITY	6
	7) ATTITUDE CONTROL DURING CONSTRUCTION	7
	8) THERMAL CYCLING DURING CONSTRUCTION	6
	9) ACCURACY & INTEGRITY TESTS	8
	10) STRUCTURAL REPAIR	7
	11) STRUCTURE/CONTROL/INTERACTION	7
SOLAR ARRAY	1) CONSTRUCTION & DEPLOYMENT	8
	2) LOW COST, HIGH EFFICIENT SPACE FAB BLANKET	8
	3) ARRAY TO STRUCT INSTALLATION	7
	4) CONCENTRATOR INSTALLATION	7
	5) THERMAL CYCLE	6
	6) FAULT ISOLATION & REPAIR	7
POWER DISTRIBUTION	1) INSTALL INTEGRATED STRUCTURE/BUS SYSTEM	6
	2) INSTALL DEDICATED SYSTEM WITH SWITCH GEAR & CIRCUIT PROTECTION	8
	3) INSTALL STORAGE SYSTEM	5
	4) INSTALL POWER CONDITIONING UNITS	7
	5) INSTALL ROTARY POWER TRANSFER DEVICE	8
	6) HI VOLTAGE OPERATION	8
	7) LEAKAGE PREDICTION	7
	8) FAULT ISOLATION & REPAIR	7
POWER TRANSMISSION	1) DC TO RF CONVERSION IN STEPS	8
	2) INTEGRATED PROOF-OF CONCEPT	10
	3) THERMAL CYCLING TESTS ON WAVE GUIDES & PHASE CONTROL	6
	4) IONOSPHERE TESTS	4
	5) GEO PERFORMANCE (HI VOLTAGE & START)	8
	6) LIFE TESTS	4
	7) DEMO TRANSMISSION TO GROUND	8
PROPULSION	1) INSTALL PROPULSION UNIT FOR ATTITUDE CONTROL & STATION KEEPING	7
	2) VERIFY EFFECTS OF EXHAUST PRODUCTS	3
	3) FAULT ISOLATION & REPAIR	5
STABILIZATION & CONTROL	1) CONTROL OF LARGE FLEXIBLE BODIES USING CENTRALIZED & DISTRIBUTED SYSTEMS	7
	2) SURFACE CONTOUR CONTROL	8
	3) POINT 1 LARGE MASS RELATIVE TO 2ND	7
	4) STATIONKEEPING	5
	5) FAULT ISOLATION & REPAIR	4

PROBLEM AREA	DEMO/TEST OBJECTIVE	DEMO NEED WEIGHT
REFLECTOR MIRROR FACETS	1) PLACEMENT & INSTALLATION	9
	2) POINTING & CONTROL ON FLEXIBLE BODY	10
	3) FAULT ISOLATION & REPAIR	7
RADIATORS	1) POSITIONING & ASSEMBLY OF RADIATOR ELEMENTS	8
	2) CONSTRUCT GAS TIGHT JOINTS	6
	3) FAULT ISOLATION & REPAIR	4
THERMAL CAVITY	1) POSITIONING & ASSEMBLY	8
	2) GAS TIGHT JOINTS	6
	3) CAVITY PERFORMANCE THROUGH CONSTRUCTION	8
	4) CONTROL WITH ROTATING MACHINERY	8
LARGE MIRROR SURFACE	1) POSITIONING & ASSEMBLY	8
	2) CONTOUR CONTROL	8
	3) EFFICIENCY MEASUREMENT	5
	4) LIFE TESTING	4
ASSEMBLY OPERATIONS	1) INITIAL PLACEMENT OF CONSTRUCTION PLATFORM	8
	2) SITE LOGISTICS	7
	3) RESUPPLY & STORAGE	6
	4) HABITATION	4
	5) SITE COMMUNICATIONS	5
	6) SITE LIGHTING	5
	7) RADIATION SAFETY (GEO)	6
	8) PRODUCTIVITY GOALS	8
	9) REMOTE CONTROLLED MANIPULATORS	7
	10) SPACE FABRICATION (AUTO ASSEMBLY)	8
	11) USE OF EVA	6
	12) MAINTENANCE OF CONSTRUCTION EQUIPMENT	6
PROCESSES	1) FASTENER OPTIONS (WELD, BOND, ETC)	7
	2) FAB IN METALLICS & NON METALLICS	6
	3) VAPOR DEPOSITION FOR REPAIR	8
MISSION OPS	1) COMMUNICATIONS	5
	2) REMOTE CONTROL FROM GROUND	8
	3) MISSION PLANNING	4
ANTENNAS	1) RIB STRUCTURE FABRICATION	6
	2) ACTIVE CONTOUR CONTROL	8
	3) WIRING INSTALLATION	5

Figure 2-3 OCDA Mission Objectives

	DEMO NEED WGT.									
	1	2	3	4	5	6	7	8	9	10
TECHNOLOGY	FULLY DEVELOPED & SPACE QUAL'ED		PARTIALLY DEVELOPED & PLANNED FOR SPACE DEMO IN NEAR TERM		KNOWN BUT NOT DEVELOPED & WOULD BE AUGMENTED BY SPACE DEMO		NOT KNOWN BUT CHANCE OF BECOMING KNOWN GOOD IF SPACE DEMO USED		NOT KNOWN, SPACE DEMO MANDITORY TO FINDING SOLUTION	
HARDWARE	OFF-THE SHELF OR PROTOTYPE AVAILABLE WITH REQ'D FUNCTION & PERFORMANCE		FUNCTIONALLY EQUIVALENT HARDWARE AVAIL NEEDING MODIFICATION		FUNCTIONALLY EQ'V. HARDWARE BEING DEVELOPE. DEVELOPMENT NEEDING ORBIT VERIFICATION		NO HARDWARE IN USE – NEEDS SPACE DEMO DATA INPUT		HARDWARE NOT AVAILABLE UNLESS BREAKTHROUGH ACHIEVED VIA SPACE DEMO	
GROUND TEST	CAN FULLY BE ANSWERED BY GROUND TEST		DESIRABLE TO HAVE GROUND TEST AUGMENTED WITH FLT TEST		HIGHLY DESIRABLE TO HAVE GROUND TEST AUGMENTED WITH FLT TEST		MANDITORY TO HAVE GROUND AUGMENTED WITH FLT TEST		ONLY FLIGHT TEST WILL GIVE ANSWER	

Figure 2-4 Space Demonstration Value Criteria

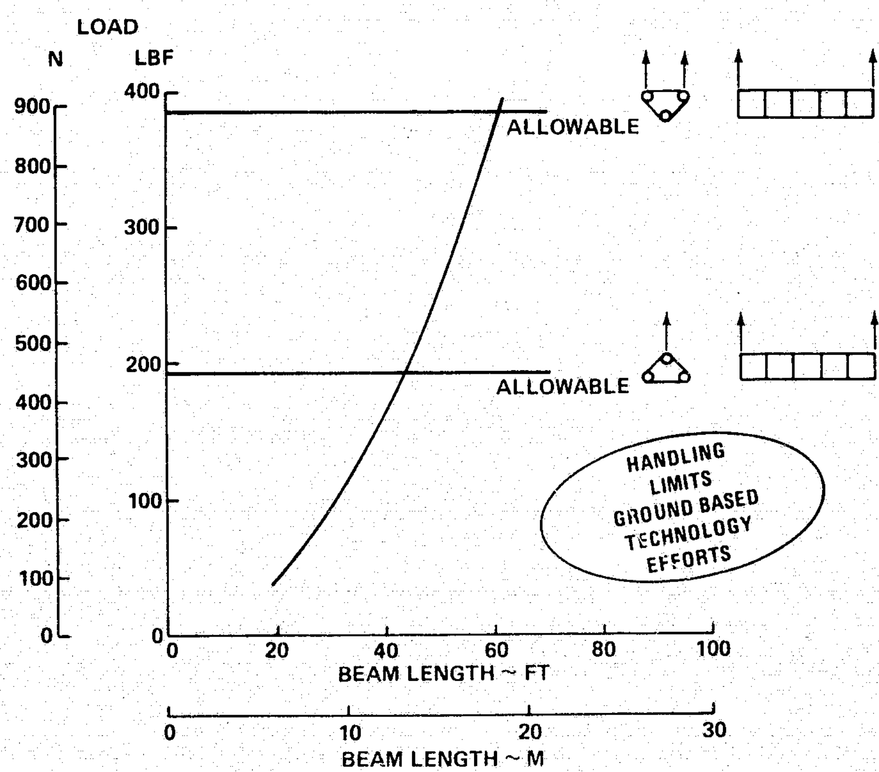


Figure 2-5 Ground Handling Limitations on Typical Space Beam

Of the 76 problem areas identified, the demonstration need weight for 46 ranked seven or above (Figure 2-3). Space experimentation of construction technique and structural approaches is a necessary endeavor to verify, in the total operational environment, along with the operations and structural technology needed to deploy and assemble large structures in space.

2.2 CONSTRUCTION APPROACH

The five representative future missions were studied functionally for construction problems, and one, the Microwave Power Transmission System (MPTS) antenna, was studied in detail to determine near-term construction demonstration requirements. The data base on the MPTS is greater than other configurations identified. The work performed by Raytheon/Grumman on the basic antenna design and the assembly studies performed by Martin provided a good point of departure for penetration into construction issues.

The basic approach was to first study construction techniques for the structure, considering different support equipment and structural approaches. The construction base showing the most potential was used to analyze subsystem installation, fabrication approach, logistics requirements and habitation needs.

As a means of assessing the quality of construction approaches, a study was done to determine the productivity requirements for assembly of the SPS. Consideration was given to such parameters as construction base costs, crew rotation policy, and Shuttle crew transport capability. Figure 2-6 is a plot of the relationships between SPS construction cost ($/kW) and the $/manhour that can be allocated given a production rate (kg/manhour). It was found that construction base costs have a significant impact on productivity requirements. At a base cost of $20 x 10^6/man, (amortized cost of $7.25 x 10^6/manyear) an average productivity of between 40 and 100 kg/manhour (LEO assembly or 60 to 110 kg/manhour (GEO assembly)) would be required to meet SPS cost targets of 75$/kW. This suggests that a compromise between the level of automation and the capital cost of construction equipment is needed. High production rates are not the only consideration in achieving cost effective power from space.

Figure 2-7 presents an overview of four construction options studied for MPTS assembly. The first is the Martin "Post Walker" approach in which a set of equipments, including two manipulators, is supported on bases attached to the antenna vertical posts. After completing one structural cube (18 x 18 x 25 m) the manipulator base is swivelled or "walked" to the just-completed set of vertical posts. The second approach uses a construction jig, which is a beam 830-m long and 24-m deep, that contains 46 sets of

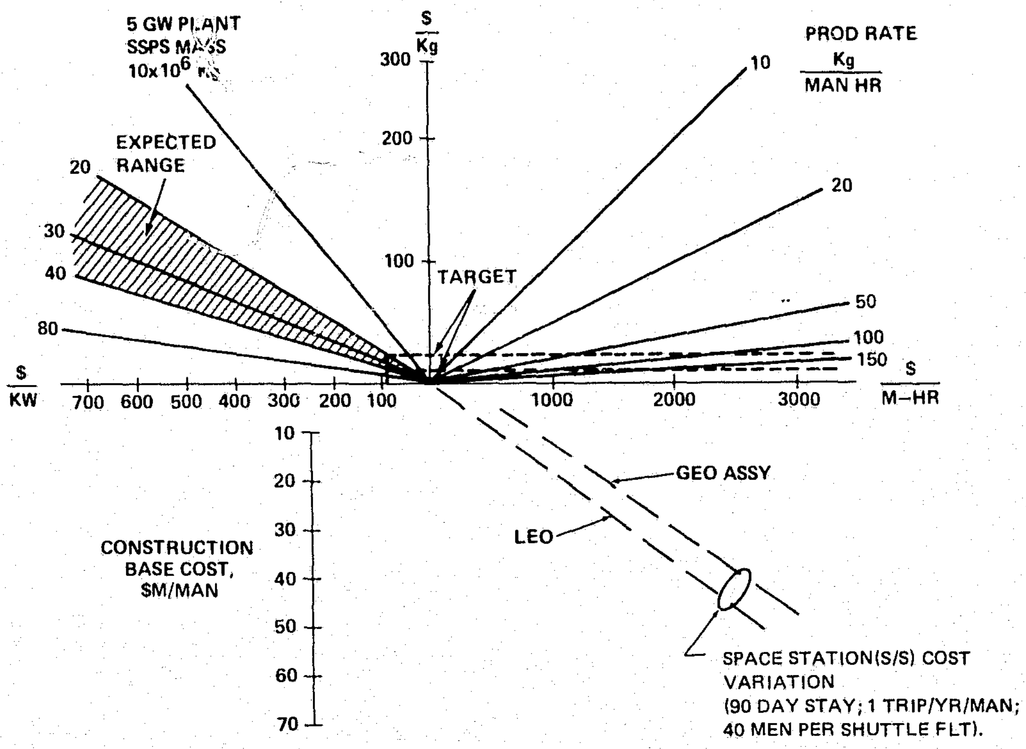


Figure 2-6 Productivity Relationships

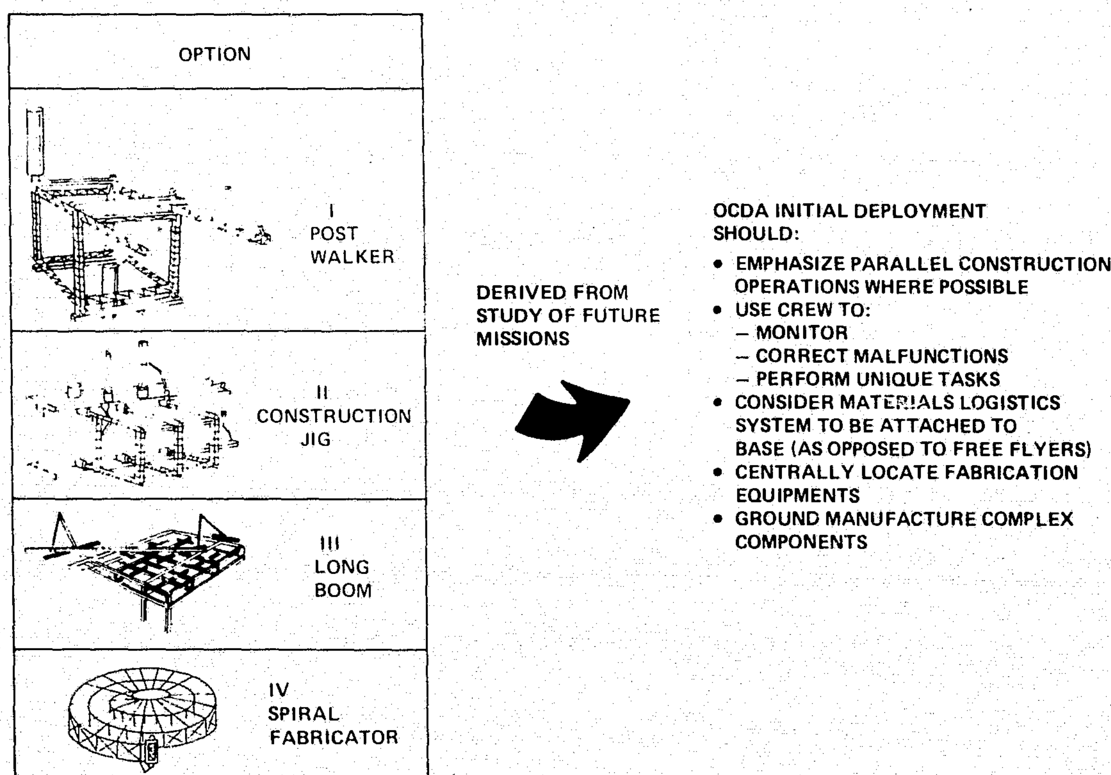


Figure 2-7 Guidelines Used for Selection of Assembly Techniques for Initial OCDA Deployment

manipulators and construction equipments. This approach facilitates parallel production of an entire row of antenna structure. The third approach uses a "long boom" attached to a centrally located base. Equipments for construction are mounted to the "long boom" for access to the immediate assembly location. The fourth approach utilizes a travelling fabrication unit which forms a continuous spiral, 25-m deep circumferential and periodically installs spacers (radial elements) to build up a spoke structural arrangement.

Option II, the construction jig, showed the greatest potential for meeting productivity requirements of the MPTS, though more analysis and base definition is needed to determine capital costs of the base. Because of this potential, the construction jig was then used to assess secondary structure assembly, subsystem installation, logistics requirements and crew size.

The study of construction techniques led to the following general conclusions for future ultra-large structure assembly:

- Emphasize parallel construction operations where possible.
- The crew should be used to monitor, correct malfunctions, perform unique installations and repair automated machinery.
- The logistics system for moving materials around the construction base should be attached to the based structure. Devices like long-rotating booms were used for this function.
- The structure should be space-fabricated in a centrally located facility to reduce capital costs.
- Complex, close tolerance components, such as the MPTS microwave subarrays, should be ground manufactured.

These principals where used to formulate concepts for the near-term OCDA program. The demonstration article should assess, either during initial OCDA construction or as part of the follow-on experiment, mass production techniques, attached logistics for materials handling, and complex tight tolerance subsystem installations. The OCDA should represent a scaled down version of the basic structure for mounting automated equipments and provide the power, stabilization and materials handling facilities to enhance technology experiments that lead to the ultimate construction base makeup.

2.3 BUILDING BLOCK STRUCTURE AND JOINTS

Once the top level construction approach groundrules were established, a study of building block structure and joints was made to select a family of options for demonstration on the OCDA, either in the initial deployment or as follow-on experiments. This study concentrated on the study of deployable beams and the work performed by Grumman under contract NAS8-31876, "Space Fabrication Techniques Study Program," used as the data base for the definition of space fabricated beams and associated equipment. The centroidal joint and lap joint were studied in terms of ease of construction, and mass as it applies to future mission applications.

Figure 2-8 summarizes the result of an industry search of prepackaged deployable structures. After an initial screening of 12 candidates, seven concepts were selected for further evaluations:

- A2 - The Martin folded beam concept allows the upper longeron and frames to lie flat against the two lower longerons.
- A6 - A coilable lattice astromast whose continuous longerons are coiled to stow the configuration.
- A7 - Rockwell International's "Y" shaped girder concept, consisting of three webbed beams hinged to a central shaft for stowing. The outer tubular beam caps (3) culminate at each end of the girder to an integral end coupling.
- A9 - An articulated lattice astromast which consists of rigid triangular battens and longeron sections which pivot at each bay for stowing.
- A10 - Grumman's building block configuration, a double-folded beam designed to achieve a minimum stow volume. The frames (battens) and longitudinal members are foldable. The deployed structure is rigidized by two locked telescoping diagonal members.
- A11 - The Boeing Warren-trussed triangular beam. The rigid frames provide pivots at their apex to allow the adjacent frames to stow. The longitudinals are hinged at their midspan and pivot at each frame to allow them to stow between the folded frames.
- A13 - Grumman's continuous longeron, batten foldable beam.

Each prepackaged deployable structure candidate was configured to a 1.5-m deep x 23-m long trussed beam. Each concept was then sized for an end column compression load

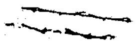
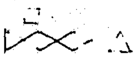
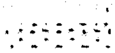
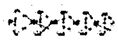
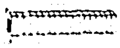
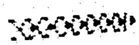
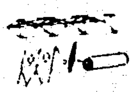
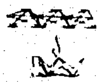
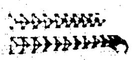
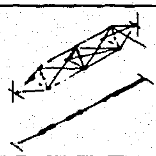
CONCEPT	SCHEMATIC	COMMENTS	RECOMMENDATION
A-1 FOLDED BEAM		• EFFICIENT STRUCTURE • HEAVY DUE TO PULLEYS, CABLES AND LATCHED JOINTS • LOW PACKAGING DENSITY	• REJECT
A-2 FOLDED BEAM COLLAPSED √		• GOOD STRUCTURAL CONCEPT • HEAVY DUE TO THE NUMBER OF PYROTECHNICS REQUIRED TO LOCK THE TELESCOPING DIAGONAL • FAIR PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-3 LAZY-TONGS		• FLEXIBLE STRUCTURE • LOW LOAD CARRYING CAPABILITY • HIGH PACKAGING DENSITY	• REJECT
A-4 THREE AXIS LAZY TONG		• POOR STRUCTURE • LOW BENDING & TORSIONAL STIFFNESS • HIGH PACKAGING DENSITY	• REJECT
A-5 EXTENSIBLE TRUSS		• LOW TORSIONAL STIFFNESS • HEAVY SINCE LAZY TONGS ARE BASICALLY INEFFICIENT COLUMN MEMBERS • HIGH PACKAGING DENSITY	• REJECT
A-6 COILABLE LATTICE √		• HEAVY SINCE LONGITUDINALS ARE SOLID COIL SPRING MEMBERS FOR COILING • MATERIALS APPLICATION MAY BE LIMITED • GOOD PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-7 FOLDED SPACE GIRDER √		• INEFFICIENT COLUMN MAY BE HEAVY • RIGGING FOR ALIGNMENT COMPLEX • FAIR PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-8 BOX BELLOWS		• CLOSED SECTION MAY BE THERMALLY UNDESIRABLE • HIGH PACKAGING DENSITY	• REJECT
A-9 ARTICULATED LATTICE √		• EFFICIENT BEAM • HEAVY DUE TO COMPLEXITY AND NUMBER OF JOINTS • GOOD PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-10 DOUBLE FOLDABLE √		• EFFICIENT STRUCTURE • HEAVY DUE TO COMPLEXITY & NUMBER OF HINGED JOINTS • HIGH PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-11 FOLDED-BEAMS COLLAPSED √		• EFFICIENT BEAM • HEAVY DUE TO LARGE NO. OF HINGED AND LATCHED JOINTS • HIGH PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-12 TRIANGULAR WIRE		• NO DIAGONAL BRACING, LOW SHEAR STIFFNESS • EULER BUCKLING MAY BE LOW • HIGH PACKAGING DENSITY	• REJECT
A-13 GRUMMAN CONTINUOUS LONGERON		• GOOD STRUCTURAL CONCEPT • CONTINUOUS LONGERONS ELIMINATE STRUCTURAL DEAD BAND RESULTING FROM JOINT CLEARANCES • GOOD PACKAGING DENSITY?	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE

Figure 2-8 Summary of Prepackaged Deployable Structures

of 576 lb ultimate at a temperature of 100°F. Tubes of 0.015 minimum gage, 2219 aluminum alloy was used for the structural element of each concept with the exception of the coilable astromast which uses S-glass. Figure 2-9 presents the relative merit of the candidates as to weight, packaging volume and launch costs. The astromast concepts A6-2 and A9-1 require the least launch dollars when utilizing the Heavy Lift Launch Vehicle (HLLV), and concept A9-2, the articulating lattice astromast, and Grumman's A10 and A13 concept requires the least Shuttle launch dollars.

A space beam fabrication approach was then compared with concept A-13 for application to a near term OCDA which requires in the neighborhood of 1000 to 2000 m of 1-m deep beams. Figure 2-10 summarizes this comparison. The maximum amount of deployable structure that can be carried in the Shuttle cargo bay is limited by volume rather than mass. A total of 8944 m of deployable structure, with two supporting pallets, can be carried. The amount of space-fabricated structure that can be carried is limited by the Shuttle cg envelope. A maximum of 18,340 m of space-fabricated structure and the associated machinery can be delivered.

Although the study trends indicate that space-fabricated structure is very beneficial for constructing the ultimate future mission structure (specifically the SPS) the small amount of structure required by an OCDA size demonstration may not warrant the approach. If we do not fabricate the initial OCDA, the platform can be used to demonstrate space fabrication during follow-on missions. The key decision to be made then is to determine if demonstrating space fabrication techniques on the initial construction of the OCDA is a valuable technology contribution to justify the added cost, or is it sufficient to wait until the OCDA platform is constructed using deployables before space-fabrication experiments are performed. This study opted for the more conservative approach of utilizing deployables for initial OCDA construction and to perform space-fabrication concepts during follow-on OCDA experiments.

A typical triangular building block beam and two basic joining methods (the lap and the butt (centroidal) joint) for assemblies of one cap member and two posts is shown in Figure 2-11. A lap joint is defined as any joint where load lines or centroids do not intersect at a common point and thereby produce a moment into the joint. A centroided joint is defined as one where all load lines intersect and balance at a common centroidal point.

Criteria used for evaluating candidate joints include methods of attachment (weld, bond or mechanical); ease of alignment and possibility of realignment; joint integrity which includes reliability, producibility and quality control requirements. Unique requirements

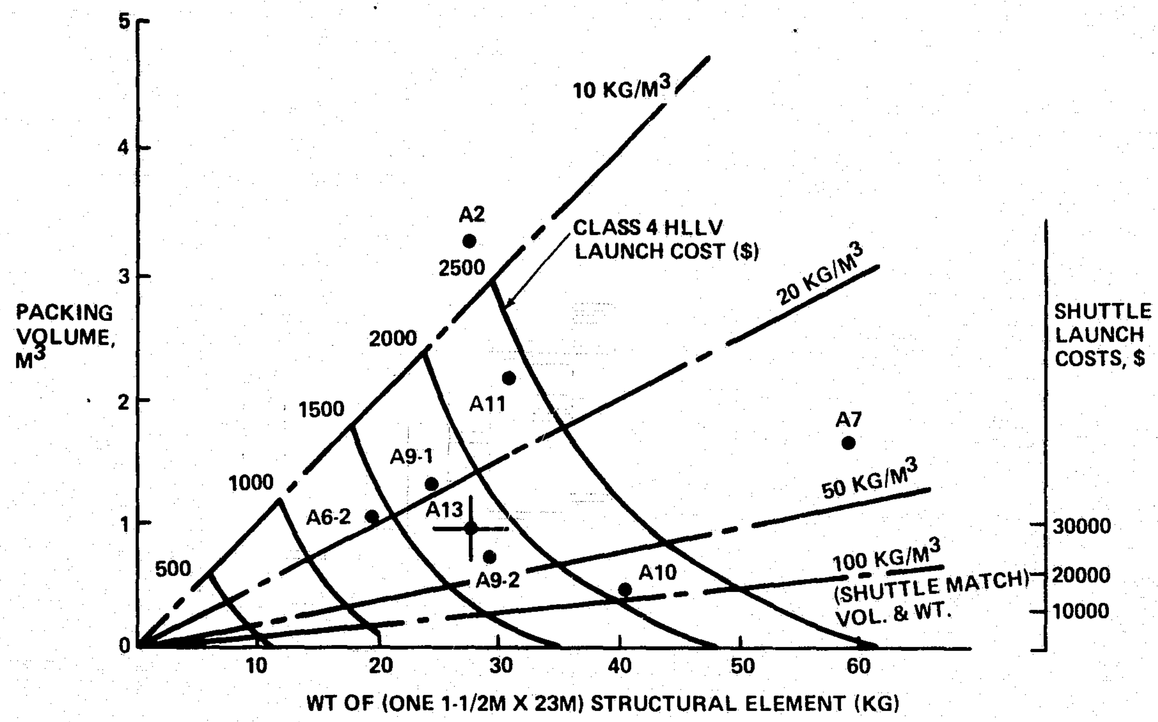


Figure 2-9 Concept Ranking—Weight, Volume and Launch Costs

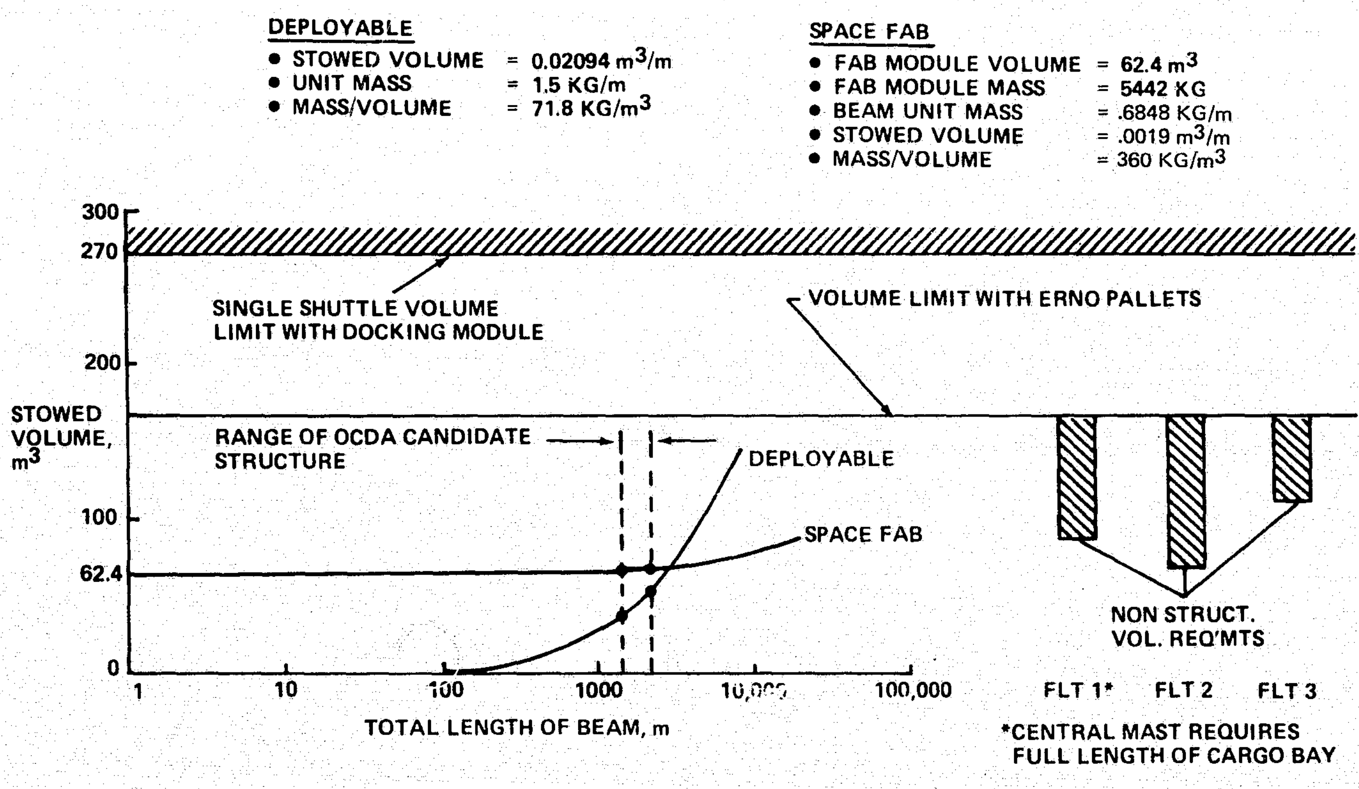


Figure 2-10 Deployable vs Space Fabrication

such as electrical conducting or isolated structural joints must also be eventually evaluated. The productivity of the joining systems which relates number of joints per unit time to cost will be a function of the degree of automation and modular design employed. After analysis of the two joint concepts, the centroidal joint was recommended for use in future missions and adopted for the OCDA design approach. Further technology level efforts are needed to come to a final understanding of this important tradeoff.

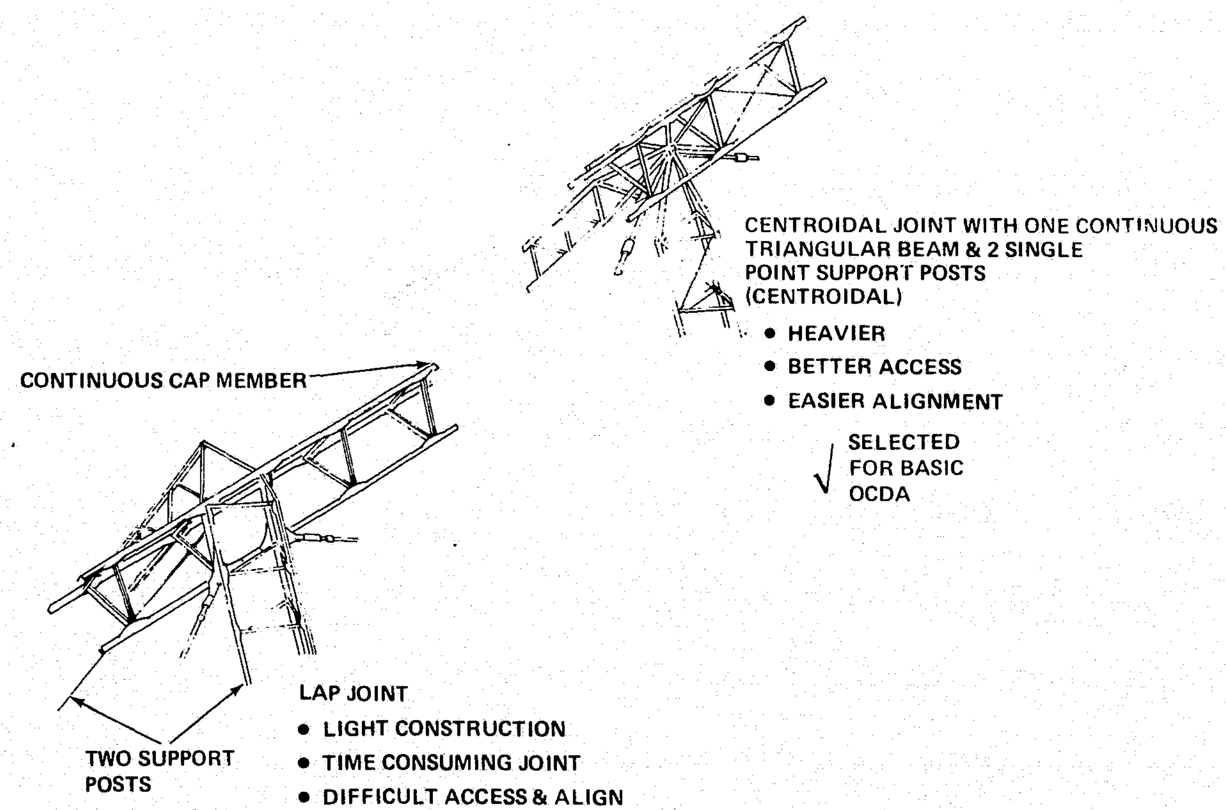


Figure 2-11 Candidate Joint Approaches

Section 3

ORBITAL CONSTRUCTION DEMONSTRATION ARTICLE CONCEPTS EVALUATED DURING INITIAL STUDY

This section summarizes the rationale for selecting a multipurpose construction facility as the near-term demonstration article (initial nine-month study). The initial nine-month study utilized the demonstration objectives identified by studying future large structures missions to formulate two basic OCDA concepts: one that utilized the OCDA as a general purpose Shuttle-tended construction base, and the second, a Solar Power Satellite pilot plant that doubles as a construction base. The general purpose construction base was selected based on cost effectiveness and low risk. The OCDA selected in the initial study was used as a baseline vehicle for the add-on effort which defined three follow-on program scenarios to determine their impact on the basic OCDA design.

The description of the two basic OCDA programs evaluated during the initial nine-month study are summarized in Figure 3-1. Each program was evaluated for one growth mission giving four concept options that span a range in complexity and potential cost. The first option, part of concept 1, is designed to assemble a multipurpose construction demonstration base which is used to perform basic technology and operations experiments associated with construction of large structures in space. The second option tests the growth potential of Concept 1 by utilizing the construction base to assemble a 100-m parabolic antenna. Option 3 is the starting point for the second program. It utilizes a large 1 MW solar array to demonstrate the ability to construct a large power source. The fourth option is the growth version of Option 3 (Concept 2). A microwave power transmitter antenna is added for purposes of a "proof-of-concept" for SPS by transmitting power to the ground with 10 kW output power. These options were studied in more detail during the add-on study with results discussed in Section 6.

3.1 CONCEPT 1 - GENERAL PURPOSE CONSTRUCTION BASE

Figure 3-2 is a conceptual drawing of a stand alone multipurpose demonstration article. The configuration is composed of twenty 8-m x 8-m bays. Each bay is outfitted with fixtures compatible with a Shuttle pallet of experiments and equipments. A large 24-m x 32-m open area is used for demonstrating procedures for mounting solar blankets, thin film

CONCEPT	OPTION	DESCRIPTION	APPROX COST, $M	OBJECTIVES MET
I	1	BASIC CONSTRUCTION BASE WITH 250 KW SOLAR ARRAY	200 TO 400	29
	2	OPTION 1 PLUS BUILDING OF 100 M RADIOMETER	425 TO 675	33
II	3	BASIC CONSTRUCTION BASE WITH 1 MW SOLAR ARRAY	375 TO 600	34
	4	OPTION 3 PLUS BUILDING OF TRANSMISSION ANTENNA FOR SPS PROOF OF CONCEPT	570 TO 880	37

✔ SELECTED AS BASELINE OCDA PROGRAM (CRITERIA - COST EFFECTIVENESS)

Figure 3-1 OCDA Program Options

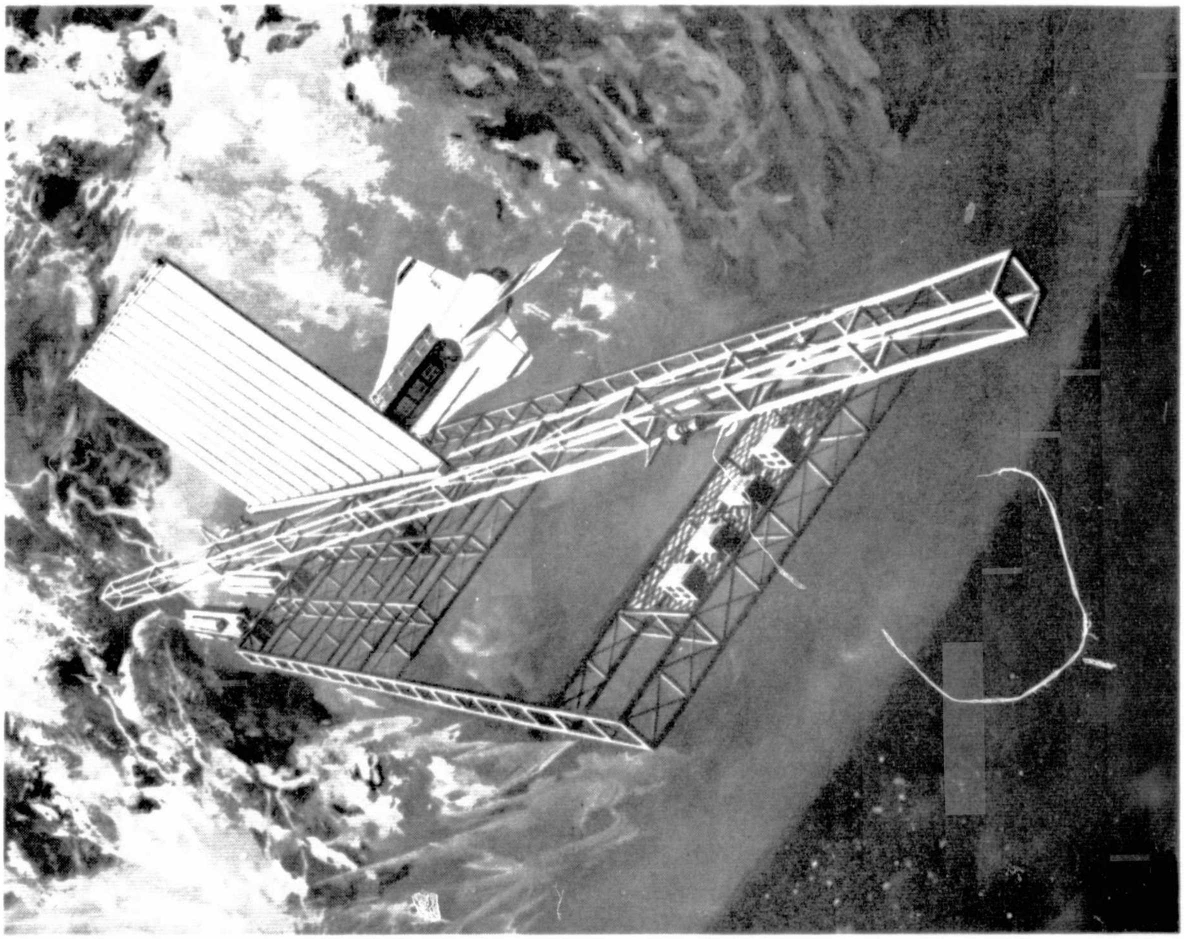


Figure 3-2 Conceptual Rendering of Stand-Alone Multi-Purpose Demonstration Article

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mirror surfaces of wire mesh and receiving rectenna mesh. The large area can be enclosed by a safety net for EVA joint and fastener experiments.

A core module contains the article's subsystems including attitude control, stationkeeping, communications and data handling. A Shuttle-compatible core module docking mechanism is included; additional docking mechanisms are mounted to the periphery of the main structure for materials storage pallets.

A 108-m long boom outfitted with a Shuttle manipulator arm transports equipments and materials on the main structure deck and assists in construction of large beams outside the confines of the demonstration article itself.

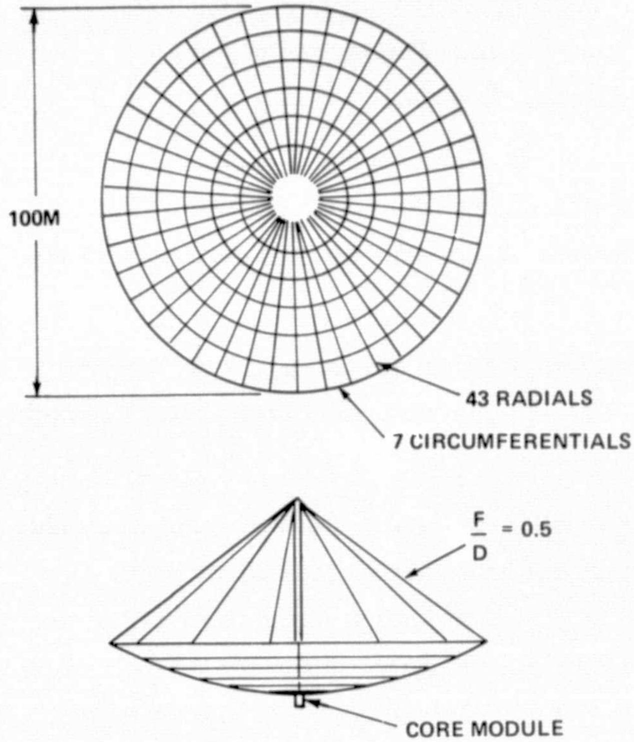
The 250-kW array is composed of 13 modified SEPS roll-up solar cell blankets. This level was selected after a review of OCDA continued utility experiment requirements discussed in more detail in Section 5. Some of the space fabrication simulation follow-on experiments would require as much as 70 kW average power. Accounting for housekeeping power requirements and efficiency of the power distribution system and energy storage systems, 250 kW is approximately the array size needed to perform these experiments.

The characteristics of a 100-m parabolic antenna for use in earth resource observation as a radiometer and radar are summarized in Figure 3-3. This device is typical of the structure that can be built on the multipurpose construction base (Option 1). The antenna mass was scaled from a device presented in a LaRc final report prepared by Astro Research (ARC-R-1008, "Design Concepts and Parametric Studies of Large Area Structures"). The subsystem mass characteristics are derived from a LaRc document "Benefit/Cost Study of Large Area Space Structure" (Contract NAS1-12436).

The antenna structure utilizes 43 radials and 7 rings (circumferentials) to provide a rf wire mesh surface accuracy of $\lambda/10$. The electronics are mounted at the end of a central mast with a length equal to half the diameter of the antenna. The mast is an "Astromast" providing the capability to partially retract and therefore change the focal length of the antenna. Retractable stays from the mast to the edge of the antenna provide added stiffness and contour control.

Figure 3-4 is a conceptual rendering of the OCDA used as a construction base for the 100-m earth resource antenna (Option 2). A hub is placed at the corner of the open bay, along with jigs, for holding the radials placed along the edge of the OCDA.

The antenna is constructed by space-fabricating a radial, inserting it into the hub, fixing the radial to the jig and attaching the circumferentials. The hub is rotated 8.4°.



ELEMENT	MASS ESTIMATE Kg		MASS ESTIMATE LBM	
• ANTENNA	(4130)		(9107)	
– SURFACE MESH		200		441
– STRUCTURE				
• CIRCUMFERENTIALS		230		507
• RADIALS		1,900		4,190
– HUB		600		1,323
– BOOM		200		441
– MECHANICAL SYST		1,000		2,205
• SUBSYSTEMS	(935)		(2062)	
– STRUCTURE/THERMAL CONTROL		200		441
– ATTITUDE CONT (ACS)		40		88
– COMM		200		441
– ELECT POWER		180		397
– DATA MANG (DM)		315		695
• OCDA				
– BASIC	23,500		51,817	
– ADDED JIGS, ETC.	(2,000)		(4,410)	
TOTAL	30,565		67,396	

Figure 3-3 Option 2—Construction Demonstration Article Used to Construct 100-m Antenna

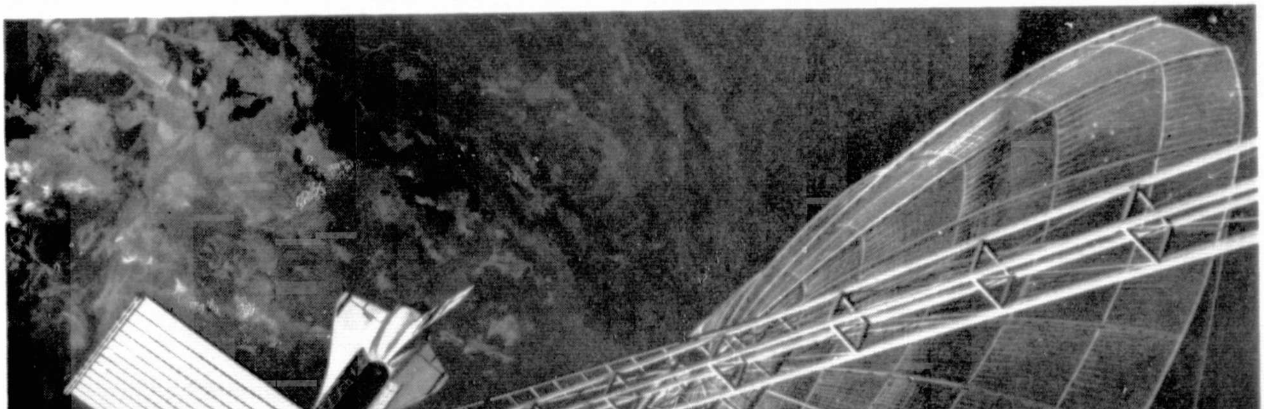


Figure 3-4 Conceptual Rendering of OCDA Used as Construction Base for 100-m Earth Resource Radiometer

The next radial is inserted into the hub and tied to the jig and circumferentials. The mesh is then assembled using the radials and circumferentials as a base. This procedure is repeated until the entire antenna is assembled. More details of this antenna construction can be found in Section 6.

3.2 CONCEPT 2 - SPS PROOF-OF-CONCEPT

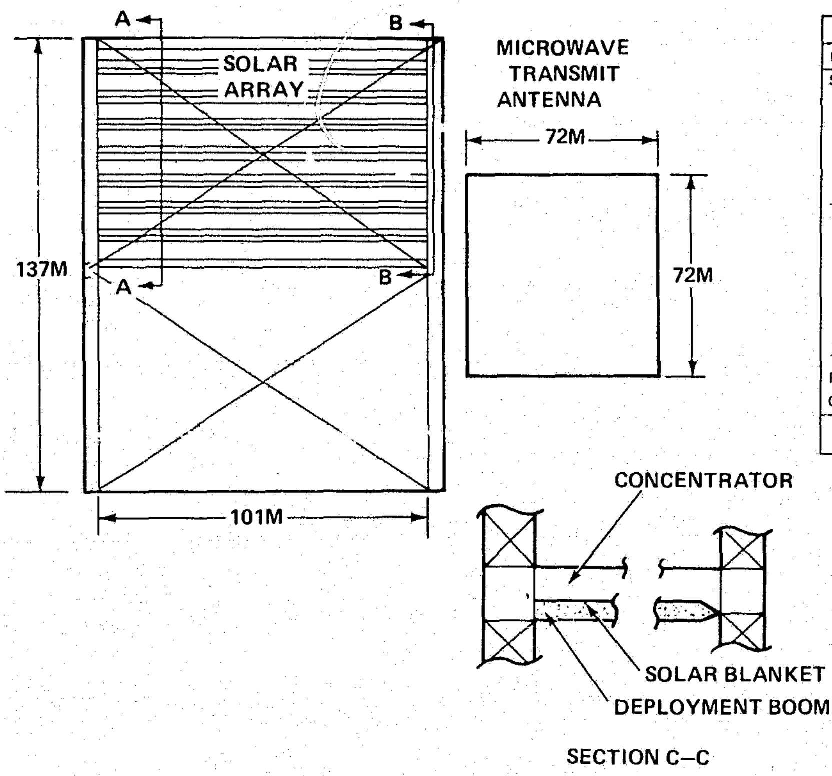
A Photovoltaic Solar Power Satellite Demonstration Article, shown conceptually in Figure 3-5, is a "proof-of-concept" of power generation in space and microwave transmission of the power to a ground-based receiving antenna. The array generates 1 MW of power which is converted to 10 kW at the ground rectenna. The solar array is assembled using SEPS solar blankets modified in length. The configuration uses mirrors to operate at a concentration ratio of 2. The microwave transmitting antenna has an aperture of 72 m while the ground rectenna has a 100-m dimension.

Figure 3-6 presents two relationships used to size the SPS demonstration article. The first shows the relationship between the rectenna efficiency as a function of microwave power input; the second relates dimension of the rectenna to power density on the boresight of the receiving aperture. A rectenna small chip area Si-W element, operating at high impedance and using a Schottky Barrier Junction with low barrier voltage, has the potential to operate at acceptable efficiency levels for a low power level demonstration. Using this rectenna element, it would be possible to generate 10 kW of power using a 100-m to 300-m rectenna.

The relationship between transmitted power and antenna dimensions for two levels of ground output power and rectenna dimension is shown in Figure 3-7. If 10 kW of output power is considered acceptable in terms of demonstrating the feasibility of generating power in space and transmitting the power to ground, a transmitting antenna must be larger than 40 m to avoid excessive support structure temperatures.

The configuration selected for further study assumes a 100-m x 100-m rectenna with an output power of 10 kW. The smaller rectenna size was selected because the size is more in line with the power output for demonstration value. Based on this rectenna output level, the required transmitted power versus the mass of a solar array needed to generate the power is shown in Figure 3-8. A 1 MW array was selected based on the potential to deliver the array to the assembly site with one Shuttle launch operating at a 50% load factor.

In this program scenario, initial placement of the OCDA (Option 3) would include the construction platform and supporting rotating boom for construction. The growth version of



MASS		
ELEMENT	Kg	LBM
SOLAR ARRAY	(13,726)	(30,232)
BLANKETS	9685	21333
CONCENTRATORS	553	1219
DEPLOYMENT STRUCT.	2724	6000
SUPPORT BEAMS	454	1000
BUS SYSTEM	310	683
TRANSMIT ANTENNA	(13,724)	(30,163)
MW TUBES	972	2141
POWER DISTRIBUTION	887	1954
PHASE CONTROL ELECT	978	2154
WAVEGUIDES	7941	17491
STRUCTURE	1548	3410
CONTOUR CONTROL	1368	3013
ROTARY JOINT	(13,620)	(30,000)
CORE MODULE	(2286)	(5035)
TOTAL	43,366	95,431

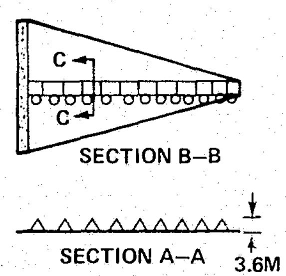


Figure 3-5 Photovoltaic SPS Demonstration

ASSUMPTION: 500 Km OCDA ORBIT ALT.

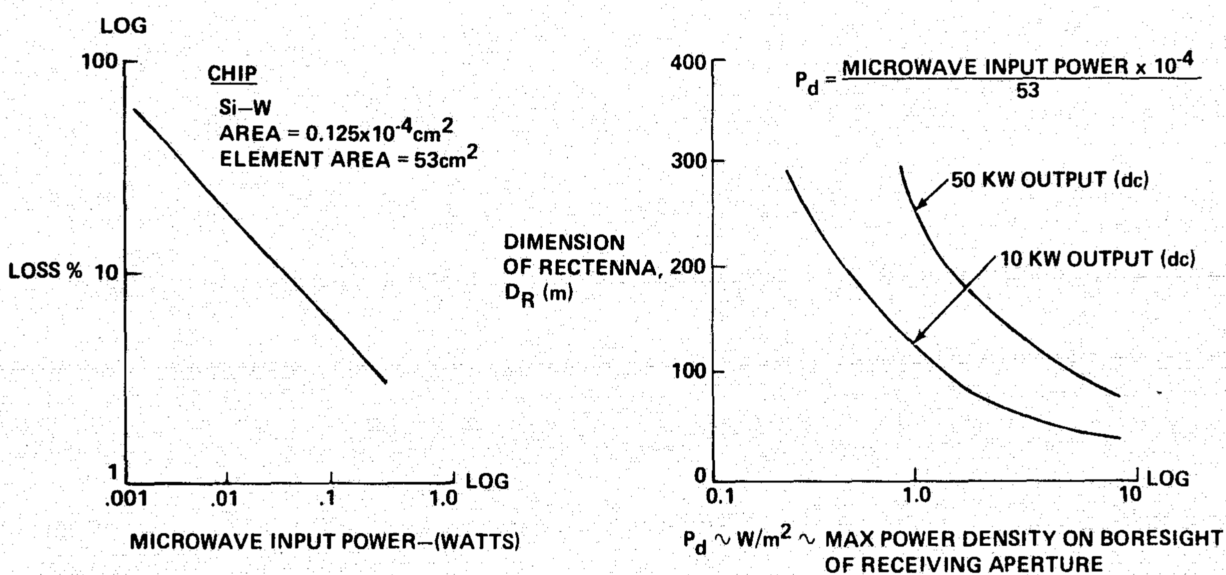


Figure 3-6 Receiving Aperture Dimensions

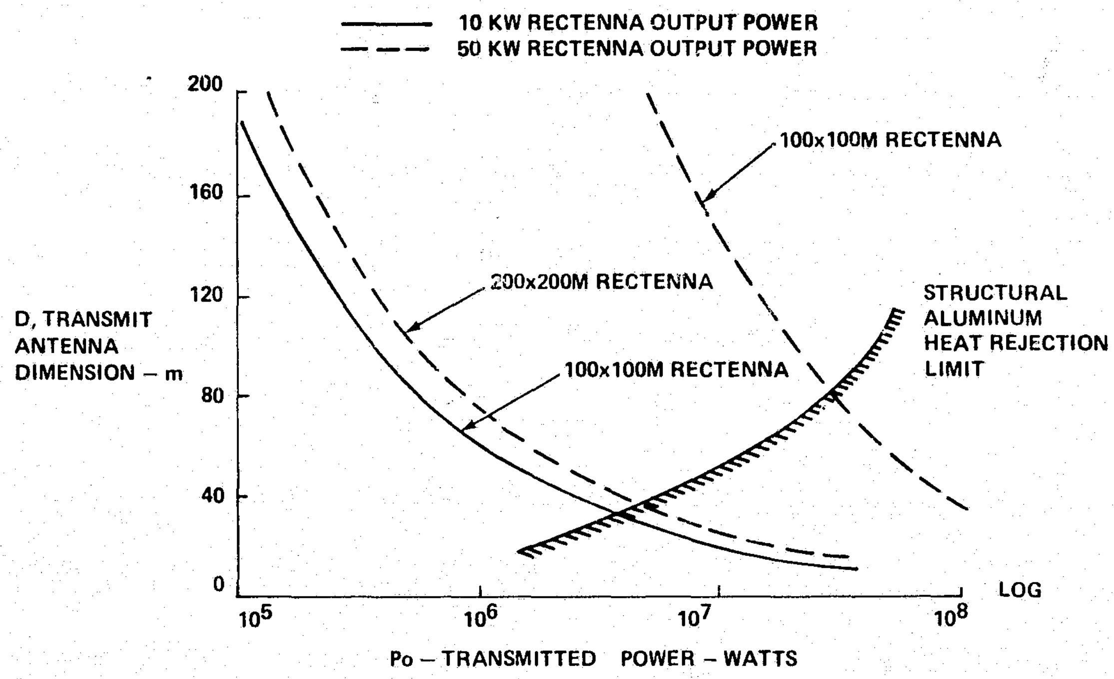


Figure 3-7 Transmit Antenna Dimensions, 500 km OCDA Orbit Altitude

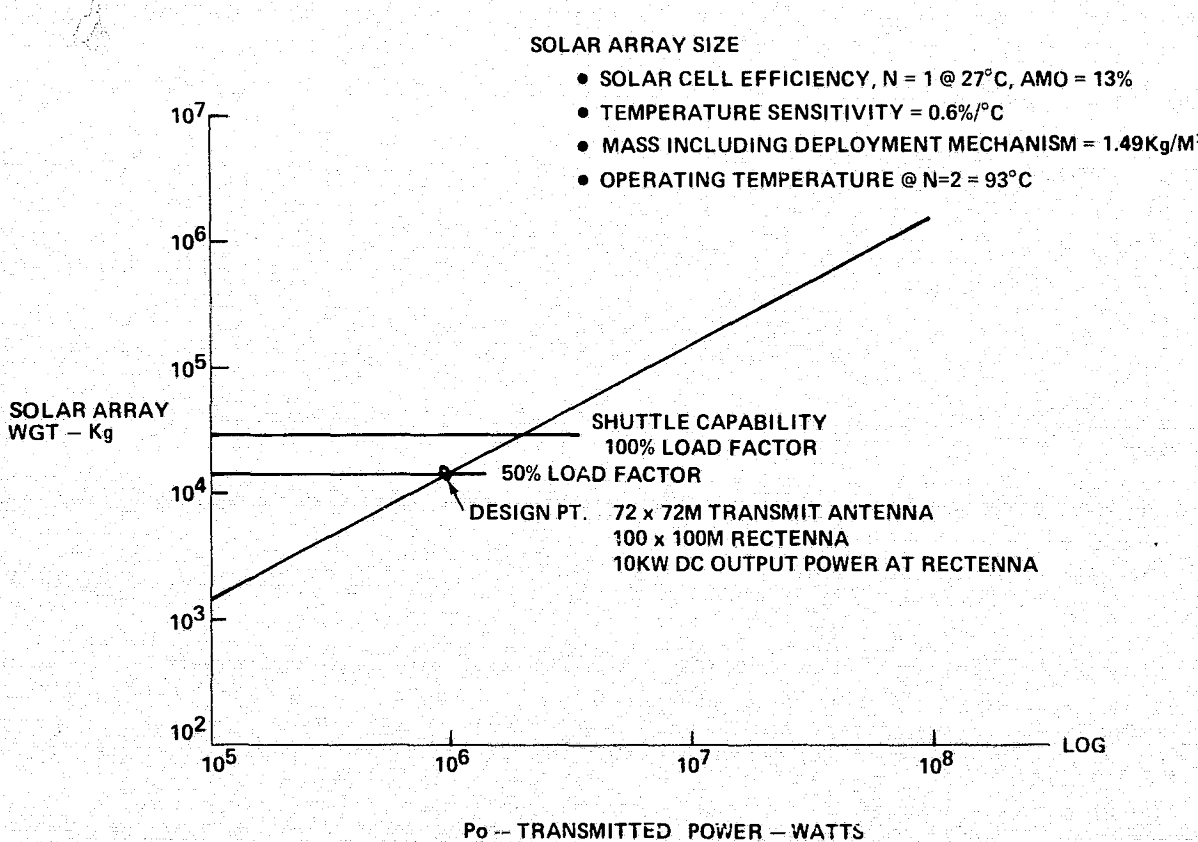


Figure 3-8 Solar Array Size

this base is a SPS proof-of-concept. Option 4, shown in Figure 3-9 utilizes the 1 MW array to drive the microwave elements of a 72-m aperture antenna. The antenna itself is constructed using the platform as a work area.

3.3 CONCEPT SELECTION

This subsection discusses the OCDA concept evaluation and ranking. The ranking was established using the following four criteria:

Rank	Criteria
1	Mission Suitability (% objectives met on initial OCDA deployment)
2	Cost/Number of Flights for Deployment
3	Continuing Utility Potential
4	State-of-the-Art (Risk)

The potential number of demonstration objectives met during initial deployment was rated the highest criteria for selection. Cost and the number of flights needed for initial deployment of the demonstration article was of second importance. The continuing utility potential of the article was ranked third in importance, and the state-of-the-art (or risk) involved with the article's development is fourth.

The figure-of-merit criteria used in the comparison of OCDA options in terms of the demonstration objectives each article can meet is summarized in Figure 3-10. Each demonstration objective identified in the mission analysis effort was ranked as to the value a space demonstration would have in resolving the given problem. A set of mission suitability criteria was then assigned to each OCDA option.

Figure 3-11 summarizes the figure-of-merit mission suitability of each OCDA option. Option 4 is ranked the highest while Option 1 is ranked the lowest. The difference between options in terms of figure-of-merit percentage of objectives met is not so great as to single out any one option as a clear leader. The major reason why all options did not score high (80 to 90%) in mission suitability was the criteria that weighed the ability to meet the given objective in the initial deployment of the article. A second reason for low score is a scale uncertainty which produced a reluctance on the part of the assessment team to assign a high percentage mission suitability to OCDAs that are small relative to the future mission configuration.

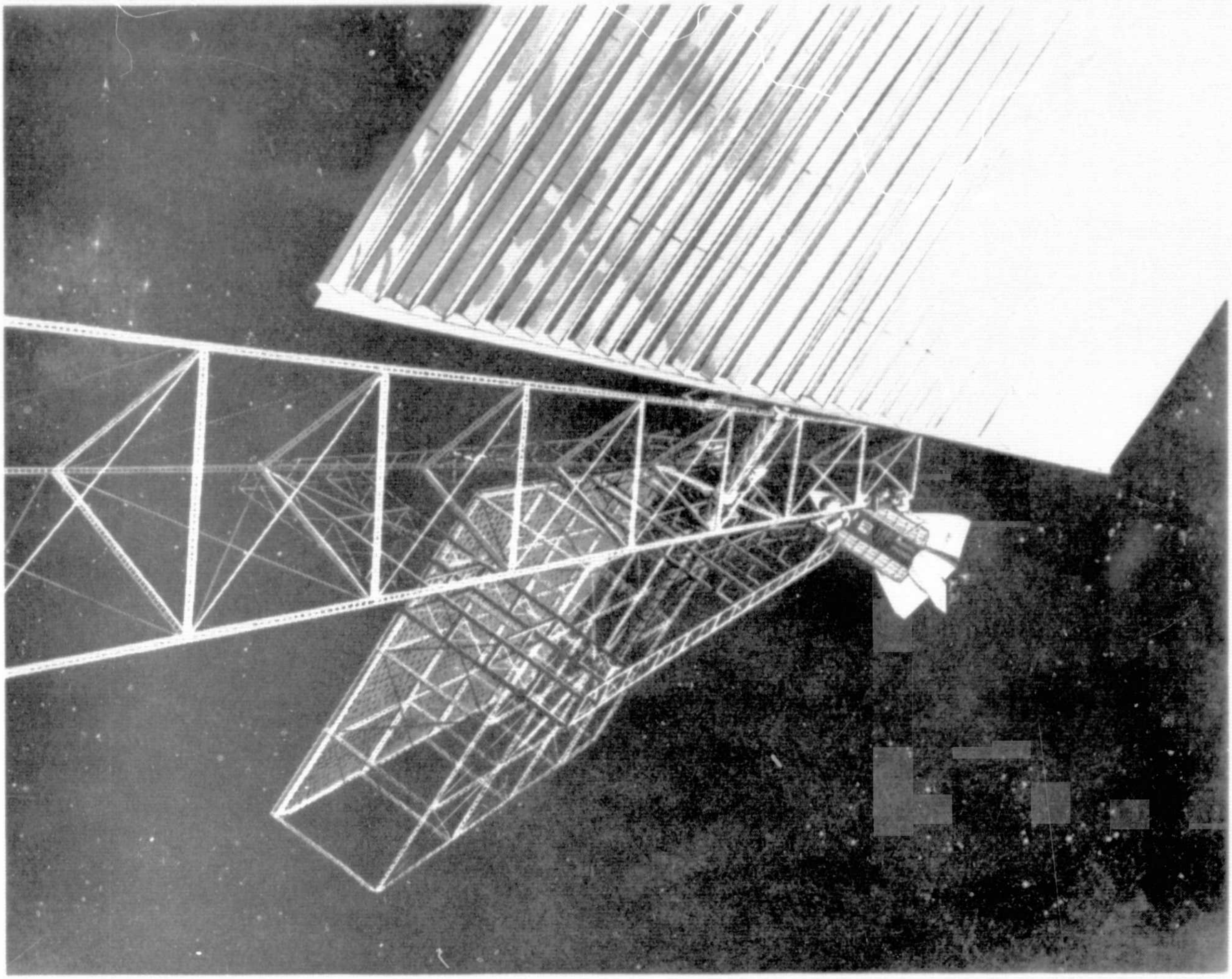
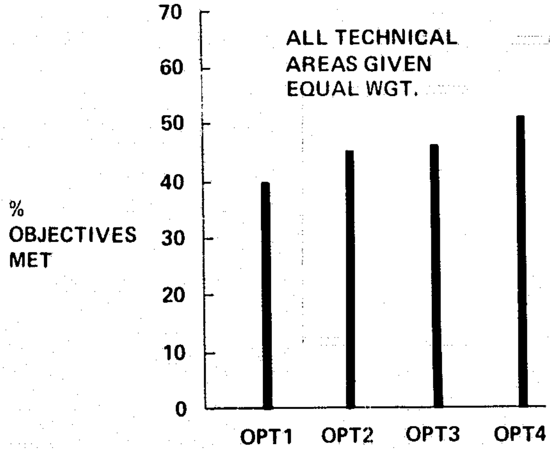


Figure 3-9 Utilization of 1 MW Array to Drive Microwave Elements of a 72-m Aperture Antenna

	MISSION SUITABILITY FOR MEETING OBJECTIVES									
	1	2	3	4	5	6	7	8	9	10
OCDA DEMO INPUT TO CONFIDENCE LEVEL FOR DECISION	• LITTLE OR NO VALUE		• PARTIAL DATA INPUT PROVIDED IN INITIAL DEPLOYMENT. NEED HIGH DEGREE OF FOLLOW ON ADDED EXPERIMENTS TO MEET OBJECTIVES		• PARTIAL DATA INPUT PROVIDED DEPLOYMENT. MODERATE FOLLOW-ON ADDED EXPERIMENTS NEEDED TO MEET OBJECTIVES		• HIGH LEVEL DATA INPUT IN INITIAL DEPLOYMENT. LIMITED FOLLOW-ON ADDED EXPER NEEDED TO MEET OBJECTIVES		• HIGH LEVEL DATA INPUT IN INITIAL DEPLOYMENT. ADDED EXPERIMENTS DESIRABLE BUT NOT MANDITORY TO MEETING OBJECTIVES	

Figure 3-10 OCDA Mission Suitability Criteria



	% OBJECTIVES MET			
	PROGRAM 1		PROGRAM 2	
TECH. AREA	OPT 1	OPT 2	OPT 3	OPT 4
• STRUCTURE	35	47	51	56
• POWER DISTRIBUTION	39	39	50	60
• SOLAR ARRAY	34	34	41	41
• PROPULSION	50	50	50	50
• TRANSMISSION	22	22	22	53
• STABILIZATION	60	60	70	80
• RF REFLECTORS	30	90	30	30
• MIRRORS	40	40	50	50
• RADIATORS	40	40	50	50
• THERMAL CAVITIES	30	30	30	30

Figure 3-11 Figure of Merit Mission Suitability Comparison

	SHUTTLE FLTS			
	OPT 1	OPT 2	OPT 3	OPT 4
HI EST.	5	6	7	12
LOW EST.	2	2	2	4

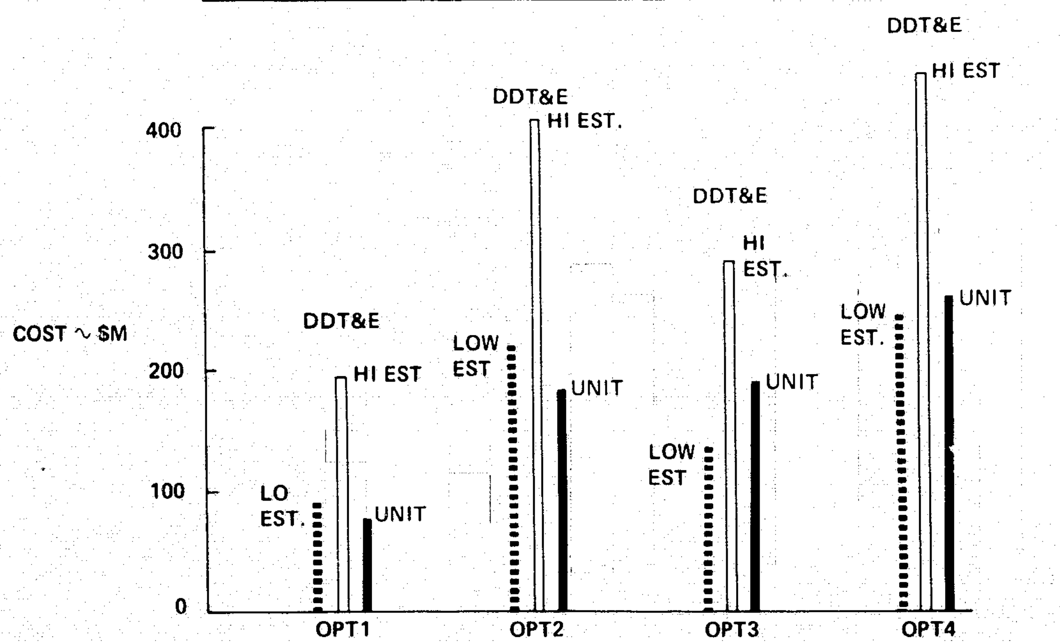


Figure 3-12 Initial Concept Cost Comparison

A cost comparison of the four OCDA options is shown on Figure 3-12. Cost ranges are given for DDT&E, first unit and the number of Shuttle flights required to deploy and construct the article. The following groundrules were used in these estimates:

- Cost in 1977 constant dollars
- Cost data excludes crew equipments and orbital construction facilities/equipments
- Core vehicle will consist of 75% off-the-shelf NASA standardized spacecraft subsystem modules
- Solar array development costs are the same as that for SEPS program.

The initial total cost estimates are as follows:

- Option 1: \$199 to \$362 million
- Option 2: \$434 to \$698 million
- Option 3: \$379 to \$622 million
- Option 4: \$583 to \$939 million

assuming \$19.5 million per Shuttle flight.

The information used to establish the lower limit of flights required for deployment are summarized in Figure 3-13. The Shuttle was assumed configured for a 7 man crew, and carries a docking module and four pallets. A second RMS was added and consumables for 252 manhours of EVA capability added to the inventory. Two Manned Maneuvering Units (MMUs) were included with sufficient propellant for 252 manhours of operation. The payload capability with these equipments were 40,500 lb (18,387 kg) up and 17,900 lb (8,127 kg) down. A cargo volume of 6000 cu ft (170 m^3) was available. Under the assumption that deployment and construction techniques will bring assembly cost within the standards for terrestrial mass-produced products, a productivity of between 12 and 40 lb/manhour (5.4 and 18 kg/manhour) was assumed reasonable for purposes of preliminary estimates of Shuttle flights required. It was assumed that 252 manhours per flight would be available for construction duties. Using these assumptions for mass and construction time, Options 1 through 4 could be assembled in the required six flight limit.

Option 1 (Figure 3-14) was selected for concept definition in Tasks 2 through 5. The 250-kW array or smaller was judged adequate to meet near-term construction demonstration objectives with Shuttle revisits to the OCDA. Costs for Option 1 were considered modest for a program of this type. The low risk of equipments was also a factor. The

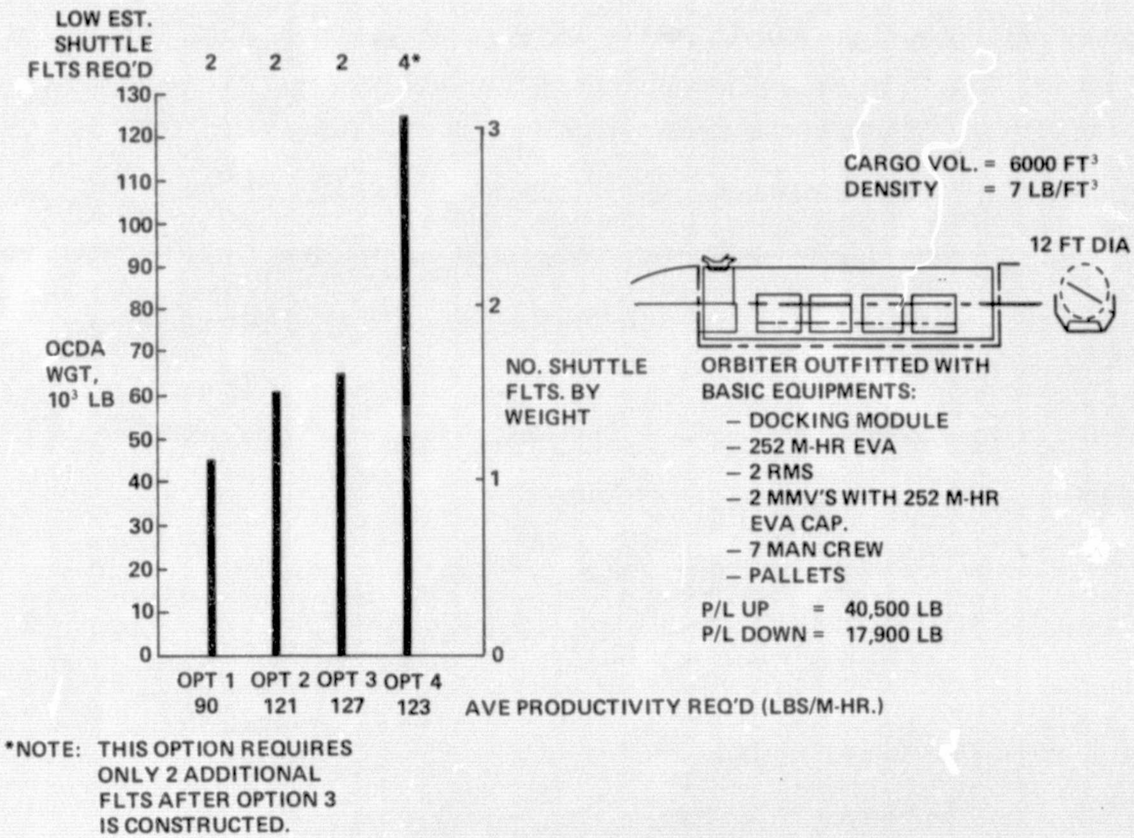


Figure 3-13 Shuttle Flights Required by Weight

		PROGRAM 1		PROGRAM 2	
CRITERIA		OPT 1	OPT 2	OPT 3	OPT 4
MISSION SUITABILITY (%)		40	45	47	51
COST	DDT & E ($M) UNIT ($M) FLTS	90 TO 195 70 2 TO 5	205 TO 400 180 2 TO 6	150 TO 295 195 2 TO 7	250 TO 450 260 4 TO 12
CONTINUING UTILITY POTENTIAL		GOOD	VERY GOOD	EXCEL.	EXCEL.
STATE-OF-ART. (RISK)		LOW	HIGH	MODERATE	HIGH

SELECTED FOR CONCEPT DEFINITION STUDY

- 250KW ARRAY IS SUFFICIENT TO MEET NEAR TERM MODEST CONSTRUCTION DEMO OBJECTIVES
- COST IN LINE WITH BUDGETS
- RISK IN LINE WITH IOC

Figure 3-14 Concept Comparison

major risk factor for Option 1 was then contained to the actual assembly operations themselves and not the hardware.

3.4 DEMONSTRATION/TEST OBJECTIVES MET ON INITIAL DEPLOYMENT

The OCDA structure can be built up out of a basic building block structure divided between aluminum and composites. This feature, along with other OCDA merits shown in Figure 3-15, meets 35% of the demonstration objectives in the field of large structures. An option to use either space fabricated or deployable members, or both, exists. Over 100 joining operations are required providing an opportunity to demonstrate many joining options. Several candidate structural approaches showing promise for future systems could be embodied into the program.

The technologies of man/machine interactions are addressed with use of the rotating boom and manipulator. A first cut at productivity potential of man and machine in a space environment will also be provided. The challenge of attitude control, and structural alignment in a varying thermal environment will be addressed during construction of the OCDA.

The installation of secondary structure and subsystem mounting for solar arrays and high voltage power distribution systems will be addressed during assembly of the OCDA itself.

Several key technologies can be explored in the large solar array area as shown in Figure 3-16. The deployment and reaction of a large area array can be demonstrated. The issues of interfacing the "ganged" array to the structure and power distribution system will be addressed. The array has tentatively been configured to operate at 200 volts but could be configured to generate high voltages of 20 kv to evaluate switching and protection problems.

Even at 200 volts, the selection of the bus system approach, and the routing and support bracket design involves many similar issues associated with the future large scale Solar Power Station. Construction operations and handling of the system with man's involvement should provide insight on developing the needed safety procedures.

Many of the basic construction operations issues associated with future construction bases will be addressed during OCDA assembly. The difficulty of resupply and storage, site logistics, site communications, power and signal routing, lighting, and safety will be solved because of the OCDA endeavor. Valuable data on productivity in a space environment will be collected as well as data on the capabilities of man and machinery performance

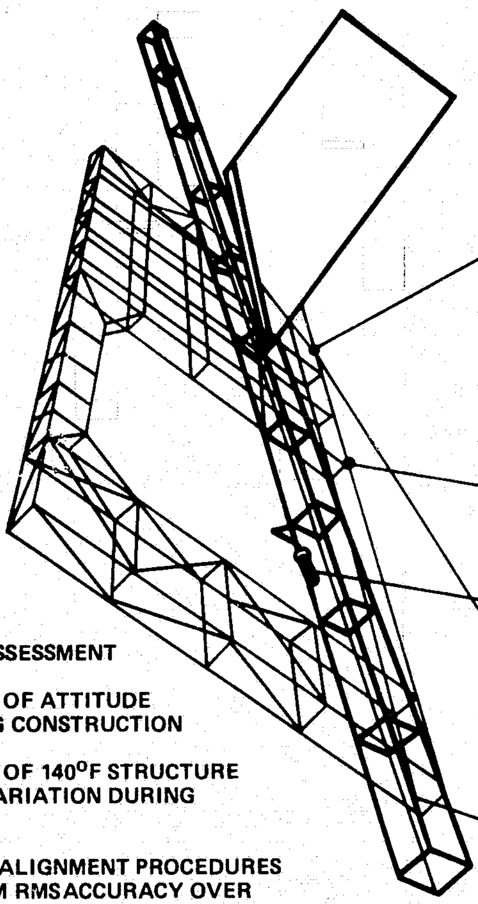
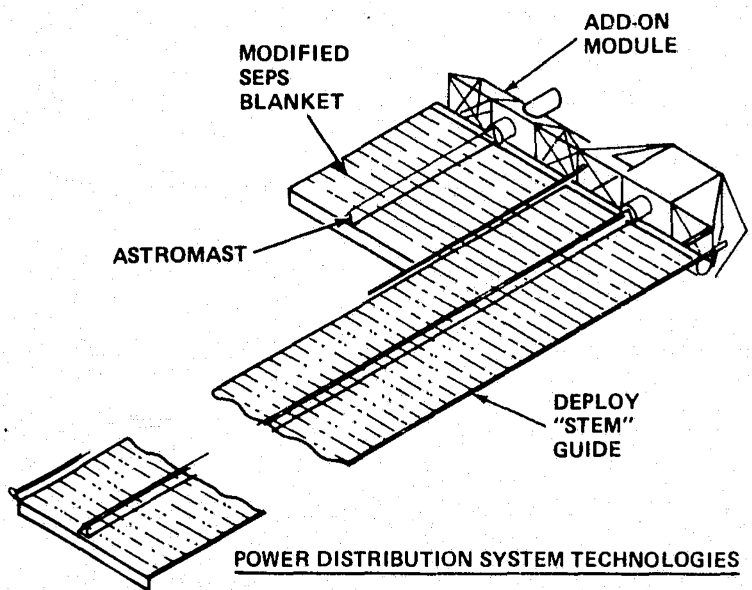


Figure 3-15 Large Structures Objectives Met on Initial Deployment



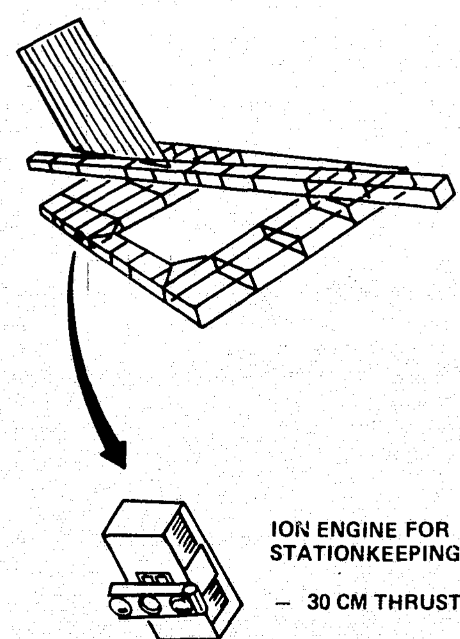
LARGE SOLAR ARRAY TECHNOLOGIES

- DEMONSTRATES ONE METHOD TO DEPLOY LARGE AREAS OF SOLAR BLANKET.
- DEMONSTRATES BLANKET INTERFACE WITH STRUCTURE, POWER BUS AND MONITOR/COMMAND SYSTEMS
- ADDRESSES ISSUES OF C/O AND FAULT ISOLATION
- COULD BE CONFIGURED TO OPERATE AT 20KV TO ADDRESS HI VOLTAGE ISSUES
- ADDRESSES THERMAL CYCLING ISSUES

POWER DISTRIBUTION SYSTEM TECHNOLOGIES

- DEMONSTRATES INSTALLATION OF BUS SYSTEM INCLUDING CONDUCTORS, POWER CONDITIONERS AND SWITCH GEAR
- ADDRESSES ISSUES OF ENERGY STORAGE FOR ATTITUDE CONTROL, SYSTEM HEATING, ETC.
- ADDRESSES ISSUES OF LARGE ROTARY JOINT INSTALLATION AND OPERATION
- ADDRESSES ISSUES OF C/O, FAULT ISOLATION & REPAIR

Figure 3-16 Solar Array and Power Distribution System Objectives Met on Initial Deployment



ION ENGINE FOR STATIONKEEPING

– 30 CM THRUSTERS

PROPULSION TECHNOLOGIES

- DEMONSTRATES ON ORBIT INSTALLATION OF LOW THRUST PROPULSION SYSTEMS FOR ORBIT KEEPING & ATTITUDE CONTROL
- ADDRESSES ISSUES OF PROPELLANT RESUPPLY
- ADDRESSES ISSUES OF EXHAUST CONTAMINATION OF SOLAR ARRAY

STABILIZATION & CONTROL

- ADDRESSES ISSUE OF CONTROL OF LARGE FLEXIBLE STRUCTURE
  - LOCATION OF SENSORS & ACTUATORS
- ADDRESSES CONTROL ISSUES OF CONFIGURATIONS WITH CHANGING GEOMETRY DURING CONSTRUCTION & DURING OPERATIONS
- ADDRESSES DESIGN ISSUES OF ROTARY JOINT CONTROL & ACCURACY

Figure 3-17 Propulsion and Stabilization Objectives Met on Initial Deployment

in the construction of an integrated spacecraft. Because the OCDA will eventually be used as a platform for other construction experiments, the problems associated with the mounting of construction equipment will be addressed and solved in a timely fashion.

Figure 3-17 summarizes the issues addressed in the areas of propulsion and stabilization and control. The installation of propulsion units including tankage and feed lines will be covered. Resupply of propellants to maintain attitude control and station-keeping will be an integral part of the program.

The control of large flexible structure that varies in dimensions and inertia typifies the conditions expected at the ultimate, future construction base. The installation and operation of a modest size rotary joint will provide insight to the ultimate SPS design.

In all, 40% of the demonstration objectives listed in Figure 2-3 can be met during the initial placement of the OCDA. The remainder of the objectives can be met with judicious selection of follow-on activities that use the OCDA as a technology advancement facility.

Section 4

BASIC OCDA DESIGN REQUIREMENTS

A series of OCDA follow-on activity concept studies were performed to determine the sizing factors for the platform, boom and solar array. The work platform was sized to facilitate construction of a 100-m antenna and a large solar array. More details of these experiments are discussed in Section 5. The rotating boom was sized to provide manipulator access to all points on the platform. The solar array was sized to provide continuous 70 kW power to the construction missions, over and above the 10 kW (average) required for OCDA housekeeping and construction support functions, and 25 kW (average) for Shuttle support.

The work platform was sized at 72 m x 32 m. The 72-m length was selected based on the future (follow-on) mission desired to build 100-m diameter antennas for radiometry and communications. A minimum of 50 m is required to build the antenna, and approximately 20 m was judged necessary to house the core module, power mast, etc. The 32-m width was selected based on initial construction requirements. The Shuttle-based Remote Manipulator System (RMS) reach constrains the platform width to 32 m if the back edge set of the platform structural cubes are to be constructed with assistance from the Orbiter.

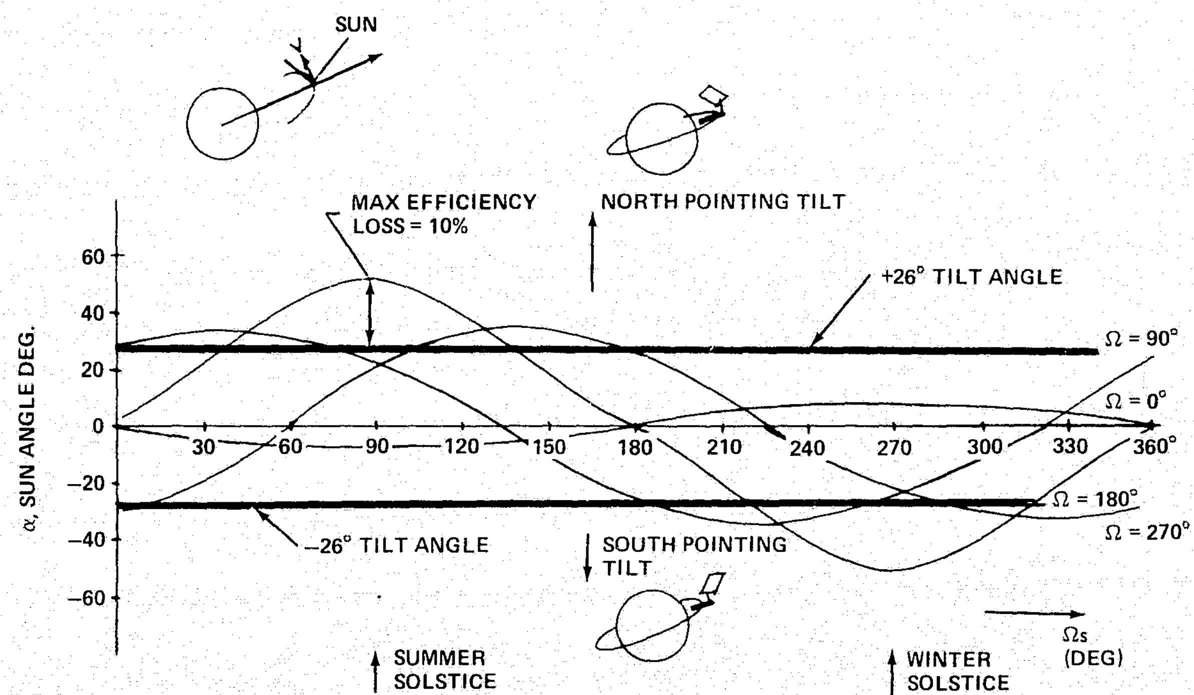
The OCDA power requirements vary considerably from the very low value of approximately 10 kW needed for housekeeping between orbiter visits, to that required by follow-on missions. The follow-on activites evaluated for purposes of selecting the OCDA power level are listed in Table 4-1. The power requirements needed to simulate mass production of segments of the ultimate SPS were used for basic sizing of 250 kW. Other potential uses of 250 kW are indicated in the table. A recommendation by Raytheon for testing the phase control electronics of a linear power transmitting array would be within the capability of the OCDA.

4.1 FLIGHT MECHANICS AND CONTROL

Studies were performed to determine OCDA attitude control and orbit-keeping requirements. These studies, performed as part of Task 5 (see Figure 1-2), were needed to assess the technical feasibility of the concept and to provide basic design data for solar array, control system and structural sizing.

Table 4-1 Experiment Power Requirements

EXPERIMENT	LOAD POWER	ARRAY POWER
1. SIMULATED MASS PRODUCTION OF LARGE STRUCTURES	20 TO 64 KW	64 KW TO 210 KW
2. LINEAR WAVEGUIDE		
• 100M LONG, FULL MPTS RANGE OF POWER DENSITY	100 TO 200 KW	140 TO 280 KW
3. DC-TO-RF CONVERSION IN STEPS (18 X 18m SUBARRAY)		
• 1/3 POWER FOR 10 DB SUBARRAY	250 TO 300 KW	350 TO 420 KW
• FULL POWER FOR 10 DB SUBARRAY	700 TO 900 KW	980 TO 1260 KW
• 1/3 POWER FOR 5 DB SUBARRAY	800 TO 1000 KW	1120 TO 1400 KW
• FULL POWER FOR 5 DB SUBARRAY	2.5 TO 3 MW	3.5 TO 4.2 MW
• 1/3 POWER FOR 0 DB SUBARRAY	2.5 TO 3 MW	3.5 TO 4.2 MW
• FU'L POWER FOR 0 DB SUBARRAY	8 TO 9 MW	11.2 TO 12.6 MW
4. DEMO TRANSMISSION TO GROUND	1 TO 10 MW	1.4 TO 14 MW



Ω = ORBIT LINE OF NODE RELATIVE TO VERNAL EQUINOX

Ω_s = SUN'S LOCATION ON ECLIPTIC RELATIVE TO VERNAL EQUINOX

YEARLY VARIATIONS OF SUN ANGLE

Figure 4-1 Solar Array Test Angle Requirements

The configuration-dependent factors which were considered in the development of the orbit and attitude control requirements include:

- Drag and inertia effects of a fully and partially deployed array
- Inertia and disturbance torque effects of the tilted, rotating solar array
- Construction boom position
- Potential follow-on activities, including some which significantly change mass distribution
- Special orientation requirements of some activities which may require slewing away from the nominal earth-oriented attitude for periods of time
- Inertia, geometry and orientation characteristics during OCDA buildup.

The major impacts were found to be caused by the tilted, rotating array and the effect of the orbiter mass which changes the inertias, moment arms and disturbance torques.

4.1.1 Effects of Sun Angle

The yearly variation of the sun relative to the solar array was evaluated to determine the need and approach for array steering. The relative orientation of the orbit plane with respect to the ecliptic plane is described by the angle Ω_S which varies over the year as shown in Figure 4-1. The possible sun angles are described by the total area between the set of curves representing the full range of angles for the line of nodes relative to the vernal equinox. A pitch-oriented array with its plane perpendicular to the orbit plane would experience up to a 38% reduction in efficiency. Tilting the array plus or minus 26°, as required, reduces the maximum efficiency loss to 10%. An evaluation of the orbit time history shows that the solar array tilt will be changed every 22 days due to the effects of orbit nodal regression.

4.1.2 Disturbance Torques

The disturbance torques affecting the control system requirements were estimated for the following disturbance forces:

- Aerodynamic
- Gravity Gradient
- Solar Pressure
- Magnetic.

The mass properties used for these estimates are summarized in Table 4-2.

Table 4-2 Mass Properties Summary

CONFIGURATION (ALL 0° BOOM ANGLE	WEIGHT 10^3 Kg (LB)	CG (m)			INERTIAS, 10^3 Kg - m^2 (SLUG - Ft^2)					
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}
FULL ARRAY, 0° CANT										
• WITH ORBITER										
– 0° ARRAY ROTATION	115.4 (254.4)	0	-4.0	-8.8	45.1 (33.3)	36.6 (27.0)	10.7 (7.9)	0	0	5.9 (4.4)
– 90° ARRAY ROTATION	115.4 (254.4)	0	-4.0	-8.8	44.2 (32.6)	36.6 (27.0)	11.6 (8.6)	0	0	5.9 (4.4)
• WITHOUT ORBITER										
– 0° ARRAY ROTATION	15.6 (34.4)	0	12.3	20.9	15.3 (11.3)	11.4 (8.4)	4.8 (3.5)	0	0	-2.9 (2.1)
– 90° ARRAY ROTATION	15.6 (34.4)	0	12.3	20.9	14.4 (10.6)	11.4 (8.4)	5.6 (4.1)	0	0	-2.9 (2.1)
FULL ARRAY, 26° CANT										
• WITH ORBITER										
– 0° ARRAY ROTATION	115.4 (254.4)	0.4	-4.0	-8.8	44.0 (32.5)	37.3 (27.5)	10.3 (7.6)	1.9 (1.4)	0.39 (0.29)	5.8 (4.3)
– 90° ARRAY ROTATION	115.4 (254.4)	0	-4.0	-9.2	43.1 (31.8)	36.5 (26.9)	10.5 (7.7)	0	0	3.8 (2.8)
– 180° ARRAY ROTATION	115.4 (254.4)	-0.4	-4.0	-8.8	44.0 (32.5)	37.3 (27.5)	10.3 (7.6)	-1.9 (-1.4)	-0.39 (-0.29)	5.8 (4.3)
– 270° ARRAY ROTATION	115.4 (254.4)	0	-4.0	-8.5	44.6 (32.9)	38.1 (28.1)	10.5 (7.7)	0	0	7.7 (5.7)
• WITHOUT ORBITER										
– 0° ARRAY ROTATION	15.6 (34.4)	2.8	11.6	20.9	14.6 (10.8)	12.0 (8.9)	4.6 (3.4)	1.2 (0.89)	-0.91 (-0.67)	-2.6 (-1.9)
– 90° ARRAY ROTATION	15.6 (34.4)	0	11.6	18.1	16.1 (11.9)	13.8 (10.2)	4.9 (3.6)	0	0	-3.8 (-2.8)
– 180° ARRAY ROTATION	15.6 (34.4)	-2.8	11.6	20.9	14.6 (10.8)	12.0 (8.9)	4.6 (3.4)	-1.2 (-0.89)	0.91 (0.67)	-2.6 (-1.9)
– 270° ARRAY ROTATION	15.6 (34.4)	0	11.6	23.7	12.5 (9.2)	10.2 (7.5)	4.9 (3.6)	0	0	-1.4 (-1.0)
RETRACTED ARRAY, 0° CANT										
• WITH ORBITER										
– 0° ARRAY ROTATION	115.4 (254.4)	0	-4.7	-8.8	39.3 (29.0)	36.6 (27.0)	5.0 (3.7)	0	0	5.1 (3.8)
• WITHOUT ORBITER										
– 0° ARRAY ROTATION	15.6 (34.4)	0	7.0	20.9	11.9 (8.8)	11.4 (8.4)	1.4 (1.0)	0	0	-1.1 (0.81)
RETRACTED ARRAY, 26° CANT										
• WITH ORBITER										
– 0° ARRAY ROTATION	115.4 (254.4)	0.03	-4.7	-8.8	39.3 (29.0)	36.6 (27.0)	5.0 (3.7)	0.16 (0.12)	0.03 (0.02)	5.1 (3.8)
• WITHOUT ORBITER										
– 0° ARRAY ROTATION	15.6 (34.4)	0.2	7.0	20.9	11.8 (8.7)	11.4 (8.4)	1.4 (1.0)	0.12 (0.09)	-0.07 (-0.05)	-1.1 (-0.81)

4.1.2.1 Aerodynamic Torques. The disturbance torque due to aerodynamic drag is caused largely by the rotating solar array which produces equally large bias and cyclic terms. A drag coefficient C_D of 2.0 was assumed for the solar array and orbiter with 2.5 used for the boom and platform corresponding to open beams with cavities. The resulting torques are based on a Jachia Model nominal atmosphere.

4.1.2.2 Gravity Gradient Torques. The estimate for gravity gradient torques includes the effect of the rotating canted solar array. The variation over one orbit is shown in Figure 4-2. The orbiter has a significant effect, especially on the x-axis (velocity vector direction) displacing the principal axes approximately 15° from the control axes.

4.1.2.3 Solar Pressure and Magnetic Disturbance Torques. Solar pressure and magnetic disturbance torques are conservatively estimated with the magnetic based on an uncompensated magnetic moment of 90,000 pole-cm per axis without the orbiter, and 530,000 pole-cm with the orbiter.

4.1.2.4 Disturbance Torque Summary. The primary disturbance torque sources are aerodynamic drag and gravity gradient as shown in Table 4-3. The gravity gradient torques shown include the effect of the sun-tracking, tilted solar array which results in a cyclic disturbance. The Orbiter was also shown to have a significant effect, especially on the x-axis, shifting the principal axes approximately 15° from the control axes. The disturbance torques were divided into a constant (unidirectional) bias term and a cyclic term with a frequency of orbital rate. The dominant aero torque was due to the rotating solar array which causes equally large cyclic and bias terms. A drag coefficient (C_D) of 2 was assumed for the solar array and orbiter, and 2.5 was used for the boom and platform corresponding to open beams with cavities.

4.1.3 Control System Requirements

Based on the estimates of torque disturbances, the fuel requirements for a control system are shown in Figure 4-3 for various values of specific impulse (I_{SP}).

Assuming that under worst-case conditions, the cyclic terms were all in phase, the total bias and cyclic torques were added resulting in a conservative estimate for the total cyclic torque. The cyclic torque impulse values on a half cycle basis indicate sizable angular momentum requirements. This results in unnecessary propellant consumption which can be alleviated by using momentum storage devices.

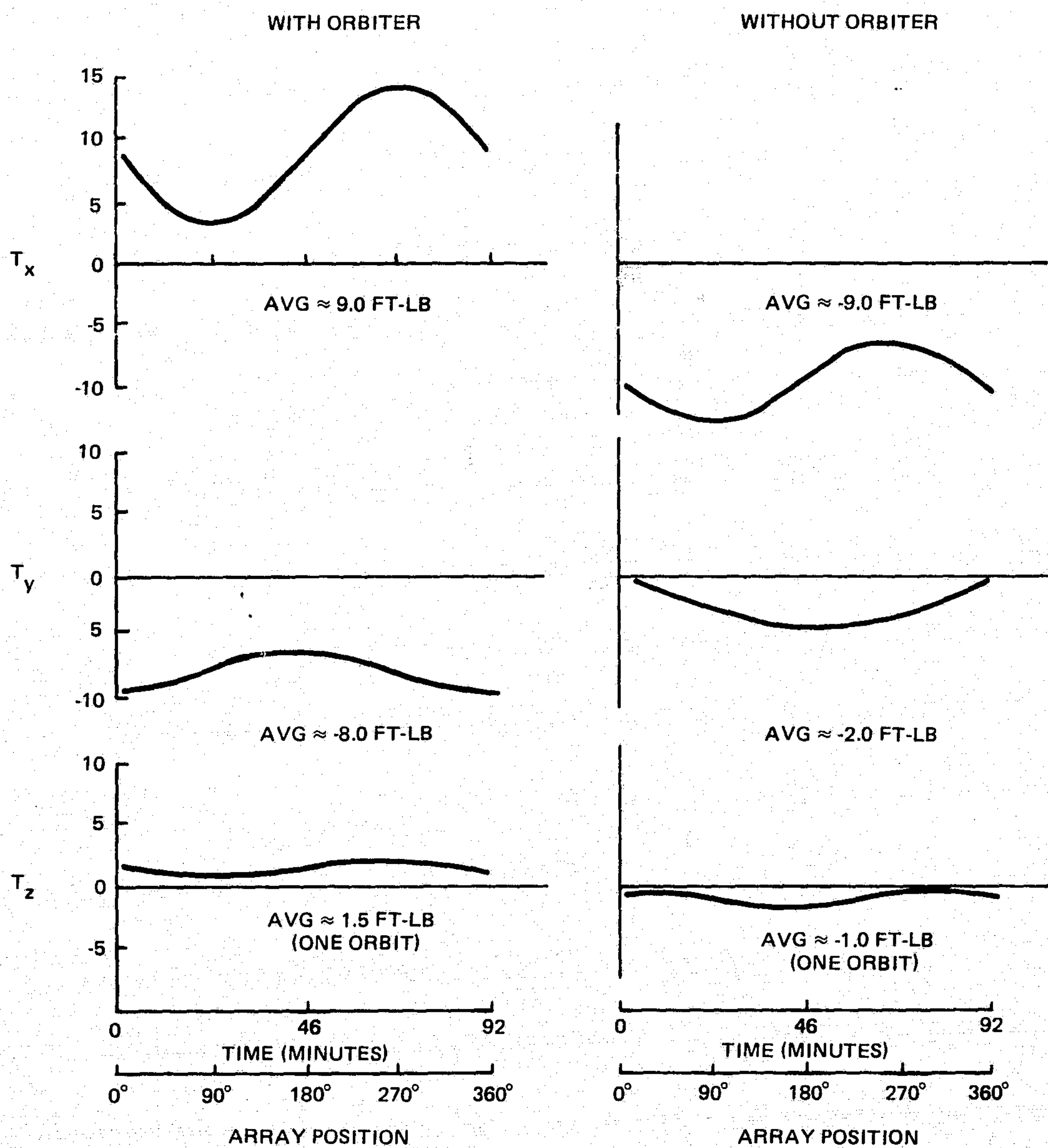


Figure 4-2 Gravity Gradient Torque — Full Array

Table 4-3 Distrubance Torques

	TORQUES (FT-LBS)											
	WITH ORBITER						WITHOUT ORBITER					
	T_x		T_y		T_z		T_x		T_y		T_z	
	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC
AERODYNAMIC	0	0	- 5.5	±4.8	21.5	±20.2	-0	0	8.5	± 8.7	12.0	±12.3
GRAVITY GRADIENT	9.0	±5.6	- 8.0	±1.6	1.5	± 0.5	-9.0	±3.5	-2.0	± 2.2	- 1.0	± 0.6
SOLAR PRESSURE	0	±0.4	0	0	0	± 0.4	0	±0.3	0	0	0	± 0.3
MAGNETIC (UNCOMP)	0.02	0	0	0	0.02	0	0.003	0	0	0	0.003	0
TOTALS	9.0	±6.0	-13.5	±6.4	23.0	±21.1	-9.0	±3.8	6.5	±10.9	11.0	±13.2

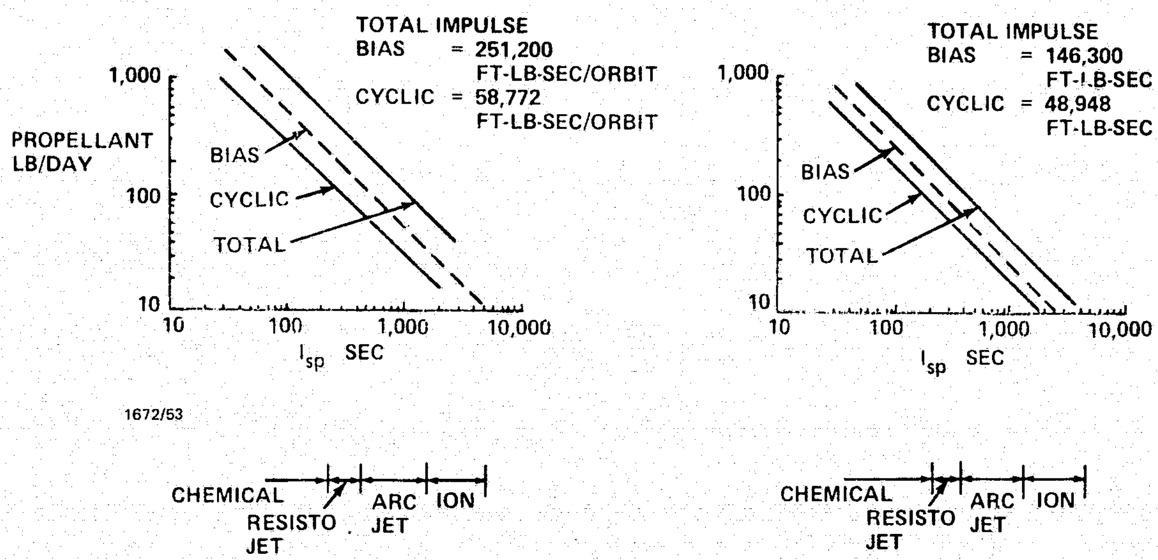


Figure 4-3 Control System Requirements

4.1.4 OCDA Orbit Decay Profile

The ballistic coefficient of the fully deployed OCDA is approximately 1.5 resulting in the decay profiles indicated in Figure 4-4 for the nominal and 95 percentile atmospheres using the Jachia Model. The orbit decays 24 km in six months for the nominal model. The solar array is the primary source of drag. Retracting the array partially when power requirements are low is one technique for reducing the effect but implies operational constraints. The approach selected for orbit-keeping consists of low level continuous thrusting to counter the drag force.

4.1.5 Aerodynamic Drag Forces

The effect of aerodynamic drag at 190 n mi (352 km) on the OCDA, was determined by estimating the ballistic coefficient of each major section individually as follows:

BALLISTIC COEFFICIENTS, W/C_DA

• Array	0.25
• Boom	12.3
• Platform	16.4
• Mast	23.2
• Orbiter	44.5

A drag coefficient of 2 was used for the solar array, mast and Shuttle, and 2.5 for the boom and platform. An effective drag area of 60% of maximum was assumed for the array. The array was by far the dominant effect, resulting in a drag force of approximately 0.18 lb (0.8 N) opposing the orbited velocity. This would require about 460 lb (209 kg) of propellant per year using an argon ion thruster with an I_{SP} of 6,000 sec.

The Space Transportation System (STS) capability for delivery cargo to circular orbits as a function of orbit altitude is shown in Figure 4-5, including rendezvous capability with no OMS kits. The effect of orbit inclination vanishes above about 227 n mi (420 km) over the inclination range 28.5° to 50°. The launch weights for the three flights required for OCDA construction (see Section 4) indicate the ability to attain an altitude of about 227 n mi (420 km) even for a 50° inclination when the reduced orbit-keeping subsystem weight at higher altitudes is considered.

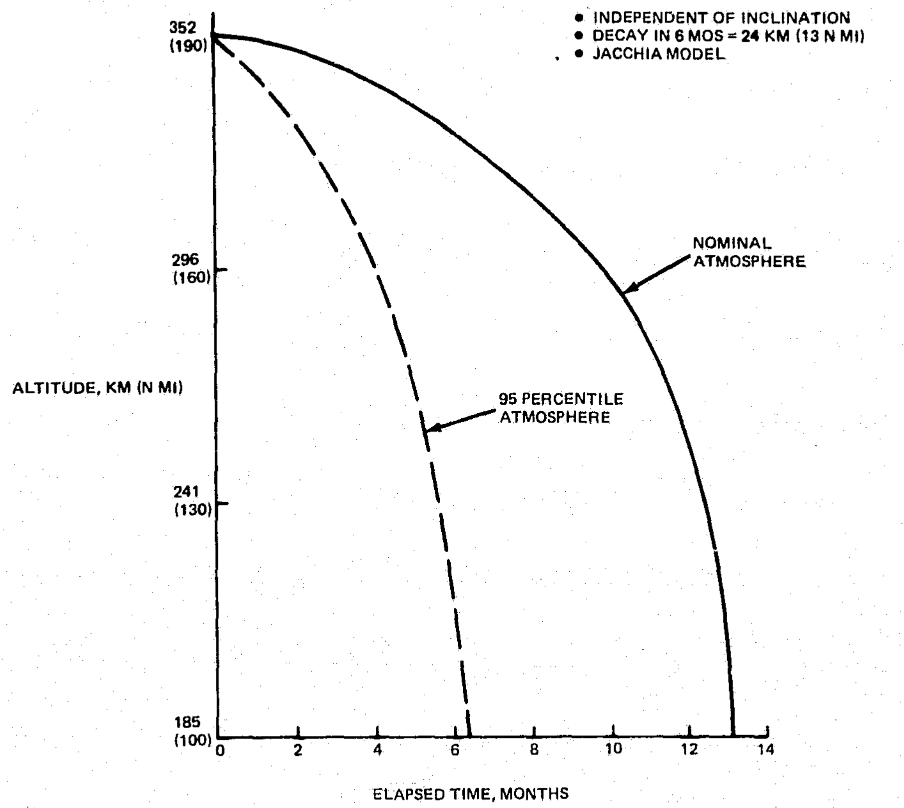


Figure 4-4 Decay Profiles

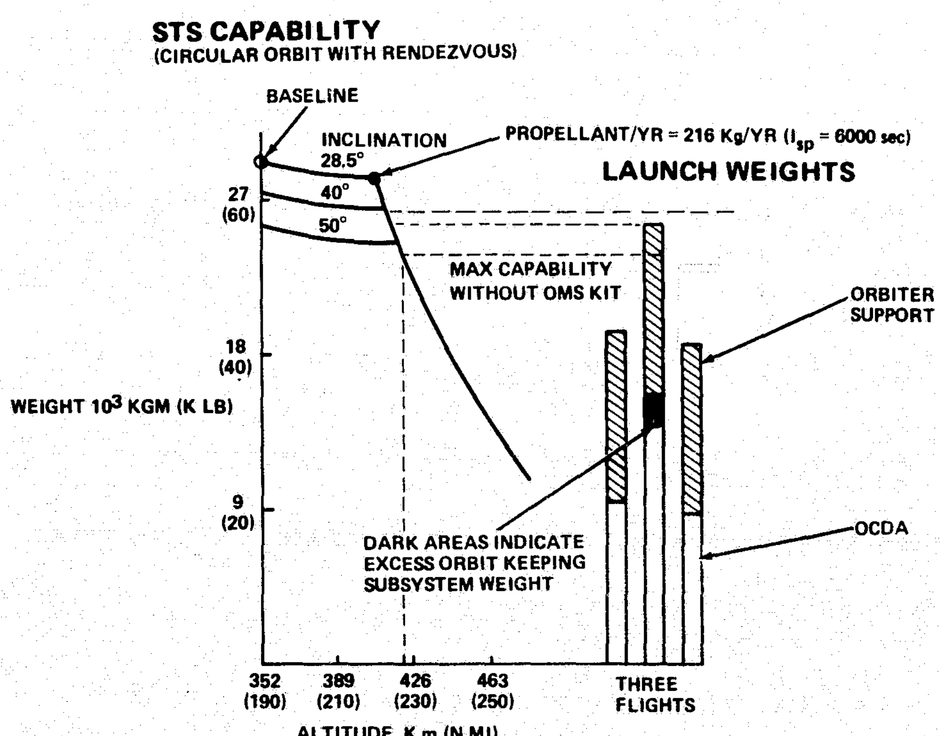


Figure 4-5 OCDA Launch Envelope

4.2 STRUCTURAL DESIGN REQUIREMENTS

Structural design loads for the OCDA are summarized in Figure 4-6. Loads due to aerodynamics and gravity gradient are given for the vehicle in a 190 n mi (352 km) orbit. From these loads, two conditions (docking and manipulator jam) were judged most critical and were investigated further. Manipulator to jam produces the most critical sizing load. Stiffness requirements for control system stability were analyzed and the structural fundamental frequency was calculated to be well in excess of the control system requirements. These requirements and frequencies are shown on Figure 4-7.

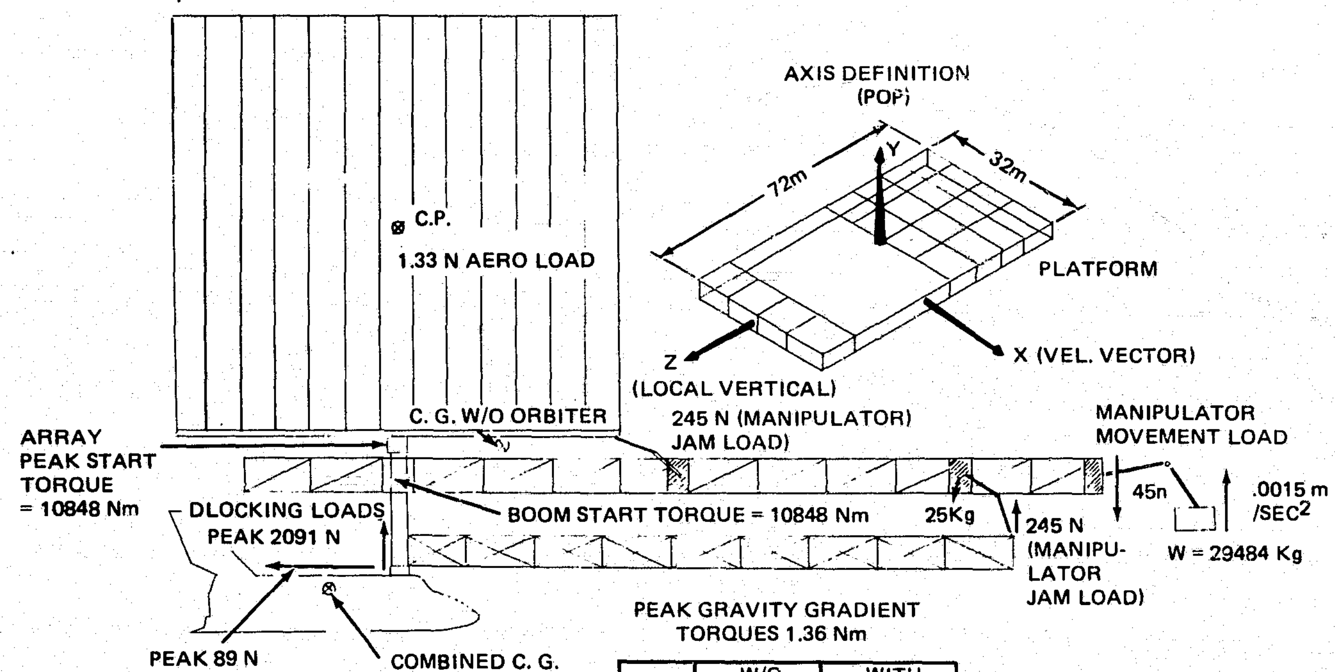
Preliminary docking loads were calculated for the Shuttle Orbiter docking to the OCDA. Closing velocities of 0.5 fps (0.15 mps) axial and 0.1 fps (0.04 mps) lateral were used in combination with a constant force attenuator with a 1-ft (0.3-m) stroke to obtain interface loads. The resulting interface loads were increased by a factor of 2 to account for actuator nonlinearities and design the limit loads of 235-lb (1045 N) axial, and 10-lb (44.5 N) lateral.

The Shuttle manipulator is capable of producing a 55-lb (244 N) force. Bending moments of 14,800 ft-lb (20,080 N-m) on the boom and 13,000 ft-lb (17,637 N-m) on the platform result if this load is applied at the platform extremities. A torsion load of 2890 ft-lb (3921 N-m) will be induced on the platform when the manipulator load is applied at the outboard edge. To account for the situation where the manipulator jams and suddenly releases, a magnification factor of 2 was applied to these loads for purposes of structural sizing.

To determine the OCDA platform internal loads, static deflections and required pretension values for diagonals, a finite element model of the OCDA structure was established using COMAP-ASTRAL. The OCDA consists of four major elements:

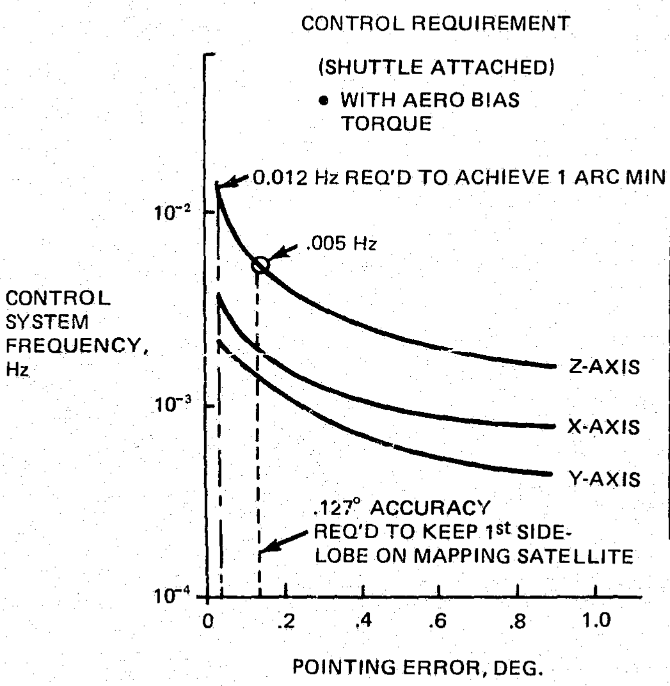
- Platform
- Boom
- Mast
- Solar Array.

The platform and boom were modeled as an array of axial load carrying members while the mast was modeled as a beam which carries bending and torsion. The solar array which consists of 13 separate blankets and support masts was modeled as 13 membranes (strings) under preload. The effects of differential stiffness due to preload (35 lb) were modeled. The total structural model has 1046 members and 1378 degrees of freedom.



AXIS	W/O ORBITER	WITH ORBITER
X	5.0	8.7
Y	-5.2	-9.4
Z	0.9	1.6

Figure 4-6 OCDA Structure Design Conditions



OCDA BENDING MODES
(NASTRAN)

MODE	DESCRIPTION	FREQUENCY, Hz
1	S.A. 1st NORMAL TRANS.	.048
2	S.A. 1st TORSION	.055
3	S.A. PANEL MODES	.061
14	S.A. 2nd NORMAL TRANS.	.084
15	S.A. SIDE BENDING	.092
16	MAST TORSION	.110
29	VERTICAL BOOM & PLATFORM	.116
45	PLATFORM NORMAL BENDING	.174
47	PLATFORM TORSION	.226
52	PLATFORM LAT. BENDING	.308

MODE SHAPE
S.A. 1st NORMAL TRANSLATION

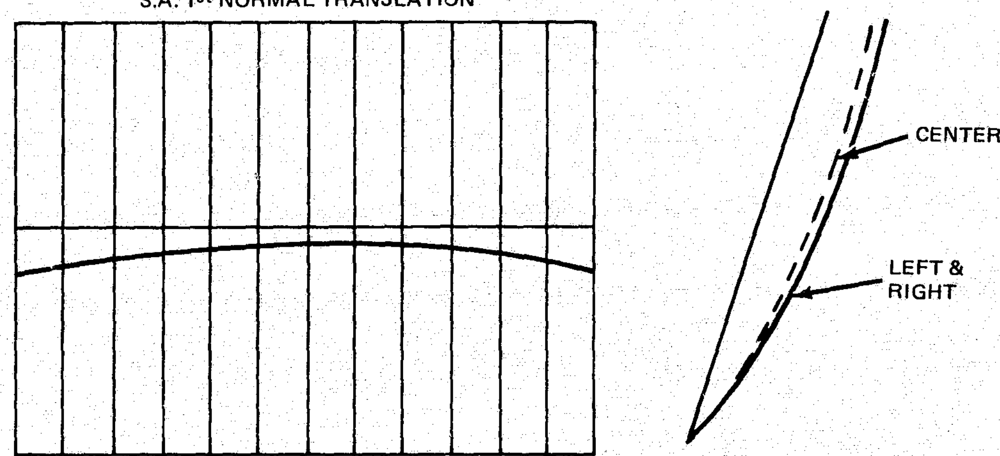


Figure 4-7 OCDA Structural Suitability

The most severe loading condition has been shown to be a manipulator jam load at the extreme end of the platform. These conditions cause a platform deflection of 55.7 cm (21.93 in.) for an ultimate load of 367 N (82.5 lb) and a boom deflection of 14.2 cm (5.6 in.).

Using the structural mathematical model, the flexibilities of the mass points of the dynamic mathematical were calculated. The dynamic model has 249 degrees of freedom. The vibration modes were calculated and a summary of the modes and frequencies calculated is given in Figure 4-7. The fundamental frequency was calculated at .048 Hz. This mode consists of solar array mast support bending with first membrane motion of the blankets. Since the solar array consists of 13 separate pretensioned blankets, a multitude of array modes were calculated (39 modes in the range of .048 to .15 Hz). Figure 4-7 shows typical mode shapes for first membrane motion ($\cong$ .06 Hz). The first mode of the boom-platform occurs at .11 Hz and consists of mast torsion which rotates the boom and platform. A vertical "scissor" mode between the boom and platform occurs at .116 Hz.

Section 5

OCDA DESIGN DEFINITION

The OCDA concept selected was based on the evaluation of several OCDA design candidates which best embodied the structural principle associated with large structure and employed manned and automated techniques for assembly operation demonstration. The design for the selected OCDA provides the work area, support, control and power required for conducting the construction (assembly and fabrication) and test of large space structures.

5.1 CONFIGURATION

The OCDA configuration shown in Figure 5-1 consists of four major assemblies: platform, core module/mast, solar array and rotating boom.

The platform provides a 32-m x 72-m work area with equipment tie down points, two cargo berthing ports and support for the ACS and orbit-keeping propulsion units. The 72-m length was selected based on a follow-on mission desire to construct a 100-m diameter antenna for radiometry. A minimum of 50 m is required to construct the antenna and approximately 20 m was judged necessary to house the core module/mast and provide clearance to the OCDA rotating solar array. Centrally located at the platform edge, the core module/mast provides the support for the solar array/rotating boom drive unit orbiter docking port and houses the OCDA subsystems including attitude control, orbit-keeping, power regulation and control, and communications and data handling.

Mounted to the drive unit of core module/mast is a 108-m long rotating boom which provides a track system for a manipulator and material conveyor (traveler). The 108-m length was selected to allow for the transportation of equipment and materials to any area on the work platform and the construction of large structures outside the confines of the demonstration article itself. When mounted to the drive unit, a 16-m section of the boom extends to one side of the unit and the remaining sections (88 m) on the other. The 16-m section overhangs the platform edge and is located approximately 11 m above a docked orbiter payload bay. This 16-m section is primarily used to assist in the loading/unloading of orbiter payloads.

To provide power for OCDA and its experiments, a solar array located above the rotating boom is mounted to the solar array/rotating boom drive unit. The solar array is

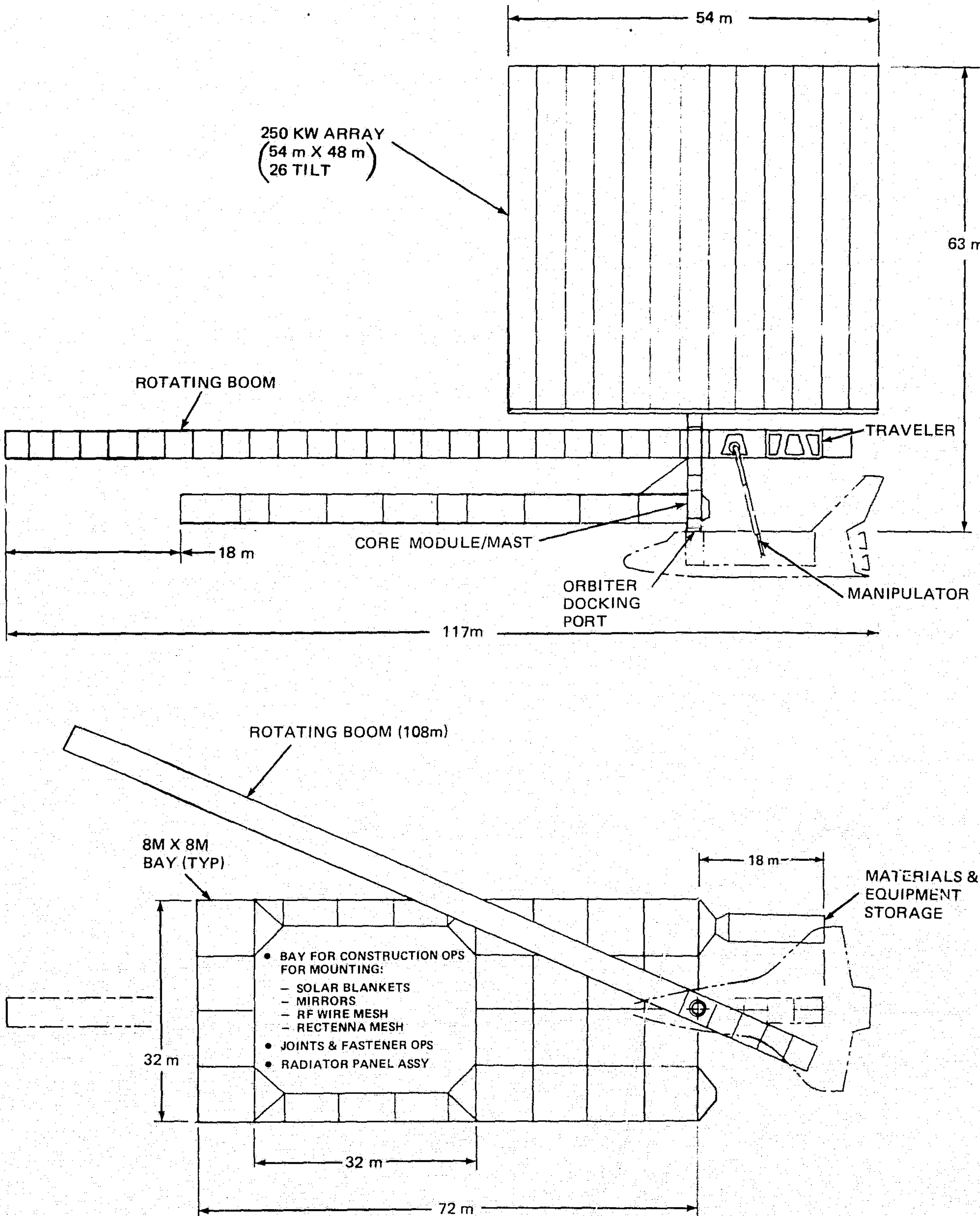


Figure 5-1. General Purpose Demonstration/Test Facility for Construction Technology

modularized to facilitate assembly. The modules (13) when assembled and deployed provide a solar cell blanket area of 48 m x 54 m producing 250 kW of power.

The OCD mass is 37,093 kg, including a six-month supply of consumables for the ACS and orbit-keeping subsystems, and a 20% contingency, as shown in the mass summary Figure 5-2. The heaviest element of the core module/mast assembly is the electrical power system, primarily due to the wire weight needed to route power from the solar array to the rotating boom and platform. The platform (8327 kg) is the heaviest major assembly with the structure and power distribution system conductors making up 80% of the mass. The rotating boom mass (6869 kg) is influenced most by the conductors (4394 kg) which are required to perform follow-on mission experiments in the field of microwave testing. The solar array's 13 modules including structure, solar blankets power cables, etc., constitute 23% of the spacecraft's dry mass.

5.1.1 Platform

The platform (8327 kg) shown in the structural arrangement Figure 5-3 provides a 32-m x 72-m platform and a depth of 4 m. The platform is constructed of 4-m and 8-m length, structural members. These building block members consist of deployable triangular trussed beams (1-m deep) with centroidal end fittings assembled into 8-m x 8-m and 4-m x 8-m bays. The bay corner members are 4-m long tubular posts which contain toe holes or hard points for the construction crew. The node points (fittings) at the bay corners contain provisions to secure equipment to the platform. Diagonal bracing is used to rigidize the bays and provide shear and torsional stiffness to the structure. A large open bay is provided with the surrounding structure arranged to provide a continuous edge to permit the mounting of test equipment such as solar blankets, thin film mirror surfaces, wire mesh and rectenna structures. The platform supports the core module/mast at three levels. The nine structural members used are not the common triangular building block members but consist of deployable rectangular beams. Each of the beams provides two attach points for the mast. Two cargo module docking rings located either side of the orbiter docking port are stabilized with trusses which carry the docking loads into the edge of the platform structure. Similarly, trusses attached to the platform edge nodal points are used to support the ACS and orbit-keeping propulsion units.

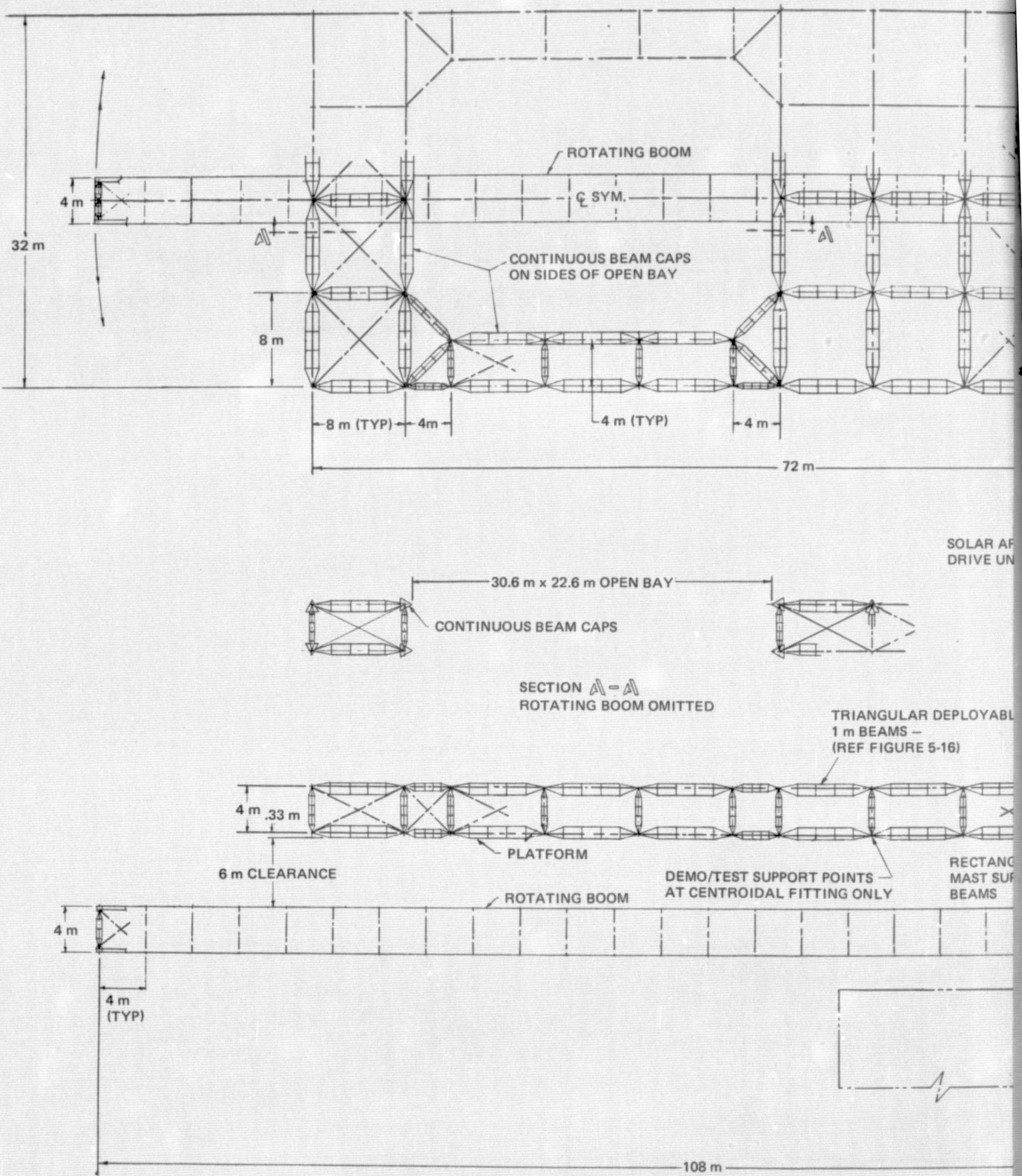
5.1.2 Core Module/Mast

The central mast (3477 kg) shown in Figure 5-4 consists of a 1.4-m square open truss structure, 10.5-m long. It is structurally connected to the platform at three levels, each level contains six shear pin attachment points which provide the shear, bending, and torsional load path between the platform and rotating boom/solar array.

		LBM			Kg
• CORE MODULE/MAST	(7669)			(3477)	
– STRUCTURE		316			143
– DOCKING MODULE (PASSIVE)		320			145
– COMM & DATA HANDLING		270			122
– ELECT POWER		3519	①		1596
– ACS MODULE & REACTION WHEELS		1144			519
– SOLAR ARRAY/ROTATING BOOM DRIVE UNIT		2100			952
• PLATFORM	(18,361)			(8327)	
– STRUCTURE		7421			3365
– PWR DISTRIBUTION		7194	②		3263
– PROPULSION ORBIT KEEP MODULE (2)		436			198
– ORBIT KEEP MODULE SUPT STRUCT		265			120
– LOGISTIC DOCKING PORT (2)		640			290
– PROPULSION, ATTITUDE CONTROL MODULE (2)		1907			865
– ATTITUDE CONT MODULE SUPT STRUCT		375			170
- COMM-ANTENNA'S (KU-BAND & S-BAND)		123			56
• ROTATING BOOM	(15146)			(6869)	
– STRUCTURE		4349			1972
– MANIPULATION & CARRIAGE		966			438
– TRAVELLER		143			65
– POWER DISTRIBUTION		9688			4394
• SOLAR ARRAY	(12,304)			(5458)	
– STRUCTURE		593			269
– SOLAR BLANKET & DEPLOY MECH.		9634			4369
– POWER DISRTIBUTION		1746			792
– ACS, SUN SENSORS (2)		28			13
-- TILT MECHANISM		33			15
TOTAL		53210			24131
20% CONTINGENCY		10642			4827
		63852			28958
CONSUMABLES		17938	③		8135
		81790			37093

① INCLUDES 583 lbM POWER MODULE
② INCLUDES 1818 lbM ORBIT KEEP BATTERIES & 452 lbM POWER REGULATION
③ INCLUDES 6 MONTH SUPPLY OF ACS HYDRAZINE (16,700 lbM)
6 MONTH SUPPLY OF ACS He (86 lbM)
6 MONTH SUPPLY OF ORB KEEP ARGON (1152 lbM)

Figure 5-2 Mass Summary



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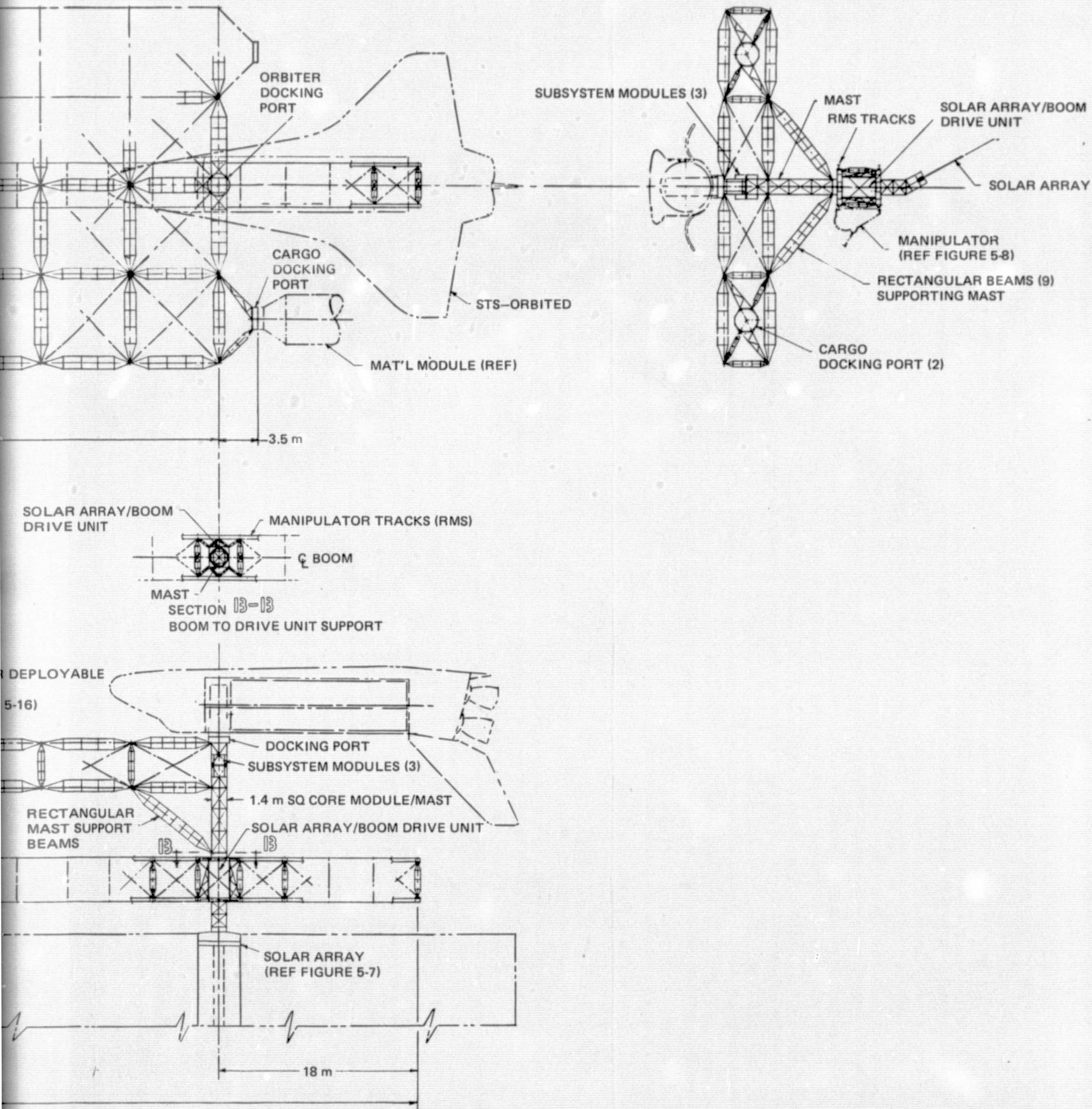


Figure 5-3 OCDA Structural Arrangement

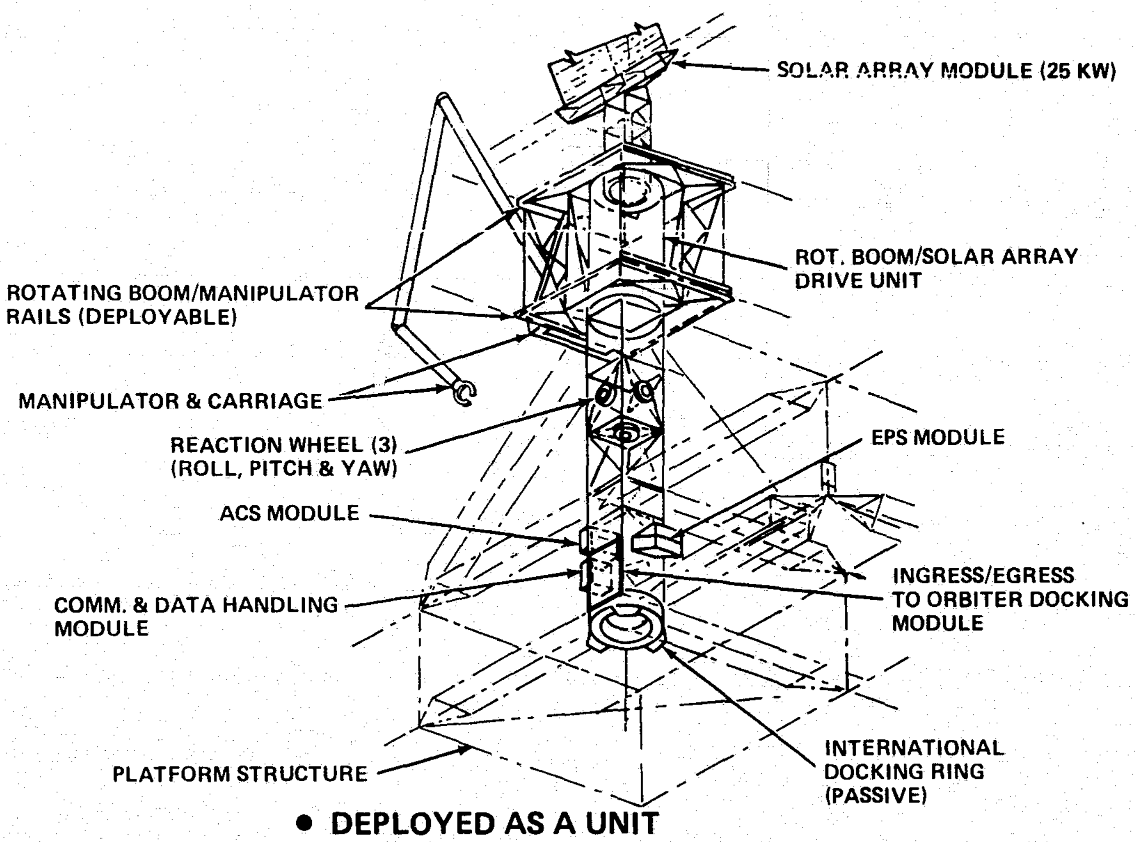


Figure 5-4 OCDA Core Module/Mast Configuration

The Shuttle docking mechanism (passive) is mounted on the end of the mast. A 1.2-m x 2-m opening on the face of the mast provides ingress/egress to the orbiter docking module. The ACS and C&DH modules are mounted on the side of the mast, close to the docking ring. The EPS module is mounted with a shade box on the opposite side in a position which shades its radiator surface from direct rays of the sun. Three reaction wheels (ACS), roll, pitch, and yaw are mounted midway between the platform and boom.

The solar array/boom drive unit (952 kg) is mounted on four fittings on the end of the square mast. A deployable 3.5-m length of the RMS rails/boom and support structure are attached to the boom drive. The docking ring, mast and drive unit with the deployable RMS/boom structure make up 15 m of the core module which is preassembled and removed from the orbiter payload bay as one unit. The solar array modules and its support structure are attached at four points to the drive unit and, together with the 15-m length of core, complete the core module.

The solar/boom array drive, shown in Figure 5-5, contains two separate drive units in one package; a solar array drive and a drive unit to rotate the OCDA boom. Both drive mechanisms apply torques against the OCDA mast structure and both driving functions are completely independent of each other. In summary:

- Solar Array Drive - The solar array is supported from a flange at the upper end of the drive unit. The solar array drive contains a slip ring assembly capable of transferring 250 kW at 200 V. Rotation rates are orbital speed (approximately one revolution every 90 min) and a higher speed tracking mode.
- Boom Drive - The rotating boom structure is mounted to the outer housing of the drive unit. This drive unit provides structural support as well as rotating torque for the boom. All rotating parts, motors, bearings, etc. are enclosed within this unit.

The design life of the solar array/boom drive unit is 10 years.

5.1.3 Solar Array

The OCDA solar array shown in Figure 5-6 consists of a number of array modules mounted on the "upper" end of the rotating boom mast. The array is intended to serve in two configurations: a modest sized array (19.2 kW) to provide housekeeping power for the platform functions and moderate experiment load, as well as a very large array (250 kW) for a specific experiment requiring high power. The array design is modularized to facilitate assembly and match the deployed array with the power requirements.

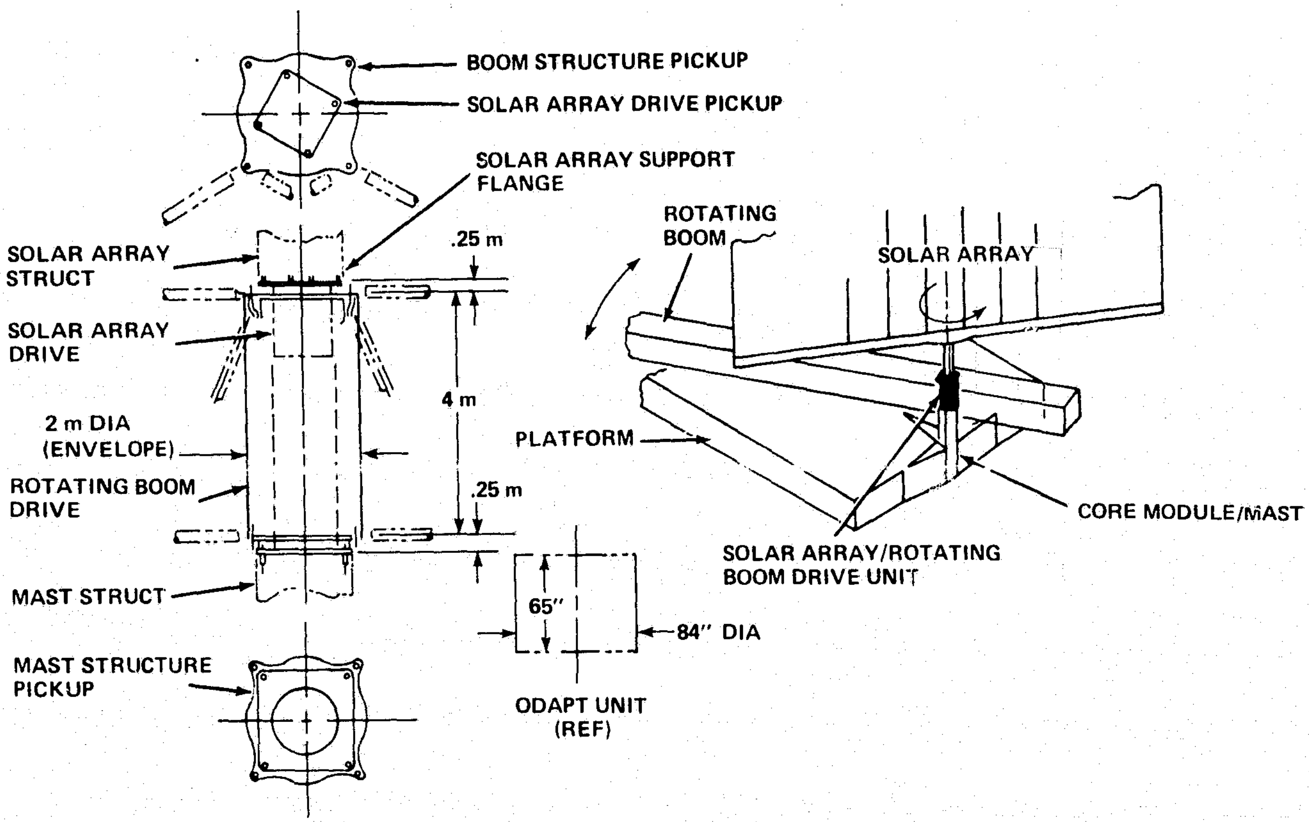


Figure 5-5 OCDA Solar Array/Rotating Boom Drive Unit

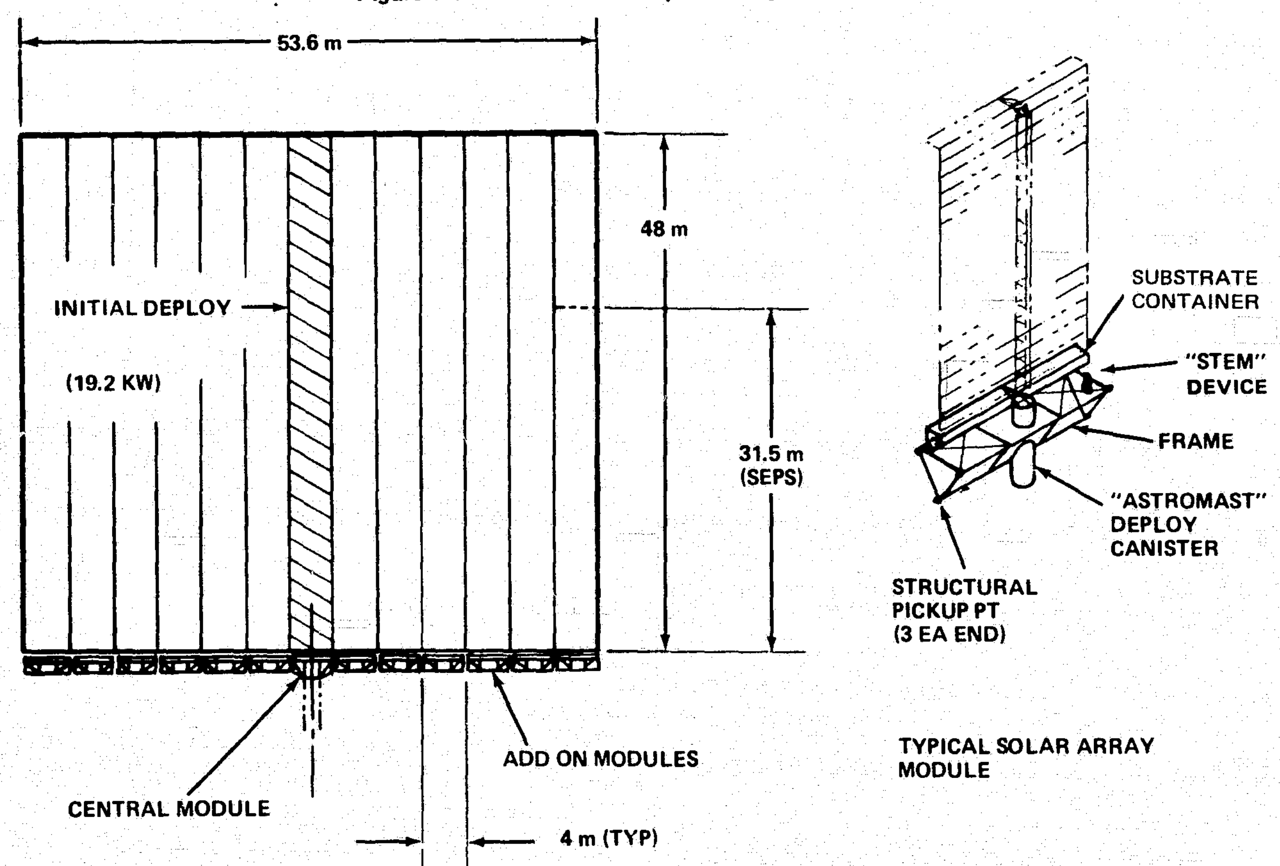
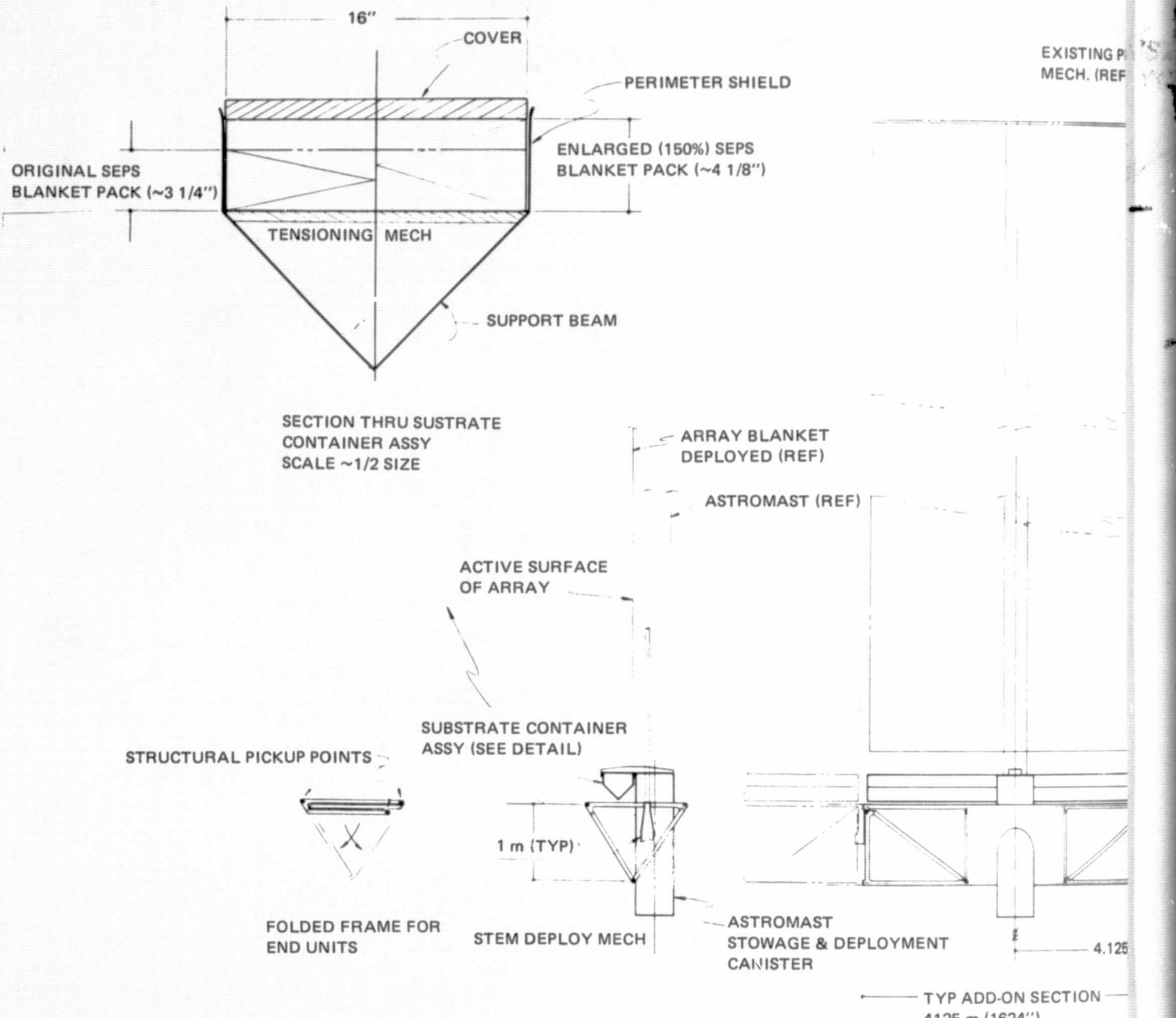


Figure 5-6 OCDA Solar Array (250 kw)



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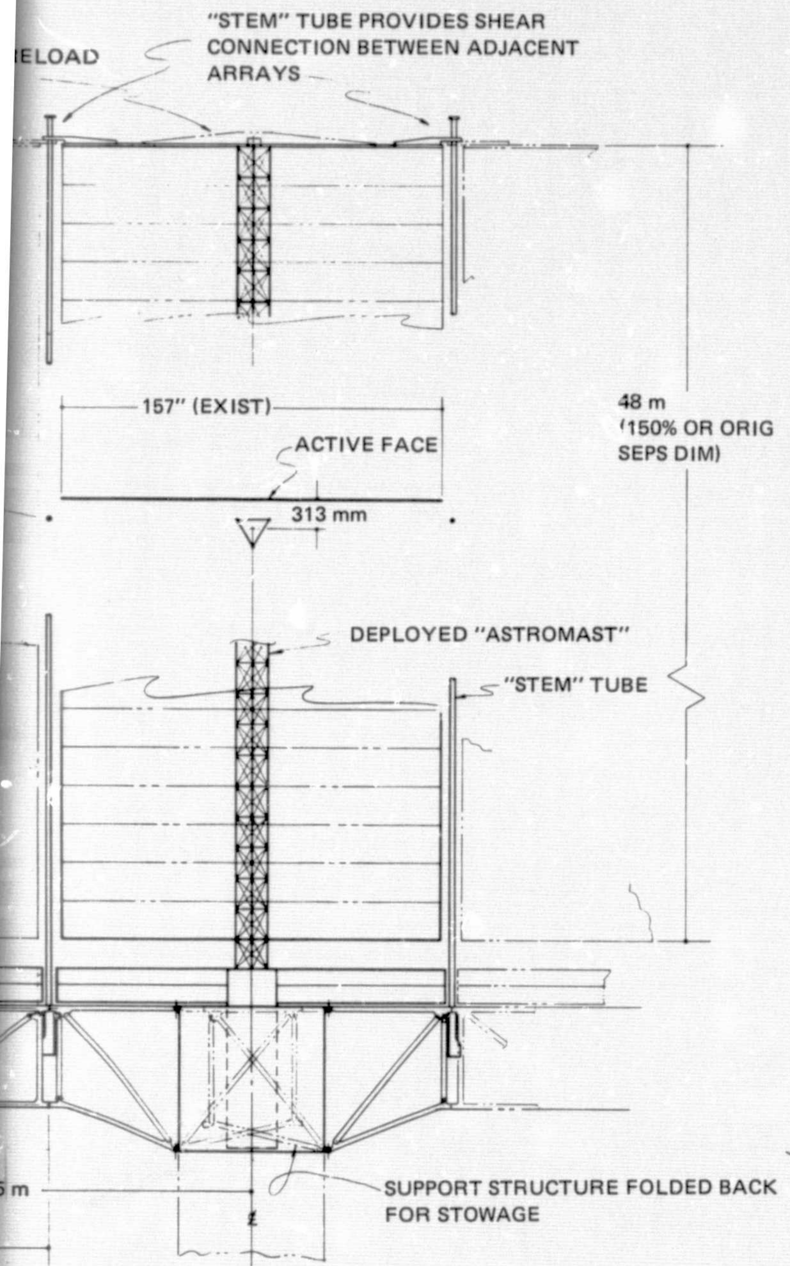
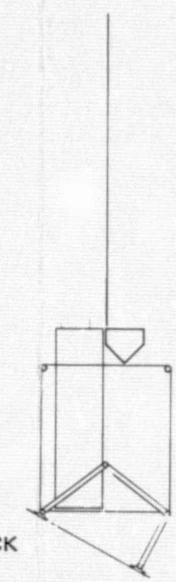
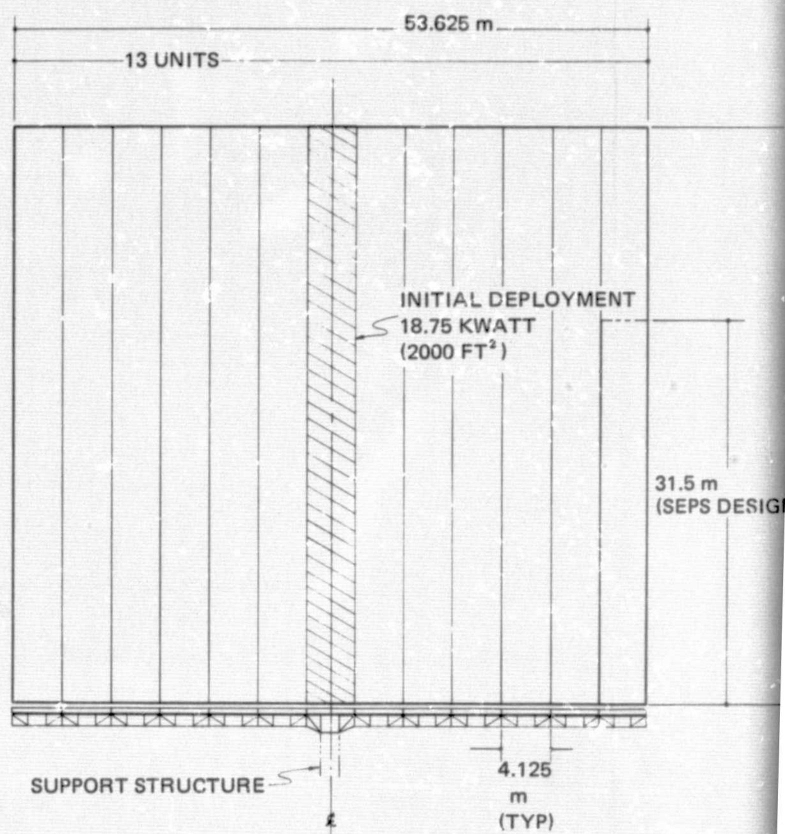
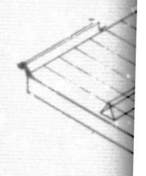


VIEW OF ARRAY ASSY
LOOKING AT BACKFACE
SCALE ~2" = 1 meter





PLAN VIEW OF ARRAY
SCALE ~1" = 4 m



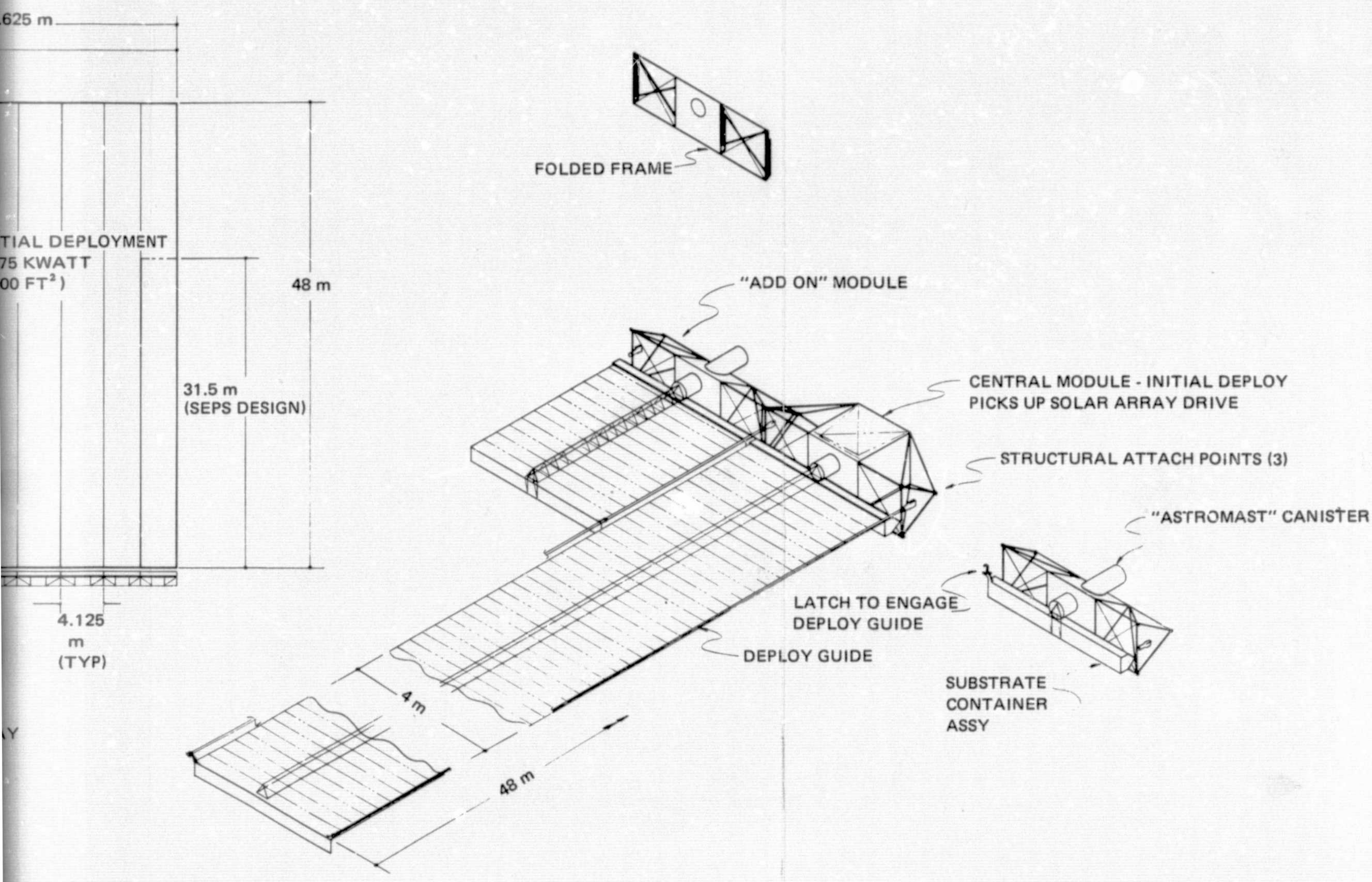


Figure 5-7 OCDA Solar Array

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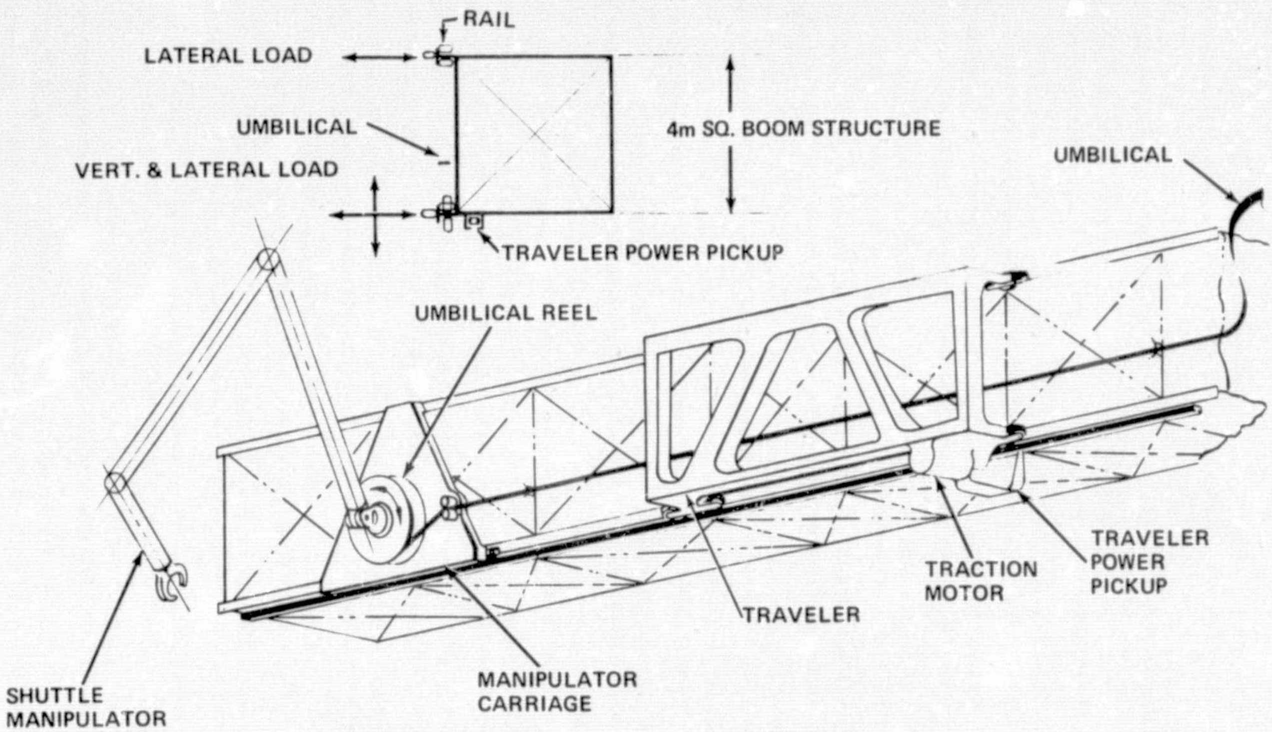
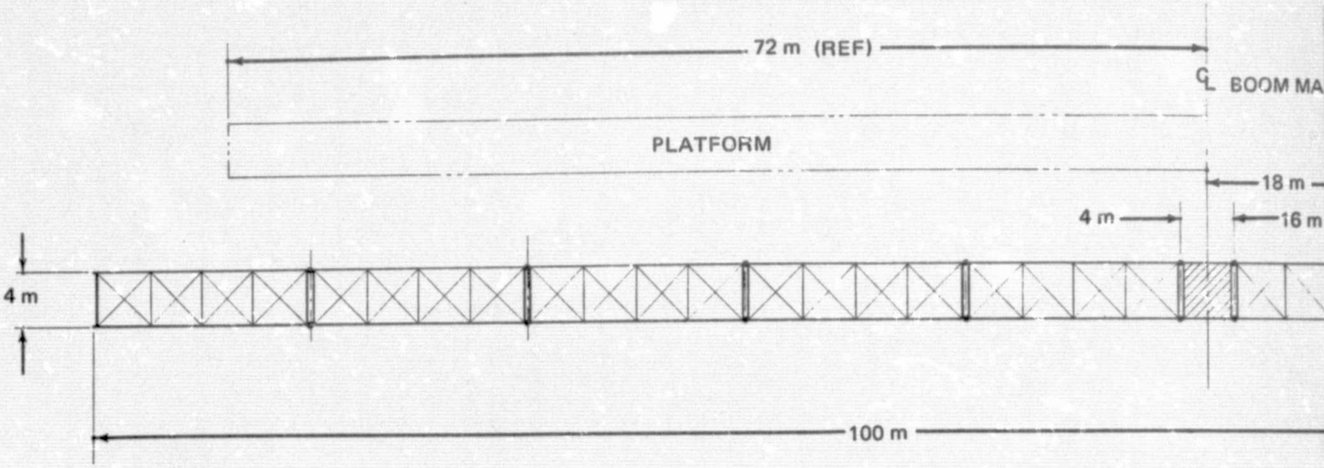
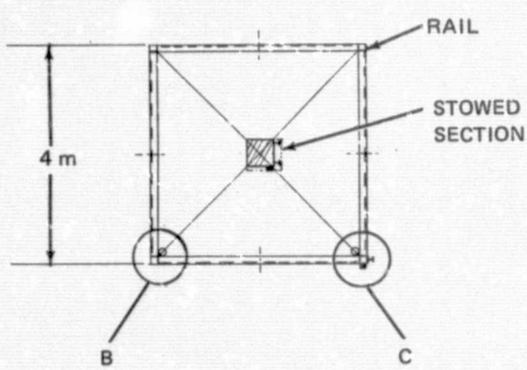
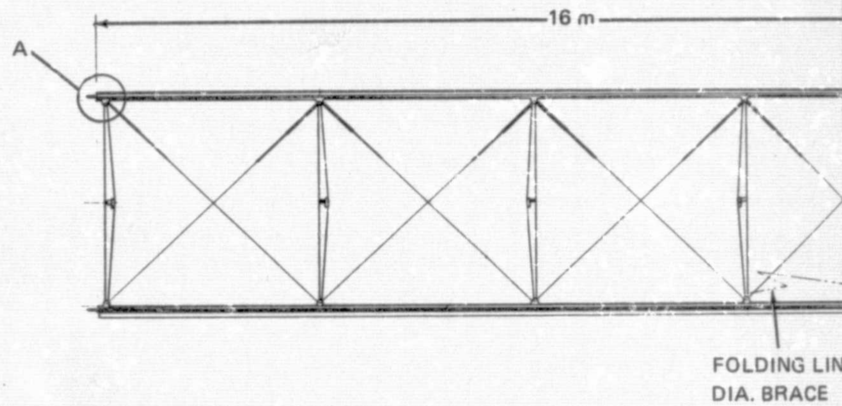


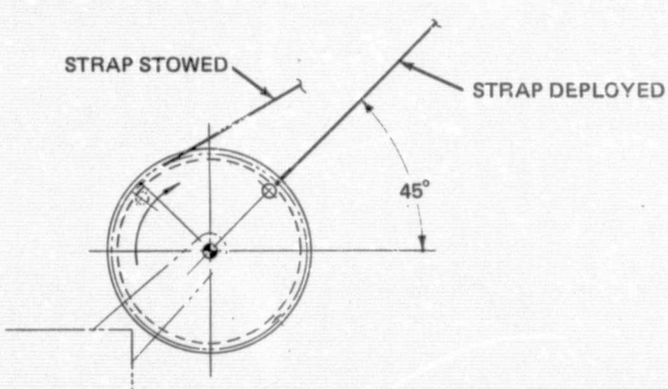
Figure 5-8 OCDA Rotating Boom Manipulator and Traveler



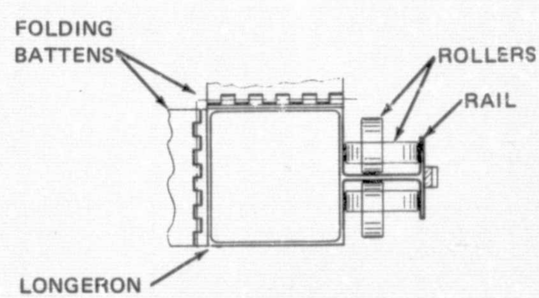




DEPLOYABLE BOOM SECTION



DETAIL B
DIAGONAL STRAP REEL
END BAY



DETAIL C

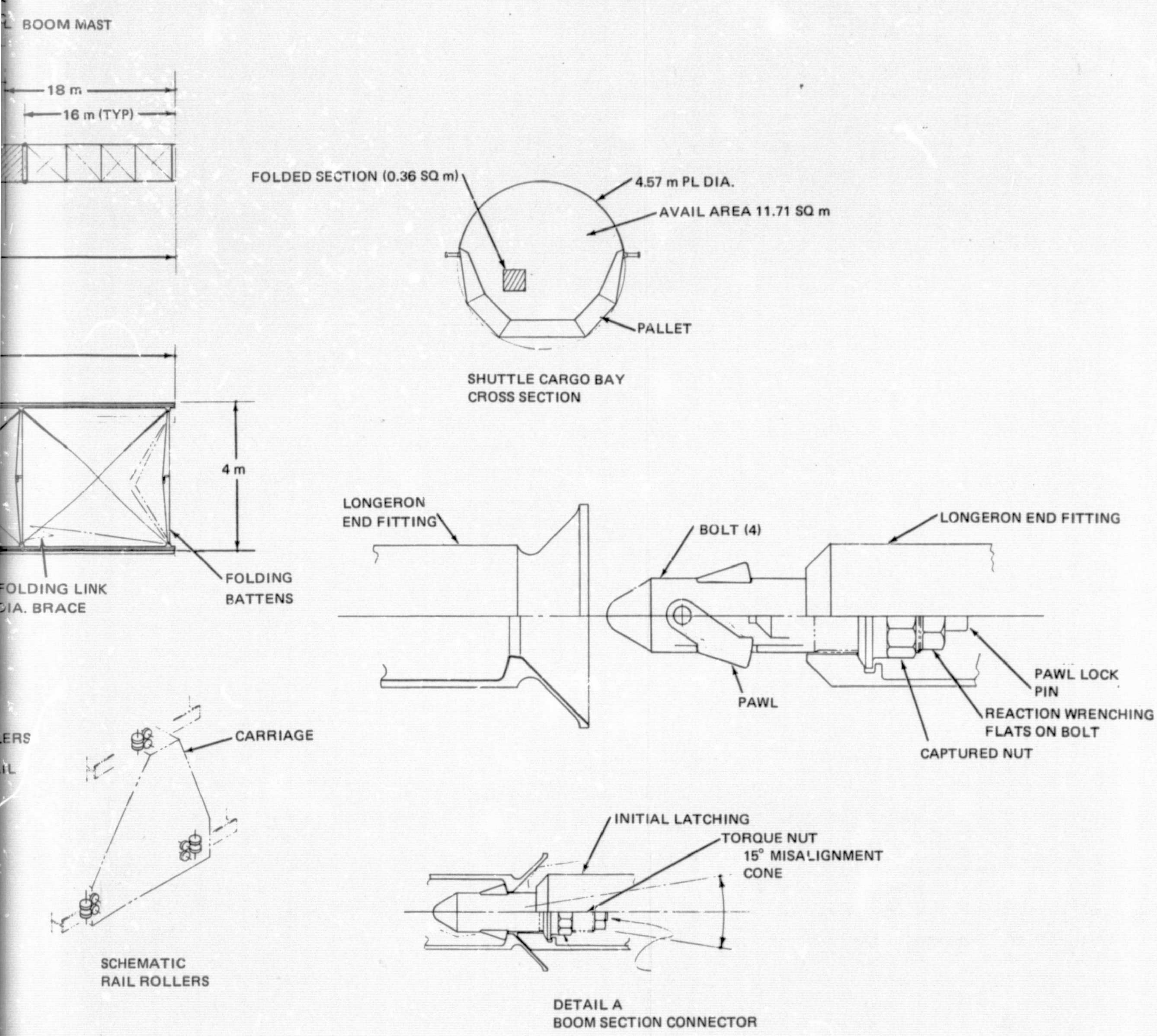


Figure 5-9 Rotating Boom Deployable Structure

The basic component of the modules is an expanded capacity SEPS solar array. The capacity is increased by extending the deployed length by 50%. The array modules (each contain their own extension mechanisms) are deployed side by side to achieve the required power level (250 kW maximum). The entire array consists of a central module and 12 add-on units. The overall size of the full array is 48 m x 54 m. The assembled units, including structure, solar cell blankets, deploy mechanisms and power cables weigh 5458 kg.

The central module structure, as shown in Figure 5-7, is prepared by erecting and securing the folded structure. The astromast, substrate and STEM devices are attached. The assembly is now installed on the solar array drive unit. This drive unit rotates the array in an axis parallel to the boom mast. The array is tilted 26° for maximum average power generation. The STEM guidance units and the astromast propelled substrate are deployed. This initial array (and every additional module) will produce 19.2 kW of power. Subsequent modules are assembled and attached outboard of the preceeding module. As each new module is attached, electrical connections for deployment power and solar power output are made. The solar array assembly procedure is accomplished with the manipulator on the rotating boom. The manipulator operations are guided by EVA crewmen with MMU. Probe/drogue fittings at each corner of the triangular support structure are engaged and locked interfacing in the process, the power busses and avionics wiring. The close proximity of the solar array components to the boom insures that all important assembly functions are performed within easy reach of the boom mounted manipulator.

5.1.4 Rotating Boom

The major elements of the rotating boom (6869 kg) are the 108-m long x 4-m square structure that supports a manipulator carriage and materials traveler. These elements are conceptually shown in Figure 5-8.

The boom structure shown in Figure 5-9 is made from 8-m and 16-m long deployable sections, which are joined by drogue and probe fittings. The boom is built up by assembling sections to the short boom section that is part of the initially deployed core module/ mast. The boom has a square cross section, formed by four longerons, two of which are rails that support the manipulator carriage and traveler. The lower rail supports vertical, lateral, and traction loads. The upper rail supports lateral loads only.

The 8-m and 16-m sections are divided into two and four bays, respectively. The bay battens fold to provide high density stowage and are locked in the extended (deployed) position by overcenter lock mechanisms. Each bay of the section is braced by diagonal tension straps. A section of power pickup rail is premounted on each boom section.

The manipulator (438 kg) used on the OCDA is a standard Shuttle RMS as shown in Figure 5-10. The manipulator is attached to a carriage mounted on the rails and can move along the boom. The manipulator carriage is unpowered and is moved by the traveler. When the manipulator carriage is at the desired location, it is locked to the rail and uncoupled from the traveler. An electrical umbilical runs from the umbilical reel down the boom to the docking port on the core module. Operation of the manipulator is accomplished from the RMS operator station in the Shuttle, using lights and tv cameras on the manipulator to provide visibility. The umbilical is hard wired to the RMS; reeling in and out is accomplished by rotating the reel and manipulator together, with each revolution of the reel providing a 4-m relocation of the carriage. Erectable fairleads support the umbilical along the boom.

The traveler (65 kg) is a powered cart that moves up and down the boom to relocate the manipulator carriage and bring men and materials to the work site. The traveler runs on the boom rails and is moved by an electrical traction drive acting against the lower rail. Power to run the traveler is drawn from a power pickup rail mounted on the boom structure.

5.2 BUILDING BLOCK STRUCTURE

While the space fabrication of structural members becomes a necessity when the structure being assembled is very large, the quantity of structure required to construct the OCDA does not justify adapting that technique. The use of Automatic Fabrication Modules (AFM) becomes most advantageous when it is brought up and left at a factory site, with subsequent flights made solely to deliver high density cargoes of supply material. The structural requirements of the OCDA, however, are small enough to be met in less than one dedicated Shuttle flight of deployable members or space fabrication equipment.

The development and application of space fabricated structures has been studied at Grumman under Contract No. NAS 8-31876. This study investigated a number of structural configurations and the equipment required to fabricate each configuration. The most promising candidate is a building block structure of 1-m depth with 1.5-m long bays, diagonally braced. The structure is made of roll formed .015-in. aluminum alloy sections. The general configuration of the structure is shown in Figure 5-11. A prototype automatic fabrication module for the fabrication of this structure as it would be installed in the aft end of the Shuttle cargo bay, is shown in Figure 5-12. The structure is fitted with connecting attachments at each end. A foldable tripod end attachment is shown in Figure 5-13.

A literature search was made of various deployable structures which might be applicable to the OCDA construction. The configurations studies ranged from off-the-shelf units such as astromast devices to designs not developed beyond the conceptual stage.

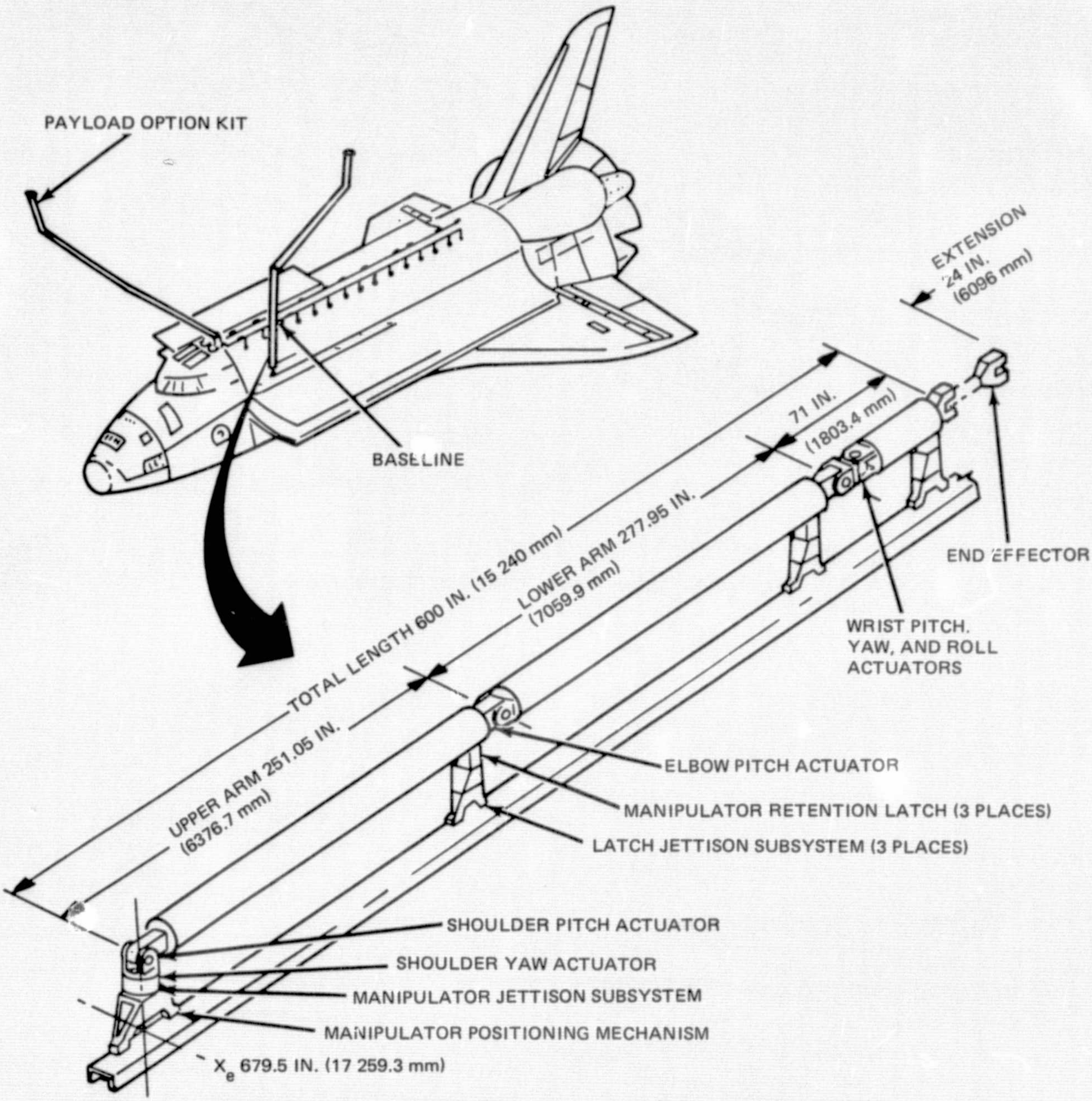


Figure 5-10 STS RMS Manipulator Arm Assembly

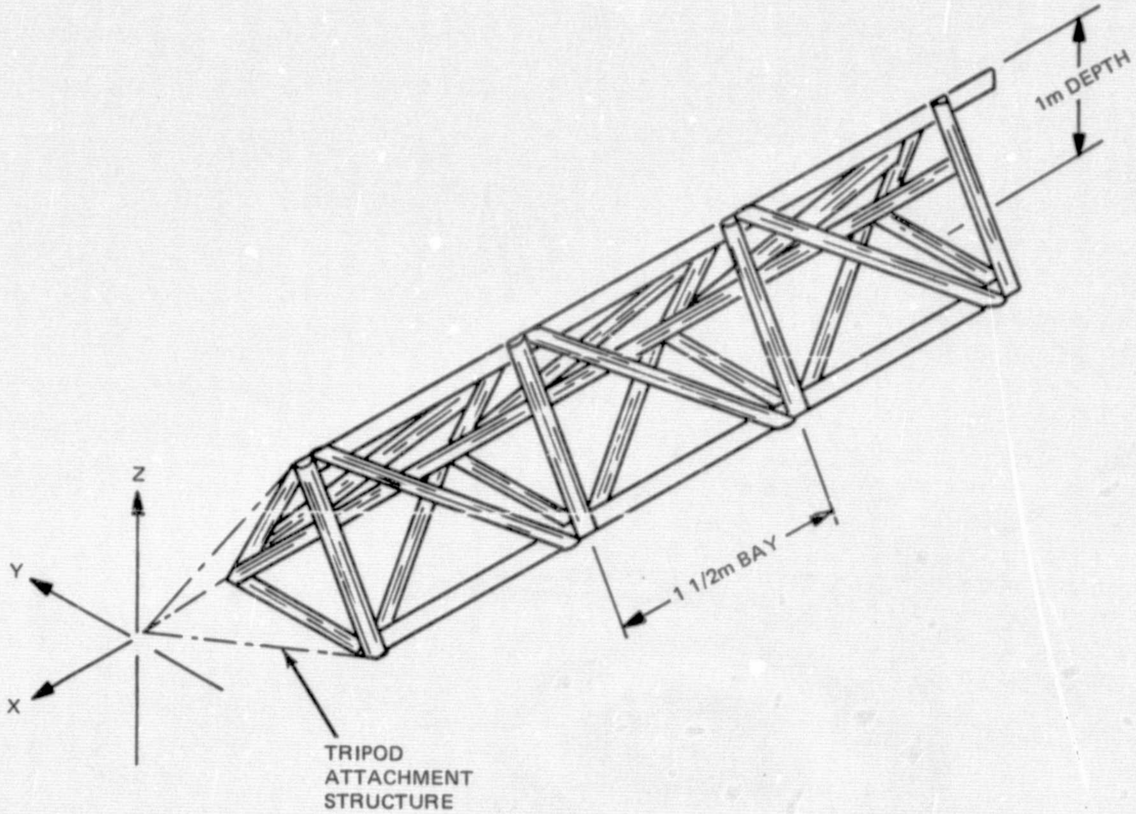


Figure 5-11 Space Fabricated Building Block Structure

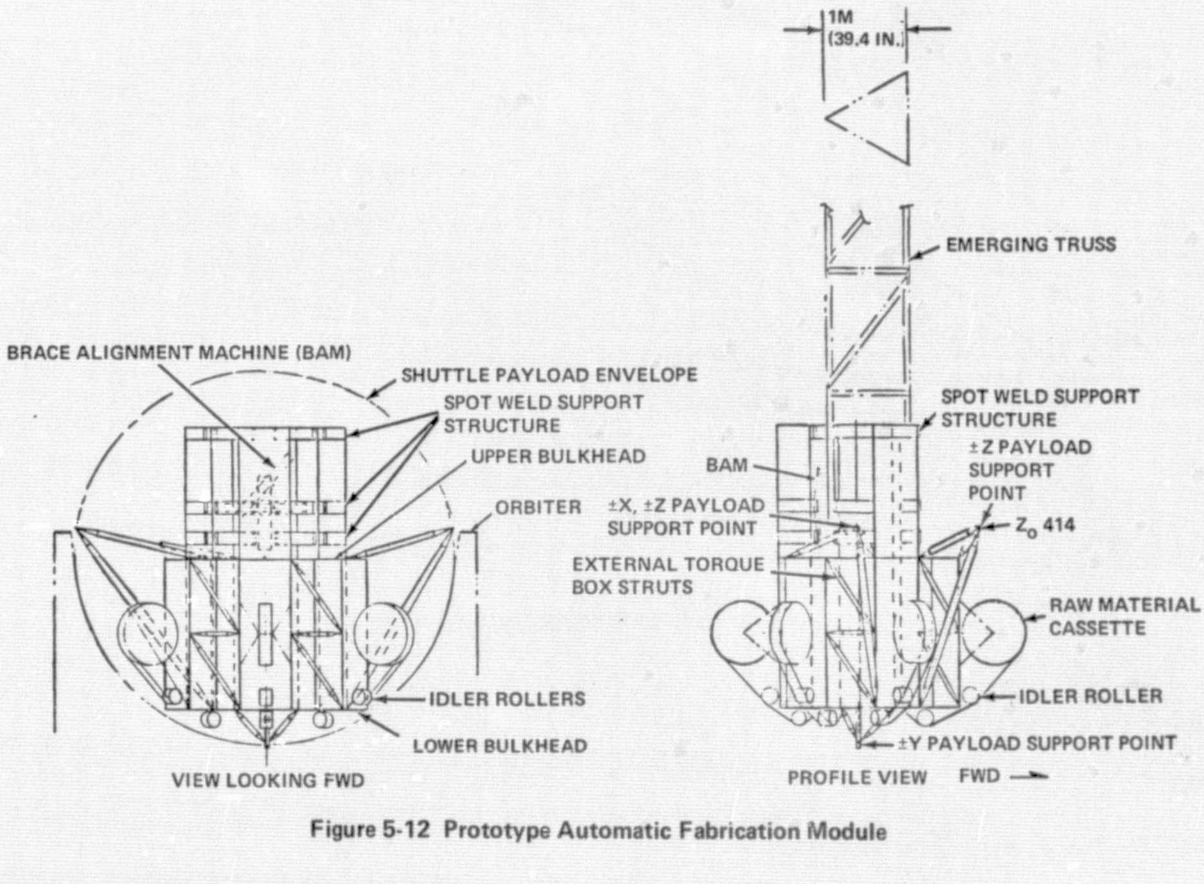


Figure 5-12 Prototype Automatic Fabrication Module

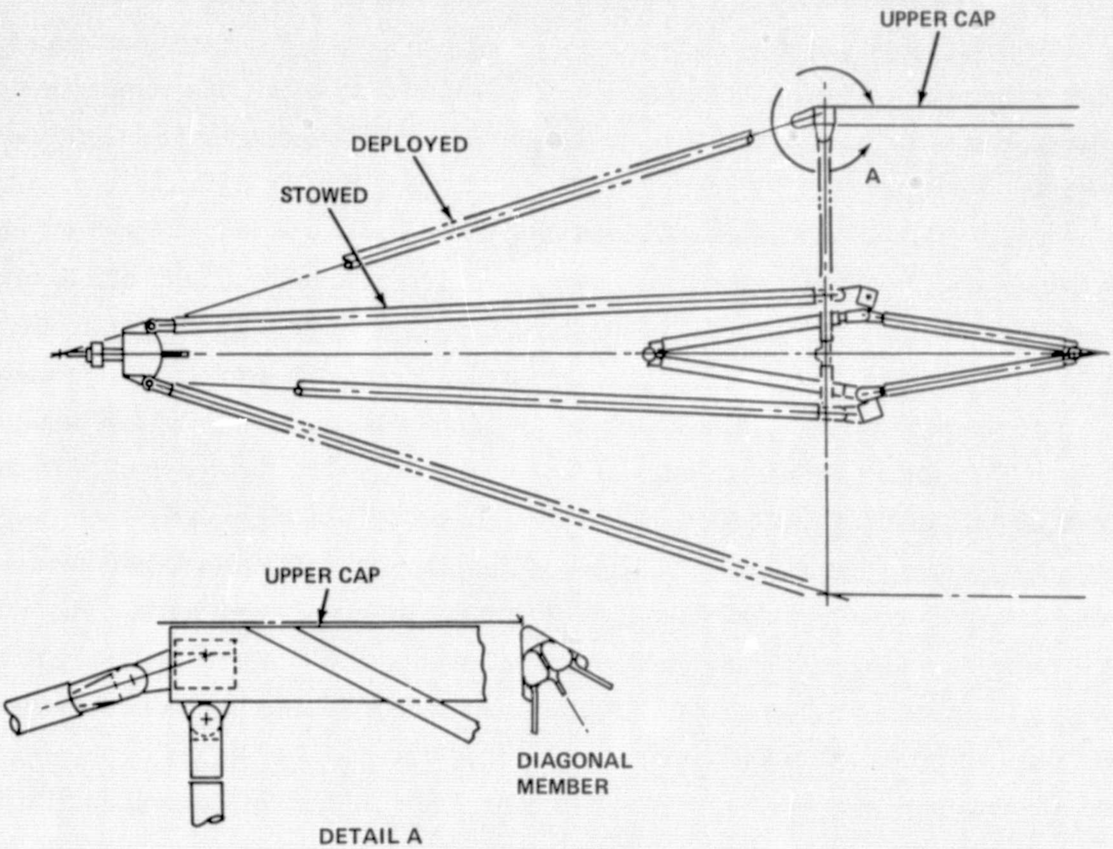


Figure 5-13 Foldable Tripod End Attachment

The results of this search are summarized in Figure 5-14. The thirteen configurations shown were screened to eliminate the least desirable. General statements judging the suitability of each configuration are listed in the table in the comments column. The list consists of eleven designs gleaned from industry literature, and two Grumman designs. These configurations (designated A10 and A13) were intended to meet certain specific requirements: A10 (See Figure 5-15) represents a maximum packing configuration and A13 (See Figures 5-16 and 5-17) represents a structure with continuous longerons and simplified deployment. The screening process resulted in seven surviving concepts. Further selection of the seven concepts was made by configuring each type of structure to satisfy the requirements of a specific application. The application chosen was the smallest building element used on the Space-Based Solar Power Conversion and Delivery System Study (Contract No. NAS 8-31308, ECON Corp.). The building element has a length of 23 m with a depth of 1.5 m. Each candidate was configured to this size and designed to carry a column load of 576 lb ultimate at a temperature of 100°F. While the OCDA structure is made mostly of 1-m deep x 8-m long structure, the evaluation of 1.5-m x 23-m structural concepts is still valid on a comparative basis. For the purposes of this evaluation, all compression members were considered to be tubes of 2219 aluminum alloy material with a minimum wall thickness of .015 in. The exception to this is concept A6 (coilable lattice structure) which typically uses S-Glass for its structural elements. The weight, packaging, volume and launch costs were computed for each of the seven candidate concepts. The data is summarized in Figure 5-18. The analysis was based upon full packing of the launch vehicle. Concept A6-2 (coilable lattice with hollow longerons) requires the least cost for Heavy Lift Launch Vehicle (HLLV) delivery with concepts A9-1, A9-2 and A13 about equal in next place standing. In terms of packing volume and Shuttle launch costs, the A10 concept is best (least volume and launch cost) with concepts A9-2 (articulated lattice) and A13 next in that order.

In addition to the packing characteristics, other properties were considered, in particular, how rigid the deployed structure would be. A multiplicity of joints in a structure produces a member having a structural deadband, particularly if the joints are in the major longitudinal members of the structure. In this respect, the A13 concept is far better then either of the A9 concepts, both of which have complex joints. Since it had this advantage, did reasonably well in the packing comparison, has the added advantages of being deployed without the need for a deployment cannister, and is adaptable to several types of end connections, the A13 concept was adopted as the most promising deployable concept for the OCDA structure.

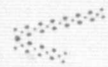
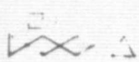
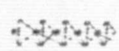
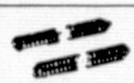
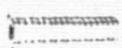
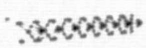
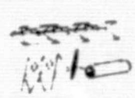
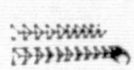
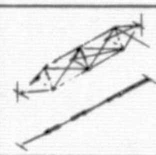
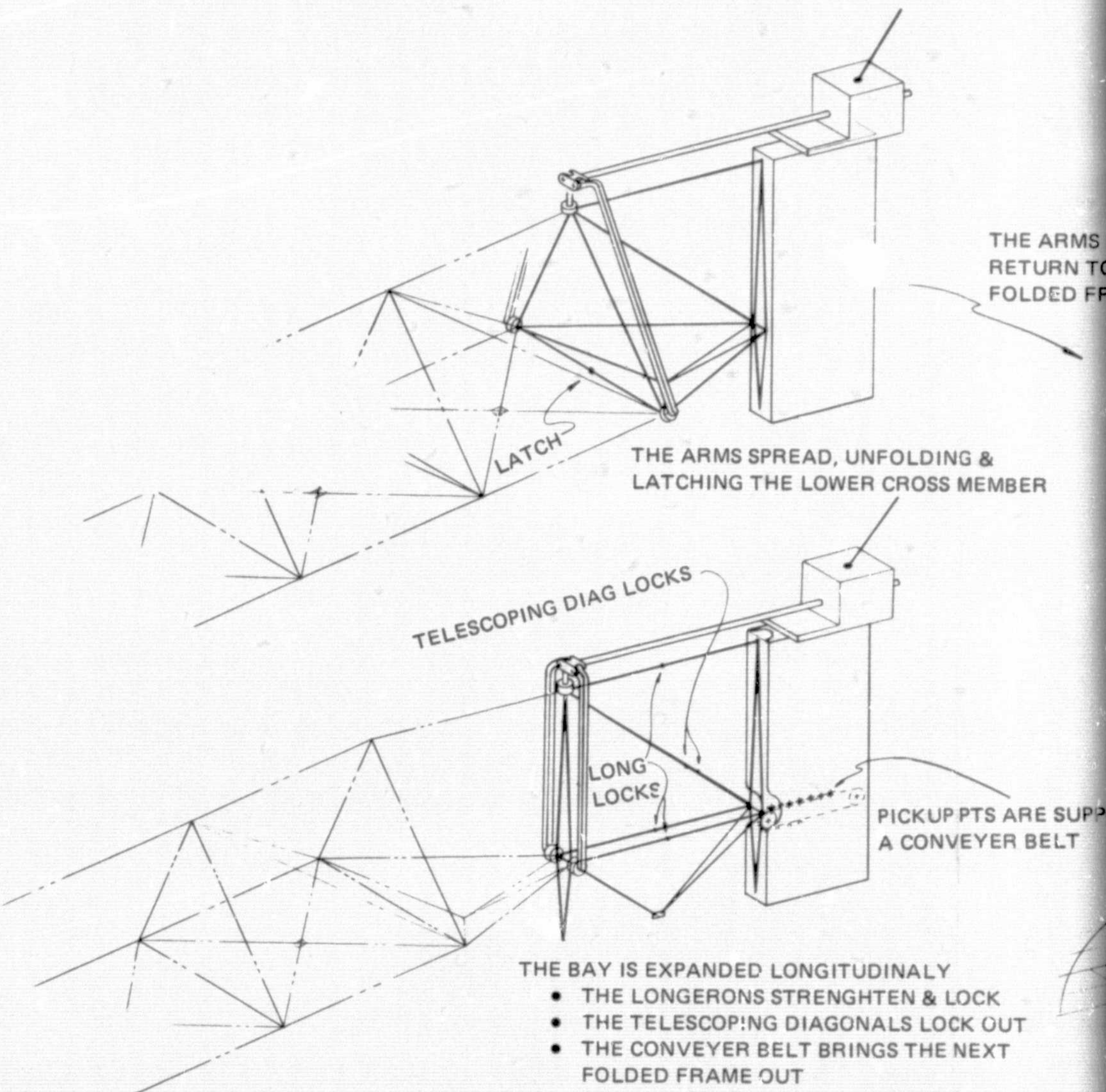
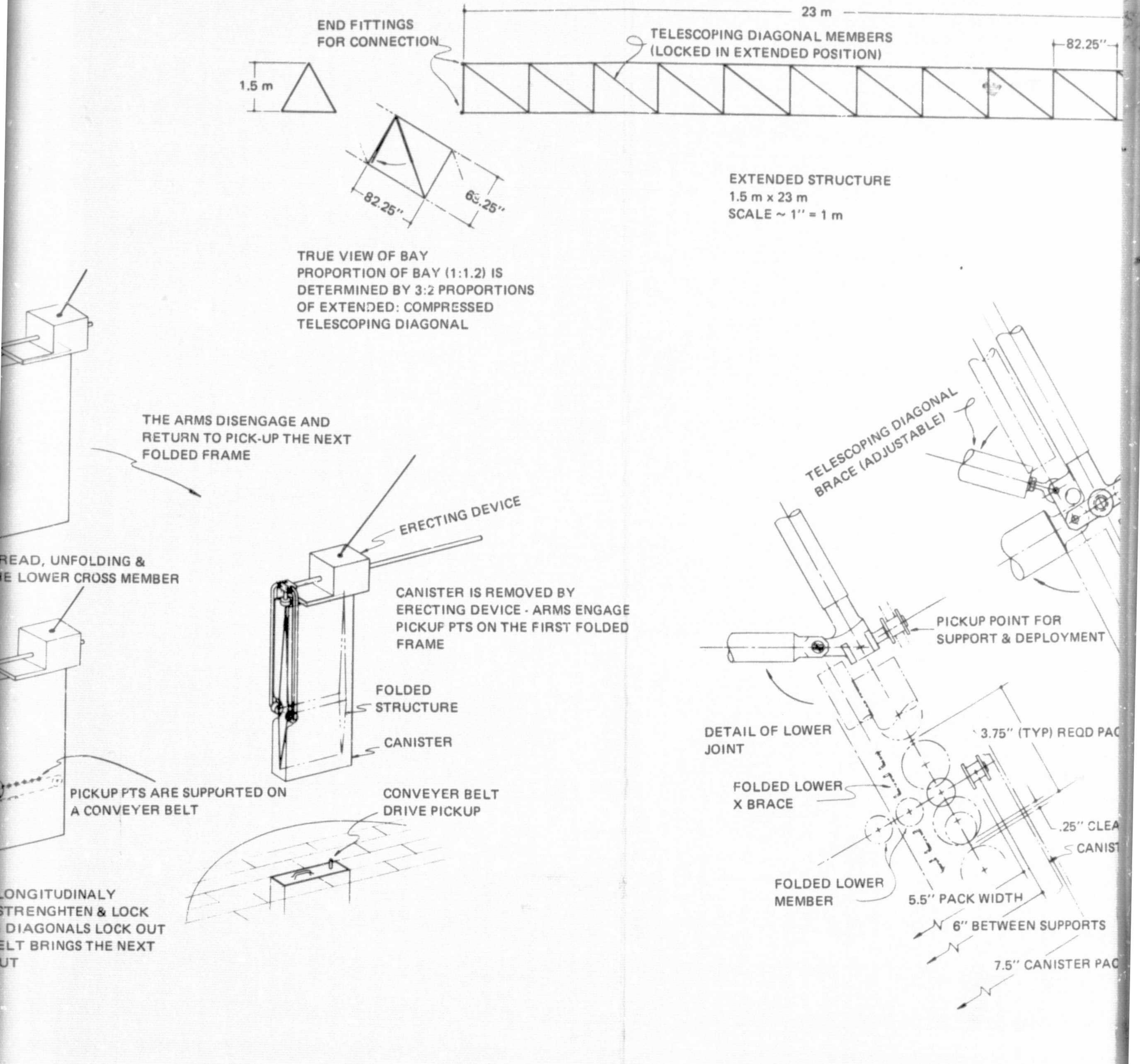
CONCEPT	SCHEMATIC	COMMENTS	RECOMMENDATION
A-1 FOLDED BEAM		• EFFICIENT STRUCTURE • HEAVY DUE TO PULLEYS, CABLES AND LATCHED JOINTS • LOW PACKAGING DENSITY	• REJECT
A-2 FOLDED BEAM COLLAPSED ✓		• GOOD STRUCTURAL CONCEPT • HEAVY DUE TO THE NUMBER OF PYROTECHNICS REQUIRED TO LOCK THE TELESCOPING DIAGONAL • FAIR PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-3 LAZY TONGS		• FLEXIBLE STRUCTURE • LOW LOAD CARRYING CAPABILITY • HIGH PACKAGING DENSITY	• REJECT
A-4 THREE AXIS LAZY TONG		• POOR STRUCTURE • LOW BENDING & TORSIONAL STIFFNESS • HIGH PACKAGING DENSITY	• REJECT
A-5 EXTENSIBLE TRUSS		• LOW TORSIONAL STIFFNESS • HEAVY SINCE LAZY TONGS ARE BASICALLY INEFFICIENT COLUMN MEMBERS • HIGH PACKAGING DENSITY	• REJECT
A-6 COILABLE LATTICE ✓		• HEAVY SINCE LONGITUDINALS ARE SOLID COIL SPRING MEMBERS FOR COILING • MATERIALS APPLICATION MAY BE LIMITED • GOOD PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-7 FOLDED SPACE GIRDER ✓		• INEFFICIENT COLUMN MAY BE HEAVY • RIGGING FOR ALIGNMENT COMPLEX • FAIR PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-8 BOX BELLOWS		• CLOSED SECTION MAY BE THERMALLY UNDESIRABLE • HIGH PACKAGING DENSITY	• REJECT
A-9 ARTICULATED LATTICE ✓		• EFFICIENT BEAM • HEAVY DUE TO COMPLEXITY AND NUMBER OF JOINTS • GOOD PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-10 DOUBLE FOLDABLE ✓		• EFFICIENT STRUCTURE • HEAVY DUE TO COMPLEXITY & NUMBER OF HINGED JOINTS • HIGH PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-11 FOLDED BEAMS COLLAPSED ✓		• EFFICIENT BEAM • HEAVY DUE TO LARGE NO. OF HINGED AND LATCHED JOINTS • HIGH PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE
A-12 TRIANGULAR WIRE		• NO DIAGONAL BRACING, LOW SHEAR STIFFNESS • EULER BUCKLING MAY BE LOW • HIGH PACKAGING DENSITY	• REJECT
A-13 GRUMMAN CONTINUOUS LONGERON		• GOOD STRUCTURAL CONCEPT • CONTINUOUS LONGERONS ELIMINATE STRUCTURAL DEAD BAND RESULTING FROM JOINT CLEARANCES • GOOD PACKAGING DENSITY?	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE

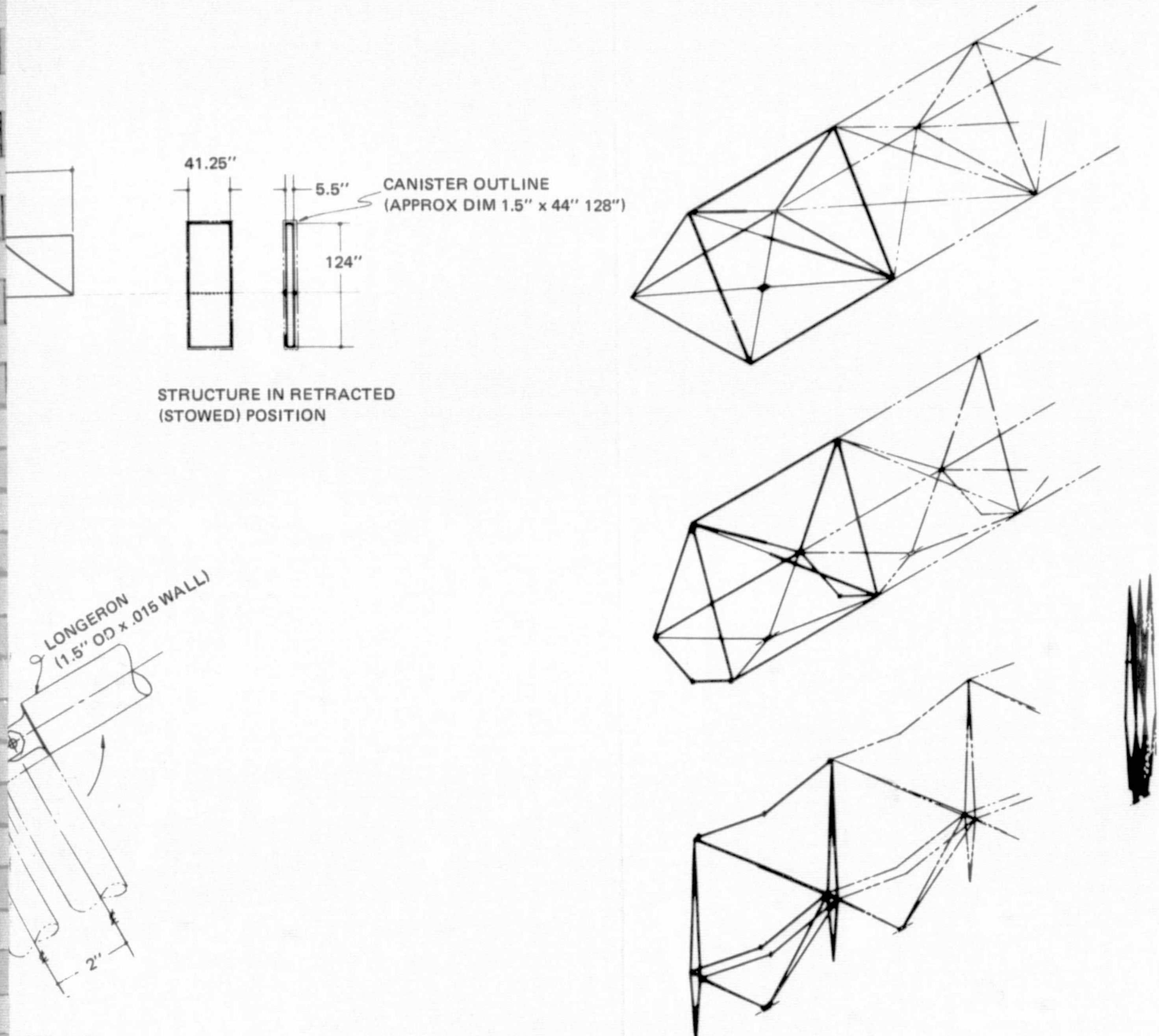
Figure 5-14 Summary of Prepackaged Deployable Structures



THE ARMS
LATCH
THE ARMS SPREAD, UNFOLDING & LATCHING THE LOWER CROSS MEMBER
TELESCOPING DIAG LOCKS
LONG LOCKS
PICKUP PTS ARE
A CONVEYER BELT
THE BAY IS EXPANDED LONGITUDINALY
• THE LONGERONS STRENGHTEN & LOCK
• THE TELESCOPING DIAGONALS LOCK OUT
• THE CONVEYER BELT BRINGS THE NEXT FOLDED FRAME OUT



FOLDOUT FRAME 2

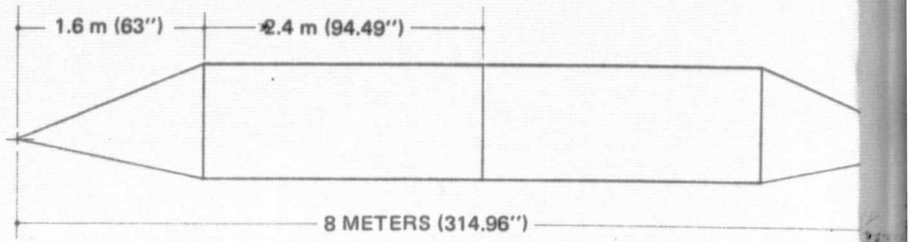


K PER BAY

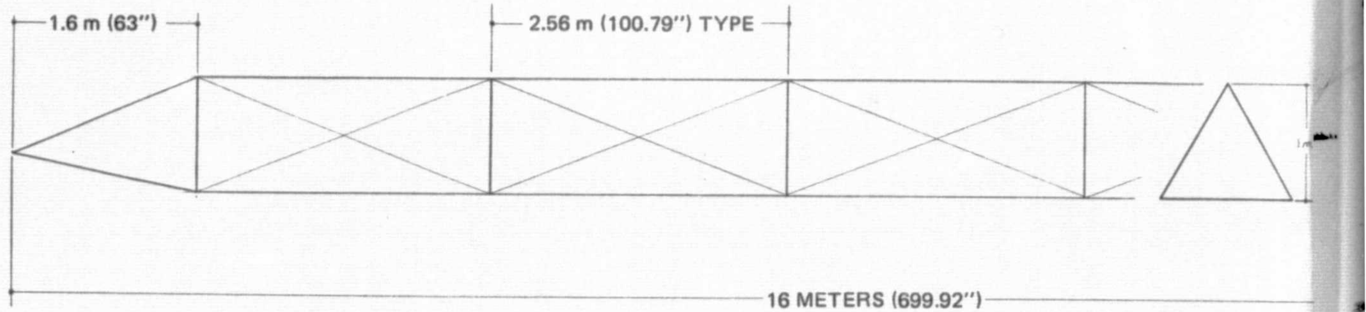
R
TER

KING WIDTH

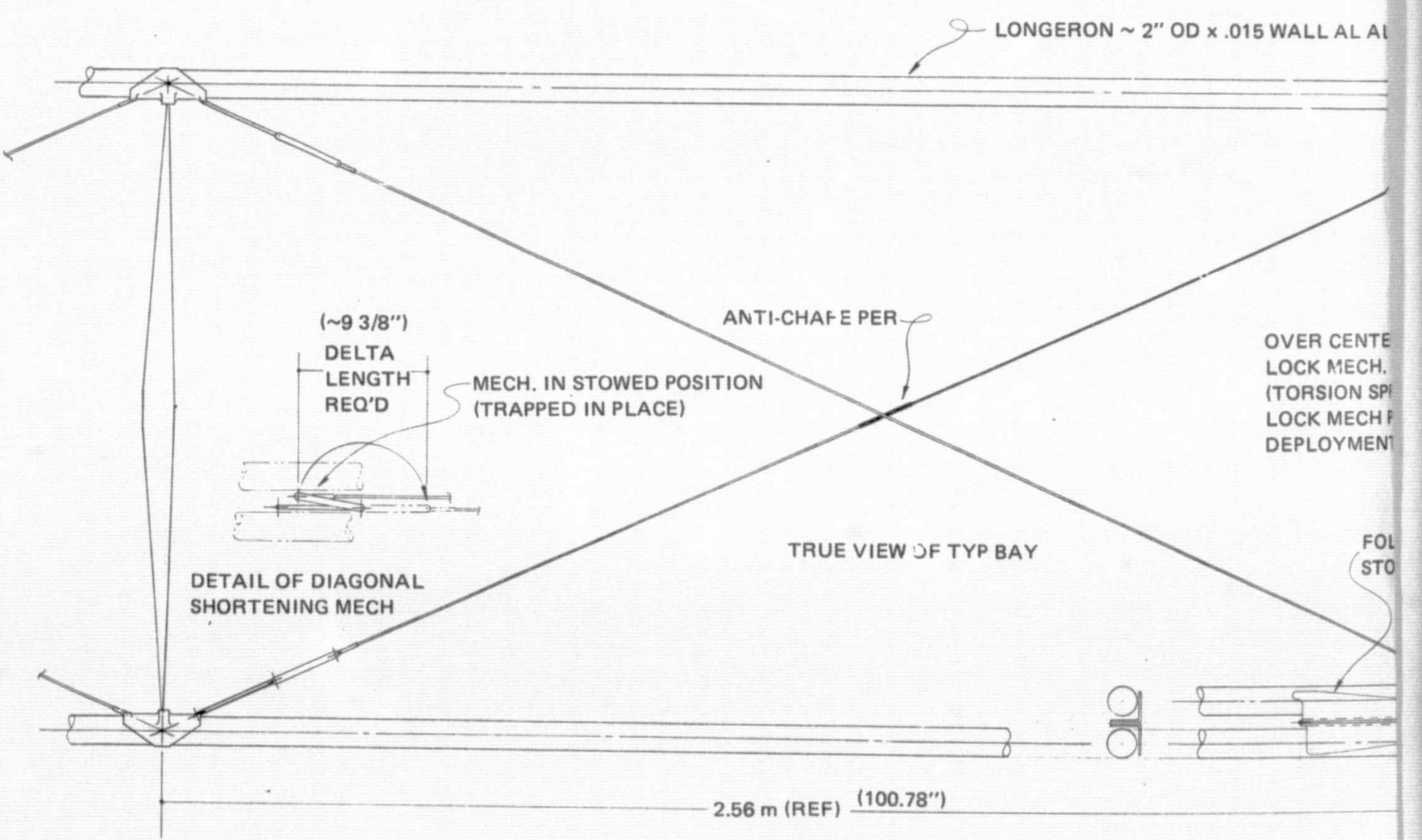
Figure 5-15 Double Foldable Beam



8 METRIC BEAM



16 METER BEAM
SCALE ~2" = 1 m



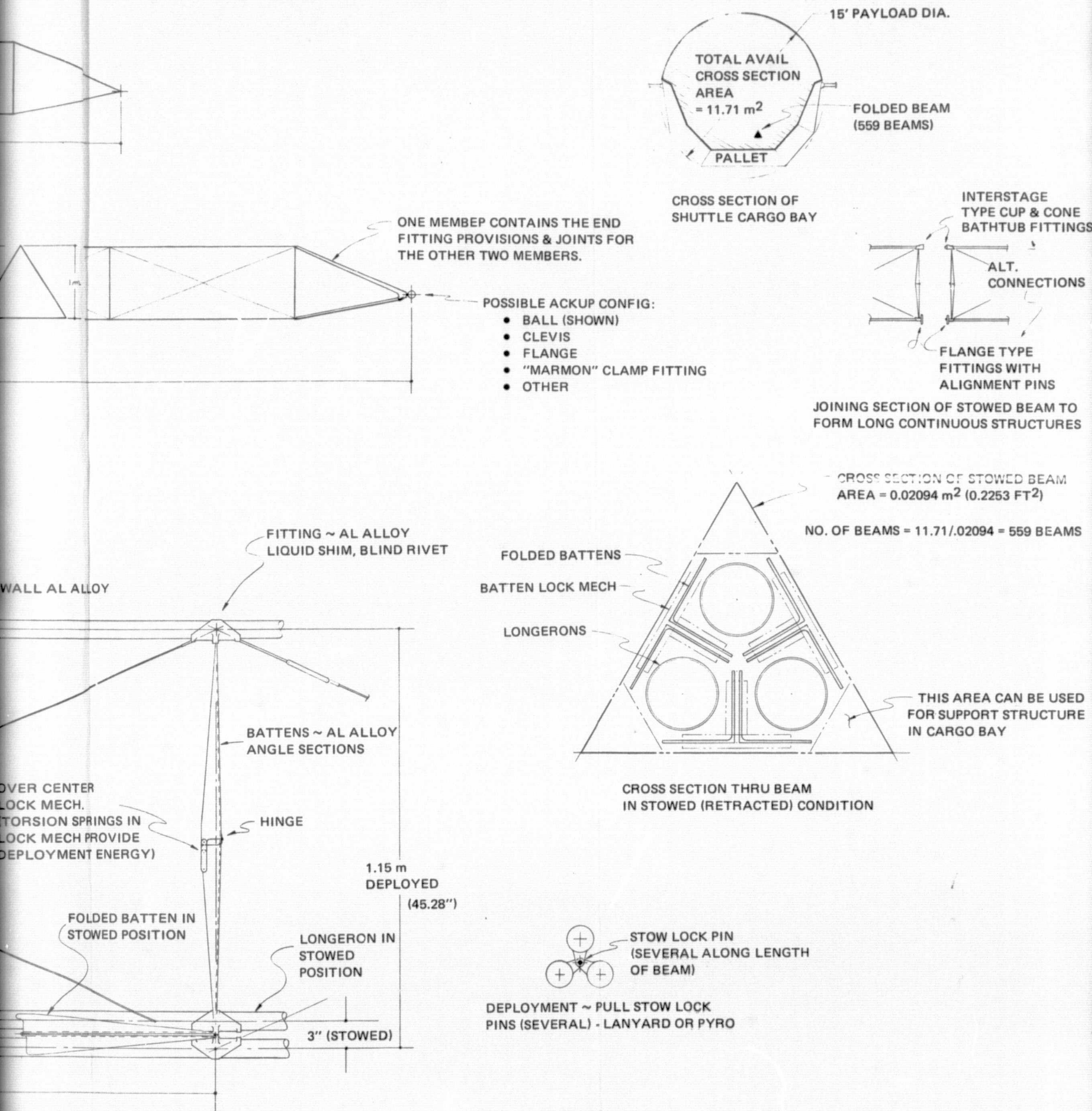


Figure 5-16 OCDA Building Block Deployable Structure

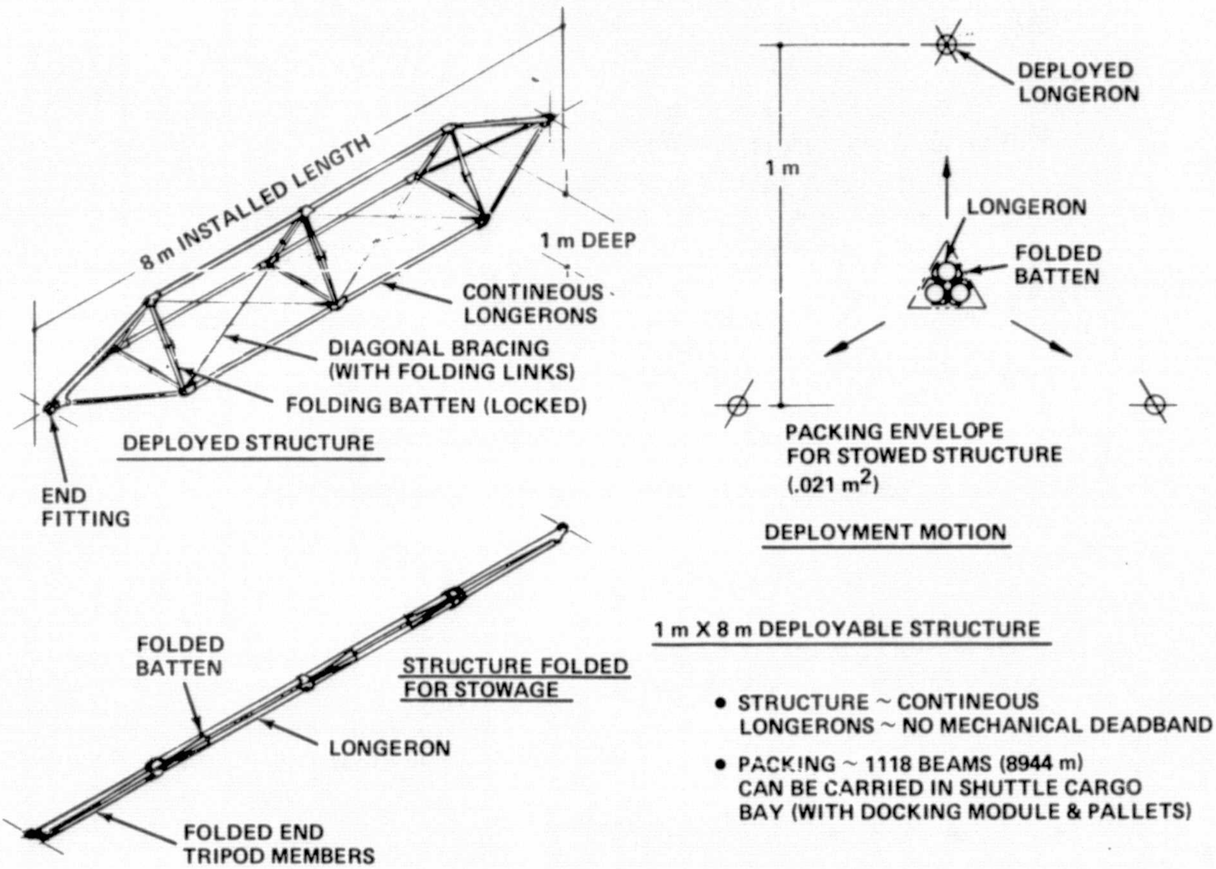


Figure 5-17 OCDA Candidate Structural Building Block

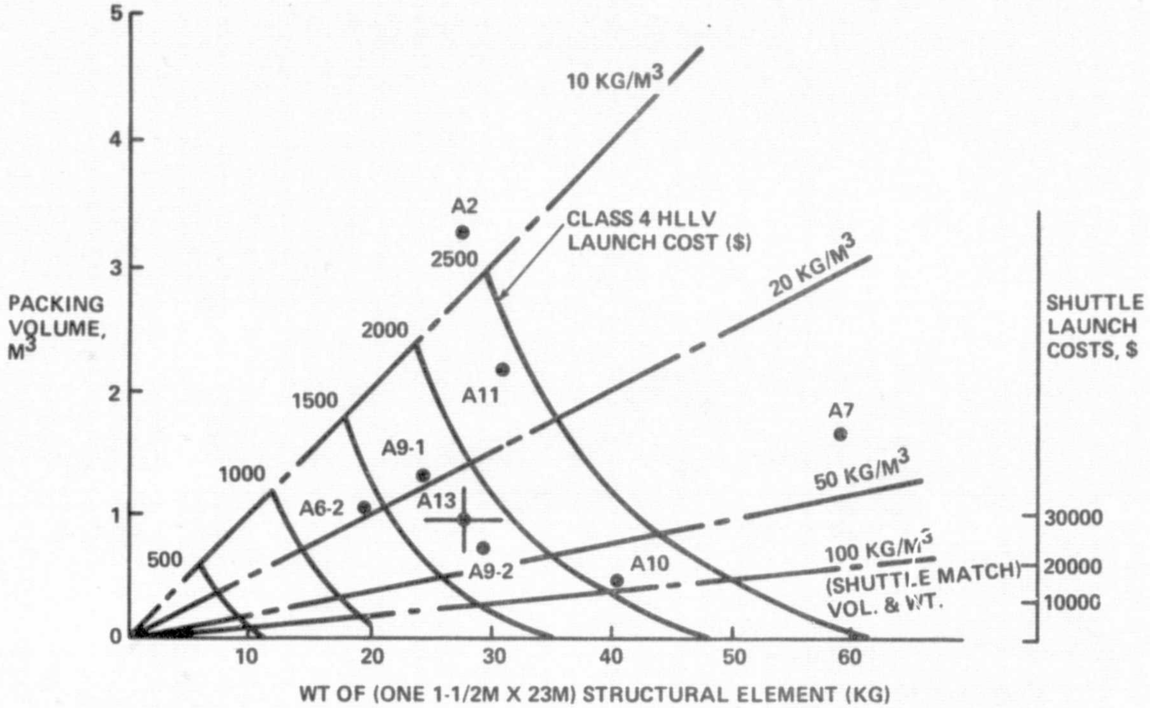


Figure 5-18 Concept Ranking—Weight, Volume & Launch Costs

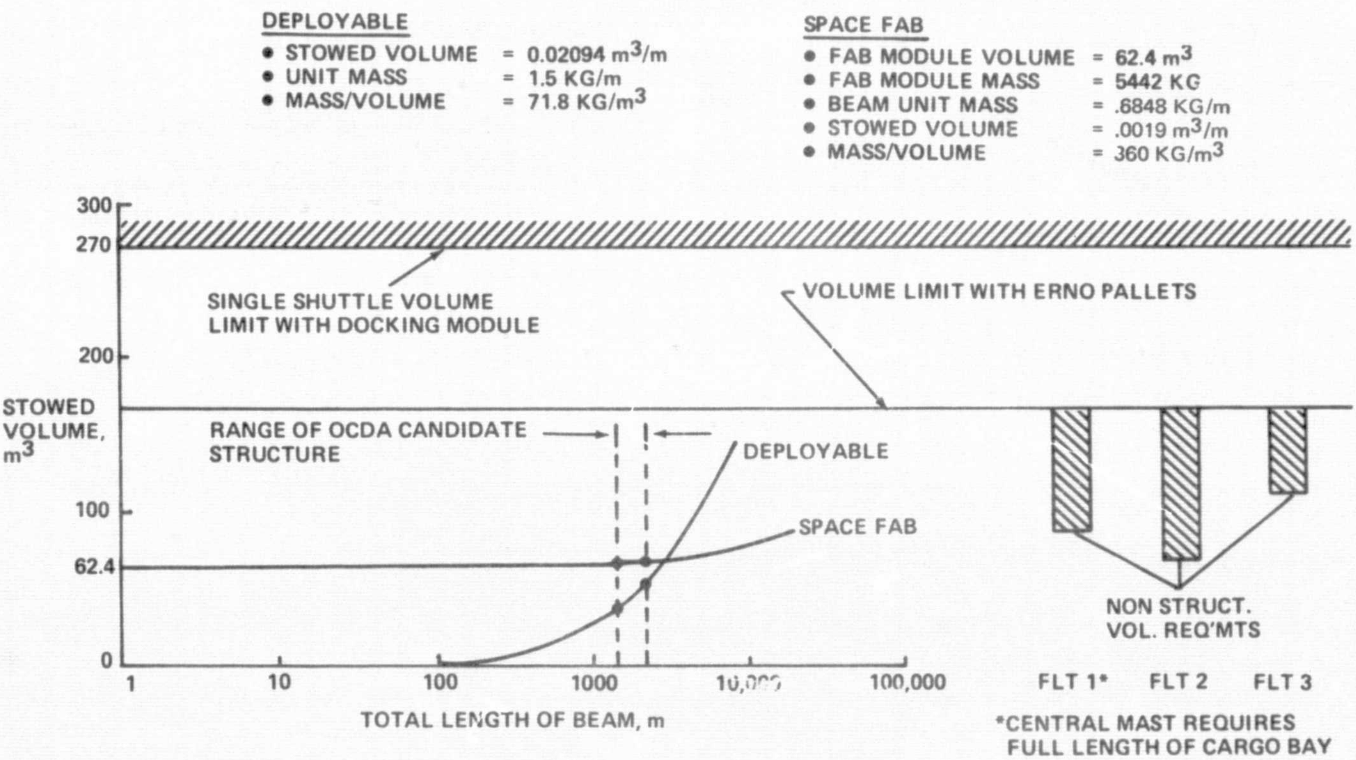


Figure 5-19 Deployable vs Space Fabrication

The general arrangement of the A13 concept is shown in Figure 5-17.

The structure shown has a 1-m depth triangular section and is shown in an 8-m length. The 8-m length is compatible with the OCDA structural arrangement. Because structures this size fit easily within the Shuttle cargo bay, continuous longerons are used to eliminate the structural deadband that results from joint clearances. The structure is compacted by folding the battens of each bay, shrinking the cross section. The folded battens are entrapped between longerons and are therefore supported during liftoff. On deployment the battens unfold and are locked in the extended position by over-center locks. Cross bracing is used to stabilize each bay. A set of folding links takes up the cable slack when the structure is folded. This deployment approach can be used for structures to be fastened end-to-end to make continuous members, as well as the centroidal node structure shown.

The retracted structure has a cross section area of 0.021 sq m and a volume of 0.335 cu m. A dedicated shuttle flight could deliver 8944 m of structure. (Approximately 1000 m are required for the OCDA platform structure). The structure is held in the retracted position by pins that hold the longerons together. Deployment is initiated by pulling the lock pins with a lanyard or pyro actuator. The structure is deployed by the energy stored in the batten lock torsion springs.

This deployable building block structure concept adapts itself well to a wide variety of materials such as aluminum alloy or composite structure.

A comparison of how well the Shuttle cargo bay is utilized is shown in Figure 5-19. The figure shows that in the range of structures required for the OCDA, the use of deployables makes better use of the cargo volume. The range of structural requirements shown in the figure represents two cases: one in which it is assumed that all of the structure might be space fabricated, and the other assumes that only a portion of the structure should be considered. This last view is more realistic since, as the design progressed, it became evident that much of the structure is special (such as the booms and the platform posts) and they were not candidates for a deployable/space fabrication tradeoff. A breakdown of what structure is concerned in each case is shown in Figure 5-20.

The assembly of the basic OCDA proceeded on the basis that it would be fabricated of deployable structures. This represents a low risk approach from the standpoint of the OCDA program. Recognizing, however, that the construction of space fabricated structures will make an important technology contribution to future missions, these techniques have been incorporated in nine of the follow-on activities.

Figure 5-20 Candidate OCDA Structure for Deploy/Space Fabrication Comparison

	IF ALL STRUCTURES WERE SPACE FABRICATED	PRESENT OCDA DESIGN: SPECIAL STRUCTURE	PRESENT OCDA DESIGN: CANDIDATE FOR DEPLOY/SPACE FAB. TRADE
PLATFORM			
• 8 m (130 REQUIRED)	992		992
• 5.6 m (16 REQUIRED)	90		90
• 4 m (16 REQUIRED)	64		64
• 4 m V. POSTS (50 REQUIRED)	200	200	
MAST SUPPORTS			
• 10 m (3 REQUIRED)	30	30	
• 8 m (6 REQUIRED)	48	48	
BOOM			
• 4 m BATTENS (104 REQUIRED)	416	104*	
• 104 m CAPS (4 REQUIRED)	416		
SOLAR ARRAY STRUCTURE			
• 4.13 m X 12 UNITS	50	50	
	2306 MAX		1146 MIN

*DEPLOYABLE BOOM STRUCTURE CONSISTS OF FIVE 16 m SECTIONS AND THREE 4 m SECTIONS.

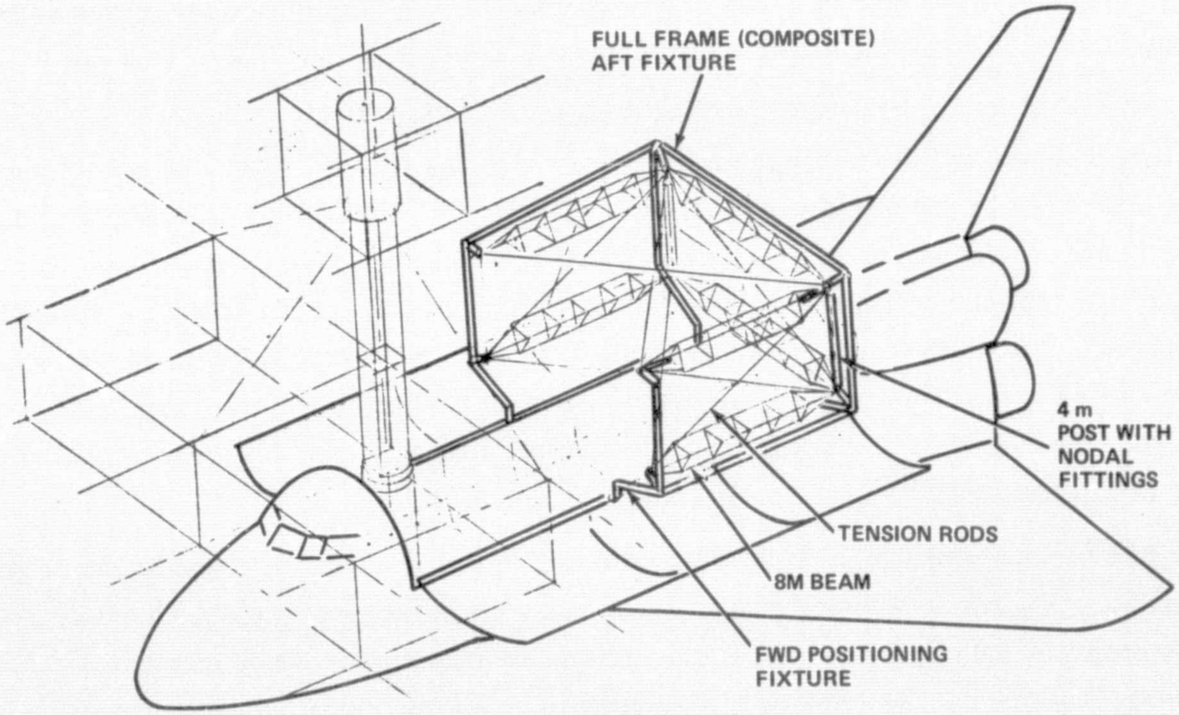


Figure 5-21 Platform Assembly Fixture

5.3 PLATFORM ASSEMBLY FIXTURE

The OCDA platform is constructed by assembling partial cubes at the Shuttle and installing them in place on the platform. The partial cubes are put together in an assembly fixture erected over the aft end of the open orbiter cargo bay. An illustration of the platform assembly fixture installed on the docked orbiter is shown in Figure 5-21.

This method of construction allows the bulk of the assembly effort to be conducted close to the components stowed in the cargo bay and in an area where the orbiter RMS can be used as an assembly aid. The pickup points on the fixture assure that the partial cubes will be initially aligned. Final alignment of the cube is accomplished in place on the platform. The fixture is stowed at the top of the cargo bay packing for easy access and assembly. The vertical support fixture members are removed from the cargo pack and fastened to the orbiter payload bay longeron attach points. The remaining pieces are attached to form a frame that would enclose an 8-m x 8-m x 4-m structural cube, with the side of the frame facing forward on the orbiter open. The components of the fixture are of composite construction to minimize thermal distortion. The platform structure is built by drawing components from the orbiter cargo bay (8-m beams, 4-m posts, tension rods and attaching hardware) and assembling the pieces within the fixture into a partial platform cube. The cubes will take the form of an open C or L figure, stabilized by the tension rods. The complete frame at the aft end of the fixture can be fully pretensioned, the remaining side(s) are merely positioned by the tension rods. Upon completion, the partial cube is detached from the fixture, and using the orbiter RMS, is passed up to the traveler where it can be carried out to the work site. Upon completion of the mission, the fixture may be either disassembled and repacked into the shuttle or left attached to the OCDA for subsequent construction.

5.4 PLATFORM JOINT SYSTEM

A study of joining methods was made to determine the best method of connecting triangular section structure. One of the most obvious methods is the lap joint. A lap joint is the connection between two triangular sections turned back-to-back, as illustrated in Figure 5-22. This system has the appearance of providing a simple interface between the structures, however, as the number of beams intersecting increases and/or the intersection becomes non-perpendicular, the number of struts required at the intersection to connect up all the beam caps becomes excessive. Adopting this approach would require separate intersection clusters as incorporating the cluster structure within the beam would place a heavy requirement on building block design and make each member special.

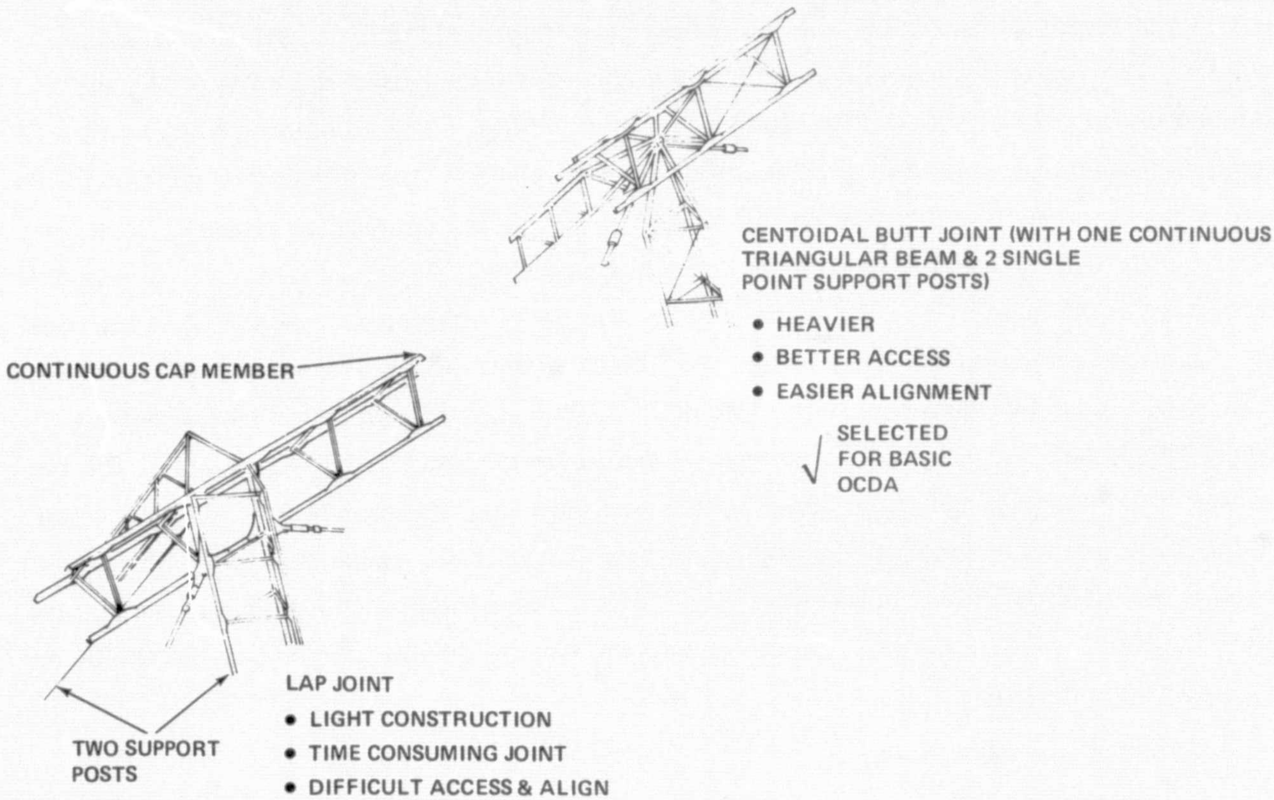


Figure 5-22 Joint System Concepts

The lap joint also has an inherent load line displacement that induces eccentric loading in the joint. For these reasons the lap joining of structural members is not considered a viable technique.

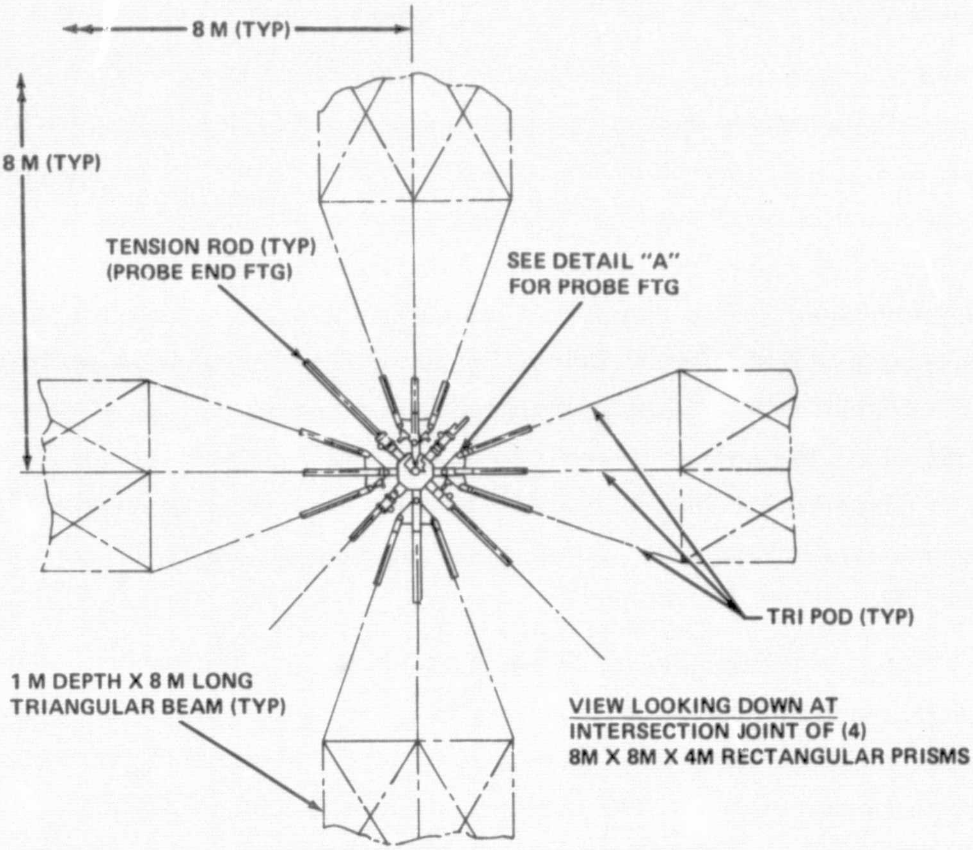
Another approach to the problem in joining beams is the butt joint. The underlying principle of this joint is the intersection of all the load lines to prevent eccentric loading. The butt joint can be formed by connecting the cap members of intersecting beams, but this forms as complicated an interface as the lap joint. The most attractive configuration of the butt joint utilizes tripod end fittings which reduce the attachments to one connector. Such centroidal butt joints allow simplified assembly and permit many beams to be attached at the same intersection. An example of a centroidal butt joint is shown in Figure 5-22. Since the attachment point can be divorced from the nature of the structure, the centroidal butt joint allows the joining of beams having different sizes and types of construction. The nature of the centroidal butt joint allows adjustment of the completed structure without locking in strain loads. This approach was adapted for use as the basic joint used in the design of the platform structure.

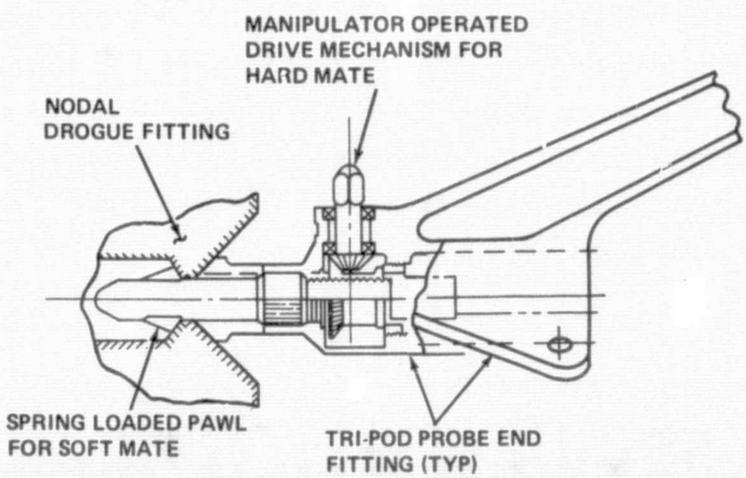
A typical platform joint is shown in Figure 5-23. The vertical post members are tubes terminated at each end by a node fitting. A typical mid-platform post receives four beams and eight tension rods at each node fitting. The attaching hardware is of the "probe and drogue" configuration. The platform posts have a funnel shaped cavity (drogue) to provide initial guidance for the beam and tension rod ends during assembly. The probe on the beam and tension rods is equipped with spring loaded pawls that allow the probe to enter the node drogue and soft latch, capturing the probe but allowing enough freedom of motion to permit further construction. The probe is equipped with a drive mechanism which is used to retract the probe against the drogue socket, locking the assembly firmly together. The drive mechanism is operated by plugging a drive unit onto the square drive shaft. The drive unit may be either a hand held unit like an electric drill motor or a special end effector for the boom manipulator.

5.5 SUBSYSTEMS

An initial assessment of the requirements for the OCDA subsystems have been made. The modular mission spacecraft (MMS) capabilities were evaluated for applicability to the OCDA because developed hardware could be utilized with the associated cost savings. The subsystems addressed were:

- Attitude Control and Orbit-keeping (AC & OK)
- Propulsion





DETAIL "A"

Figure 5-23 Platform Joint

- Communications and Data Handling (C&DH)
- Electrical Power Subsystem (EPS)
- Platform Logistics and Assembly (PL&A).

The MMS attitude control sensors and control electronics plus the MMS C&DH computer meet the OCDA attitude control and orbit-keeping requirements. Propulsion requirements for attitude control and orbit-keeping are specific to the OCDA, therefore, different approaches were evaluated and recommendations made. OCDA Communication and data handling requirements are similar to MMS requirements so the MMS module could be used. The MMS EPS module meets the basic OCDA housekeeping power requirements, therefore it could be utilized. Additional EPS equipment is required to meet much higher power needs for construction, orbit-keeping and follow-on activities. The PL&AS comprises that equipment needed to construct the OCDA and support experiments, including transportation of men and material to work sites.

5.5.1 Attitude Control and Orbit-Keeping Subsystem

The basic attitude control requirements is to maintain the long axis of the platform earth-oriented, with the platform maintained in the orbital plane. The boom is then nominally earth-oriented and the rotation axis of the solar array is 26° off-perpendicular to the orbital plane. This orientation approach minimizes the gravity gradient effect with and without the orbiter, although system sizing is without the orbiter. It is assumed that the orbiter augments the attitude control as required. The orientation also permits gravity gradient unloading maneuvers to be considered in future studies.

The large array area results in a relatively low value (1.5) for the ballistic coefficient for the overall OCDA in the nominal orientation. Orbit decay of 10 n mi (18.5 km) from the 190 n mi (352 km) altitude in six months is unacceptable and orbit-keeping is required. The drag force causing this effect is equivalent to a 0.18 lbf (.8 N) thrust acting continuously.

The attitude control concept selected represented in Figure 5-24 uses the NASA Multi-Mission Spacecraft ACS module (Reference 104) for the sensing function, and the C&DH module for signal processing and control law computations. The inertial reference data is updated by sun sensors and star trackers. The earth local vertical reference is computed from attitude and ephemeris information which is used to generate inertial reference assembly commands via onboard software. The specific actuators (e.g., wheels, and thrusters) which are tailored to the spacecraft requirements, are made compatible with

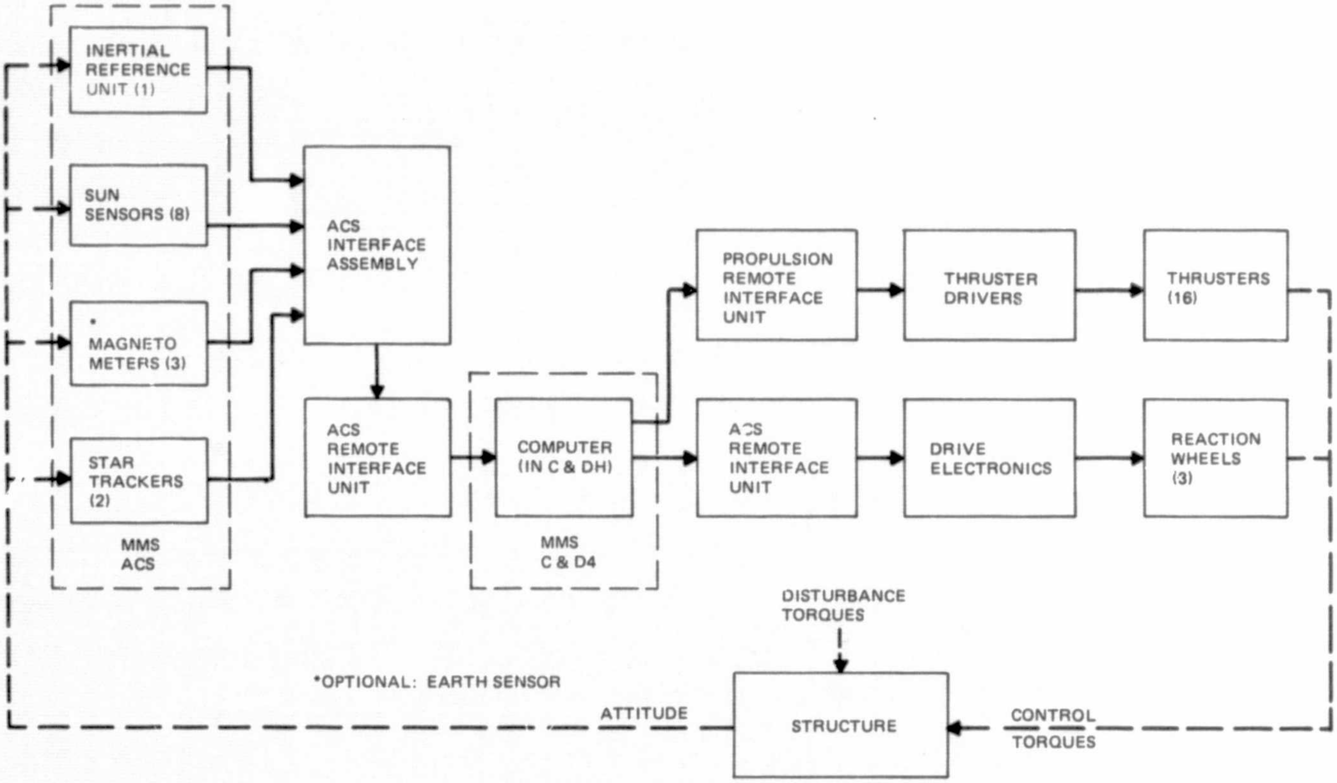


Figure 5-24 ACS Schematic

the NASA multimission module by drive electronics. The candidate equipment listed in Table 5-1 reflects NASA standard subsystem components weights for the sensors and electronics.

A more detailed analysis should be made to determine the performance impact of moving the boom relative to the platform. In particular, the momentum exchange during a repositioning maneuver and the effect of the changed configuration on the disturbance torques must be considered. Boom reposition rate constraints should be developed. Similar analyses should be conducted for conditions during the construction scenario. Platform maneuver requirements based on experiment missions, momentum unloading or boom offset inertia balancing should be developed. The ability of the orbiter to augment control of the OCDA when docked must be evaluated.

5.5.2 Propulsion Subsystem

5.5.2.1 Attitude Control. Actuator options have a major impact on system weight. Mass expulsion using various propellants were compared with momentum storage using different unloading techniques. The momentum storage devices consist of Control Moment Gyros (CMG) and reaction wheels. The high momentum storage-to-torque ratio favors reaction wheels as reflected in lower weights shown in Table 5-2 for the wheel systems. Gravity gradient unloading was ruled out at this time in favor of jets and wheels to avoid operational attitude constraints.

The lowest weight of 3350 lb (1521 kg) was calculated for wheels with electric propulsion unloading but must also include 1640 lb (744 kg) of propellant which is resupplied at six-month intervals. The next to lowest weight is for the wheels with superconducting magnets for unloading, requiring only 450 lb (204 kg) of helium at six-month intervals. This system also has a distinct power advantage over the ion thrusters, especially when the long eclipse periods are considered. However, these systems are not state-of-the-art, therefore, a more conventional system of hydrazine thrusters and wheels were selected for attitude control. Future studies should include a more thorough evaluation of actuator technology requirements.

5.2.2.2 Orbit-Keeping. The orbit-keeping approach selected consists of an ion thruster module which fires continuously to oppose the nominal drag force. The system has been sized including batteries for power during the occultation period. Two modules are oriented in the plus and minus velocity vector directions. This provides the more flexible ability to perform intermittent attitude corrections and allows operation with the +x axis oriented along the plus or minus velocity direction. Propulsion subsystem mass is shown in Table 5-2.

Table 5-1 Attitude Control and Orbit-Keeping Subsystem Weights (Non-Redundant)

EQUIPMENT	QTY	MASS	
		KG	LB
MULTI-MISSION SPACECRAFT MODULE			
• STRUCTURE	1	45	100
• INERTIAL UNIT	1	12	26
• MAGNETOMETER	3	2	5
• STAR TRACKER	2	10	22
• INTERFACE ASSY & DRIVE ELECTRONICS	1	23	50
SUN SENSORS	9	13	28
REACTION WHEELS	3	427	941
		532	1172.0

Table 5-2 Propulsion Subsystem Weights

EQUIPMENT	QTY	MASS	
		KG	LB
HYDRAZINE THRUSTERS (4-.025 LFB, 2-0.1 LBF, 4-0.5 LBF)	10	32	70
HYDRAZINE AND HELIUM TANKAGE	4	777	1,712
HYDRAZINE	-	7575	16,700
THRUSTER MODULE STRUCTURE	2	85	188
ORBIT KEEPING MODULE	2	45	100
ION THRUSTERS (.05 LBF)	8	100	220
ARGON TANKAGE	2	53	116
		8674	

5.5.3 Communications and Data Handling (C&DH) Subsystem

The Communications and Data Handling Subsystem provides the OCDA with the capability for interfacing with either the ground or orbiter for tracking; control of onboard vehicle support and platform logistics and assembly subsystems; and for transmission of housekeeping and experiment data. Implementation of the C&DH subsystem is accomplished by utilizing developed hardware from the multimission modular spacecraft (MMS) C&DH subsystem and the Shuttle orbiter communication and tracking subsystem. The OCDA C&DH subsystem block diagram is shown in Figure 5-25. Equipment derived from the MMS C&DH subsystem is shown within the broken line boundary. It is shown that this includes the S-band transponder which is used for ranging with the ground, receiving commands, and for transmitting narrowband data. It is fully compatible with the NASA STDN/TDRS systems. Uplink commands for controlling onboard support subsystems and the remote manipulator system are decoded and distributed by the standard telemetry and command control (STACC) central unit. The STACC CU interfaces with the S-band transponder, pre-mod processor, the STACC interface unit and the remote interface units (RIUs). Uplink commands are channeled through the multiplex data bus to the RIUs and from there to various onboard subsystems (e.g., RMS). Telemetry is sampled in the onboard subsystem equipment, selected by the RIUs and fed to the format generator in the CU or the onboard computer via the multiplex data bus. Downlink telemetry is fed from the CU to the pre-mod processor and then the transponder for transmission to the ground via TDRSS. A tape recorder adapted from the Shuttle orbiter is also employed for storing telemetry data. Both commands and telemetry are fed to the onboard computer via the STACC interface unit (STINT).

The OCDA requires tv cameras located at strategic points to allow access for the tasks of the construction system. In addition, remote control of the construction system from the ground will necessitate that the tv be transmitted to the ground. Consequently, a Ku-band downlink capability via the TDRSS is incorporated into the C&DH subsystem. The equipment to implement this function is extracted from the Shuttle orbiter avionics system.

The OCDA is also equipped with a Ku-band beacon transponder to augment the rendezvous capability of the orbiter. This equipment is considered a new development however, it will probably be used on many spacecraft which also have to be compatible with the orbiter and, therefore, be cost shared.

A hardware interface adapter is also provided to enable the transfer of telemetry, command, and audio while the orbiter is docked to the OCDA. In this condition, the OCDA construction system can be controlled from within the orbiter.

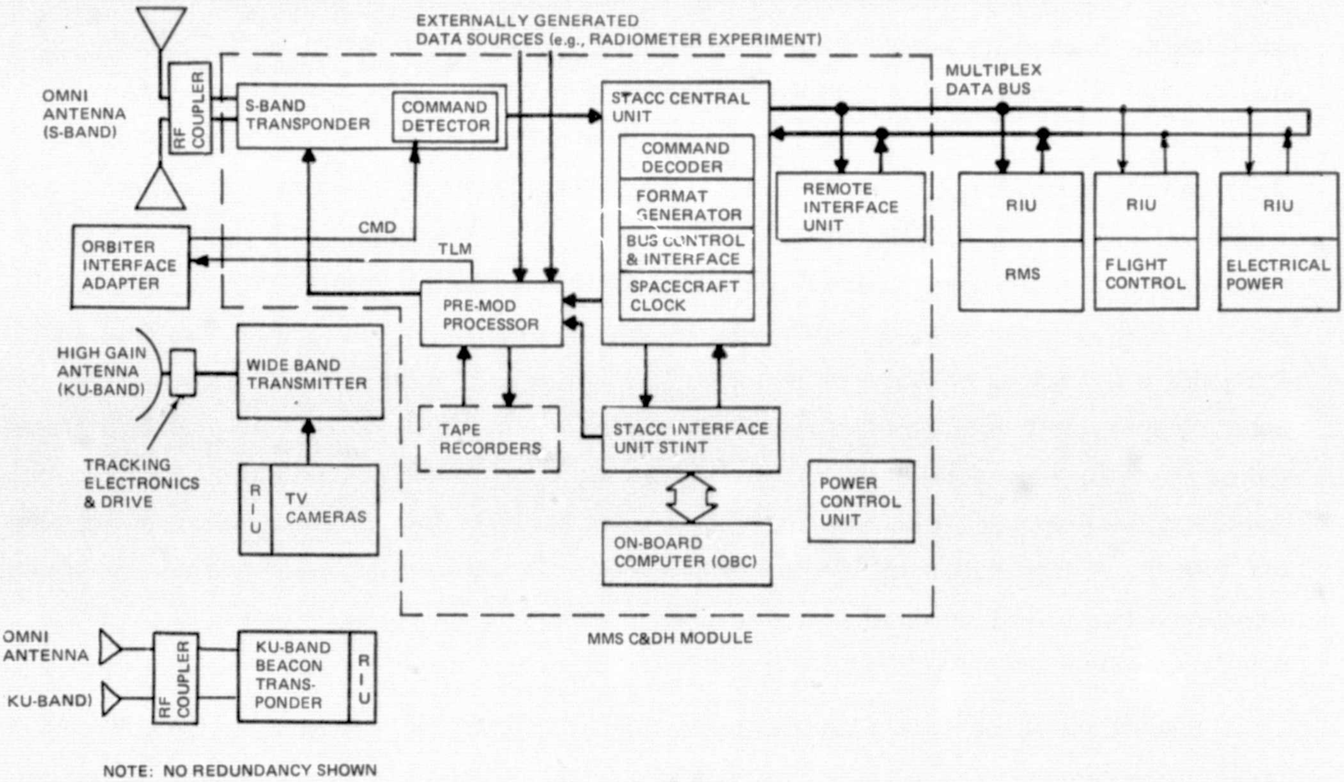


Figure 5-25 C & DH Subsystem Block Diagram

All the antennas on the OCDA are derived from the Shuttle orbiter. The number of omni antennas required and their locations is subject to further efforts taking into consideration coverage requirements, and blockage conditions.

A preliminary estimate for the C&DH subsystem weight and power is shown in Table 5-3.

5.5.4 Electrical Power Subsystem (EPS)

The Basic OCDA EPS concept design is based on requirements for OCDA construction, housekeeping power during unattended flight and follow-on activities.

Follow-on activity power requirements drive the size of the solar array. Some activities require continuous power, therefore, batteries have been provided to meet power demands during eclipse. In addition to subsystems, other equipment such as lights, boom drive, traveler, orbit-keeping engines, solar array drive and the orbiter have power allocated.

The OCDA power requirements vary considerably from approximately 8.5 kW needed during construction to higher values required by follow-on activities. This large variation in power indicates that all array elements need not be deployed during construction but could be deployed subsequently, when additional power is required. The solar array was sized considering power transmission losses as shown in Figure 5-26.

Table 5-4 lists the subsystems equipment power needs, orbiter power allocation, and power budgeted for follow-on activities. Power is also provided for battery recharge during sunlight operations. All needs are totalled to provide the basic OCDA solar array generating capability of 250 kW. Table 5-4 shows maximum power of 133.3 kW is available during sunlight operation or 75 kW continuous power for follow-on activities. Subsequent analysis (Section 6) established the power needs for follow-on activities. The solar array simultaneously provides 20 kW to the orbiter and 16.7 kW for OCDA equipment operation.

Solar array element no. 1 will be deployed on the first OCDA construction flight. This element provides 19.2 kW of power which is typical of the other 13 elements. Housekeeping and construction power requirements can be met by this element and the other elements are not needed until follow-on operations commence.

Element no. 1 shown in the EPS Functional Schematic (Figure 5-27) has a dedicated section which provides housekeeping power via the power regulation unit to the 28 V housekeeping bus. Housekeeping batteries are charged from and provide power to the 28 V bus. The output power of the other solar array elements is planned to be 200 V to permit the use of light weight conductors. The associated 200 V bus provides power to experiments and

Table 5-3 Communication and Data Handling Subsystem Weight and Power

EQUIPMENT	QUANTITY	UNIT MASS		UNIT POWER, W
		LB	KG	
MMS C&DH MODULE	1	210	95.3	112
RF CABLES	5	6	14	N/A
KU-BAND WIDEBAND COMM				
• HIGH GAIN ANT	1	76	34.5	60
• TRANSMITTER/PA	1	12	5.4	83
S-BAND OMNI ANTENNAS	2	2	.9	N/A
KU-BAND OMNI ANTENNAS	2	1	.45	N/A
S-BAND RF COUPLER	1	2	.9	N/A
KU-BAND RF COUPLER	1	.5	.23	N/A
KU-BAND BEACON TRANSPONDER	1	8	3.6	40
TV CAMERAS	3	2	.9	20
RIU	6	3.5	1.6	1
TAPE RECORDER	1	30	13.6	45
TOTAL		401.5	182.1	406 WATTS

Table 5-4 Equipment Power

EQUIPMENT	POWER, KW	
ATTITUDE CONTROL & ORBIT-KEEPING	0.315	
PROPULSION	8.330	
COMMUNICATION & DATA HANDLING	0.406	
SOLAR ARRAY DRIVE	0.090	
BOOM DRIVE	0.600	
TRAVELER	0.110	
BOOM RMS	1.400	
LIGHTS	5.429	
SUB TOTAL	16.680	
LOSSES	2.28	
BATTERY RECHARGE	14.94	
OCDA TOTAL	33.9	
ORBITER SUPPORT	20.0	
BATTERY RECHARGE (ORBITER SUPPORT)	15.6	
TOTAL (SLIP RING)	69.5	
LOSSES	16.2	
FOLLOW-ON ACTIVITIES (SUN LIGHT)	133.3 →	
LOSSES	31.0	
FOLLOW-ON ACTIVITIES (CONTINUOUS)		75.0
SOLAR ARRAY POWER	250.0	

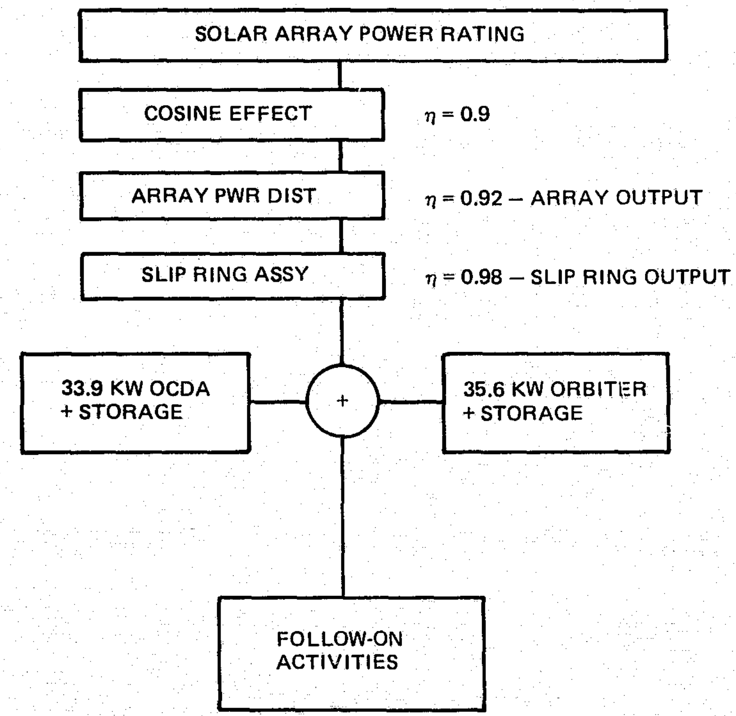


Figure 5-26 Power Transmission Losses

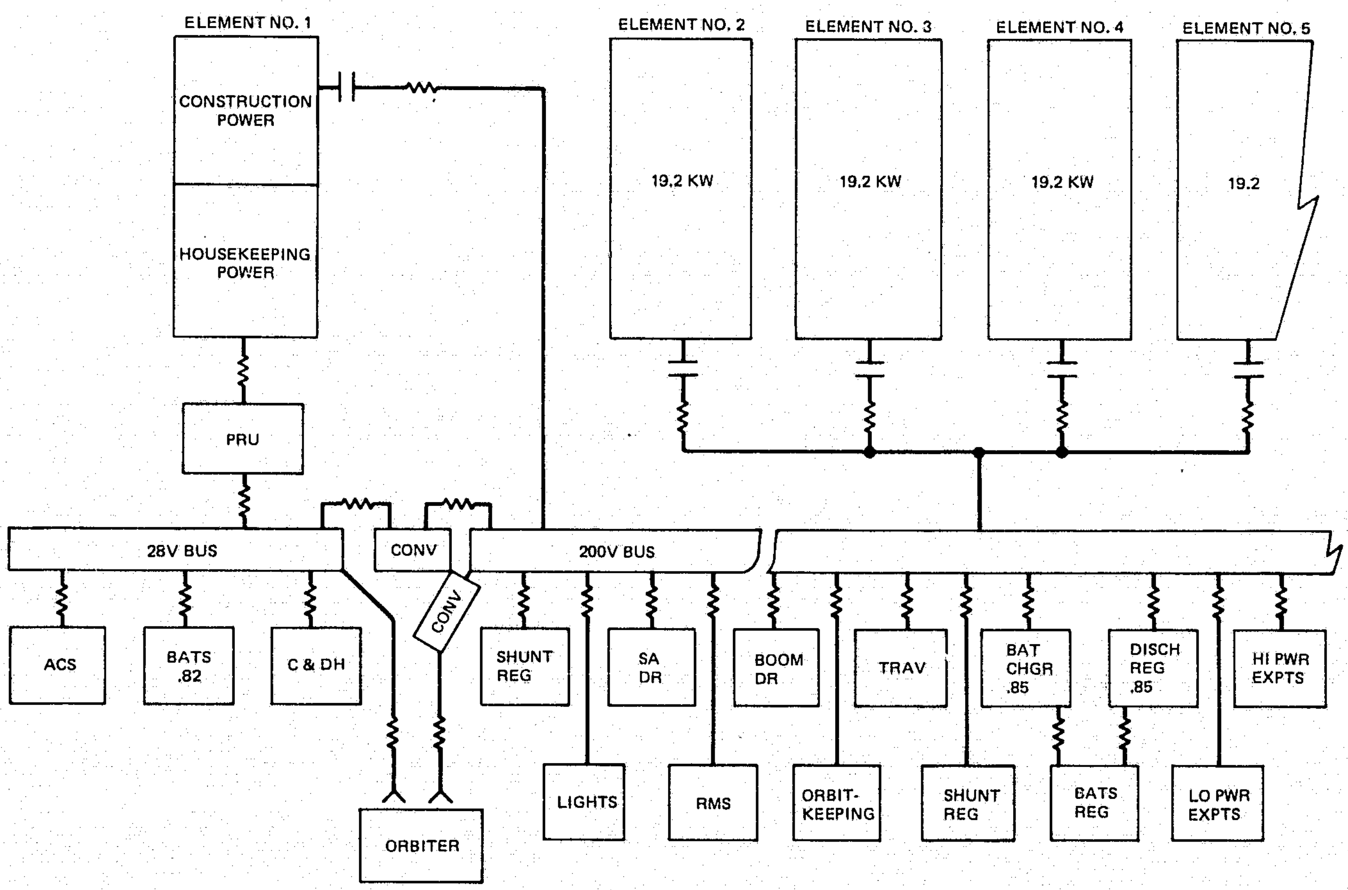


Figure 5-27 EPS Functional Schematic

construction equipment. Batteries supply power to this bus during eclipse. Power can be provided from the 200 V bus to the 28 V bus via a converter. Provisions are also made to supply the orbiter power as required.

Anything less than a voltage in the 100-300 region would cause excessively high losses in the conductors and other hardware and would incur unreasonable weight penalties for the EPS. Two hundred volts was chosen as a moderately conservative compromise. Many previous studies have shown that a long, flat weight/cost/loss minimum region exists (for the distribution and control section) between about 100 and 300 volts in a DC system. Three hundred volts, however, is too close to corona problem regions, especially with load or other transients, even at low pressures. Finally, some early hardware development of high-voltage DC to DC converters with 200 V input and 2 to 5 kV output is currently underway. For RF experiments, packaging several of these together, with outputs in series, will provide reasonably high efficiency conversion (~93%).

Since a solar array is the prime source, AC distribution was eliminated as impractical and imposing unreasonable efficiency penalties. It should also be remembered that, from a shock hazard viewpoint, AC is about three times as dangerous as DC (based on rms to average DC values). AC peak-to-peak is roughly 2.83 times its rms value (sine-wave assumed) and body capacitance increases current flow as well in an AC situation. (The body's impedance is known to bottom over the region of ~60 to ~2400 Hz.) This discussion, of course, applies to permanent or irreversible damage only. The so-called "no let-go threshold" is somewhat lower for DC due to polarization effects. (However, this phenomenon, though uncomfortable, is generally well below damage levels.) DC is also easier to control from the safety viewpoint since insulation material capacitive effects are not present. Of course, it was primarily the inversion/distribution reconversion efficiency problems which constituted the design motivation. Table 5-5 lists the factors considered in comparing two solar array power configurations. Option A was chosen for the basic OCDA.

Battery capacity is based on the power required for housekeeping and construction during dark side passes. Table 5-6 lists the considerations that influenced the choice of nickel-hydrogen batteries. The weight for batteries plus structure and thermal control is approximately 1160 kg.

The total weight allocation for the EPS is shown on Table 5-7. The multimission spacecraft standard module was selected for commonality and cost advantage.

Table 5-5 EPS Solar Array Power Configuration Options

OPTION "A" – CONFIGURED TO ~200V + WITH DC/DC CONVERTERS

- ~93% EFFICIENCY
- ~9-11 KG/KW SPECIFIC WEIGHT

OPTION "B" – CONFIGURED TO 40KV + (KLYSTRON), 20KV + (AMPLITRON) FOR ALL BUT ONBOARD & SHUTTLE SUPPORT LOADS

- DEVELOPMENT COST/TIME/RISK
- HIGH VOLTAGE ANOMALIES – SOLAR STORMS
- ION CURRENT EFFECTS
- OUT-OF-ECLIPSE TRANSIENTS
- SURFACE CHARGE
- ELECTRIC DIPOLE TORQUES
- ON-ARRAY CONTROL/DISTRIBUTION
- SLIP RING INSULATION
- DOWN CONVERSION OR SEPARATE ARRAY SECTION(S) TO SUPPORT CONSTRUCTION ACTIVITIES & ORBITER SUPPORT

Table 5-6 Battery Complement Options

OPTION "A" NI-H2 – 30 AMP-HR, 36 KWH (ON-BOARD AND SHUTTLE SUPPORT)

- 480 KG PLUS STRUCTURE & THERMAL CONTROL (3.4 KW DISS)
- HIGH DOD CAPABILITY (80%)
- GOOD CELL BALANCE CHARACTERISTICS, NO REVERSAL
- GOOD OVERCHARGE CHARACTERISTICS
- SOME FLIGHT EXPERIENCE (50 AMP-HR)
- HIGH PRESSURE SHIELD REQUIRED
- 4.5 KW LESS ARRAY RATING REQUIRED

OPTION "B" NI-CD – 100 AMP-HR, 120 KWH (ON-BOARD AND SHUTTLE SUPPORT)

- 4850 KG PLUS STRUCTURE & THERMAL CONTROL (5.5KW DISS)
- CELL UNBALANCE IN ~200V SYSTEM
- OVERCHARGE SUSCEPTIBILITY
- GREATEST FLIGHT EXPERIENCE (15, 20, 50 AMP-HR)

Table 5-7 EPS Mass

EQUIPMENT	QTY	MASS	
		KG	LB
MULTIMISSION SPACECRAFT MODULE	1	265	583
CORE WIRING	-	1332	2936
PLATFORM POWER REGULATION	1	205	452
PLATFORM WIRING	-	2235	4924
PLATFORM BATTERIES	6	1160	2560
BOOM WIRING	-	4394	9688
ARRAY POWER DISTRIBUTION	-	794	1746
ARRAY ELEMENTS & DEPLOYMENT MECH.	13	4369	9634
		14,754	32523

5.5.5 Platform Logistics and Assembly Subsystem (PL&AS)

The OCDA rotating boom, traveler, and manipulators provide the basic platform logistics and assembly subsystem for any construction scenario. Together with the OCDA platform, nodal mounting points and OCDA solar array power supply, they provide all the requirements of a construction space powered platform.

Materials must be unloaded from the orbiter payload bay and transported to the subassembly or assembly site as needed. Subassemblies and assemblies require structural positioning aides. Also, this subsystem should support the subsequent installation of experiments.

The implementation of the PL&AS requirements are dependent on the assembly approach. The method selected to transfer men and materials relies on the boom. The boom is positioned over the orbiter payload bay enabling the orbiter manipulator to transfer equipment from the payload bay to the boom traveler. The boom is rotated to the assembly site while the traveler carries men and materials. At the assembly site, the boom manipulator removes the traveler equipment and positions the equipment for assembly. When the boom manipulator requires relocation, the traveler is coupled to it and moves it to the new work area. Equipment is listed in Table 5-8.

5.5.5.1 Manipulator. The manipulator used on the OCDA is a standard Shuttle RMS. The manipulator is attached to a carriage that is mounted on rails and can move along the boom, as shown in Figure 5-28. The manipulator carriage is unpowered and is moved by the traveler. When the manipulator carriage is at the desired location, it is locked to the rail and uncoupled from the traveler. An electrical umbilical runs from the umbilical reel down the boom to the docking port on the core module. Operation of the manipulator is accomplished from the RMS operator station in the Shuttle, illustrated in Figure 5-29, using lights and tv cameras on the manipulator to provide visibility. The umbilical is hard wired to the RMS, and reeling in and out is accomplished by rotating the reel and manipulator together, with each revolution of the reel providing a 4-m relocation of the carriage. Erectable fairleads support the umbilical along the boom.

5.5.5.2 Traveler. The traveler is a powered cart that moves along the boom to relocate the manipulator carriage and bring men and materials to the work site. The traveler runs on the boom rails and is moved by an electric traction drive acting against the lower rail. Power to run the traveler is drawn from a power pickup rail mounted on the boom structure.

5.5.5.3 Future Analysis. Future analysis should investigate the best method for controlling translation of the traveler and boom manipulator. The approach to transferring control

Table 5-8 Platform Logistics and Assembly Subsystem Weights

EQUIPMENT	QTY	MASS	
		KG	LB
BOOM DRIVE	1	952	2100
BOOM MANIPULATORS	2	786	1734
TRAVELLER	1	65	143
PAYLOAD BAY ASSEMBLY FIXTURE	1	98	216
FIXTURE MANIPULATOR	1	393	867

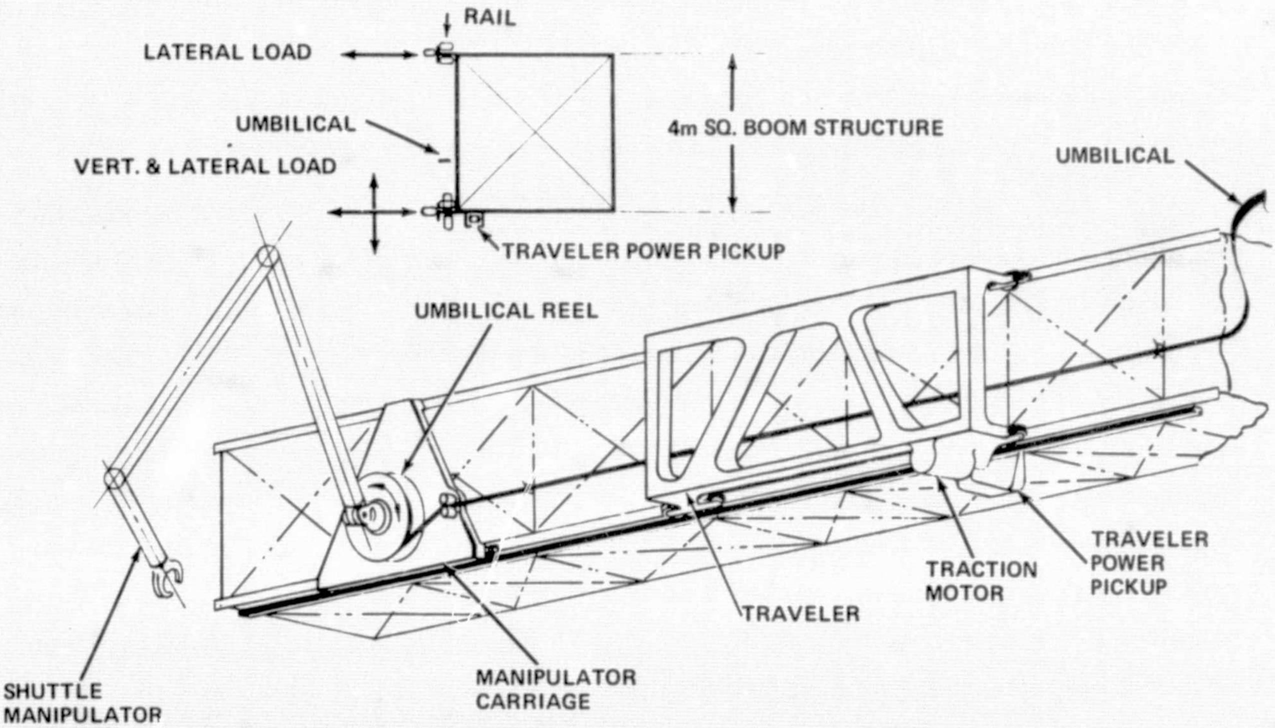


Figure 5-28 OCDA Rotating Boom Manipulator and Traveler

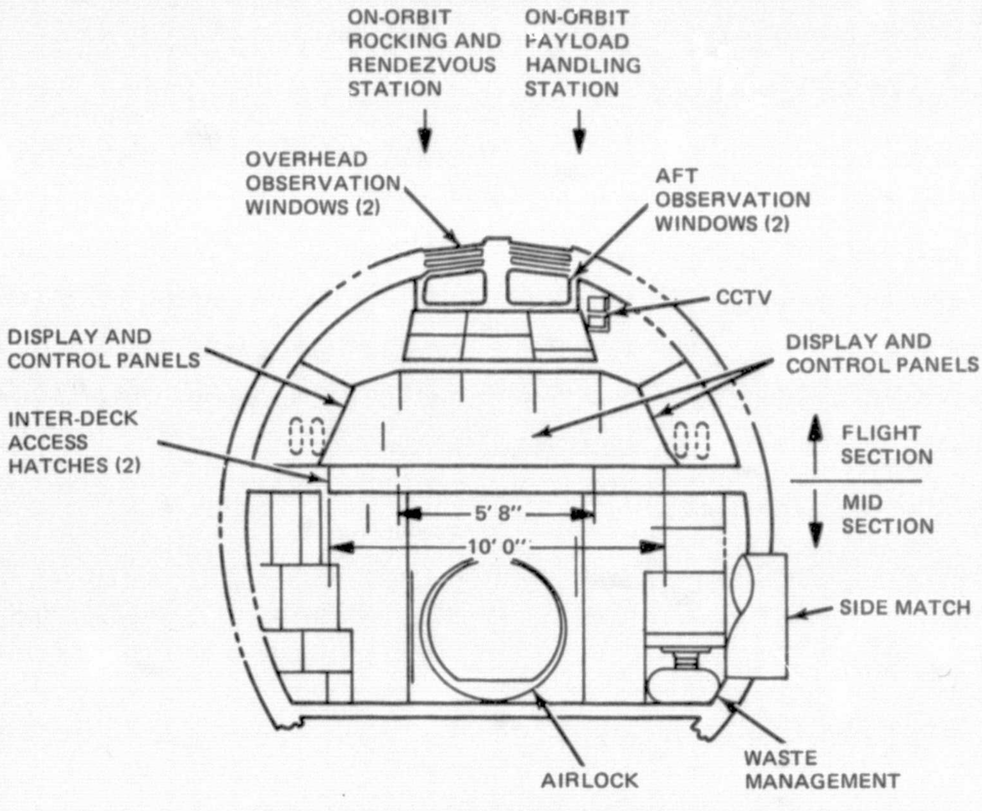


Figure 5-29 Orbiter Payload Handling Station

signals to the boom manipulator requires analysis. The baseline vehicle for study shows a hardwire connection to the manipulator that is rolled out or in when the manipulator is translated. The design of the traveler power pickup from boom mounted rails presents a challenge, as is the method of joining boom rails during assembly. The orbiter and boom manipulator control fidelity should be examined and compared with specific tasks required of the manipulators. Manipulators controls and displays in the orbiter will have to be evaluated considering task requirements. Also, manipulator camera locations and illumination at the work site must be evaluated. The location and method of controlling the boom slewing required investigation as well as orbiter payload bay equipment needs. This equipment must provide support for OCDA beams, etc., during launch and also provide ease of retrieval during construction.

5.6 ASSEMBLY OPERATIONS

Different approaches to assembling the OCDA were studied that embodied assembly scenarios for future large structure missions. One assembly approach given emphasis relied on existing STS equipment and is mainly dependent of EVA construction techniques. An alternate, and recommended approach, studied assembly of the OCDA using higher technology manipulators. Both approaches were found to need three Shuttle flights to construct the OCDA. However, the manipulator assembly approach can be completed in less construction time than the EVA approach.

5.6.1 Assembly Approaches

The five representative future missions (reference Figure 2-2) were studied for construction functional requirements. This data was utilized to develop approaches to constructing the OCDA. Four approaches were assessed:

- Manned assembly
- Man assisted by machine
- Machine assisted by man
- Major assembly by machine.

5.6.1.1 Manned Assembly. The crew removes collapsed beams from the orbiter bay, deploys them and verifies that all links are locked. Beams are transported by the crew either using MMUs to fly the beams to the assembly location or transferring them hand-to-hand over existing structure. At the assembly site, the crew maneuvers the beams into position, fastens them to existing attachment fittings, and attaches stays for positioning.

As each "cube" is completed, alignment is checked optically and adjustments made where necessary.

This approach appears viable for constructing the OCDA; however, it was not chosen as the approach for study emphasis. The construction of future large structures must rely on machines to meet productivity goals, and therefore more mechanized construction should be an integral part of the OCDA assembly.

5.6.1.2 Man Assisted by Machine. Beams are deployed by the crew and installed in a subassembly fixture. A manipulator is used to remove the subassembly from the fixture and position it on a traveller for transportation to the assembly site. Here another manipulator removes the subassembly from the traveller and positions the subassembly for attachment to the existing structure by a crewman.

5.6.1.3 Machine With Manned Assistance. Beams are space fabricated and installed in a subassembly fixture by manipulators. After the subassembly is complete, it is transported to the assembly site where remote manipulators position the subassemblies and completes beam attachment. EVA construction personnel check the assembly alignment.

This method of constructing the OCDA could be implemented if an automatic beam fabrication plant is available and if a second orbiter RMS operator's console is provided. A further need is that higher fidelity manipulators be developed to enable beam attachment tasks to be done effectively.

5.6.1.4 Major Assembly by Machine. The key to high assembly rates is the automatic, continuous flow of assembled structure from an orbital factory. This concept relies on a number of fabrication plants producing structure in parallel. First, the factory is assembled in orbit including its support systems such as electrical power and control. Raw material supplies are maintained on hand for the fabrication plants.

A one-of-a-kind orbital structure, such as OCDA, does not appear to warrant high investment in capital equipment associated with high production, multiple fabrication and assembly. The functions of control, power, etc., for highly automated assembly can be handled by a completed OCDA as part of a continued utility program.

5.6.2 Orbiter Support

Data was extracted from the Shuttle Orbiter Payload Accommodations Document that related to construction and crew activities. This data was used as the basis for planning OCDA flights and determining the impact of crew activities on the orbiter. Baseline orbiter support provides consumables and accommodations for a crew of four during a seven-day flight. Support is also provided for two men to conduct two EVAs of six hours. The necessary equipment for three additional crew men, manned maneuvering units and a second remote manipulator system are payload chargeable. Any provisions required to support the OCDA, such as a docking module are also chargeable to the payload.

5.6.3 Crew Operations

The OCDA design is presently conceptual. Definition of crew operations requires a lower level of detail than is at hand, therefore the assumptions in Table 5-9 and 5-10 were established.

To provide a comparison between OCDA construction time estimates and other study data, we plotted the data shown in Figure 5-30. The lower grouping of points is from work done by Grumman during Space Station Studies. These tasks are simple, bolt on assembly work. The line is plotted from data contained in the Orbital Assembly and Maintenance Study that emphasized manipulator operations. The upper group of data is complex assembly operations that are performed using EVA procedures.

Note that basic OCDA assembly (EVA) is in the upper group, follow-on missions straddle the plotted line, and simpler bolt-on tasks (rotary joint and ion engine installation) are comparable to the lower group of points. Therefore, good agreement exists between other study time/task estimates and those provided herein.

5.6.4 Assembly Operations

The four approaches discussed in Section 5.6.1 were evaluated for OCDA construction. One of the study objectives "The OCDA must utilize STS elements" was dominant in early thinking and led to study of the "Man Assisted by Machine" approach. This approach relies on EVA construction supported by the orbiter manipulator and a second identical manipulator mounted on the boom. Later, the "Machine Assisted by Man" approach was studied. This approach utilizes manipulators as the principle assembly mechanism. The assumption here is that high fidelity manipulators are available and a second manipulator control station is provided in the orbiter.

5.6.4.1 Man Assisted by Machine Operations. A method for constructing the relatively large structure of the OCDA while operating from the orbiter was formulated (see Figures 5-31 through 5-34). The grid structure of the OCDA led to the breakdown of the structure into the subassembly of open cubes. A fixture is assembled on the open payload bay which positions posts and beams for assembly into open cubes. Open cubes are then transported to the assembly site for attachment to the existing structure. The open cubes are moved from the subassembly fixture by the orbiter manipulator, attached to a traveller on the rotating boom for transportation to the assemble site, and removed from the traveller by

Table 5-9 Crew Design Assumptions

- ATTACHMENT POINTS AVAILABLE FOR TETHERING EQUIPMENT
- CREW CONSTRUCTION TASKS WILL BE SIMPLE
- RMS BRINGS ITEMS TO LOCAL POSITION WHERE CREW TAKES OVER
- SUBSYSTEM MODULE ACTIVATED BY A SWITCH
- DEPLOYMENT VERIFICATION BY POSITION FLAGS
- CREW ATTACHMENT HARD POINTS ARE PROVIDED
- ELECTRICAL WIRE HOOK-UPS ARE SIMPLE PUSH-TO-LOCK
- "J" BOX AND ALIGNMENT PRISM ATTACHMENT ARE A ONE STEP OPERATION
- LOCAL STORAGE CONTAINERS WILL BE PROVIDED
- BOOM RMS OPERATED FROM ORBITER
- RMS FULLY DEVELOPED AND CAPABLE OF SUSTAINED OPERATIONS

Table 5-10 Construction Operation Assumptions

- CREW TRAINED IN CONSTRUCTION TASKS
- NO TIME ALLOCATED FOR SPACE ACCLIMATION
- ILLUMINATION ADEQUATE FOR TASKS
- ONE CREWMAN ALWAYS IN ORBITER
- CONSTRUCTION TEAM CONSISTS OF AT LEAST TWO EVA CREW MEMBERS AND RMS OPERATOR

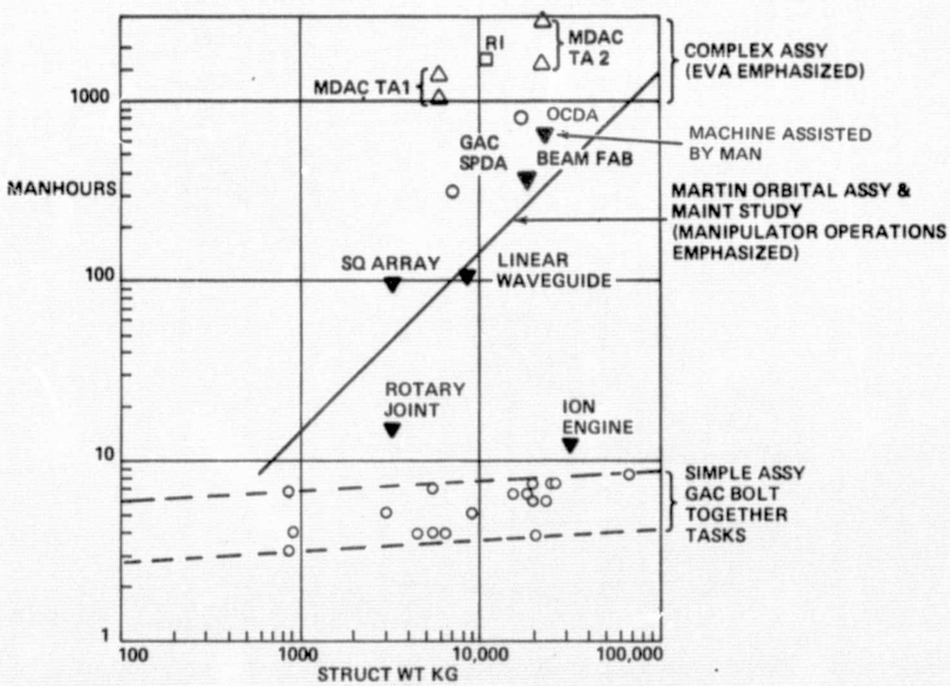


Figure 5-30 Space Construction Manhours vs Weight

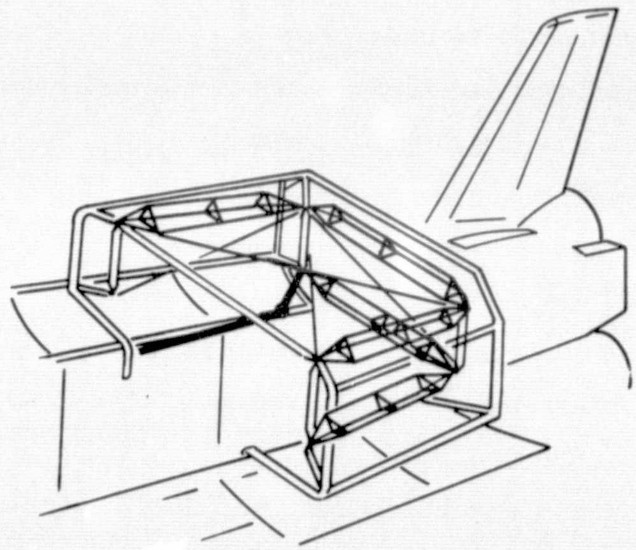


Figure 5-31 Open Cube Assembly

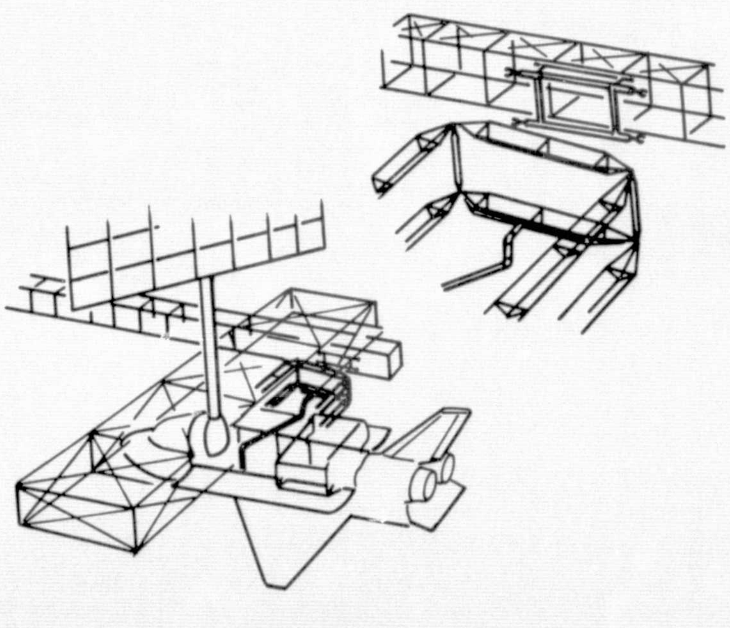


Figure 5-32 Open Cube Transportation

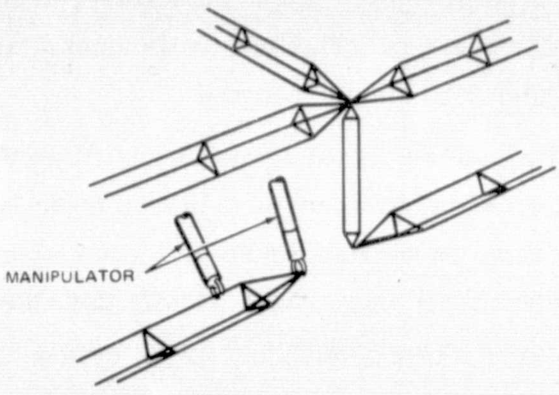


Figure 5-33 Cube Attachment

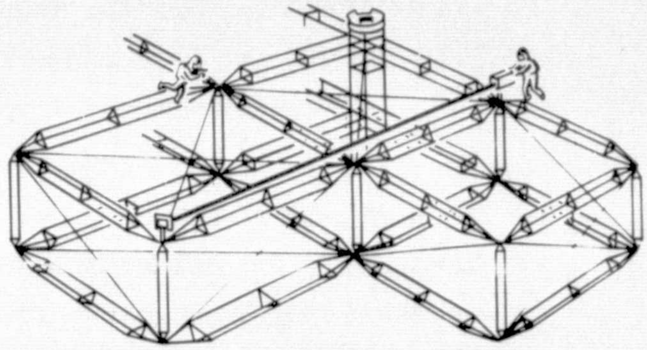


Figure 5-34 Optical Alignment

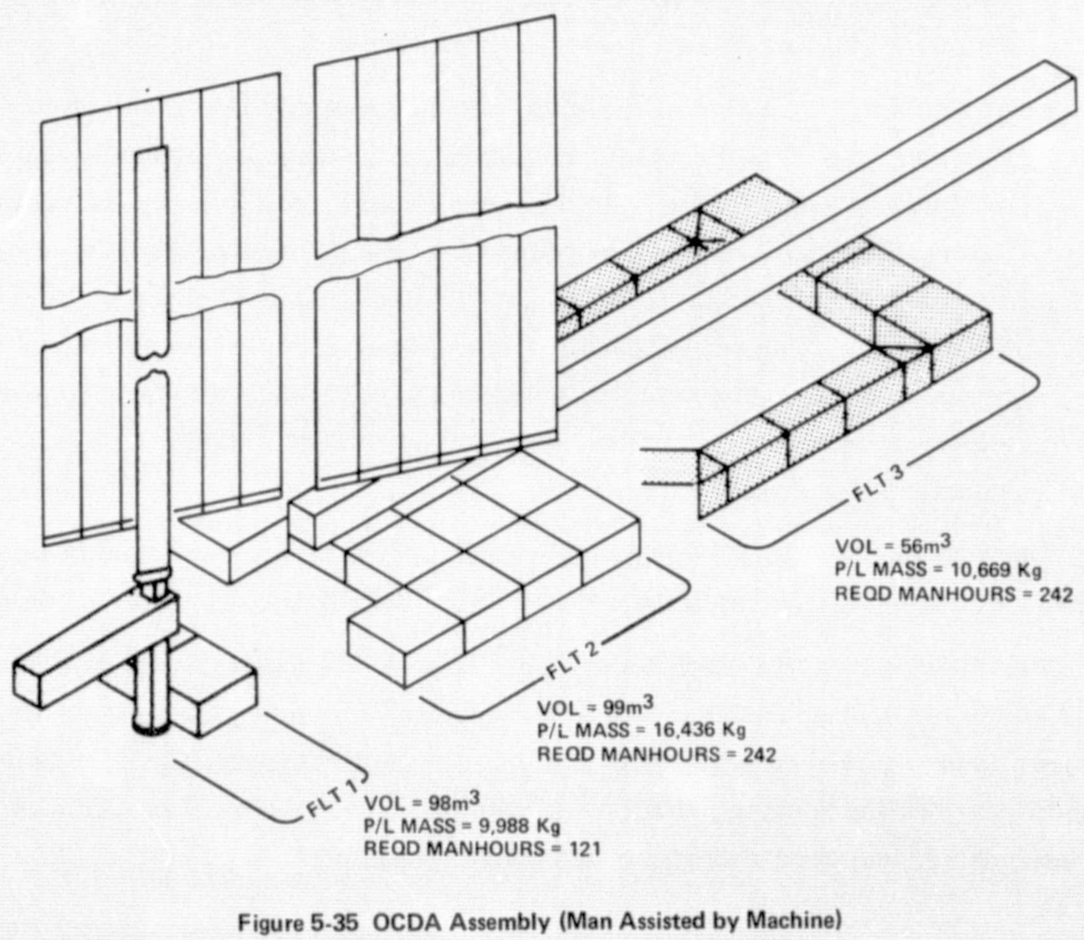


Figure 5-35 OCDA Assembly (Man Assisted by Machine)

a boom manipulator which also positions the open cube for assembly. The open cube is attached to existing structure and later alignment is done by EVA.

- Open Cube Assembly - A subassembly fixture shown in Figure 5-31 is assembled in the orbiter payload bay. One end of a beam is attached to the fixture, deployed, and then the other beam end is fastened in position. This fixture is used to assemble 3/4 cube platform sections or 1/2 cube sections as required.
- Cube Transportation - The subassembly, consisting of a partially built platform cube (Figure 5-32), is released from the assembly fixture and moved to the boom traveller by the orbiter RMS. Support arms on the boom traveller grasp the open platform cube at the posts. This subassembly is then transported to the assembly site by the boom traveller where it is removed and positioned for assembly by the boom RMS.
- Cube Attachment - The open cube subassembly is positioned for beam attachment by the boom RMS. The RMS operator is located in the orbiter using two split tv displays for position feedback information. Beams are connected to the existing structure and locked secure as shown in Figure 5-33.
- Alignment - One side of the open cube subassembly is structurally complete when it is removed from the assembly fixture (i.e., diagonal stiffening stays are tensioned to specification) and the beam lengths were "set" in the subassembly fixture. However, the horizontal and vertical position of the cube is dependent on tensioning of the stays; after each cube is assembled to the platform, alignment is required. A prism is temporarily attached to the assembly fittings and an optical beam is reflected from the prism to a Theodolite reference providing cube alignment information as illustrated in Figure 5-34. Tension stays can now be adjusted as required.

The Man Assisted by Machine construction approach was developed in three Shuttle flights. Figure 5-35 illustrates the sections of the OCDA to be constructed on each flight.

The object of the first flight is to establish a satellite that can operate autonomously and is stable for orbiter docking. Also, it is desirable to assess the capability of performing operations required on subsequent flights. On the first flight, the core is deployed and docked to the orbiter docking module, a single solar array element is deployed, the boom stud assembled, and core platform cubes constructed.

The second flight demonstrates structure assembly techniques. The boom is constructed, solar array completed and a major portion of the platform is built. Figure 5-36 illustrates solar array assembly.

The third flight provides experiment support requirements. The platform construction is completed, electrical power and mounting structure is installed for subsequent experiments.

Figure 5-37 illustrates the components required for the first construction flight of the OCDA and also indicate the volume available in the payload bay and the cg limit curve. The weight and cg location include the orbiter docking module.

The 15-m length of core/mast consist of docking ring (passive) module, MMS modules, reaction wheels, boom/solar array drive unit and manipulator. This section is preassembled on earth and removed from the payload bay as one unit. The addition of the solar array module, RCS modules, and antennas, completes the requirements for an operational satellite.

Two 8-m lengths of deployable boom section and the deployable square beams, posts, diagonal rods and hardware required to construct the two mast support cubes of platform are also included.

The crew activity time to construct the OCDA is based on the orbiter support capability. A single EVA construction period of 5-3/4 hours is available per day for each crew member. The time for the crew to complete construction tasks was estimated based on Skylab and simulation data. These times were used to plan flight activities. One construction crew is adequate for the first flight tasks and two crews are required for the second and third flights. Daily activities are shown in Figure 5-38.

5.6.4.2 Machine Assisted by Man. An alternate construction approach (Machine Assisted by Man) was formulated. The concept was to mechanize the Man Assisted by Machine approach as much as possible using manipulators. Deployed beams were utilized similarly to the previously discussed approach. Tasks were developed in somewhat greater detail because manipulators do not have the operational flexibility of the crew. Operational times were established based on previously conducted studies and simulations (see NAS9-14319 "Orbital Assembly and Maintenance Study" performed by Martin). Figure 5-39 shows a new smaller manipulator that is used to construct the open cubes in the assembly fixture. Typical operations and associated times for cube assembly are listed.

Three flights were again shown to be required to construct the OCDA (see Table 5-11) with this assembly approach. A larger amount of structure could be assembled each day

Figure 5-36 Solar Array Assembly

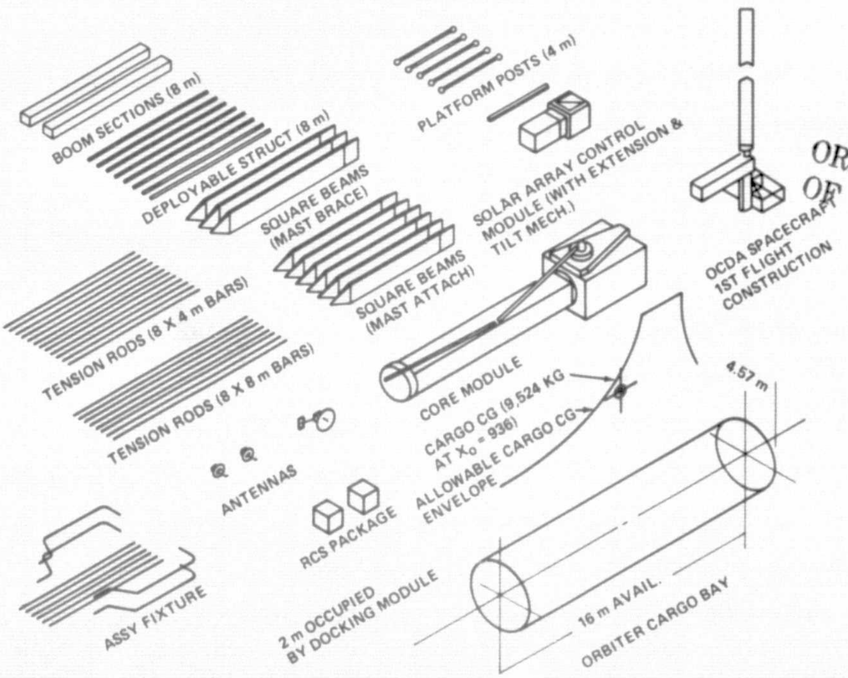


Figure 5-37 First Flight Payload

FLIGHT 1 4 MEN – ONE SHIFT (3-MAN CONSTRUCTION CREW) (121M-HRS)

DAY 1	2	3	4	5	6	7
• ASCENT • DEPLOY CORE	• DEPLOY ONE S.A. ELEMENT • ASSEMBLE FIXTURE	• ASSEMBLE BOOM STUB • CORE BEAM CONST.	• CORE BEAM CONST.	• CORE BEAM CONST. • CORE CUBE ASSY.	• CORE CUBE ASSY. • INSTALL RCS	• INSTALL ANTENNAS • STOW FIXTURE • DESCENT

FLIGHT 2 7 MEN – TWO SHIFTS (6-MAN CONSTRUCTION CREW) (241.5M-HRS)

1	2	3	4	5	6	7
• RENDEZVOUS • ASSEMBLE FIXTURE • CONSTRUCT BOOM	• CONSTRUCT BOOM • CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM	• ASSEMBLE SOLAR ARRAY	• STOW FIXTURE • RELOCATE RCS • RELOCATE OMNI ANTENNAS • DESCENT

FLIGHT 3 7 MEN – TWO SHIFTS (6-MAN CONSTRUCTION CREW) (241.5M-HRS)

1	2	3	4	5	6	7
• RENDEZVOUS • ASSEMBLE FIXTURE	• CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM • INSTALL ION ENGINES	• INSTALL POWER CABLES	• INSTALL EXPERIMENT STRUCTURE • INSTALL LOGISTIC DOCKING PORTS	• STOW FIXTURE • RELOCATE RCS • DESCENT

TOTAL (604M-HRS)

Figure 5-38 Construction Operations Summary – Man Assisted By Machine

EMPHASIZES:
- PARALLEL ASSEMBLY OPERATIONS
- CENTRALIZED STRUCTURAL FABRICATION

TYPICAL STUDY TREATMENT OF CONSTRUCTION OPERATION

ASSEMBLE 3/4 CUBE (13 TIMES)

TASKS	TIME, MIN
EXTRACT POST (ORB MANIP)	5
INSTALL IN FIXTURE (ORB MANIP.)	5
REPEAT ABOVE	10
EXTRACT FOLDED BEAM (ORB MANIP.)	3
PLUG INTO DEPLOYMENT STATION & DEPLOY	4
TRANSPORT BEAM TO FIXTURE (ORB MANIP.)	3
ATTACH BEAM (FIX MANIP.)	6
REPEAT ABOVE 5 TIMES	80
INSTALL HANDLING BEAM	6
ATTACH STAYS (10)	60
TENSION STAYS (2)	6
TOTAL	3 1/4 HR

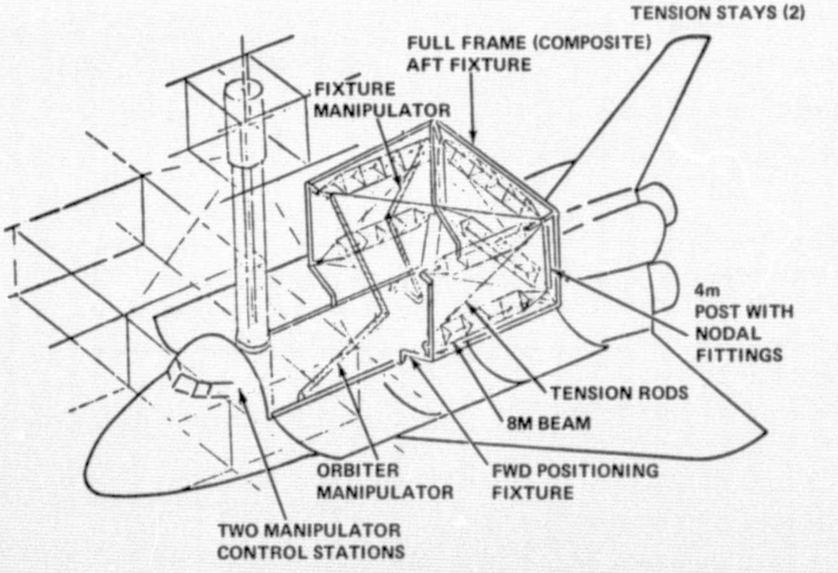


Figure 5-39 Platform Construction Approach

Table 5-11 Number of Shuttle Flights Machine Assisted by Man

TASKS	TIME, HR
FLIGHT 1	
CORE AND MAST DEPLOYMENT	2 3/4
DEPLOY AND STOW CONST RMS	1/2
ASSY AND DISASSY OF CONST FIXTURE	4
CORE BEAM ASSY	4 1/2
BOOM STUB ASSEMBLY	1/2
ASSEMBLE TWO 1/2 CABLES, TRANSPORT AND ATTACH	4 1/2
INSTALL ANTENNAS	3 1/2
	20 1/4
FLIGHTS 2 and 3	
DEPLOY AND STOW CONST RMS	1/2
ASSY AND DISASSY OF CONST FIXTURE	4
BOOM ASSY	4
ASSEMBLE 3/4 CUBES (13X)	42 1/4
TRANSPORT CUBES (28X)	10
ATTACH 3/4 CUBES (13X)	13
ASSEMBLE 1/2 CUBES (11X)	22
ATTACH 1/2 CUBES (11X)	5 1/2
ASSY SPECIAL CUBE (4X)	15
ATTACH SPECIAL CUBE (4X)	4
SOLAR ARRAY ASSY	6
POWER JB INSTALLATION	5
RCS MODULE INSTALLATION	3 1/2
ION ENG INSTALLATION	5
ANTENNA (OMNI AND STEERABLE)	5 1/4
SUPPORT STRUCTURE	5
	149
NUMBER OF WORK SHIFTS @ 10 HR EACH = 14.9 (ONE FLT 11 SHIFTS MAX.) THEREFORE 3RD FLT REQUIRED FOR 4 SHIFTS (7 SHIFT MARGIN AVAILABLE)	

than is possible with the Man Assisted by Machine approach because operational time is not limited by 6-hours EVA and the associated preparations and post EVA tasks. However, orbiter payload bay volume limitations constrain the first flight. The second flight constructs most of the platform, and the third flight completes the OCDA, including installation of platform wiring for subsequent experiment use.

Section 6

PROGRAMS EVALUATED DURING ADD-ON STUDY

The approach was to formulate a series of missions that allowed implementation of the objectives defined in the Basic Study. We also investigated different approaches for achieving satisfaction of the objectives to provide cost variation.

The three programs that were evaluated during this Add-On Study are:

- Program Scenario 1 - Construction of a 2-MW Photovoltaic SPS Pilot Plant
- Program Scenario 2 - SPS Technology advancement through element testing on the OCDA
- Program Scenario 3 - Large antenna prototype construction.

6.1 PROGRAM SCENARIO 1 - 2-MW SPS PILOT PLANT

The objective of Program Scenario 1 is to utilize the basic OCDA as a construction platform to build a demonstration photovoltaic SPS pilot plant. The SPS pilot plant is constructed using fixtures and fabrication modules mounted on the OCDA supported by a series of Shuttle flights. This pilot plant will be released after completion, and operate as an autonomous satellite collecting solar power, beaming it to earth rectennas and providing up to 50 kW of ground power.

Figure 6-1 illustrates the pilot plant which is a small version of several sections of a full-size photo-voltaic SPS. The basic SPS building component, the 20-m beam, has been used to construct the pilot plant. The pilot plant consists of three main assemblies; the microwave antenna, rotary joints and mast assembly, and the solar collector that is designed with a concentration ratio of 2:1. Propulsion subsystems shown mounted on the end of the SPS pilot plant and attitude control actuators, plus other necessary subsystems, were not sized or costed.

Seven missions are identified in addition to the construction of the OCDA to complete the SPS pilot plant. Mission 2, linear array assembly, shown in Table 6-1, is the first follow-on mission. This mission is not part of the pilot plant construction but is a technology prerequisite. It was considered important to demonstrate phase control of the amplitrons prior to pilot plant assembly. Mission 8, subsystem installation, is shown for

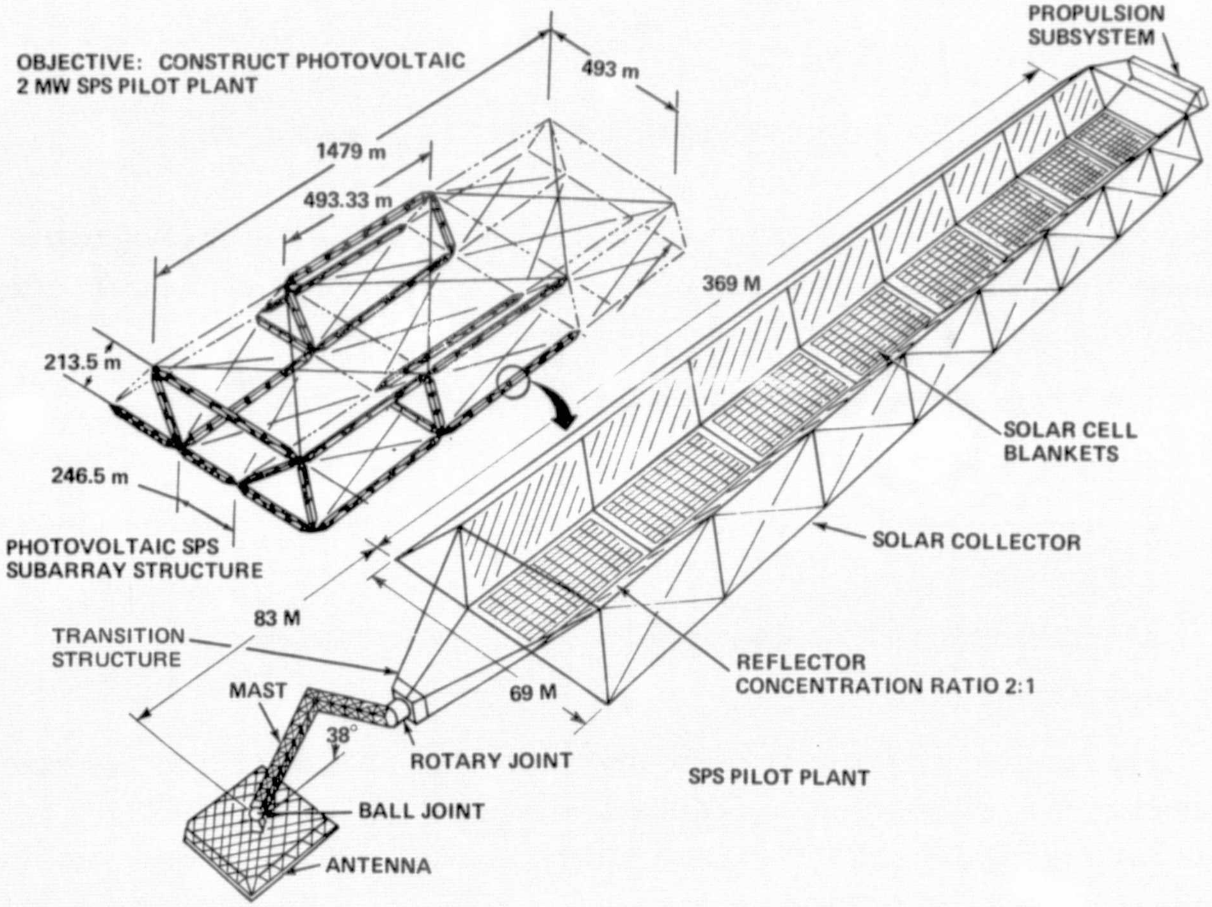


Figure 6-1 Program Scenario 1

Table 6-1 Program Scenario 1 Missions—Start With Basic OCDA

MISSION	1984	1985	1986	
1. OCDA PLACEMENT	△△△			
2. LINEAR ARRAY ASSEMBLY	△			
3. 20M BEAM FAB (COMPOSITE)	△△△△△			END ITEM SPS PILOT PLANT (items 3–8)
4. CONDUCTOR INSTALLATION	△			
5. MICROWAVE ANTENNA ASSEMBLY		△△		
6. ROTARY JOINT INSTALLATION		△		
7. SOLAR COLLECTOR ASSY		△△△		
8. SUBSYSTEM INSTALLATION		▭		

△ = 1 SHUTTLE FLIGHT

completeness. We did not investigate pilot plant subsystem requirements, installation, and release of the pilot plant because the main emphasis of this scenario is to address construction issues. Twelve Shuttle flights permit construction of the pilot plant plus three flights required for placement of the basic OCDA.

An overview of the SPS pilot plant construction scenario is illustrated in Figure 6-2. The OCDA is shown in plan view with construction fixtures and fabrication modules located on the underside. The first major item to be constructed is a 20-m beam, 369 m long. Then, the structure for the microwave antenna is deployed and mounted in the platform hole where subassemblies are installed, and the mast and rotary joints are assembled to the antenna. The 20-m beam is then translated laterally into a holding fixture and fed through to the opposite side of the OCDA platform. The solar collector assembly is initiated utilizing the previously fabricated 20-m beam as one side of the collector. The end of the collector provides attachment points for the antenna mast transition structure. The antenna and mast are removed from the platform and assembled to the end of the solar collector. At this time, construction of the solar collector proceeds at the planned rate of production, including reflector and solar blanket installation. When the collector is completed, the propulsion subassembly is installed and the pilot plant is checked out, then released to demonstrate SPS operations.

The method of defining each of the missions was to:

- Define Test Objectives and Requirements - The purpose of each mission was defined in several test objectives. Requirements were derived from the fullsize SPS for implementation on the pilot plant.

- Describe the Mission Concept - A general concept was postulated as to how the mission is to be implemented.

- Identify Functional Operations Scenario and Establish Operational Time - The mission concept was used to formulate the functional operations and from these, operations were listed and time for completion was estimated. This data was an input to determining the number of Shuttle flights required considering time of operation and crew accommodations.

- Develop Work Breakdown Structure - This provides a basis for establishing program costs.

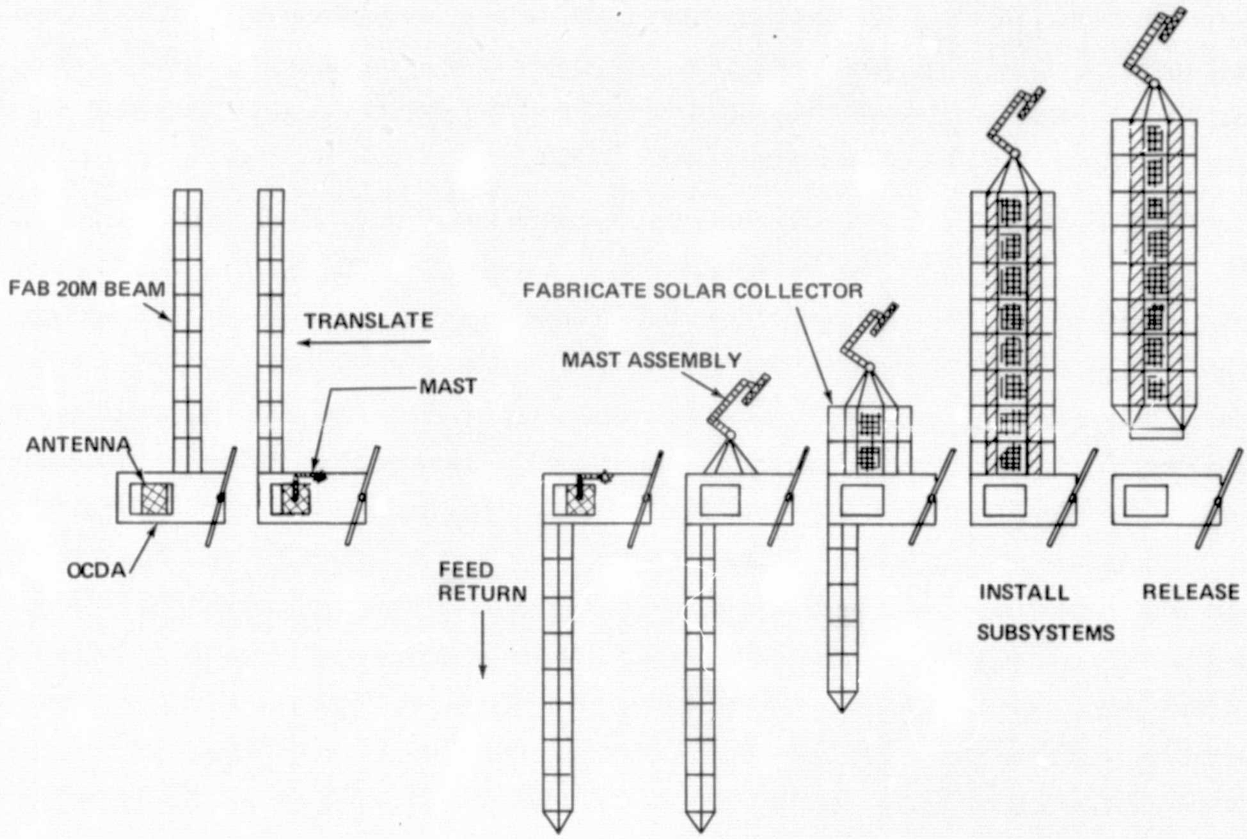


Figure 6-2 SPS Pilot Plant Assembly

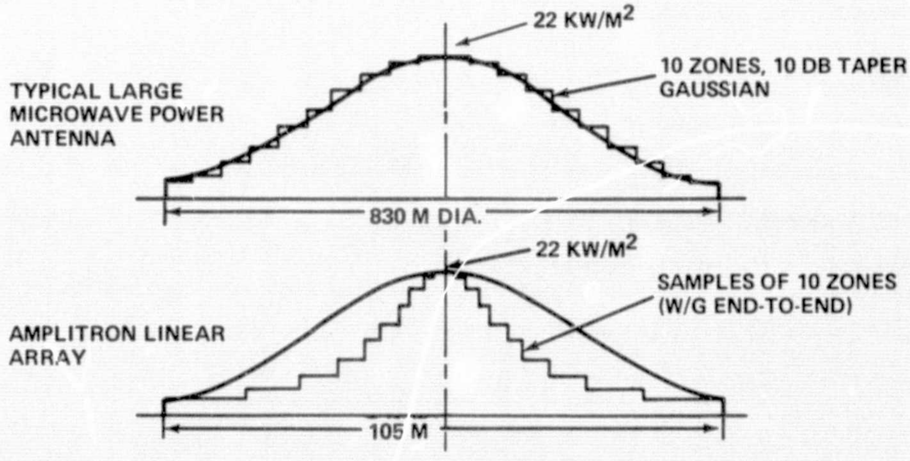


Figure 6-3 Power Density Distributions

- Identify Equipment Requirements - Description of equipment needed for each mission was used for determining the equipment to be loaded in the orbiter, hence an input to the number of flights required. This data was also used in establishing the costs associated with each mission.

6.1.1 Mission 1-OCDA Placement

Mission 1, consisting of three flights, is used to assemble and prepare the orbital construction facility for the testing that follows. The operations required on each of the three flights to achieve operational readiness are discussed in Section 3. Section 3 also discusses the technology objectives demonstrated during the erection and checkout of the OCDA.

6.1.2 Mission 2 - Linear Waveguide

This mission is a prerequisite for SPS pilot plant construction. Its primary purpose is to demonstrate phase control of amplitrons. Demonstration of amplitron space operation is significant to the success of transmitting RF power, therefore it is deemed necessary to devote mission resources to this critical issue prior to commencing the construction of the SPS pilot plant.

6.1.2.1 Mission Objectives and Requirements. The mission objectives are to demonstrate:

- Assembly of the microwave power transmission system
- Operation of amplitrons, waveguides and structure in thermal environment
- Alignment of antenna waveguide
- Phase control of amplitrons.

The test requirements are:

- Demonstrate alignment of the antenna waveguide to 1 mm/m
- Demonstrate power density distribution (10 db taper) along the waveguide antenna
- Verify RF phase control of 1 arc second.

The microwave antenna is mechanically pointed at an earth-based receiving rectenna to within 1 arc min. Precise steering of the beam is accomplished electrically by phase shifting the signal between subarrays in the antenna (such a subarray would be 18-m x 18-m squares in a fullsize antenna). In order to eliminate objectional sidelobes on the transmitted signal, power density is varied across the face of the antenna aperture with the optimum shape being a Gaussian distribution. A more practical arrangement breaks the smooth Gaussian curve into steps or zones. The example shown in Figure 6-3 has

10 zones of uniform power density with the peak value at the center of 22 kW/m^2. This peak value results in a maximum temperature on the waveguides and support structure that is at the limits of aluminum.

The test antenna waveguide characteristics are also shown in Figure 6-3. The power distribution of this array is formed by placing waveguide sections end-to-end. Each waveguide section represents a sample taken from one of the 10 zones of the typical large power antenna described above. The length of each sample waveguide section is determined by the area required to radiate the amplitron output at the appropriate power density for that sample.

6.1.2.2 Configuration. A general arrangement of the amplitron linear array installation is shown in Figure 6-4. The antenna system is a series of slotted waveguide sections fastened end-to-end, resulting in an array 105-m long. The array is supported on an adjustable structure which is attached to the OCDA boom structure. The support structure is adjusted to align the waveguide to the required straightness with an optical system providing an alignment reference. Each waveguide length is fed by an amplitron rf converter; amplitron spacing conforms to the required waveguides output power distribution. Each amplitron adds 5 kW of power to the control signal received from its control module. The control modules are fastened to the boom structure and connected to the amplitrons with flexible waveguides. The control modules receive beam steering signals from the receiving antenna and provide 1.25 kW of rf input signal to the amplitron. A screen is deployed on each side of the waveguide antenna to serve as a ground plane.

This configuration also provides an optional amplitron control method. Waveguide switches can be opened so that the waveguide is continuous, allowing one amplitron to input another, thereby controlling its output. The boom drive unit and OCDA attitude point the antenna.

6.1.2.3 Construction Operations. In order to define construction operations, the operational function shown in Table 6-2 were first specified. These functions were used as the basis for establishing assembly operations. Most of the operations are repetitive because 20 amplitrons must be mounted, controlled and provided with power. Time estimates were made for each operation, totalled, and used as an input to determine the number of Shuttle flights.

6.1.2.4 Orbital Tests. Evaluation of the signal transmitted from the antenna is accomplished by use of a beam mapping satellite. The satellite travels the same orbital plane as the OCDA and appears stationary to the transmitting antenna. The beam is

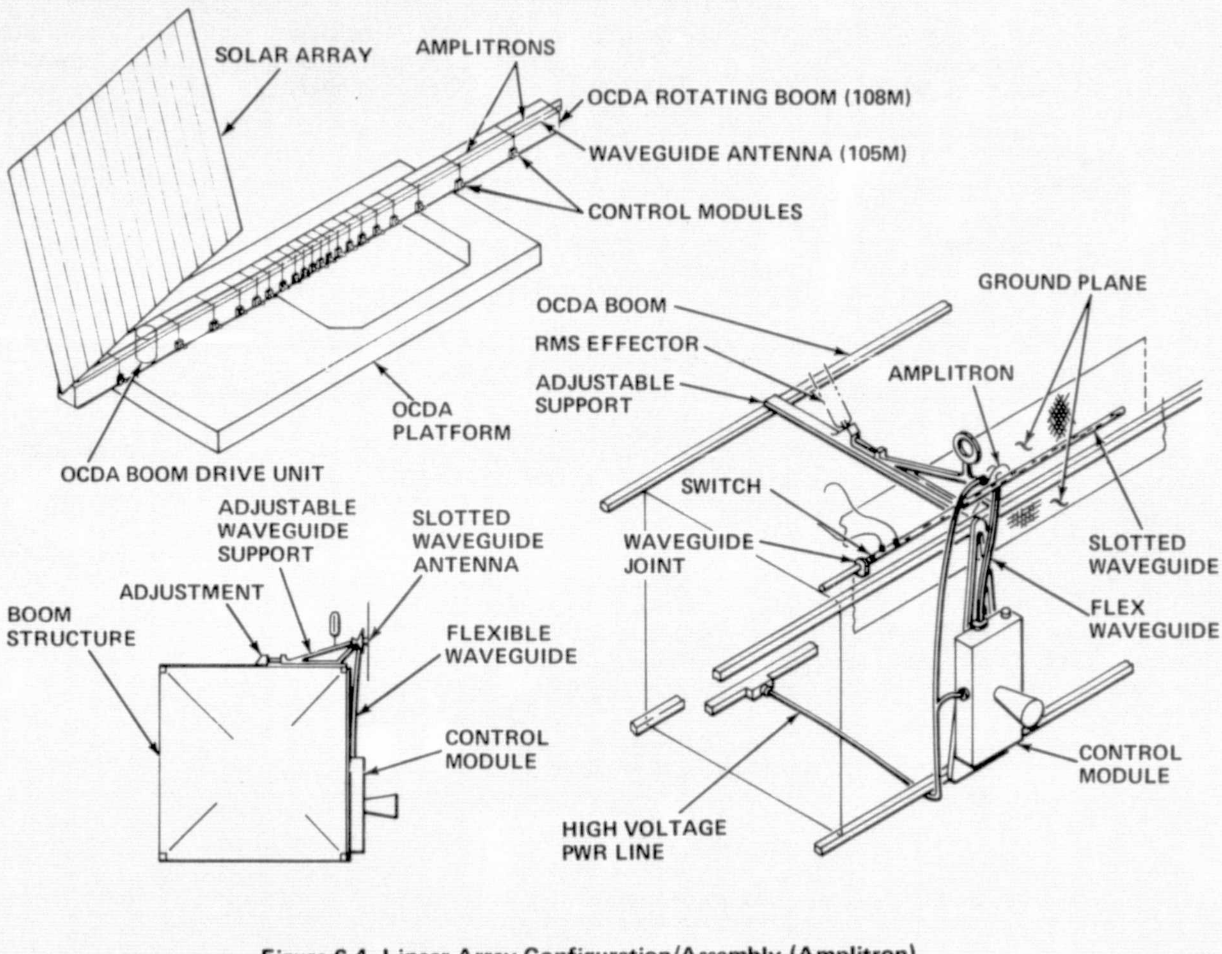
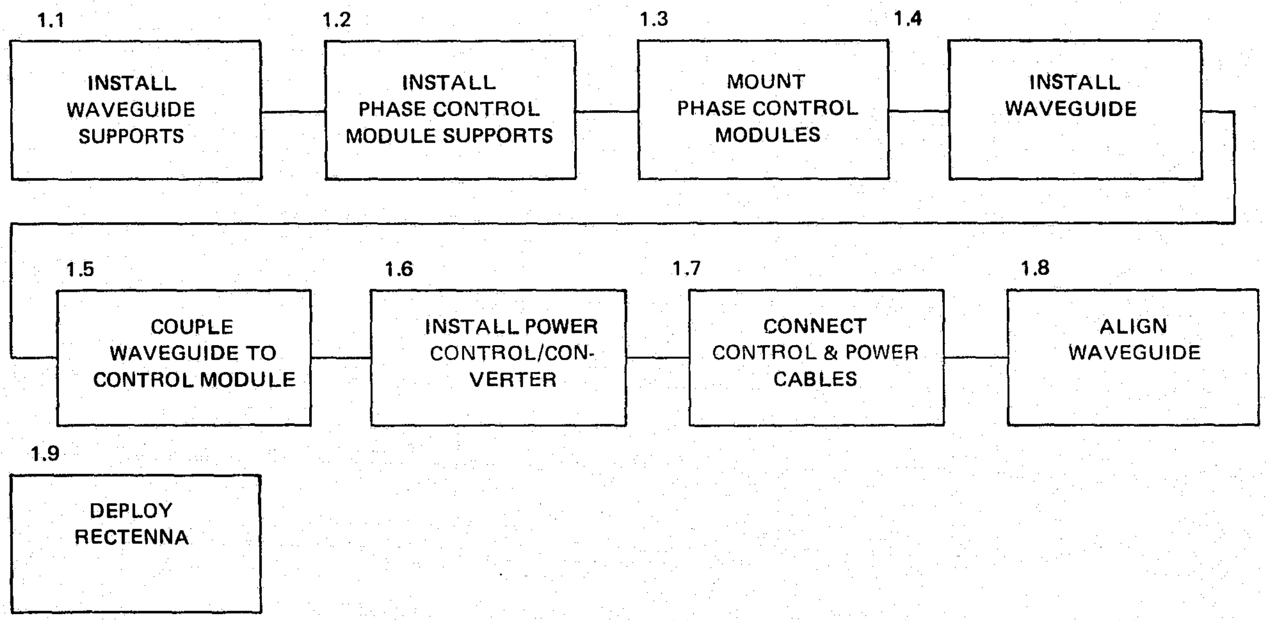


Figure 6-4 Linear Array Configuration/Assembly (Amplitron)

Table 6-2 Functional Operations Scenario — Function 1.0 Linear Waveguide



TIME HR:MIN	OPERATIONS	REMARKS
(11:00)	INSTALL WAVEGUIDE SUPPORTS (22)	
:05	REMOVE SUPPORT ASSY FROM P/L BAY	BOOM RMS
:05	TRANSLATE TO INSTALLATION LOCATION	
:05	POSITION SUPPORT ASSY	
:15	ATTACH SUPPORT ASSY TO BOOM	
(10:00)	INSTALL PHASE CONTROL MODULE SUPPORTS (20)	
:05	REMOVE MOUNTING FIXTURE FROM P/L BAY	
:05	TRANSLATE TO INSTALLATION LOCATION	
:05	POSITION MOUNTING FIXTURE	
:15	ATTACH FIXTURE TO BOOM	
(11:00)	MOUNT PHASE CONTROL MODULES (20)	
:05	REMOVE MODULES FROM P/L BAY	
:05	TRANSLATE TO INSTALLATION LOCATION	
:05	POSITION MODULES	
:15	ATTACH MODULES	
(11:40)	INSTALL WAVEGUIDE (9)	
:05	REMOVE SECTIONS FROM P/L BAY	
:05	TRANSLATE TO INSTALLATION LOCATION	
:05	POSITION WAVEGUIDE SECTION	
:10	ATTACH WAVEGUIDE	
:10	COUPLE WAVEGUIDE SECTIONS	
(6:40)	COUPLE WAVEGUIDE TO CONTROL MODULE (20)	
:05	REMOVE FLEXIBLE WAVEGUIDE SECTIONS	
:05	TRANSLATE TO INSTALLATION LOCATION	ONE END MAY PREVIOUSLY BE CONNECTED
:10	COUPLE WAVEGUIDE TO CONTROL MODULE	

Table 6-2 Functional Operations Scenario – Function 1.0 Linear Waveguide (Continued)

TIME HR:MIN	OPERATIONS	REMARKS
(1:30)	INSTALL POWER CONTROL/CONVERTER	
:05	REMOVE CONVERTER FROM P/L BAY	20 KVDC SUPPLY
:05	POSITION ON BOOM STRUCTURE	
:20	ATTACH TO BOOM	
1:00	CONNECT POWER CABLES	
(3:20)	CONNECT CONTROL AND POWER CABLES	PREVIOUSLY INSTALLED
:05	CONNECT CONTROL CABLES TO WAVEGUIDE SWITCHES	19 SWITCHES
:05	CONNECT POWER CABLES TO AMPLITRONS	20 AMPLITRONS
(5:40)	ALIGN WAVEGUIDE	
:30	INSTALL ALIGNMENT REFERENCE UNIT	
:10	ACTIVATE ALIGNMENT SYSTEM	
5:00	CALIBRATE/ADJUST ALIGNMENT	
(2:20)	DEPLOY RECTENNA	
:30	ACTIVATE SUBSYSTEMS	RELEASED PRIOR TO OCDA DOCKING
:15	ERECT SATELLITE	
1:00	DEPLOY RECTENNA ARMS	
:30	CHECKOUT SATELLITE	
:05	RELEASE SATELLITE	
63:10	TOTAL FOR CONSTRUCTION + TEST TIME REQUIRED = ~1 SHUTTLE FLIGHT	

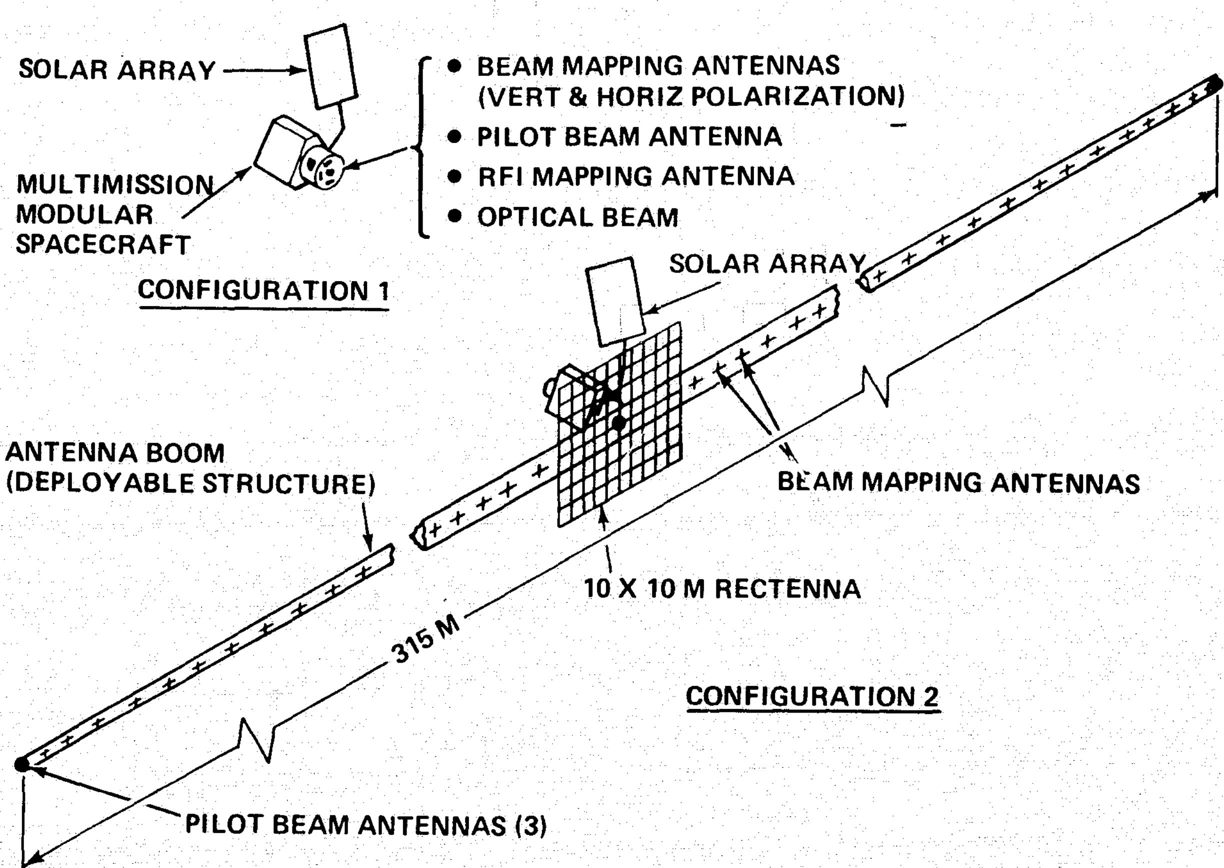


Figure 6-5 Beam Mapping Satellite Candidate Configuration

mechanically pointed at the satellite by a combination of OCDA boom rotation using the boom drive unit and rolling the platform. Two configurations shown in Figure 6-5 were considered for the beam mapping satellite:

- Configuration 1 - This configuration conducts a point measurement of the signal. It utilizes a multimission modular spacecraft carrying a compact instrumentation payload. The spacecraft is carried in the Shuttle cargo bay and, after deployment of its solar array, is operational. The satellite contains horn receiving antenna to receive both vertically and horizontally polarized signals. In addition, a broad-band receiving antenna measures RFI. A pilot beam is transmitted from the satellite to provide a reference to the microwave experiment on the OCDA. An optical beacon on the satellite is used for optical alignment of the linear waveguide and the satellite. Beam mapping is conducted by rotating the OCDA boom and sweeping the signal across the "stationary" satellite.
- Configuration 2 - The major feature of this satellite is the long boom which mounts many receiving antennas. The length of this boom allows it to span a significant part of the beam transmitted by the linear arrays and can therefore make a simultaneous map of the signal. The three pilot beam antennas shown on the boom provide three separate targets for beam steering tests. Power transfer experiments would be conducted using the 10-m x 10-m rectenna. The long antenna boom and the rectenna structure requires assembly at the OCDA platform prior to deployment. Figure 6-6 is a view of the linear array looking at this mapping satellite.

A typical signal pattern for a linear array is shown in the Figure 6-7. Dimensions apply specifically to the 105-m array. The signal forms a tall pattern along an axis perpendicular to the orientation of the linear array antenna and is quite narrow in the other direction. Beam mapping is conducted at a minimum distance of L^2/λ (90 km for the 105-m array). Orientation of the mapping satellite is not critical along the larger dimension, but is very critical along the small axis. The beam is moved in a lateral direction (along the direction of the small axis) by phase shifting the signal along the array. The beam is mapped by either sweeping the sensor across the short axis of the signal or by spanning the main lobe and several sidelobes with an array of sensors on a long boom. The maximum signal strength at 90 km is estimated to be .043 mW/sq cm with the first sidelobes down 30 db.

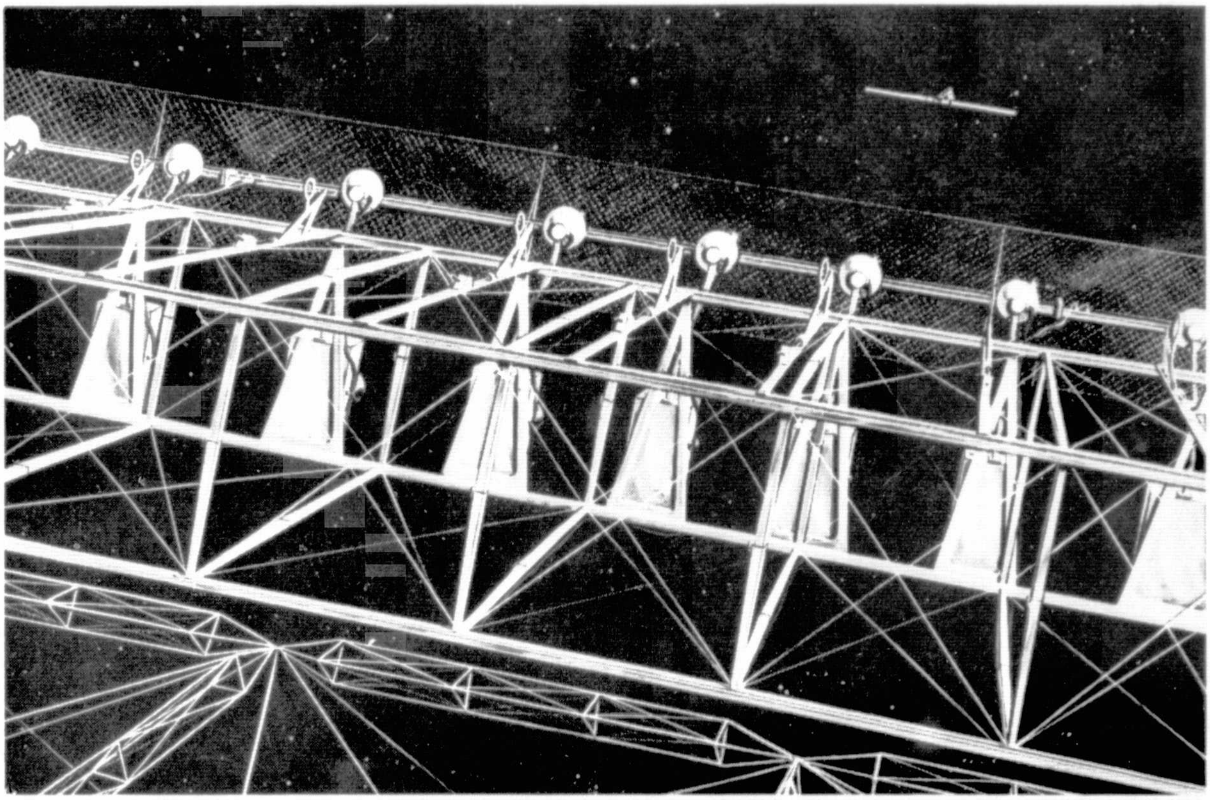


Figure 6-6 Linear Array Testing With Mapping Satellite

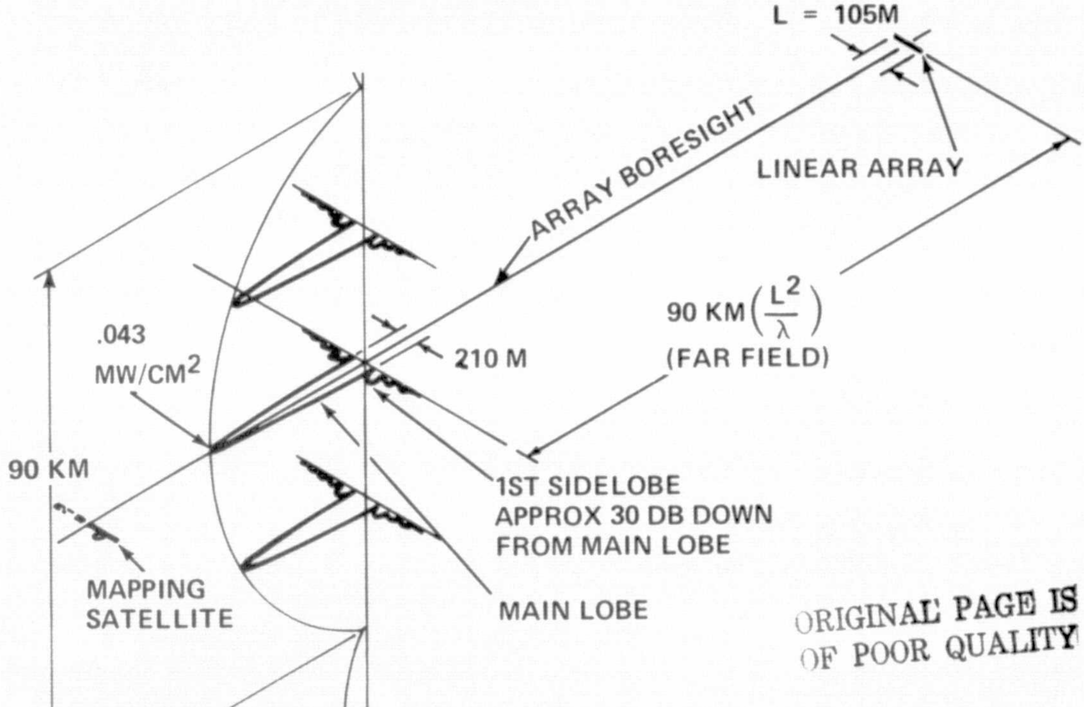


Figure 6-7 Far Field Signal Pattern 105 m Linear Array

The antenna boom length on the Configuration 2 mapping satellite must be large enough to span a significant portion of the linear array signal. The signal is mapped in the antenna far field (i.e., at a distance great enough to reduce the phase difference between signals from the center and the edge of the linear array to an acceptable level). The usual criteria is $2L^2/\lambda$; however, in the interest of minimum boom length, a criteria of half that distance was also considered (L^2/λ).

Analysis of the beam pattern is enhanced by mapping as many sidelobes as possible, with two considered the minimum. To achieve this and keep the boom within reasonable size, the beam is mapped one side at a time.

Figure 6-8 shows the relationship between array length and satellite boom length for two mapping distance criteria and for several sidelobe combinations.

The boom length chosen for the Configuration 2 Satellite is 315 m. This boom length was picked to provide a span equal to half a main lobe and two sidelobes of the 105-m array signal at a mapping distance of 90 km (L^2/λ).

Table 6-3 outlines the linear waveguide test requirements and equipment requirements with supporting rationale. The test approach discussed previously should be referred to for test details. The beam mapping satellite is costly and complex. Further investigation should be done to determine if a cheaper approach is possible (e.g., ground instrumentation).

Completion of these tests provides confidence that the amplitron phase control scheme is practical and that operational procedures and time allowances are realistic. Critical issues to be resolved during this experiment are: 20 kV power distribution, waveguide alignment, antenna pointing accuracy and amplitron phase control.

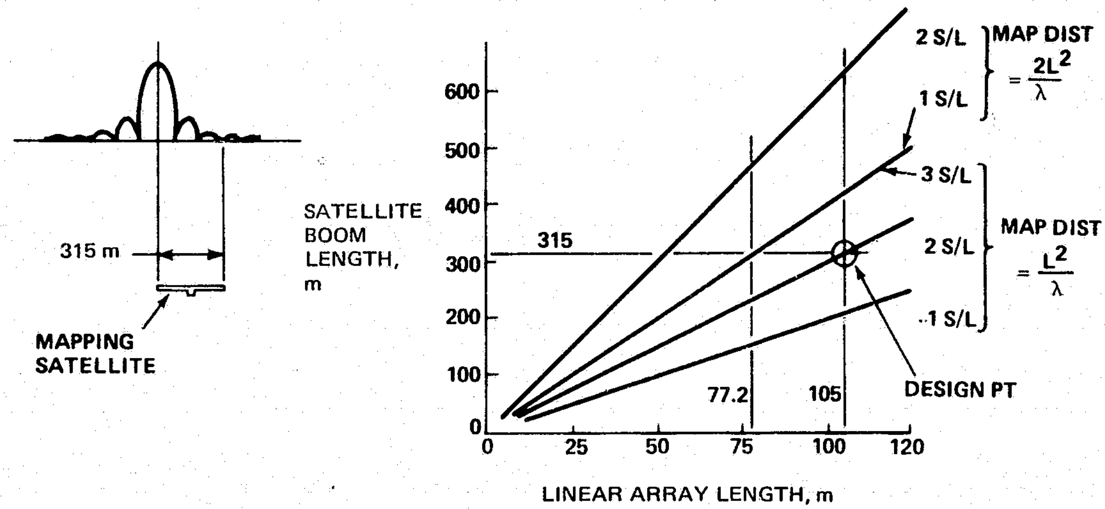
Table 6-4 contains a list of the mission peculiar equipment and the estimated mass for each item.

6.1.3 Mission 3 - 20-m Beam Fabrication

The mission objectives are aimed at verifying the technical and operational issues associated with establishing the producibility of a composite 20-m beam. This is the pivotal experiment in providing the technological base required to construct large structures for the SPS.

6.1.3.1 Mission Objectives and Requirements. The mission objectives are to demonstrate:

- Fabrication of a 20-m beam, the basic building component for large space structures
- Determine structural characteristics of the fabricated beam.



CRITERIA

- **BEAM MEASUREMENTS TO BE MADE AT FAR FIELD MAPPING DISTANCE**
- **SATELLITE BOOM MUST SPAN AT LEAST TWO SIDELOBES**

Figure 6-8 Determination of Boom Length Required on Beam Mapping Satellite

Table 6-3 Orbital Construction Experiment Definition – SPS Photovoltaic Development – Power Transmission

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
THERMAL CYCLING ON WAVEGUIDES AND PHASE CONTROL	1. DETERMINE ORBITAL ASSEMBLY RATE INCLUDING INITIAL ALIGNMENT REQUIREMENT 20 MIN/SECTION - SECTION INCLUDES WAVEGUIDE, AMPLITRON, CONTROL MODULE AND ALIGNMENT ACTUATOR 2. OVERALL ALIGNMENT OF ARRAY REQUIREMENT ALIGNMENT 1 MM/M TIME 45 MIN 3. DETERMINE GND POWER DISTRIBUTION (BEAM MAPPING) REQUIREMENT - GUASION DISTRIB WITH 10 DB TAPER 4. DETERMINE PHASE CONTROL CHARACTERISTICS REQUIREMENTS ORBIT - 350 KM GND SIGNAL-TBD DBW PHASE CONTROL 1 ARC SECOND	1. MANIPULATORS FOR INSTALLATION 2. LASER ALIGNMENT INSTRUMENTATION 3. TRANSMITTERS, RECEIVER AND SIGNAL MEASURING EQUIPMENT 4. HIGH RESOLUTION RADAR/TRANS-PONDERS FOR TRACKING OCDA 5. TELEMETRY TO TRANSMIT OCDA AND WAVEGUIDE ATTITUDE PARAMETERS 6. FREE FLYER TO PROVIDE ORBITAL MAPPING	THE PROPOSED TESTS OF THE LINEAR ARRAY AN-TENNA WILL PROVIDE INFORMATION ON THE MAJOR ISSUES (POWER DISTRIBUTION AND PHASE CONTROL AT LEO WHICH CAN BE EXTRAPOLATED TO PROVIDE A GOOD UNDERSTANDING OF THE PERFORMANCE AND EN-VIRONMENTAL PROBLEMS TO BE EXPECTED AT GEO FOR A 5 GW ORBIT SPS FACILITY. SPECIFICALLY THE PROPAGATION CHARACTERISTICS OF THE GROUND PILOT CONTROL BEAM THROUGH THE ATMOSPHERE AND THE POWER DENSITY DISTRI-BUTION OF THE MAIN BEAM OUT TO THE FIRST LOBE. TRADES WILL HAVE TO BE MADE RELATIVE TO GND INSTRUMENTATION VS FREE FLYER TO CON-DUCT EXPERIMENTS.

The test requirements are:

- Demonstrate synchronization of beam fabrication machines
- Verify dimensional accuracy to 1 ft/100 ft
- Determine beam assembly rates at 1 ft/min., minimum
- Determine thermal effects on beam integrity and straightness
- Determine stiffness and compression strength.

6.1.3.2 Configuration. The 20-m beam assembly fixture is attached to platform nodals on the platform side opposite of the rotating solar array. This location of the fixture does not restrict the OCDA boom rotation and does not require an increase in platform length, but does require the platform to increase 8 m in width. The configuration consists of a 58-m long structural frame assembly which is an assembly of shuttle delivered repackaged deployable structures. Figure 6-9 shows commencement of the fixture construction. The frame assembly provides mounting and support for 6 1-m composite beam fabrication modules, swing arms, carriages and other module components. This fixture requires the assembly track to be erected with the cherry picker operational, so that the fixture structure can be assembled. The assembly procedure relies on the boom cherry picker to reach the structure adjacent to the platform. When the structure is completed, the 6 fabrication modules are mounted. Fixture subsystems (e.g., cable rigging transportation belt, beam carriages, etc.) can now be installed. Power is routed to the equipment and material magazines are fitted to the fabrication modules. The conductor fabrication module location is shown in Figure 6-10. However, it is not installed until a subsequent mission.

The beam assembly fixture equipment is checked out in sequence and integrated operation is later demonstrated by producing a section of 20-m beam.

6.1.3.3 Construction Operations. Table 6-5 lists the functions and operations associated with fabrication of the 20-m beam. Seventy-six hours have been allocated for construction operation but this time is not the driver for determining the number of Shuttle flights. Cargo bay volume necessary to transport the 6 fabrication modules and material dispensers requires 3 flights, and assembly fixture beams require another flight for a total of 4 flights.

6.1.3.4 Orbital Tests. Sections of 20-m beam will be produced for test purposes, first to determine operational characteristics of the fabrication equipment and then the quality of the manufactured beam. Figure 6-11 illustrates an approach to measuring structural integrity of a test beam. A beam section is produced including end fittings. A cable is

Table 6-4 Linear Waveguide Mass

ELEMENT	MASS	
	LB	KG
• CHERRY PICKER	(4807)	(2187)
– STRUCT/MECH.	2187	998
– TRUCK	1250	568
– BUBBLE SYSTEM		
• CONTROLS	175	79
• ECLS	100	45
• BUBBLE HATCH	1095	497
• AMPLITRON PECULIAR	(12,278)	(5574)
– TUBES	71.2	32.3
– WAVEGUIDES	37.3	16.93
– CONTROL ELECTRONICS	3473	1576
– MECHANICAL	570	259
– POWER DISTRIBUTION	8126	3689
• ORBITAL TEST EQUIPMENT	(2192)	(996)
– FREE FLYER S/C	1720	781
– MISSION PECULIAR STRUCTURE	457	208
– MISSION PECULIAR ELECT.	15	7.0
TOTAL	19277	8757

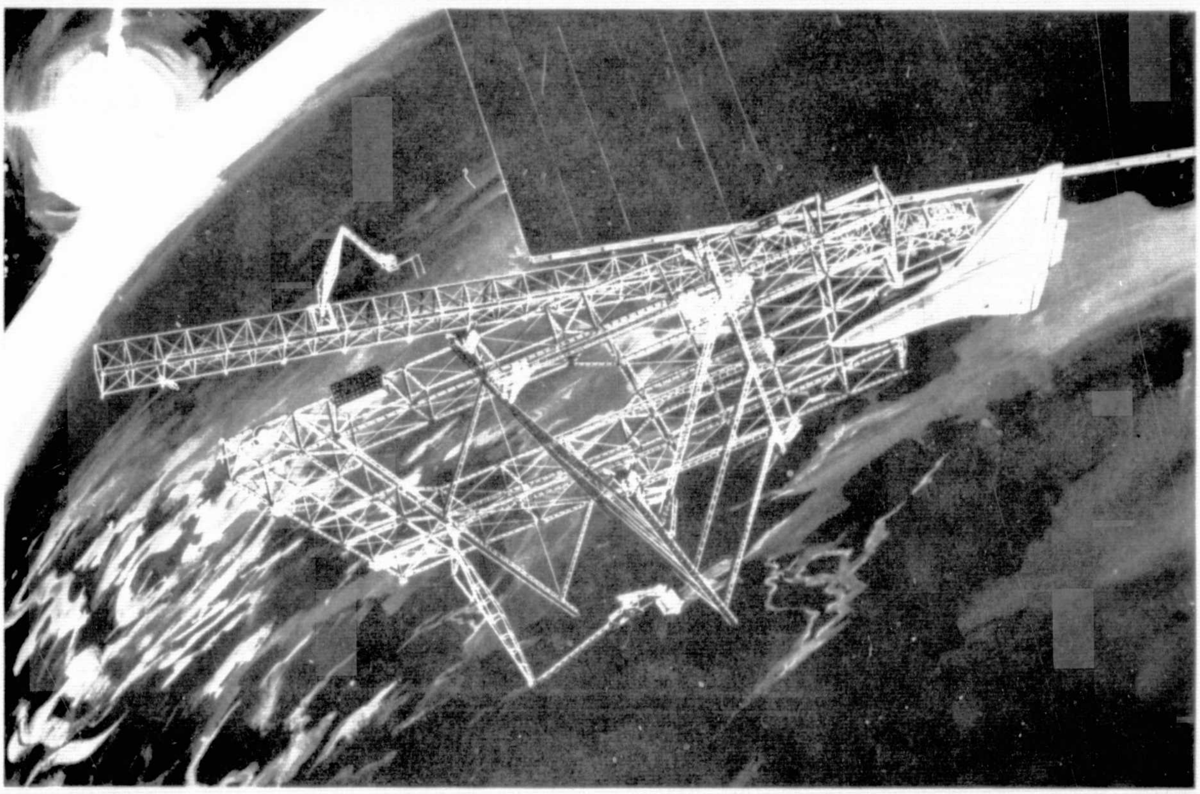


Figure 6-9 Fixture Construction

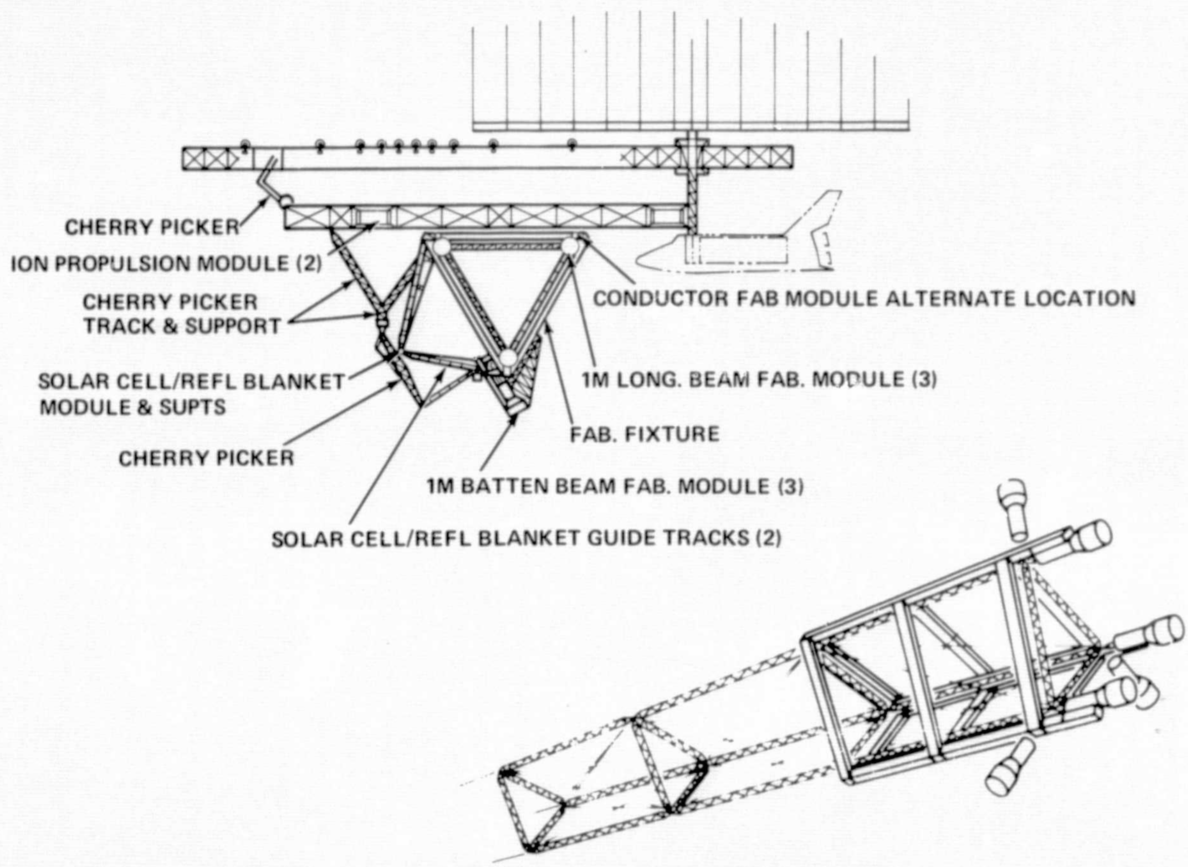
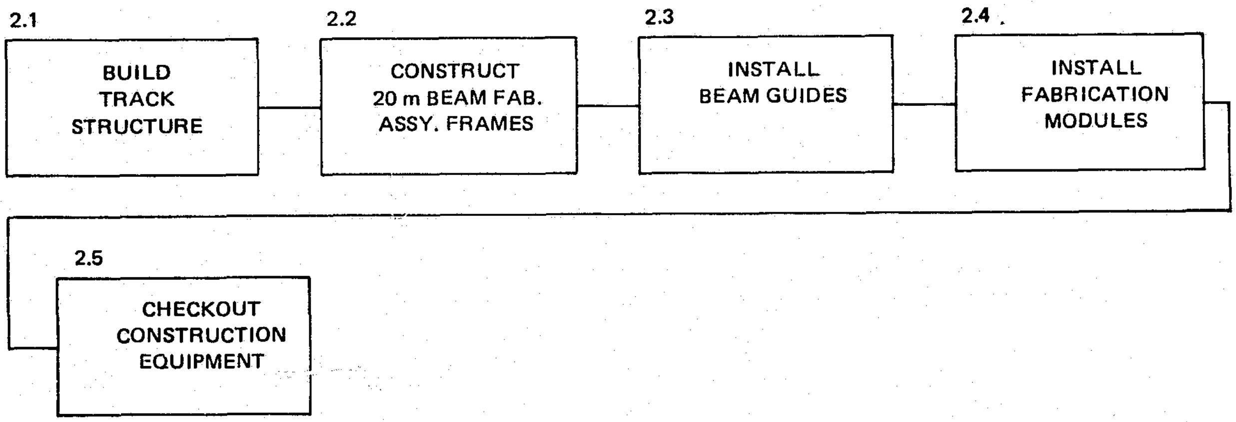


Figure 6-10 Beam Assembly Fixture Configuration/Assembly

Table 6-5 Functional Operations Scenario – Function 2.0 20-m Beam Fabrication



TIME HR:MIN	OPERATIONS	REMARKS
(12:30)	BUILD TRACK STRUCTURE	
2:00	INSTALL FRAME LEG PLATFORM ATTACHMENTS (4)	
1:00	MOUNT TRACK ASSY FIXTURE TO PLATFORM	
:45	DEPLOY TRACK STRUCTURE (3 SECTIONS)	
:45	ASSEMBLE TRACK	
1:00	INSTALL MANIPULATORS	
:30	RELEASE TRACK ASSY FIXTURE AND MANEUVER TO OPPOSITE SIDE	BOOM RMS
:30	MOUNT TRACK SUPPORT FIXTURE TO PLATFORM	
1:00	DEPLOY TRACK SUPPORT LEGS (4)	
2:00	INSTALL LEGS AND CABLES TO PLATFORM AND TRACK STRUCTURE (4)	
:30	INSTALL POWER CABLING	
:30	CHECKOUT MANIPULATORS OPERATION	
2:00	ERECT TRACK SUPPORT STRUCTURE AND SECURE	TRACK MANIP-ULATORS
(17:30)	CONSTRUCT 20 m BEAM FABRICATION ASSY FRAMES	
3:00	INSTALL FRAME ATTACHMENT SUPPORTS (6)	BOOM RMS AND TRACK RMS
1:30	INSTALL A FRAME ASSY JIG IN PLATFORM	
2:15	DEPLOY A FRAME BEAMS (9)	
1:30	ASSEMBLE A FRAMES (3)	
3:00	REMOVE A FRAMES FROM JIG AND ATTACH TO SUPPORT (3)	
1:30	DEPLOY LONGERONS (6)	
3:00	ATTACH LONGERONS TO A FRAMES (6)	
1:00	INSTALL STIFFENING STAYS (12)	
(16:30)	INSTALL BEAM GUIDES	
6:00	MOUNT CARRIAGE TRACK SUPPORT STRUCTURE	
6:00	INSTALL CARRIAGE TRACKS (18)	
3:00	INSTALL BEAM CARRIAGES (6)	
1:30	INSTALL CABLE RIGGING CONTINUOUS BELT	
(21:00)	INSTALL FABRICATION MODULES	
12:00	MOUNT FAB. MODULE SUPPORT STRUCTURE	
6:00	INSTALL FAB. MODULES AND ALIGN (6)	3 FLIGHTS
1:30	CONNECT ELECTRICAL POWER CABLES	
1:00	MOUNT END FITTING SCAFFOLD ATTACHMENT	
1:00	INSTALL SCAFFOLD	

Table 6-5 Functional Operations Scenario — Function 2.0 20-m Beam Fabrication (Continued)

TIME HR:MIN	OPERATIONS	REMARKS
(8:30)	CHECKOUT CONSTRUCTION EQUIPMENT	
1:30	INSTALL MATERIAL CASSETTES TO FAB. MODULES	1 FLIGHT
1:30	OPERATE EACH FAB. MODULE	
1:30	VERIFY BEAM ALIGNMENT	
1:00	VERIFY CARRIAGE OPERATION	
1:30	VERIFY CABLE RIGGING	
1:30	VERIFY JOINT MODULE OPERATION	
76:00	TOTAL FOR CONSTRUCTION ~SHUTTLE FLIGHTS = 4	

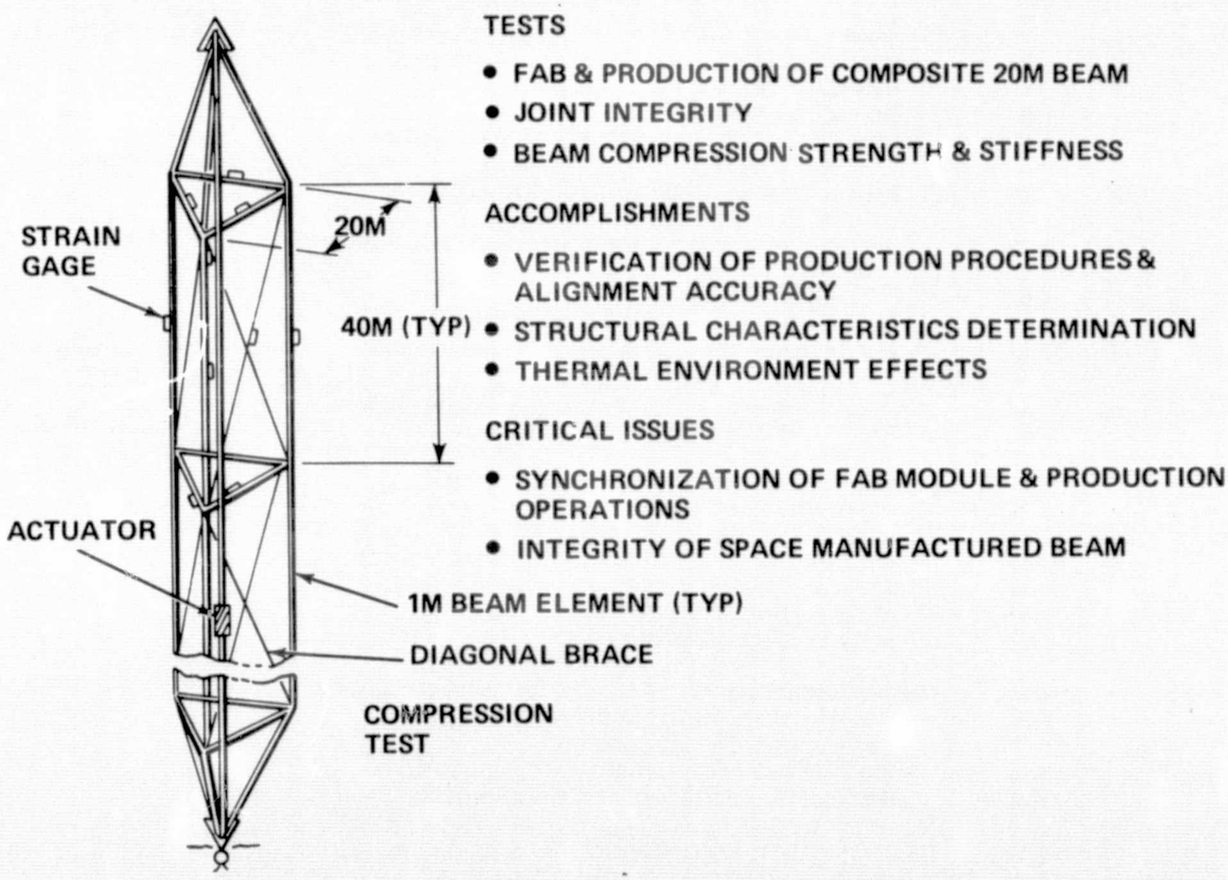


Figure 6-11 Beam Tests

attached to the end fittings and connected to an actuator. The actuator tensions the cable, thereby loading the structure. Strain gages are used to record loads on individual structural members.

Table 6-6 lists some of the parameters considered in choosing the test specimen against the nominal 5 GW SPS pilot plant discussed in NASA Study, Contract No. NAS 8-31308 dated 30 June 1976 which was used as the design reference point. Option 2 was chosen because it will provide information on one of the design reference beam lengths (246.5 m). Composites were selected rather than 2219-T6 aluminum used for the design reference beam because temperature problems associated with aluminum will likely drive the nominal SPS design to the use of composites.

As a consequence of performing the above test and others listed in Table 6-7 (e.g., vibration survey, joint test) production procedures and assembly rate were determined. The environmental effects were also assessed and dimensional accuracy determined. Finally, a full length beam of 369 m was produced to be used subsequently in the construction of the SPS pilot plant. Completion of this mission will resolve the critical issues listed:

- Synchronization of fabrication module and production operations
- Integration of space manufactured beam.

Table 6-8 contains a list of the mission peculiar equipment and the estimated mass for each item.

6.1.4 Mission 4 - Conductor Installation

Conductor installation for any of the SPS systems is a critical operation because of the many miles of conductor involved, and the high voltage and currents which the conductor must carry. The activities described here will provide some of the pertinent verification data required. The 597-m long conductor with a .04-cm x 15-cm cross section will be loaded to slightly over the 795 amps/sq cm, duplicating the current density of the ultimate SPS conductor. A separate test will evaluate conductor performance at 20 kV. This will provide data relative to the losses, heating and proper isolation of SPS conductors.

6.1.4.1 Mission Objectives and Requirements. The mission objectives and test requirements shown below will verify the capability to fabricate conductors and integrate the operations with construction of the 20-m beam. It also demonstrates the ability of the conductor to carry high current without producing local hot spots at joints or connections. High voltage effects (i.e., local plasma isolation from adjoining structure, and

Table 6-6 Solar Array 20 m Structural Tests

SPS SOLAR ARRAY STRUCTURAL MEMBER DESIGN REQUIREMENTS	5 GW SPS NOMINAL	OCDA TEST REQUIREMENTS		
		OPTION 1	OPTION 2	OPTION 3
SIZE OF PRIMARY STRUCT. MEMBERS	246.5 m X 20 m 493 m X 20 m *1479 m X 213 m	246.5 m X 20 m	246.5 m X 20 m	369.4 m
MATERIAL	AL 2219 - T6	2219 - T6	GRAPHITE EPOXY	GRAPHITE EPOXY
WEIGHT	1.08 LB/m	1.08 LB/m	.864 LB/m	.864 LB/m
E	10.5 X 10^6 Psi	10.5 X 10^6 Psi	8 X 10^6 Psi	8 X 10^6 Psi
ρ	.103 LB/m^3	.103 LB/m^3	.06 LB/$IN.^3$	
AXIAL LOAD FOR 1479 m X 213 m BEAM	1932 LB			

OPTION 2 RECOMMENDED FOR TEST

Table 6-7 Orbital Construction Experiment Definition — SPS Photovoltaic Development — Structures

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
BUILDING BLOCK STRUCT FAB AND/OR DEPLOY - FABRICATE 20 M BEAMS FOR SPS PRIMARY STRUCT.	1. VERIFY SYNCHRONIZATION OF MACHINES REQUIRED TO BUILD 20 m BEAMS REQUIREMENT 1 FT/MIN 2. VERIFY DIMENSIONAL ACCURACY REQUIREMENT 1 FT/100 FT 3. VERIFY INDIVIDUAL MACHINE OPERATING PARAMETERS, I.E., PINCH UP FORCES, SPEED OF CONTROL SYSTEM PLUS OVERALL SENSING AND SYNCHRONIZATION SYSTEM REQUIREMENTS MACHINE OPS ROLLER FORCES-TBD FEED RATES-TBD LINEAR FEED-TBD SENSING AND CONTROL 4. DETERMINE ASSEMBLY TIMES FOR 20 m BEAMS REQUIREMENTS ASSEMBLY RATE - 1 M/MIN 5. DETERMINE EFFECTS OF LEO TEMP VARIAT ON FAB, BEAM INTEGRITY AND STRAIGHTNESS EXPECTED -50° TO 200°F Δ 100°F BETWEEN UPPER AND LOWER CAPS 6. STRUCTURAL INTEGRITY TESTS REQUIREMENTS COMPRESSION - LOAD TO ULTIMATE IN 20 LB STEPS STARTING AT 1000 LB VIBRATION - MEASURE LATERAL AND VERTICAL AXIS NATURAL FREQUENCY 0.5 TO 5 CPS EXPECTED	1. TELEMETRY SYSTEM FOR SPACE FAB MACHINE PARAMETERS 2. OPTICAL ALIGNMENT SYSTEM (LASER) 3. VIDEO EQUIPMENT TO RECORD AND MEASURE ASSEMBLY RATES 4. SPACE FAB PRODUCTION RATE SENSORS	THE OBJECTIVE IS TO VERIFY THE ABILITY TO GANG 1 M SPACE FAB MACHINES (DEVELOPED ON SORTIE MISSIONS) TOGETHER TO PRODUCE 20 M BEAMS WHICH WILL BE USED FOR THE PILOT SPS PHOTOVOLTAIC SOLAR ARRAY. MAJOR THRUST WILL INCLUDE ALIGNMENT, SYNCHRONIZATION AND CONTROL OF MACHINES REQUIRED TO PRODUCE 20 m BEAM. VERIFICATION OF INDIVIDUAL MACHINE OPERATING PARAMETERS PLUS OVERALL FABRICATION AND ASSEMBLY RATES. THESE TEST RESULTS WILL VERIFY THE PRODUCEABILITY OF 20 m BEAMS AND IDENTIFY THE CRITICAL AREAS AS A PRECURSOR TO PRODUCTION OF LARGE SPACE STRUCTURES. THE STRUCTURAL INTEGRITY OF THE SPACE PRODUCED BEAMS WILL ALSO BE VERIFIED.

Table 6-8 20-m Beam Fabrication Mass

ELEMENT	MASS	
	LB	KG
• FRAME ASSEMBLY (1)	(3657)	(1705)
– MAIN STRUCTURE		693
– PLATFORM	300	136
– RAILS	170	123
– SCAFFOLD	400	181
– CARRIAGE	300	136
– PRETENSION DEVICE	20	9
– POWER DIST. AND CONTROL	300	136
– SWING ARMS	330	150
– ALIGN FIXTURE	180	82
– LIGHTING	30	14
– CABLE RIGGER	100	45
• FABRICATICN MODULE (6)	33000	14982
• CREW MODULE	6000	2724
• SPECIAL MANIPULATORS	–	–
• MATERIAL	4300	1952
TOTAL	46957	21318

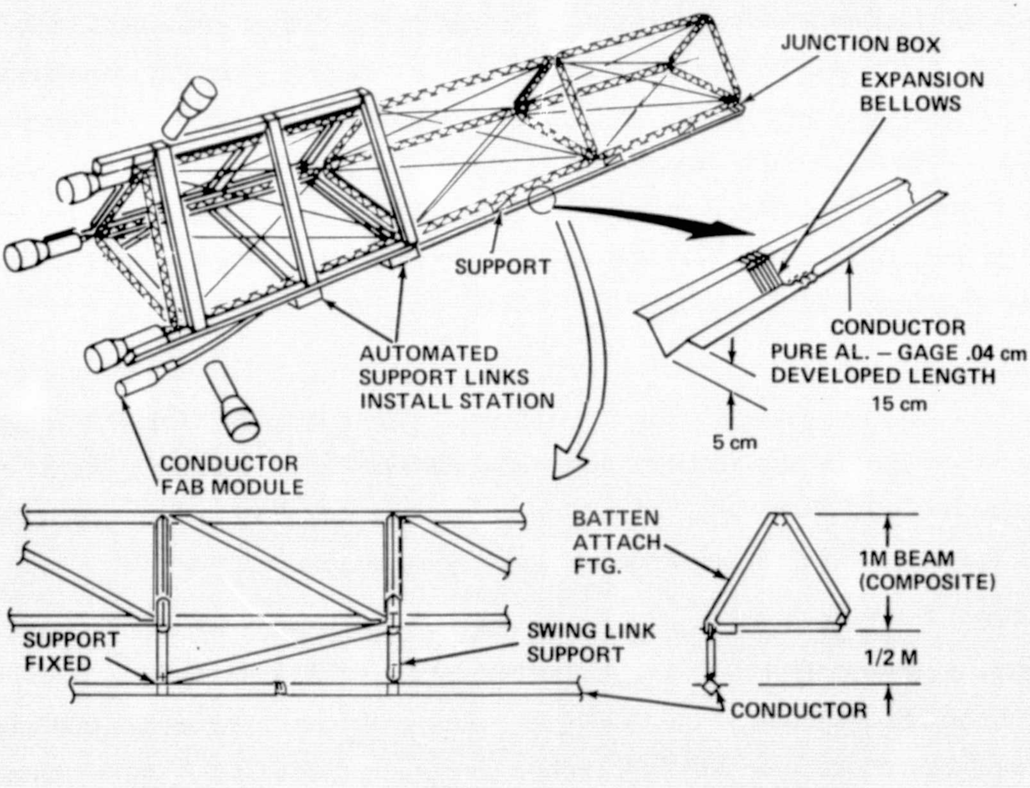


Figure 6-12 Conductor Configuration/Assembly

electrostatic surface charges) would be investigated. Thermal effects and electrical properties of the conductor would also be established.

The mission objectives are to demonstrate:

- Fabrication and installation of power busses
- Integration of electrical power conductor with large space structure

The test requirements are:

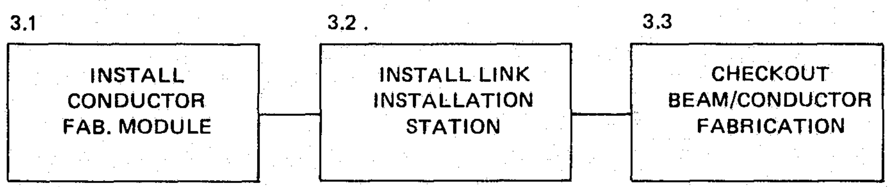
- Demonstrate fabrication rate of 1 ft/min.
- Determine operation at current density $>$795 amps/sq cm
- Show adequacy of electrical isolation for 20 kV
- Investigate thermal cycle at maximum power and maximum solar heating vs. zero power and darkness
- Determine conductor and connection voltage drop.

6.1.4.2 Configuration. Figure 6-12 illustrates the conductor installation integrated with the 20-m beam fabrication. The top of the illustration shows the conductor fabrication module incorporated into the 20-m fabrication fixture so that it can be synchronized with the beam fabrication module operation. The conductor design concept is based on minimum weight conductors with high current density and, therefore, large surface area for heat rejection. The conductor configuration employs a deep V trough for stiffness with expansion bellows between a fixed support and swing link support. This permits the conductor to expand independently of the 1-m composite support beam. The supports are attached at the battens of the 1-m beams. This allows the support stations to be spaced at intervals which will satisfy dynamic requirements.

6.1.4.3 Construction Operations. Construction operations shown in Table 6-9 are simple compared to previously discussed tasks. The conductor fabrication module is much smaller than the beam fabrication module and installation alignment is not as critical as the fabrication module. However, the automatic support link station presents a challenge because it connects the conductor to the support structure.

6.1.4.4 Orbital Tests. The approach to selecting the photovoltaic SPS requirements to be demonstrated was to first define the requirements for the ultimate SPS, then determine how they could be implemented at the OCDA by defining optional approaches that match a few operational conditions, and finally to select an approach for OCDA implementation that meets the greatest number of test conditions and is within the constraints of the OCDA.

Table 6-9 Functional Operations Scenario Function 3.0 Conductor Installation



TIME HR:MIN	OPERATIONS	REMARKS
(3:15)	INSTALL CONDUCTOR FABRICATION MODULE	
2:00	MOUNT FAB. MODULE SUPPORT STRUCTURE	
1:00	INSTALL FAB. MODULE AND ALIGN	
:15	CONNECT ELECTRICAL POWER CABLES	
(4:00)	INSTALL LINK INSTALLATION STATION	
1:00	MOUNT INSTALLATION STATION SUPPORT STRUCTURE	
2:00	MOUNT LINK INSTALLERS (4)	
1:00	CONNECT ELECTRICAL POWER CABLES	
(2:30)	CHECKOUT BEAM/CONDUCTOR FABRICATION	
1:45	INSTALL MATERIAL CASSETTES TO FAB. MODULES	
:15	OPERATE CONDUCTOR FAB. & ASSOCIATED STRUCTURE MODULE	
:30	VERIFY BEAM/CONDUCTOR ALIGNMENT	
9:45	TOTAL FOR CONSTRUCTION ~1 SHUTTLE FLIGHT	

Table 6-10 Orbital Construction Experiment Definition — SPS Photovoltaic Development — Power Distribution

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
INSTALL INTEGRATED STRUCTURE/BUS SYS - SPACE FAB NON STRUCTURAL DC SOLAR ARRAY BUS.	1. VERIFY ORBITAL FAB AND ASSEMBLY RATE FOR SOLAR ARRAY SCALED DOWN BUS. REQUIREMENTS MATERIAL - AL6101 @ 3$\mu\Omega$ cm^2/cm CROSS SECT AREA .629 cm^2 FAB RATE 1 FT/MIN ASSEMBLY RATE 10 MIN/SECT. 2. VERIFY CONDUCTIVITY OF ASSEMBLY REQUIREMENTS I_D (CURRENT DENSITY) = 795 I/cm^2 3. CONDUCT HIGH VOLTAGE INSULATION BREAKDOWN TESTS REQUIREMENT ISOLATION = 20 KV 4. DETERMINE THERMAL CYCLE EFFECTS INCLUDING ALIGNMENT 5. DETERMINE OPERATIONAL PROBLEMS.	• VIDEO RECORDERS TO MEASURE FAB AND ASSEMBLY RATES • TEMP, VOLTAGE AND CURRENT INSTRU PLUS TELEMETRY • ALIGNMENT TOOLS	THE OBJECTIVE OF THIS TEST WILL BE TO MANUFACTURE AND INSTALL A TYPICAL SPS BUS SECTION TO EVALUATE PERFORMANCE CHARACTERISTICS PRIOR TO BUILDING PILOT POWER PLANT. THIS EXPERIMENT WOULD UTILIZE THE 20-M BEAMS IN ORDER TO REPRESENT TYPICAL SPS STRUCTURE FOR EVALUATION OF INSTALLATION AND THERMAL CYCLE CONSIDERATION. IT WOULD UTILIZE THE END CAP FAB UNIT TO PRODUCE THE CONDUCTOR.

Table 6-10 lists the prime test requirements, test equipment and test rationale. Table 6-11 indicates the results of a trade study conducted in choosing the test specimen. Since the OCDA would have 100 kW available for this activity as against 5 GW for the ultimate SPS design, current density and insulation test requirements must be compromised. With 500 amps and 200 V available, option 3 test procedures shown in Table 6-11 were selected because:

- It provides the desired current density
- It utilized the nominal .04 cm (.015 in.) gauge Al to produce the test conductor
- It utilizes the end cap space fab machine to produce the test specimen.

The only significant parameter that is not duplicated is the conductor span, 15.9 cm as compared to the nominal SP^ design reference of 3 m. This, in turn, will require an installation which does not duplicate the nominal design configuration. Standoff insulators (types and distances) can be duplicated for the insulation/isolation tests. For these high voltage tests, the normal 200 VDC OCDA voltage source must be boosted to 20 VDC using DC to DC converters.

After the initial setup and the production cycle is underway, the fabrication/installation rates are measured and the conductor fabrication checked for dimensional accuracy. After completion of the production/assembly of the SPS pilot plant, voltage and current measurements are taken to check out the adequacy of thermal and insulation/isolation provisions. Also dipole, plasma, and electrostatic effects associated with high currents will be observed. This assembly will provide operational information on the methods used to connect and terminate high power conductors, circuit protection devices and power switches.

Table 6-12 contains a list of the mission peculiar equipment and the estimated mass for each item.

6.1.5 Mission 5 - Microwave Antenna Assembly

Construction of a 2-dimensional microwave antenna will confirm proposed assembly techniques and reveal problems associated with the thermal environment of the antenna. A baselined deployable structure was used for the antenna support structure so that emphasis will be placed on the installation of subassemblies to the primary antenna structure. This antenna will eventually be incorporated into a demonstration SPS to transmit usable power to an earth-based rectenna.

Table 6-11 Experiment Selection Approach

- ESTABLISH PHOTOVOLTAIC SPS REQUIREMENTS
- DETERMINE EXPERIMENT OPTIONS
- SELECT EXPERIMENT REQUIREMENTS FOR OCDA

TYPICAL TEST REQUIREMENTS
ELECTRICAL BUS

DESIGN PARAMETERS	SPS	OPTION 1	OPTION 2	OPTION 3 ✓ SELECTED
SOLAR ARRAY	5 GW	500 AMPS	500 AMPS	500 AMPS
DIST VOLTAGE	20 KV	200V*	200V*	200V*
CROSS SECTIONAL AREA (CM^2)	12.5	.63	1.6	.65
THICKNESS CM	.04 (.015 IN.)	.004	.01	.04
SPAN	3.12 m	1.57 m	1.57 m	15.9 CM
CURRENT DESNITY I/CM^2	795	795	318	795
*200V INCREASED TO 20 KV FOR ISOLATION TEST				

Table 6-12 Conductor Installation Mass

ELEMENT	MASS LB	MASS KG
• FRAME ASESMBLY INTERFACE EQUIPMENT		
– CONDUCTOR FAB MODULE SUPPORTS	220	100
– GUIDES		
– SUPPORT LINKS INSTALL. STATION	N/A	N/A
– SWITCH BOX AND JUNCTION INSTALL STATION	N/A	N/A
• CONDUCTOR FAB MODULE		
– FAB MODULE	2200	999
– MATERIAL		
• SUPPORT EQUIPMENTS		
– SUPPORT LINK INSTALLER	230	104
– SWITCH BOX AND JUNCTION INSTALLER	N/A	N/A
• ORBITAL TEST EQUIPMENT	N/A	N/A
TOTAL	2650	1203

The means of attaching subarrays to the primary structure at the required planarity must be demonstrated. Thermal issues of operating subarrays at the maximum power expected of a full size SPS will be addressed. Distribution and control of power to the subarrays will be addressed in a timely fashion.

6.1.5.1 Mission Objectives and Requirements. The mission objectives are to demonstrate:

- Construction of microwave power antenna, emphasizing subassembly installation
- Transmission of RF power for useful ground rectenna output of 10 to 50 kW
- Structure thermal interaction.

The mission requirements are:

- Antenna power output 1 MW, aperture 20 m
- Subarray element power output minimum 2.2 kW/sq m, maximum 22 kW/sq m
- RF coherent ground transponding
- Start up and shutdown of subarray elements.

The rationale for the antenna aperture selected (20 m) is illustrated in Figure 6-13. With an input power of 1 MW a 20-m antenna provides an incident RF density of .04 mW/sq cm and the rectenna operates at an efficiency of 55%. Subarray size of approximately 3 m x 3 m is compatible with orbiter payload bay size constraints with reasonable packing efficiency.

The center subarray has 36 amplitrons (Figure 6-14) providing density of 21 kW/sq m, and the other 48 subarrays each have 4 amplitrons for a power density of approximately 2.1 kW/sq m simulating the central sections and edge sections of the ultimate MPTS. The high power density section will provide a thermal test of structure and waveguide integrity.

6.1.5.2 Configuration. The antenna structure is constructed completely of 3-m long rods, geometrically configured in octahedra and tetrahedra (oct-tet) form as shown in Figure 6-15. It is planned to be deployed to final size in a single operation. The antenna will be attached in the platform hole by a structure which permits it to pivot. The side of the antenna that will radiate power to earth is positioned to face the long side of the OCDA boom. Microwave elements (2.6-m x 3-m panels) are complete subassemblies consisting of waveguides, amplitrons and electrical power cables. Elements are mounted on the antenna in a patch work fashion as illustrated in the right hand corner of Figure 6-15 until the entire surface of the antenna is covered. Each element is positioned on the antenna structure by the boom cherry picker and attached to the structure by three alignment jacks.

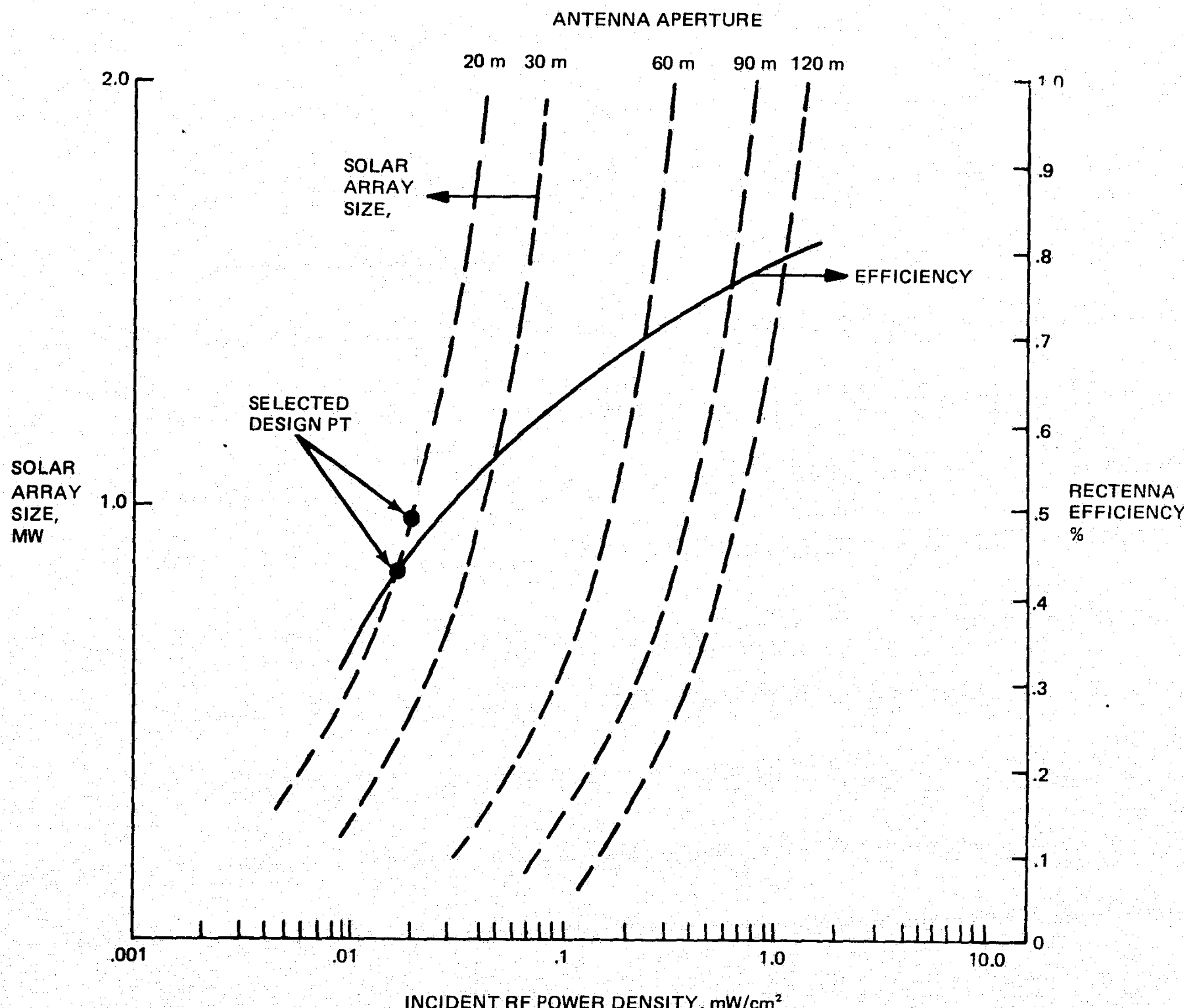


Figure 6-13 LEO (350 Km) SPS Demo SAT. Characteristics

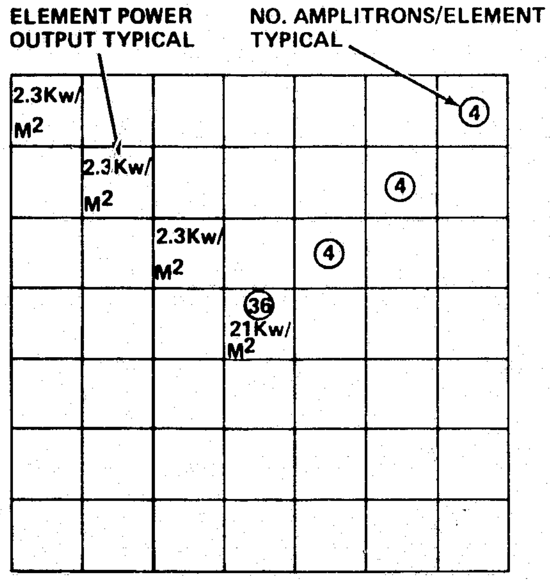


Figure 6-14 Antenna Element Output Power

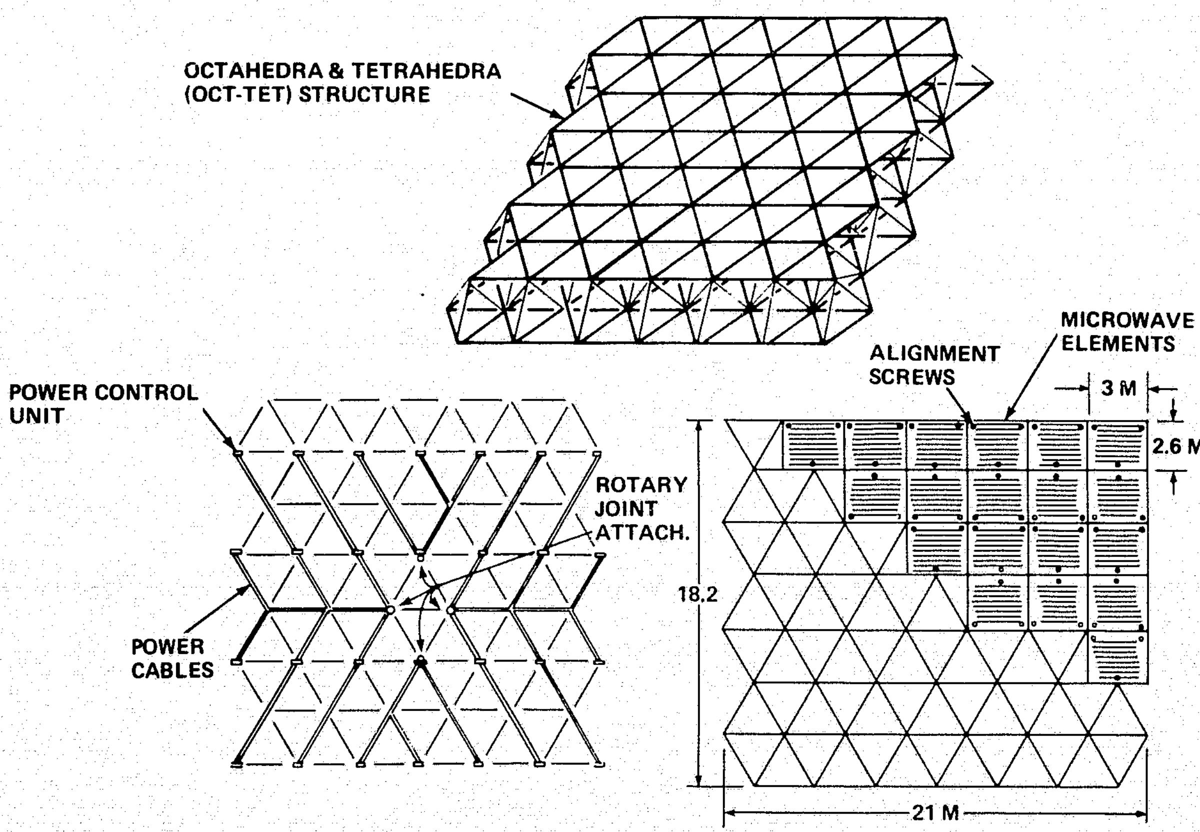


Figure 6-15 Antenna Configuration/Assembly

Now the antenna is rotated 180° and the power harness and control cables fastened to the opposite side to the rf elements. Power control units are also mounted on the structure and the electrical cables from the element panels are attached to the control units. The power harness and signal cables are also attached to the control units as shown in the lower left hand drawing of Figure 6-15. Power is provided to the alignment jacks so that the elements can be leveled to the required planarity. This antenna location is satisfactory for subsequent attachment of the ball joint, mast structure and antenna mass balance structure.

Table 6-13 contains a list of the mission peculiar equipment and the estimated mass for each item.

6.1.5.3 Construction Operations. Table 6-14 lists the functions and operations associated with assembly of the microwave antenna. Two Shuttle flights are required to complete the antenna. Two primary factors dictate Shuttle flight requirements. First, the volume needed to stack the 49 3-m x 3-m subarray element panels in the cargo bay and, secondly, the time necessary to install the panels, the power busses, and control wiring.

6.1.5.4 Orbital Tests. The microwave antenna test requirements are listed in Table 6-15. As indicated, the antenna size and power will be a scaled down version of the 5 GW reference configuration based on rectenna requirements. Other parameters, i.e., power, planarity and transponder RF characteristics will be the same as the reference design mission.

Construction and installation tests evaluation will be done on completion of the antenna assembly. Other tests that demonstrate complete antenna operation must await assembly of the solar collector.

Demonstration of power out on the ground rectenna, even for the short period of the microwave antenna overpass, will resolve the issues associated with the antenna operation. Some of the critical issues are:

- Subarray element alignment
- Power control and distribution
- RF wave front phase control
- Antenna thermal distortion.

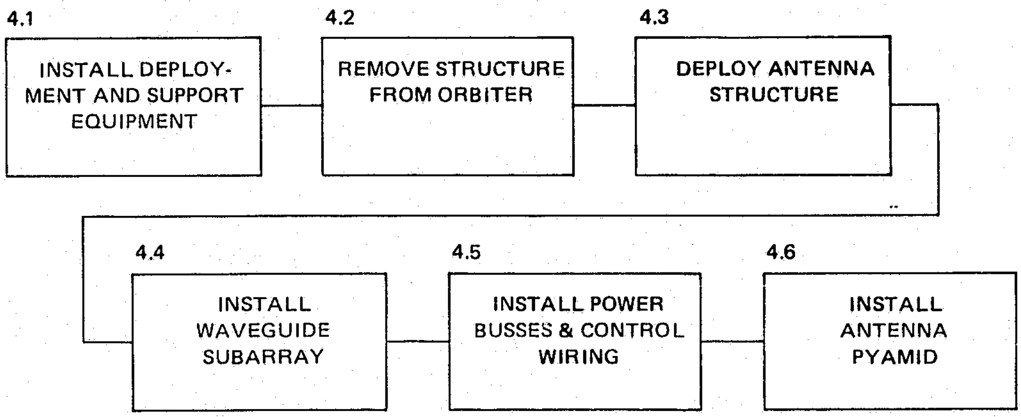
6.1.6 Mission 6 - Rotary Joint Installation

The rotary joints for the SPS must provide for transfer of power, as well as support for rotation of the solar array related to the antenna; mating operations are a critical issue because of their size and the environment. The proposed OCDA activity of mating a scaled

Table 6-13 Microwave Antenna Mass

ELEMENT	MASS	
	LB	KG
INTERFACE FIXTURES/JIGS	(69)	(20.5)
DEPLOYMENT FIXTURE	11	5
PIVOT SUPPORT (2)	48	11
SUPPORT EQUIPMENT SUBARRAY PICKUP TOOL	10	4.5
TRANSMIT ANTENNA	(23175)	(10521)
• PRIMARY STRUCTURE	40	18
• SUBARRAY/ELEMENT MEN INT.	2850	1294
• RF CONVERTERS	712	323
• PHASE CONTROL ELECT.	17365	7884
• POWER DISTRIBUTION	990	449
• WAVEGUIDES	1218	553
• ROTARY JOINT INTERFACE	—	—
TOTAL	23,244	10542

Table 6-14 Functional Operations Scenario – Function 4.0 Microwave Antenna Fabrication



TIME HR:MIN	OPERATIONS	REMARKS
(2:00)	INSTALL DEPLOYMENT AND SUPPORT EQUIPMENT	
:30	INSTALL DEPLOYMENT SUPPORT FIXTURE	
1:00	INSTALL STABILIZING PIVOT SUPPORT	2 FIXTURES
:15	PROVIDE WAVEGUIDE SUBARRAY LIFTING FIXTURE	
:15	PROVIDE POWER BUS/HARNESS INSTALLATION TOOL	
(:45)	REMOVE STRUCTURE FROM ORBITER	
:15	ATTACH BOOM MANIPULATOR TO STRUCTURE PKG.	
:15	LIFT CLEAR OF PAYLOAD BAY	
:15	TRANSPORT TO PLATFORM	
(1:00)	ANTENNA DEPLOYMENT	
:15	ATTACH STRUCTURE PACKAGE TO FIXTURE	7 m LONG
:15	DEPLOY ANTENNA & VERIFY LOCKS	
:30	ATTACH STABILIZING PIVOT SUPPORT	
(69:30)	INSTALL WAVEGUIDE SUBARRAY	
8:15	REMOVE PANELS IN SEQUENCE FROM ORBITER	17 PANELS FLIGHT 1
12:15	TRANSPORT PANELS TO ANTENNA	32 PANELS FLIGHT 2
24:30	POSITION PANELS AND INSTALL ALIGNMENT SCREWS	
12:15	COURSE ADJUST SUBARRAY	
12:15	FINE ALIGN PANEL PLANARITY	
(88:30)	INSTALL POWER BUSSES AND CONTROL WIRING	
:15	RELEASE DEPLOYMENT FIXTURE ATTACHMENT	
:30	ROTATE ANTENNA 180°	
:30	ATTACH DEPLOYMENT FIXTURE	
24:30	MOUNT POWER CONTROL BOXES	
24:30	CONNECT POWER CABLES	
16:00	DEPLOY POWER DISTRIBUTION BUS BARS	
	ATTACH BARS TO STRUCTURE	
2:00	WELD PRIMARY BUS SECTIONS TOGETHER	
12:15	CONNECT BUSSES TO CONTROL BOXES	
8:00	INSTALL CONTROL WIRING	
(4:00)	INSTALL ANTENNA PYRAMID	
2:00	MOUNT ANTENNA ATTACHMENT PYRAMID	
2:00	INSTALL POWER BUSSES & WELD	
165:45	TOTAL FOR CONSTRUCTION ~2 SHUTTLE FLIGHTS	

Table 6-15 Orbital Construction Experiment Definition - SPS Photovoltaic Development – Power Transmission

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
CONSTRUCTION OF MICROWAVE POWER ANTENNA, EMPHASIZE SUBASSEMBLY INSTALLATION.	• ANTENNA SIZE AND POWER COMPATIBLE WITH GROUND RECTENNA USEFUL POWER OUTPUT APERTURE 20 M POWER 1 MW • SUBARRAY POWER THE SAME AS REFERENCE SPS FOR THERMAL EVALUATION MAX POWER 21 KW/M² MIN POWER 2.1 KW/M² • SUBARRAY PLANARITY THE SAME AS REFERENCE SPS TBD • VERIFY RF COHERENT TRANSPONDING AND GROUND RECTENNA POWER OUTPUT TBD • START-UP AND SHUT-DOWN OF SUBARRAYS	VIDEO AND TIMING EQUIPMENT FOR VERIFYING CONSTRUCTION/INSTALLATION TIMES AND PROCEDURES. • STRUCTURE THERMAL RECORDING/MONITOR, -100° TO +500° F. • SUBARRAY POWER IN, VOLTAGE, CURRENT • RECTENNA RECEIVED POWER RECORDING. • SUBARRAY POWER OUTPUT	COMPLETE OPERATIONAL ANTENNA WILL HAVE NOT BEEN BUILT PREVIOUSLY. MUST VERIFY TECHNIQUE OF INSTALLING SUBARRAYS TO REQUIRED PLANARITY, POWER DISTRIBUTION SYSTEM AND CONTROL HARDWARE. EFFICIENCY OF POWER TRANSMISSION FROM ORBIT TO GROUND REQUIRES DEMONSTRATION FOR SPS DEVELOPMENT DECISION.

down SPS rotary joint will provide the verification data for one of the rotary joint concepts currently being considered. The rotary joint article is a scaled down version of the rotary joint included in the JSC report JSC 11568, "Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts - Volume II," dated 31 August 1976.

Similar to the antenna, all test requirements cannot be satisfied until the SPS pilot plant has been assembled. Assembly of the rotary joints to the support structure meets part of the requirements; however, transfer of high power must be deferred until a later mission.

6.1.6.1 Objectives and Requirements. The mission objectives are to demonstrate:

- Assembly of the rotary power transfer device
- Transfer high voltage and power.

The test requirements are to:

- Verify installation of the rotary joint for a 20-m microwave antenna
- Demonstrate operation of the rotary joint
- Demonstrate transfer of 1.3 MW of power at 20 kV
- Verify satisfactory operation in the thermal environment.

6.1.6.2 Configuration

The rotary joint geometry is configured for a 28.5° low earth orbit that is able to track a ground site while the pilot plant solar array is held perpendicular to the ecliptic. To achieve sufficient antenna pointing flexibility, the support mast was configured with a 38° dog leg (Figure 6-16) and two 360° rotary joints. The rotary joint located at the base of the dogleg structure rotates a full 360° approximately every 22 days while the ball joint at the antenna interface rotates 360° every orbit (approximately 90 minutes). A third degree of freedom, located at the ball joint provides an up-down motion of 9° to provide rectenna tracking when the satellite orbit does not pass directly over the ground site. The antenna ball joint is located 83 m from the solar array in order to provide a clearance between the beam and the solar array.

The installation consists of four major components:

- The Transition Structure - A tapered isosceles trapezoid between the solar array and the single axis rotary joint. It consists of four 1-m beams and cross braced cables.
- A Single Axis Rotary Joint - The bearings and slip ring assemblies are similar to the Ball Brothers ODAPT unit.

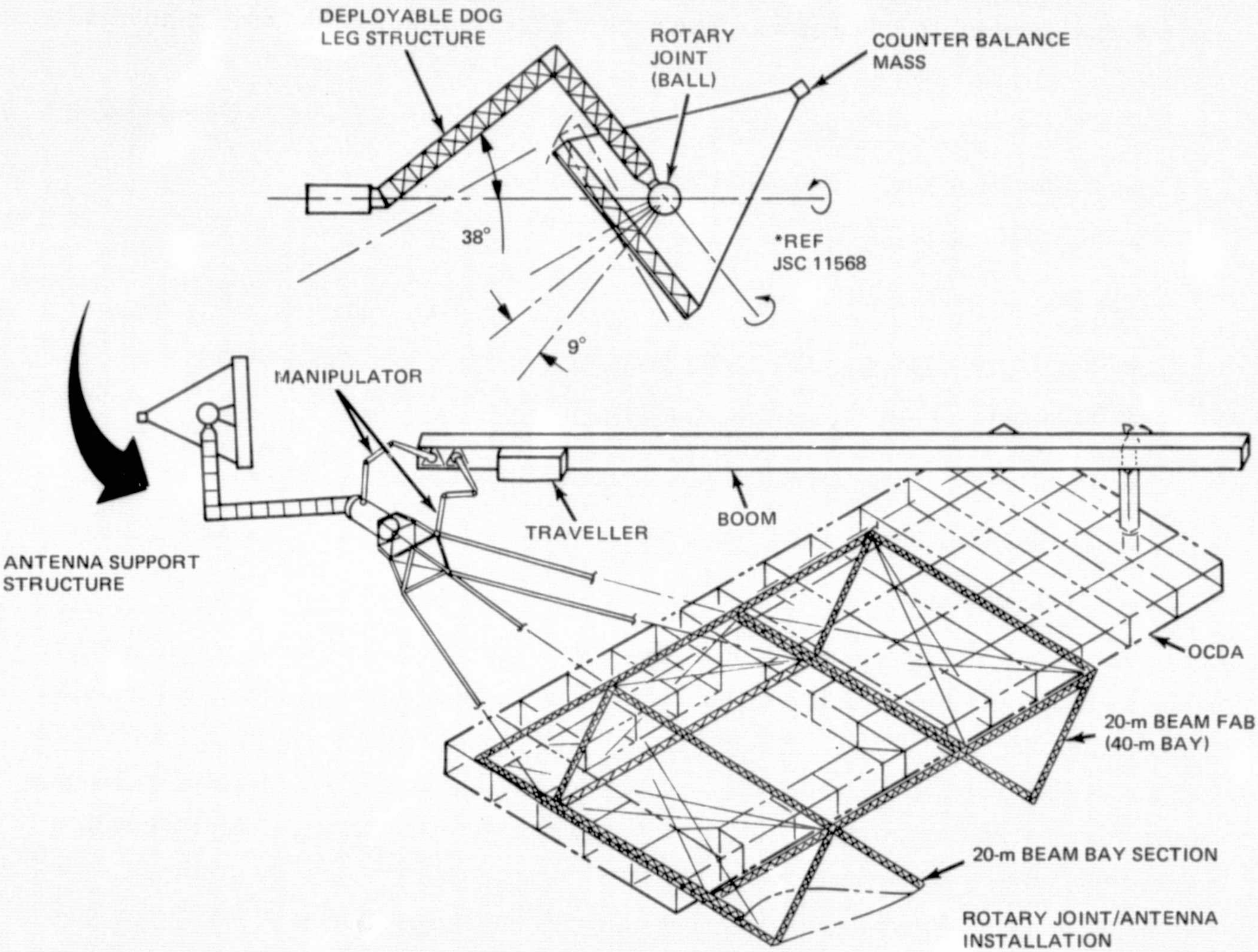


Figure 6-16 Antenna Attached to Solar Collector

- The Dogleg Structure - This consists of three deployable segments of 2-m square sections. The structural arrangement is similar to the OCDA boom structure.
- A Rotary Ball Joint - This concept is identified in NASA Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts. Report JSC 11568.

Figure 6-17 illustrates the subassembly of the two rotary joints and dogleg structure on the OCDA platform. Support fixtures are used to align the single axis rotary joint with the ball joint.

6.1.6.3 Construction Operations. The microwave antenna is mounted in the OCDA platform hole as illustrated in Figure 6-17 and discussed previously. This is a convenient location for installation of the ball joint and attachment of the dogleg structure.

Supporting fixtures are deployed and mounted at nodal points on the upper surface of the platform. The ball joint pyramid structure is attached to the antenna, and the ball joint is removed as a completed assembly from the orbiter and mounted on the pyramid structure. Next the dogleg structure is deployed, mounted on the platform fixtures and attached to the ball joint. Now the rotary joint assembly is located in a platform fixture and attached to the dogleg structure. Rotary joint transition support structure is deployed and attached to the rotary joint.

Electrical power cables are installed in the dogleg structure and attached to the ball joint and the rotary joint. Also, the antenna power cables are run on the pyramid structure and mechanically and electrically connected to the ball joint. Control cables are similarly installed in the structure and attached to the joints. Control cables route signals to the rotary joint actuators and to power control units on the antenna. Electrical resistance tests are implemented to assure the integrity of connections.

The last item to be assembled prior to removal of the antenna from the platform is the antenna counter balance mass. The support structure is deployed, and mounted on the back face of the antenna to form a pyramid as illustrated in Figure 6-16. The mass is then attached at the apex of the support structure.

The joints will be completely assembled and checked on the ground. Table 6-16 contains the operations required to assemble the rotary joints to their associated structure.

6.1.6.4 Orbital Tests. The rotary joints cannot be fully tested until the antenna is mounted on the solar collector as shown in Figure 6-16. Limited ball joint actuation tests

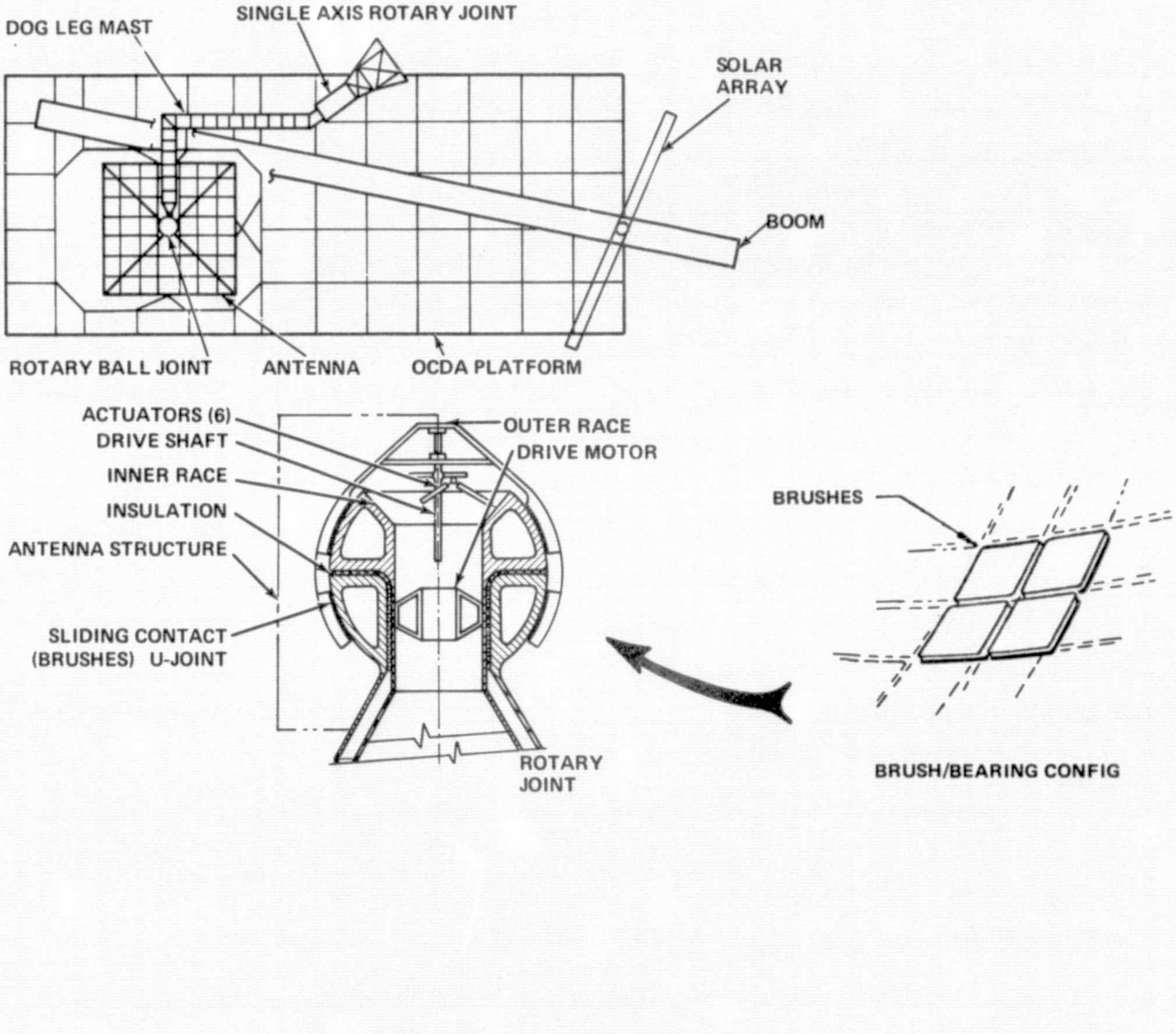
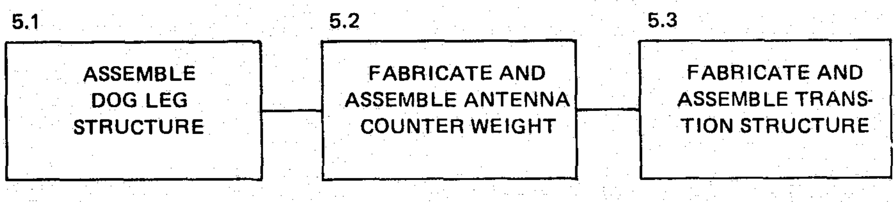


Figure 6-17 Rotary Joint Configuration/Assembly

Table 6-16 Functional Operations Scenario — Function 5.0 Rotary Joint Installation



TIME HR:MIN	OPERATIONS	REMARKS
(10:15)	ASSEMBLE DOG LEG STRUCTURE	
1:00	MOUNT DOG LEG ASSY FIXTURES TO PLATFORM (2)	
2:00	ALIGN FIXTURES	
:30	INSTALL SINGLE AXIS JOINT IN FIXTURE	
1:00	INSTALL BALL JOINT TO ANTENNA PYRAMID	
:45	DEPLOY DOG LEG STRUCTURE (3)	
3:00	INSTALL DOG LEG IN FIXTURE AND ATTACH TO JOINTS	
2:00	WELD CONDUCTORS TO BALL JOINT	
(4:30)	FABRICATE AND ASSEMBLE ANTENNA COUNTER WEIGHT	
1:00	MANUFACTURE FOUR BEAMS	
1:00	INSTALL ANTENNA ATTACHMENT FIXTURES	
2:00	ASSEMBLE BEAMS TO ANTENNA AND MASS INTERFACE	
:30	MOUNT COUNTER BALANCE MASS	
(3:00)	FABRICATE TRANSITION STRUCTURE	
1:00	MANUFACTURE FOUR BEAMS	
2:00	ASSEMBLE BEAMS TO ROTARY JOINT AND POSITION WITH JURY STRUTS	BOOM RMS
17:45	TOTAL FOR CONSTRUCTION ~1 SHUTTLE FLIGHT	

could be done by releasing the antenna platform attachments and provide power temporarily to the actuators. Also, limited power transfer tests could be accomplished by utilizing OCDA power.

Table 6-17 provides the rotary joint test requirements. The primary concern is the mechanical fit of the parts as a result of the loads imposed by the solar array and or the antenna, plus the effect of the thermal environment on the mechanical fit. The ability of the brushes to transfer power without creating local heating problems is also a concern. Option 2 of Table 6-18 was chosen because with the available current (45 amps) it should provide the desired .78 amps/sq cm with approximately 1/2 scaled brush cross sectional area based on the design reference point.

The critical issues addressed by these tests are:

- High power and voltage transfer across rotating brushes
- Low joint friction forces.

Table 6-19 is a list of the mission peculiar equipment and the estimated mass for each item.

6.1.7 Mission 7 - Solar Collector Construction

The solar collection, conversion and distribution system is one of the technology areas that is critical to the development of a viable SPS. The tests of the 2-MW solar array discussed in this section will provide one of the essential data verification points in the overall SPS program. The solar array chosen for this mission activity is patterned after the 5-GW photovoltaic system described in report NAS 8-31308 having an overall size of 13.1 km x 4.9 km, a concentration ratio of 2:1 and a primary structure made up to 20-m beam elements. The 2-MW pilot plant is 369 m x 69 m, has a concentration ratio of 2:1 and utilizes 20-m beam elements for its primary structure.

6.1.7.1 Objectives and Requirements. The solar collector requirements are driven by the output needs of the microwave antenna. The equipment efficiency chain shown in Figure 6-18 illustrates that for an antenna output of 1 MW the solar collector must generate 2 MW of power.

The construction should duplicate as many operations as possible that are planned for the full scale SPS. Also, if possible, the same hardware should be used to maximize benefits for subsequent work.

Table 6-17 Orbital Construction Experiment Definition – SPS Photovoltaic Development – Power Distribution

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
INSTALL ROTARY POWER TRANSFER DEVICE · INSTALL ROTARY JOINT FOR 1 MW SPS PILOT FACILITY	1. VERIFY INSTALLATION OF ROTARY JOINT FOR ~1 MW SPS AND 60 m ANTENNA INSTALLATION REQUIREMENT INSTALLATION AND VISUAL INSP 2 HRS 2. VERIFY OPERATION OF BALL JOINT DRIVE AND SUSPENSION SYSTEM REQUIREMENT ROTATION 15°/HR + .5°/MIN ELEVATION ±10 3. VERIFY POWER TRANSFER REQUIREMENT DISTRIBUTION SYSTEM 20 KV 7.75 A/cm² PER BRUSH 4. VERIFY TEMPERATURE DISTRIBUTION AND VARATIONS DURING OPERATION IN LEO ENVIRONMENT REQUIREMENT TEMP VARIATIONS -50° TO -200°F MEASURE TEMP OF DRIVE MECHANISM OUTER RACE INNER RACE BRUSHES	• VIDEO AND TIMING EQUIPMENT FOR VERIFYING INSTALLATION PROCEDURES AND TIMES • BALL JOINT DRIVE AND BALL JOINT INSTRUMENTATION FOR MEASURING BALL JOINT DRIVE SERVO-OPERATION, ANTENNA ROTATION, TEMPERATURES OF BALL JOINT BRUSHES, SERVOS STRUCTURE ETC. • TELEMETRY SYSTEM	THE OBJECTIVE OF THIS TEST IS TO INSTALL A ROTARY JOINT ASSEMBLY ON THE SPS SOLAR ARRAY AND THE 60 m ANTENNA TO EVALUATE THE POTENTIAL PROBLEMS ASSOCIATED WITH THE INSTALLATION OF CLOSE TOLERANCE ASSEMBLIES. OF SPECIAL INTEREST WILL BE THE PERFORMANCE DURING THE VARIATION IN THE LEO THERMAL ENVIRONMENT, I.E., BINDING, JITTER ABNORMAL HEATING AND POWER TRANSFER. THIS TEST WILL BE PERFORMED AFTER GROUND TESTS HAVE DEFINED THE NORMAL OPERATING PARAMETERS AND MEASURED THE OUTGASSING CHARACTERISTICS OF THE MATERIALS USED ESPECIALLY FOR THE BRUSHES.

Table 6-18 Solar Array Rotary Joint Test Requirements

SOLAR ARRAY ROTARY JOINT DESIGN PARAMETERS	5 GW SPS NOMINAL DESIGN	OCDA 1 MW ARRAY TEST REQUIREMENTS	
		OPTION 1	OPTION 2
ROTARY BALL JOINT OUTER DIAMETER	7.6 mD	3 mD	3 mD
POWER TRANSFER REQUIREMENT	40 KV 250 KA	20 KV 45 A	20 KV 45 A
CONDUCTOR RESISTANCE	2.9×10^{-8} /m AL	TBD	TBD
LOSS	1824 W/m	TBD	TBD
BRUSHES			
• NUMBER	5000	10*	2*
• CROSS SECTIONAL AREA	64.5 cm^2	5.77 cm^2	29 cm^2
• CURRENT DENSITY	.78 A/cm^2	.78	.78
ROTATION	15°/HR	15°/HR	15°/HR
ELEVATION	10° (±1 ARC SEC)	±10°	±10°

*NUMBER OF CONDUCTING BRUSHES

OPTION 2 RECOMMEND FOR TEST

Table 6-19 Rotary Joint Mass

ELEMENT	MASS	
	LB	KG
• INTERFACE FIXTURES/JIGS		
ROTARY JOINT DOS LEG LEG TO PLATFORM FIXTURE	420	191
• ROTARY JOINT/MAST	(12,807)	(5814)
– ROTARY JOINT (ODAPT)	2100	952
– BALL JOINT	3150	1430
– MAST STRUCTURE (DOG LEG)	1070	485
– MAST STRUCTURE TRANSITION	615	279
– POWER DISTRIBUTION	5872	2665
• SUPPORT EQUIPMENT		
– CABLE TENSION DEVICES	N/A	N/A
– ALIGNMENT OPTICS		
TOTAL	13,227	6,005

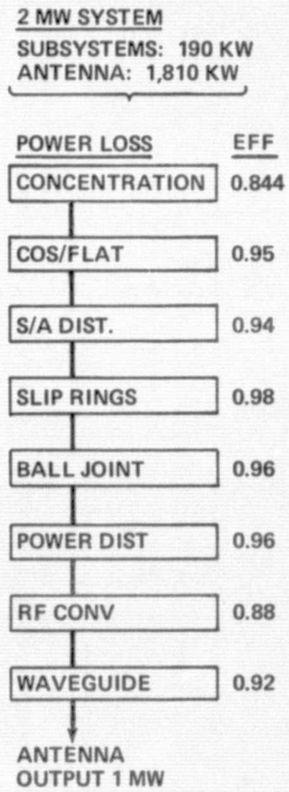


Figure 6-18 Solar Collector Power Required

The mission objective is to demonstrate the construction of a photovoltaic solar collector, with a concentration ratio 2:1 providing 2 MW at 20 kV.

The test requirements are:

- Fabrication and assembly of a concentrator utilizing 20-m beams
- Verification of installation procedures for solar blankets and concentration reflectors
- Verification of collector output of 2 MW at 20 kV
- Verify power distribution system efficiency of 94%.

6.1.7.2 Configuration. Part of the construction equipment shown in Figure 6-19 was assembled for fabricating the 20-m beam. It is necessary to extend the length of the OCDA platform to accommodate the beam return guide fixture that is used to support the beam fabricated in the 20-m beam fab module previously installed. Note that the beam return guide fixture does not house fabrication modules. Lateral structure is installed that ties the two fixtures together. Modules are mounted that will be used to dispense the solar reflectors and solar cell blankets. A seventh beam fabrication module is added to the assembly fixture to produce the knit structure while the existing six fabrication modules are to produce the beam.

6.1.7.3 Construction Operations. During assembly operations, the boom traveller is used for transporting material from the orbiter payload bay to the boom mounted cherry picker. This cherry picker services the fabrication and conductor modules adjacent to the platform and hands over material to the track mounted cherry pickers for servicing the other fabrication modules. The track cherry pickers will be in constant use during assembly of the solar collector. They will connect the solar blanket electrical cables to the main power line conductors and monitor the fabrication module output.

The assembly operations duplicate many of those planned for the full size photovoltaic SPS. Construction will continue at an average rate of 1 ft/min. until the 369-m long solar collector is completed.

Table 6-20 contains the operations required to assemble the solar collector.

6.1.7.4 Orbital Tests. The construction of the solar collector will resolve many important development issues associated with building a full size SPS. Measurements of full power capability of the solar collector will be done after the Pilot Plant has separated from the OCDA; however, partial output power could be obtained during solar collector construction by changing the OCDA attitude to verify integrity of electrical circuits. The test

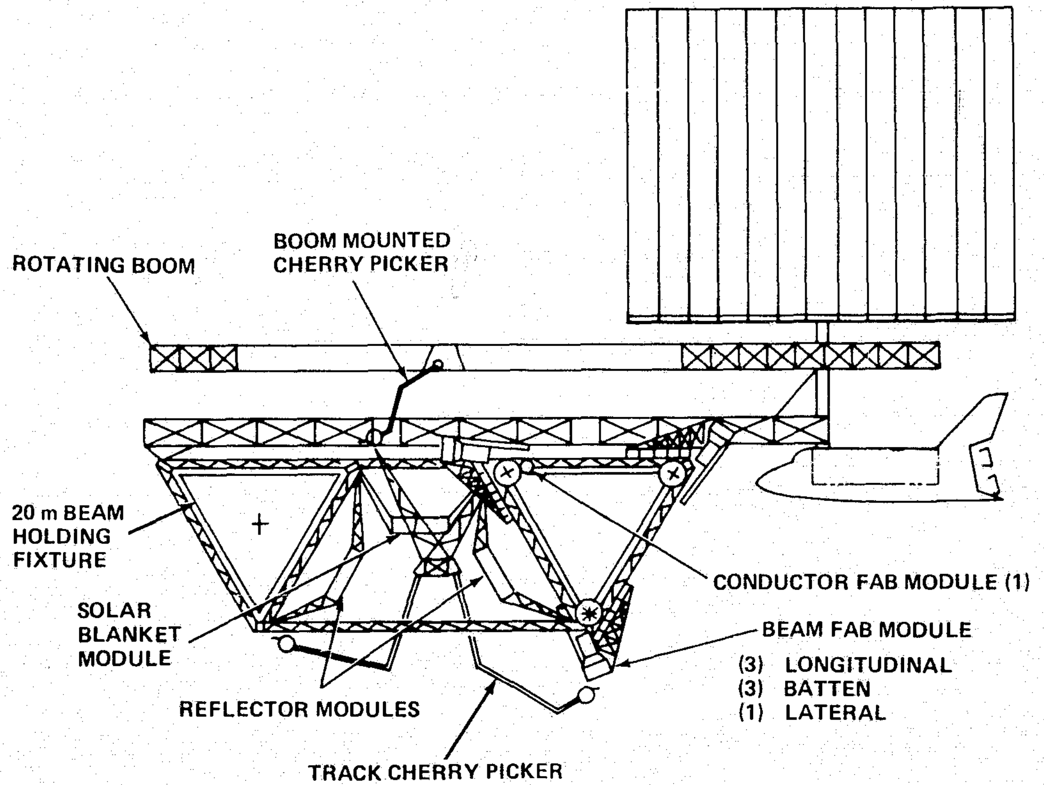
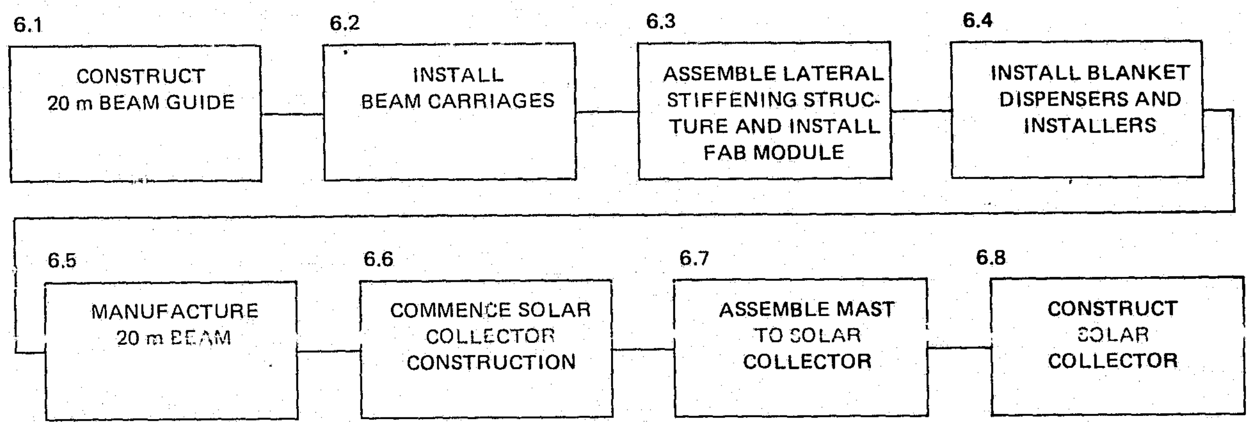


Figure 6-19 Solar Collector Configuration/Assembly

Table 6-20 Functional Operations Scenario – Function 6.0 2 MW Solar Array Fabrication



TIME HR:MIN	OPERATIONS	REMARKS
(17:30)	CONSTRUCT 20 m BEAM GUIDE	
3:00	INSTALL FRAME ATTACHMENT SUPPORTS (6)	BOOM RMS AND TRACK RMS
1:30	INSTALL A FRAME ASSY JIG ON PLATFORM	
2:15	DEPLOY A FRAME BEAMS (9)	
1:30	ASSEMBLE A FRAMES (3)	
3:00	REMOVE A FRAMES FROM JIG AND ATTACH TO SUPPORT (3)	
1:30	DEPLOY LONGERONS (6)	
3:00	ATTACH LONGERONS TO A FRAMES (6)	
1:00	INSTALL STIFFENING STAYS (12)	
(21:00)	INSTALL BEAM CARRIAGE	
6:00	MOUNT CARRIAGE SUPPORT STRUCTURE	
6:00	INSTALL CARRIAGE TRACKS (18)	
3:00	INSTALL BEAM CARRIAGES (6)	
(4:15)	ASSEMBLE LATERAL STIFFENING STRUCTURE & INSTALL FAB MOD.	
:45	DEPLOY LATERAL STIFFENING BEAMS (3)	
1:30	INSTALL BEAMS BETWEEN FABRICATION & GUIDE RETURN FIXTURES	TRACK RMS
1:00	MOUNT FAB. MODULE SUPPORT STRUCTURE	
1:00	INSTALL FAB. MODULE AND ALIGN	
(8:30)	INSTALL BLANKET DISPENSERS AND INSTALLERS	
1:00	MOUNT SOLAR BLANKET DISPENSER ATTACHMENT	
2:00	MOUNT REFLECTOR BLANKET DISPENSERS ATTACHMENT	
3:00	INSTALL DISPENSERS (3)	
3:00	MOUNT BLANKET INSTALLER ATTACHMENT SUPPORTS (6)	
1:30	INSTALL BLANKET INSTALLERS & CONNECT POWER	
(24:15)	MANUFACTURE 20 m BEAM	
6:00	LOAD FABRICATION MODULES (8)	1 FLIGHT
8:30	MANUFACTURE 20 m BEAM	1 m/MIN.
1:45	INSTALL END FITTING	
2:00	REMOVE BEAM AND MANEUVER TO GUIDE RETURN	BOOM RMS
6:00	FEED BEAM INTO GUIDE RETURN AND TRANSLATE	1 m/MIN.
(2:00)	COMMENCE SOLAR COLLECTOR CONSTRUCTION	
1:00	FAB. BEAM STUB AND LATERAL STICH BEAMS	
1:00	INSTALL STICH BEAMS AND STAYS	

Table 6-20 Functional Operations Scenario – Function 6.0 2 MW Solar Array Fabrication (Continued)

TIME HR:MIN	OPERATIONS	REMARKS
(5:15)	ASSEMBLE MAST TO SOLAR COLLECTOR	
:15	SUPPORT ANTENNA MAST	BOOM RMS
:15	RELEASE DOG LEG ASSY FIXTURES	
:15	RELEASE ANTENNA DEPLOYMENT AND PIVOT FIXTURES	
2:00	MANEUVER ANTENNA OUT OF HOLE AND ALIGN ANTENNA MAST TO SOLAR COLLECTOR STRUCTURE	BOOM RMS
2:00	ATTACH TRANSITION BEAMS TO SOLAR COLLECTOR	
:30	WELD CONDUCTORS TO ROTARY JOINT AND COLLECTOR	
(48:00)	CONSTRUCT SOLAR COLLECTOR	
6:00	LOAD FABRICATION MODULES (8)	
2:00	COMMENCE BLANKET FEED, FASTEN BLANKET END	TRACK RMS
12:00	BUILD 20 m BEAM, PARALLEL FEED COMPLETED BEAM AND INSTALL LATERAL STIFFENING STRUCTURE	
1:45	AT COMPLETION OF SOLAR COLLECTOR INSTALL BEAM END	
2:00	FITTING	
2:00	ASSEMBLE SUBSYSTEM SUPPORT STRUCTURE	
24:00	INSTALL SUBSYSTEMS & CHECKOUT	
:15	RELEASE DEMO SPS FROM OCDA	
130:45	TOTAL FOR CONSTRUCTION + TEST TIME REQUIRED ~3 SHUTTLE FLIGHTS	

requirements listed in Table 6-21 verify the installation and the performance of the solar array. The solar array will be coupled to the transmitting antenna utilizing the structures and rotary joint discussed previously.

The critical issues resolved by these tests are:

- Generation and distribution of 2 MW of power at 20 kV
- Verification of solar blanket and concentrator reflector flatness.

Table 6-22 is a list of the mission peculiar equipments and the estimated mass for each item.

6.1.8 Mission Operations Summary

This section summarizes those elements which are common to the various experiments described in previous sections. These include support equipment, electrical power, manpower and accomplishments. Together with the discussion of the individual missions contained in the preceding pages, they provide a comprehensive data base on candidate experiment concepts required to verify critical issues associated with photovoltaic SPS systems.

6.1.8.1 Equipment Mass. The total mass of the equipment required for each of the OCDA follow-on missions for Scenario 1 are listed in Table 6-23. The highest mass (21,318 kg) is required for Mission 3 beam fabrication. This mass does not exceed the orbiter capability for a single flight; however, due to volume limitations, four flights are required.

6.1.8.2 Electric Power. Power requirements for Program 1 are established by the needs of construction or test activities of the missions. Some test activities are actually construction operations (e.g., producing beams after the assembly fixture has been built). The preparation for implementing tests was found to require much less power than the test. Two tests that needed the highest power were analyzed to establish solar array requirements.

Figure 6-20 shows the power transmission efficiency chain for all of the major equipment for Mission 2, linear array tests. A listing of the power required to provide an rf output of 115 kW shows that the solar array must generate 289.9 kW. Table 6-21 lists the power needs for Mission 7, solar collector assembly. The solar array power required for an assembly of 1 ft/min. is 219.8 kW, and at 5 ft/min. is 305.9 kW. If the lower assembly rate is established, then the linear array tests requirements of 289.9 kW size the solar array for Program 1.

6.1.8.3 Manpower. Table 6-24 shows the manhours needed for construction and testing associated with each of the Program 1 missions. The number of Shuttle flights associated with each mission is also listed. The assembly of the antenna takes as many manhours (500) as basic OCDA construction. Many hours are associated with the installation of power

Table 6-21 Orbital Construction Experiment Definition - SPS Photovoltaic Development — Solar Array

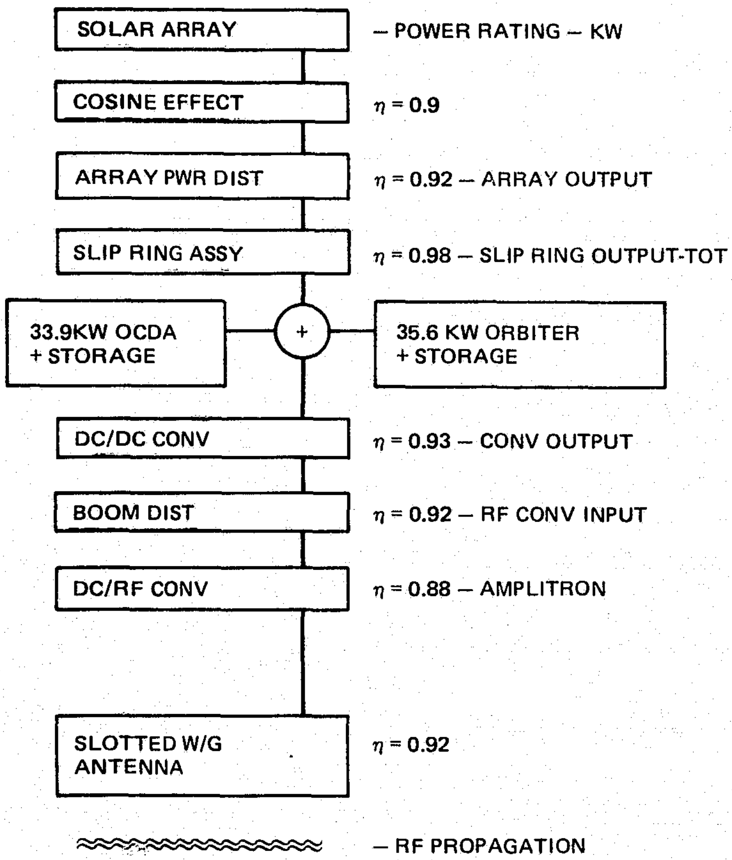
DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
ARRAY TO STRUCTURE INSTALLATION - INSTALL SOLAR ARRAY CONFIGURATION CAPABLE OF DELIVERING 1 MW	1. VERIFY INSTALLATION OF SOLAR ARRAY BLANKET ROLLS AND CONCENTRATOR REFLECTOR ROLLS ON PRIMARY STRUCTURE REQUIREMENT: SOLAR ARRAY AND CONCENTRATOR BLANKET INSTALLATION TO BE SYNCHRONIZED WITH 20 M BEAM FABRICATION 2. SOLAR ARRAY CIRCUIT PROTECTION AND DISTRIBUTION SYSTEM INSTALLATION AND OPERATION TO BE VERIFIED REQUIREMENT: 1 MW @ 20 MVDC, 50 AMPS REQUIRED @ SOLAR ARRAY SLIP RING TRANSFER; REGULATION 5 PERCENT 3. VERIFY THE EFFICIENCY OF THE SOLAR ARRAY DISTRIBUTION SYSTEM REQUIREMENT: η = 90% (FROM SOLAR ARRAY OUTPUT TO SLIP RING OUTPUT)	VIDEO EQUIPMENT FOR RECORDING AND TIMING SOLAR ARRAY CONFIGURATION INSTALLATION VOLTAGE AND CURRENT PICKUPS TO MEASURE THESE PARAMETERS FOR THE SOLAR ARRAY DISTRIBUTION, AND SLIP RING TRANSFER POINTS AS WELL AS VOLTAGE REGULATOR PERFORMANCE TELEMETRY AND DATA MANAGEMENT SYSTEM MOTOR GENERATOR LOAD BANKS	THE OBJECTIVE OF THIS MISSION IS TO VERIFY THE ABILITY TO SYNCHRONIZE THE SOLAR ARRAY AND REFLECTOR BLANKETS INSTALLATION WITH THE FABRICATION OF THE 20 METER BEAMS. THIS EXPERIMENT WILL INCLUDE THE VERIFICATION OF THE INSTALLATION AND PERFORMANCE OF THE POWER DISTRIBUTION SYSTEM AS WELL AS THE POWER OUTPUT OF THE SOLAR ARRAY SYSTEM MEASURED AT THE OUTPUT SLIP RING.

Table 6-22 Solar Collector Mass

ELEMENT	MASS LB	MASS KG
FRAME ASSEMBLY		
• HOLDING FIXTURE AND EXT STRUCT.	1908	865
• CARRIAGE	300	135
SUPPORT EQUIPMENT	(6574)	(2982)
• FAB MODULE (1)	5500	2495
• SOLAR BLANKET MOD. (1)	100	45
• CONCENTRATOR MOD. (2)	164	74.4
• CABLE RIGGER (3)	300	135
• PRETENSION DEVICE (3)	60	27
• SOLAR/CONCENTRATE BURNER INSTALLER (6)	450	205
SOLAR ARRAY	(26,361)	(11,957)
• STRUCTURE MECH	8200	3722
• SOLAR CELL BLANKET	14785	6712
• CONCENTRATOR BLANKET	3380	1534
TOTAL	35,143	15,939

Table 6-23 Program 1 Mass Estimate

MISSION	ELEMENT	MASS LB	MASS KG
2-MW LINEAR ARRAY		(19277)	(8751)
	CHERRY PICKER	4807	2182
	AMPLITRON EXPERIMENT	12,278	5574
	FREE FLYER	2192	905
	OPS (1 FLT)		
3-20 m BEAM FAB		(46957)	(21318)
	FRAME ASSEMBLY	3657	1660
	FAB MODULES	33,000	14,982
	CREW WORK MODULE	6000	2724
	MATERIAL	4300	1952
	OPS (5 FLTS) (VOLUME LIMITED)		
4-CONDUCTOR INSTALLA-TION		(2650)	(1203)
	FRAME ASSEMBLY DELTA	220	100
	COND'TR FAB MODULE	2200	999
	SUPPORT EQUIPMENT	230	104
	OPS (1 FLT)		
5-MICROWAVE ANTENNA ASSEMBLY		(23254)	(10547)
	INTERFACE FIXTURES	69	21
	SUPPORT EQUIPMENT	10	5
	TRANSMIT ANTENNA	23175	10521
	OPS (2 FLT) (VOLUME LIMITED)		
6-ROTARY JOINT ASSEMBLY/ INSTALLA-TION		(13227)	(6005)
	INTERFACE FIXTURES/JIGS	420	191
	ROTARY JOINT/MAST	12,807	5814
	SUPPORT EQUIPMENT		
	OPS (1 FLT)		
7-SOLAR ARRAY FAB		(35147)	(15956)
	FRAME ASSEMBLY	2208	1002
	SUPPORT EQUIPMENTS	6574	2984
	SOLAR ARRAY	26,365	11,969
	OPS (3 FLTS)		
8-SUBSYSTEM INSTALLATION	TBD	TBD	TBD



POWER, KW	
AMPLITRON CONTROL	
CASCADE	PHASE
251.4	289.8
226.2	260.8
208.1	239.9
203.9	235.1
125.0	154.0
115.0	142.0
101.3	125.0
93.0	115.0

Figure 6-20 Mission 2 Power Requirement, Linear Array Test

Table 6-24 Operations Summary

MISSION	CONST MAN HOURS	EXP MAN HOURS	SHUTTLE FLIGHTS
1. OCDA	500	–	3
2. LINEAR WAVEGUIDE ASSEMBLY	190	90	1
3. BEAM FABRICATION	230	150	4
4. CONDUCTOR INSTALLATION	30	30	1
5. ANTENNA ASSEMBLY	500	100	2
6. ROTARY JOINT ASSEMBLY	55	30	1
7. SOLAR COLLECTOR ASSEMBLY	400	100	3
8. SUBSYSTEM INSTALLATION	TBD	TBD	TBD
		TOTAL	15

busses and control wiring. Mission 3, beam fabrication, takes the most Shuttle flights (4). This is not due to time in orbit needs, but cargo bay limitation. Material to build the assembly fixture, cherry pickers and fabrication modules require transportation to orbit for this mission.

6.1.8.4 Objectives Accomplished. Each of the proposed experimental missions has been examined relative to the baseline demonstration objectives.

In addition to assessing the demonstration test objectives met by the initial deployment of the OCDA the extent to which the proposed follow-on tests or activities demonstrate the stated objective are also analyzed. Table 6-25, the Mission Suitability Matrix, summarizes the results of this analysis. Engineering judgment was used to determine the extent to which the demonstration objectives are met by the individual missions. The OCDA accomplished 29 out of 76 or 38% of the objectives. The 29 figure is obtained by adding the partial and full compliance. For example, the structures technical area have a total of 8 compliances out of a possible eleven objectives.

6.2 PROGRAM SCENARIO 2 - SPS ELEMENT TESTING

Program Scenario 2 emphasizes SPS development through element testing. Figure 6-21 illustrates the specific activities (missions) designed to provide SPS technology advancement. The element testing included in the missions identified in Figure 6-21 will verify the critical technological issues associated with construction, collection and rf propagation. The element testing approach provides a low cost step-by-step verification of fundamental technical issues before committing to development of a sizeable SPS pilot plant (in the 50 to 100 MW).

6.2.1 Mission 1-OCDA Placement

Mission 1, consisting of three flights, is used to assemble and prepare the orbital construction facility for the testing that follows. The operations required on each of the three flights to achieve operational readiness are discussed in Section 3. Section 3 also discusses the technology objectives demonstrated during the erection and check-out of the OCDA.

6.2.2 Mission 2-Microwave Linear Array

Since the ability to precisely aim and transmit the solar power satellite microwave energy to a receiving rectenna is a key issue in the development of solar power, the microwave linear array antenna was selected for the first of the element tests.

Table 6-25 Program 1 Mission Suitability Correlation Matrix

PROBLEM AREA	DEMO/TEST OBJECTIVE FOR PROGRAM SCENARIO 1	DEMO NEED WT.	MISSION SUITABILITY / MISSION 1	2	3	4	5	6	7	8	% OBJ MET
STRUCTURES	1) BUILDING BLOCK STRUCT FAB AND/OR DEPLOY	6	50		75				100		75
	2) JOINT ASSEMBLY PROCEDURES	8	75		100				100		100
	3) MAN/MACHINE/INTERACTION	8	50		75				100		75
	4) LARGE ELEMENT MATING	9	75		0				75		75
	5) SECONDARY STRUCTURE INSTALLATION	8	50	75	75				100		100
	6) MEASURE PRODUCTIVITY	6	50		100				100		100
	7) ATTITUDE CONTROL DURING CONSTRUCTION	7	100		100				100		100
	8) THERMAL CYCLING DURING CONSTRUCTION	6	100	75	100				100		100
	9) ACCURACY & INTEGRITY TESTS	8	50	75	100				100		100
	10) STRUCTURAL REPAIR	7	50		50				50		50
	11) STRUCTURE/CONTROL/INTERACTION	7	75	75	50				75		75
SOLAR ARRAY	1) CONSTRUCTION & DEPLOYMENT	8	25						100		100
	2) LOW COST, HIGH EFFICIENT SPACE FAB BLANKET	8	0						0		0
	3) ARRAY TO STRUCT INSTALLATION	7	25						100		100
	4) CONCENTRATOR INSTALLATION	7	0						100		100
	5) THERMAL CYCLE	6	50						100		100
	6) FAULT ISOLATION & REPAIR	7	50						50		50
POWER DISTRIBUTION	1) INSTALL INTEGRATED STRUCTURE/BUS SYSTEM	5	75			75		100	100		100
	2) INSTALL DEDICATED SYSTEM WITH SWITCH GEAR & CIRCUIT PROTECTION	5	100			50		50	100		100
	3) INSTALL STORAGE SYSTEM	5	100			0		0	100		100
	4) INSTALL POWER CONDITIONING UNITS	7	100			0		0	100	100	100
	5) INSTALL ROTARY POWER TRANSFER DEVICE	8	75			0		100	75		100
	6) HI VOLTAGE OPERATION	8	0			100		100	0		100
	7) LEAKAGE PREDICTION	7	25			75		75	0		75
	8) FAULT ISOLATION & REPAIR	7	50			75		75	100		100
POWER TRANSMISSION	1) DC TO RF CONVERSION IN STEPS	8	0	50			75		100		100
	2) INTEGRATED PROOF OF CONCEPT	10	0	50			100		100		100
	3) THERMAL CYCLING TESTS ON WAVE GUIDES & PHASE CONTROL	6	0	100			100		75		100
	4) IONOSPHERE TESTS	4	0	0			0		25		25
	5) GEO PERFORMANCE (HI VOLTAGE & START)	8	0	0			0		0		0
	6) LIFE TESTS	4	0	0			0		0		0
	7) DEMO TRANSMISSION TO GROUND	8	0	25			100		100		100
PROPULSION	1) INSTALL PROPULSION UNIT FOR ATTITUDE CONTROL & STATION KEEPING	7	100						75	100	100
	2) VERIFY EFFECTS OF EXHAUST PRODUCTS	3	50						75	100	100
	3) FAULT ISOLATION & REPAIR	5	50						50	100	100
STABILIZATION & CONTROL	1) CONTROL OF LARGE FLEXIBLE BODIES USING CENTRALIZED & DISTRIBUTED SYSTEMS	7	50						75	100	100
	2) SURFACE CONTOUR CONTROL	8	0				100		0		100
	3) POINT 1 LARGE MASS RELATIVE TO 2ND	7	25				100		50	100	100
	4) STATIONKEEPING	7	100						100	100	100
	5) FAULT ISOLATION & REPAIR	5	50						50	100	100
REFLECTOR MIRROR FACETS	1) PLACEMENT & INSTALLATION	8	0								
	2) POINTING & CONTROL ON FLEXIBLE BODY	8	0								
	3) FAULT ISOLATION & REPAIR	5	0								
RADIATORS	1) POSITIONING & ASSEMBLY OF RADIATOR ELEMENTS	8	0								
	2) CONSTRUCT GAS TIGHT JOINTS	6	0								
	3) FAULT ISOLATION & REPAIR	4	0								
THERMAL CAVITY	1) POSITIONING & ASSEMBLY	8	0								
	2) GAS TIGHT JOINTS	6	0								
	3) CAVITY PERFORMANCE THROUGH CONSTRUCTION	8	0								
	4) CONTROL WITH ROTATING MACHINERY	8	0								
LARGE MIRROR SURFACE	1) POSITIONING & ASSEMBLY	8	0								
	2) CONTOUR CONTROL	8	0								
	3) EFFICIENCY MEASUREMENT	5	0								
	4) LIFE TESTING	4	0								
ASSEMBLY OPERATIONS	1) INITIAL PLACEMENT OF CONSTRUCTION PLATFORM	8	100	0	0	0	0	0	0		100
	2) SITE LOGISTICS	7	50	75	75	75	75	75	75	75	75
	3) RESUPPLY & STORAGE	6	50	100	100	100	100	100	100	100	100
	4) HABITATION	4	0	0	0	0	0	0	0	0	0
	5) SITE COMMUNICATIONS	5	100	50	50	50	50	50	75	75	100
	6) SITE LIGHTING	5	100	100	100	100	100	100	100	100	100
	7) RADIATION SAFETY (GEO)	6	0	0	0	0	0	0	0	0	0
	8) PRODUCTIVITY GOALS	8	50	50	75	75	75	50	75	75	75
	9) REMOTE CONTROLLED MANIPULATORS	7	75	75	75	25	25	50	75	75	75
	10) SPARE FABRICATION (AUTO ASSEMBLY)	8	0	0	100	25	25	0	75		100
	11) USE OF EVA	6	75	50	50	25	25	50	50		100
	12) FAULT ISOLATION & REPAIR OF CONSTRUCTION EQUIPMENTS	6	75	75	75	75	75	75	75	75	75
PROCESSES	1) FASTENER OPTIONS (WELD, BOND, ETC)	7	50	25	50	50	0	25	75		75
	2) FAB IN METALLICS & NON METALLICS	6	25	0	100	50	0	0	50		100
	3) VAPOR DEPOSITION FOR REPAIR	8	0	0	0	0	0	0	0		0
MISSION OPS	1) COMMUNICATIONS	5	50	100	100	100	100	100	100	100	100
	2) REMOTE CONTROL FROM GROUND	8	25	0	0	0	75	0	50		75
	3) MISSION PLANNING	4	50	25	25	25	75	25	50		75
ANTENNAS	1) RIB STRUCTURE FABRICATION	6	0	0	0						
	2) ACTIVE CONTOUR CONTROL	8	0	0	0						
	3) WIRING INSTALLATION	5	0	0	0						
	4) LENS PANEL INSTALLATION	7	0	0	0						

0 MEETS NO PCT OF OBJECTIVE
25 MEETS LOW PCT OF OBJECTIVE
50 MEETS 1/2 OF OBJECTIVE
75 MEETS HI PCT OF OBJECTIVE
100 MEETS ALL OF OBJECTIVE

MISSION	1984	1985	1986
1. OCDA PLACEMENT	△△△		
2. MW LINEAR ARRAY	△		
3. MW SQUARE ARRAY (THERMAL TESTS)	△		
4. 20M BEAM FAB	△△△		
5. CONDUCTOR INSTALLATION	△		
6. ROTARY JOINT INSTALLATION		△	
7. SOLAR BLANKET INSTALLATION		△	
8. REFLECTOR INSTALLATION		△	
9. HIGH PERFORMANCE TRANSFER STAGE INSTALLATION		△	

PROGRAM OBJECTIVE "MINIMIZE TECHNOLOGY VERIFICATION COSTS THROUGH ELEMENT TESTING"

△ = 1 SHUTTLE FLIGHT

Figure 6-21 Program Scenario 2 – SPS Development Through Element Testing

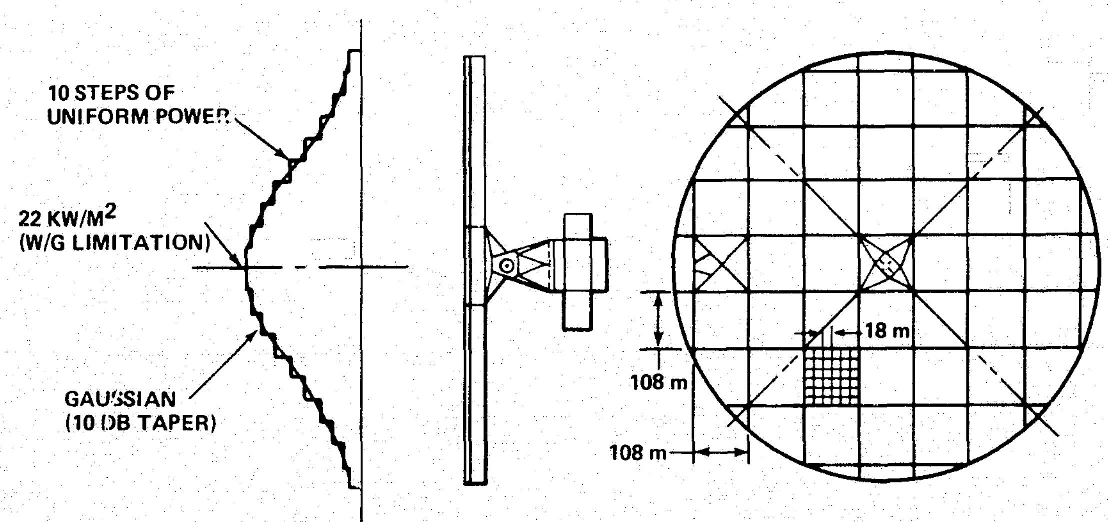


Figure 6-22 Large Full Size Microwave Power Antenna

6.2.2.1 Mission Objectives and Requirements - The mission objectives and test requirements met on this mission provide the technical and operational data base needed to verify the microwave propagation characteristics of the SPS transmission antenna. Implementation of the following requirements will provide data on beam steering, rf propagation, and antenna construction as well as information on the associated rf power distribution system performance:

Mission Objectives

- Provide SPS microwave power transmission data to:
  - Verify high voltage klystron power distribution system
  - Verify retrodirective phase control
  - Antenna pattern and noise characteristics
- Provide operational data on:
  - Cherry pickers, Manipulator, etc.
  - Man-Machine interface during antenna assembly
  - Logistics of antenna components
  - Maintenance and repair of antenna elements.

Test Requirements

- Map far field antenna radiation patterns to determine:
  - Phase control accuracy
  - RFI characteristics
- Verify rf generator efficiency (klystron) 86%
- Verify predicted thermal effects on:
  - Waveguide alignment
  - System perform
- Verify operations analysis
  - Orbital assembly productivity
  - Overall alignment of antenna

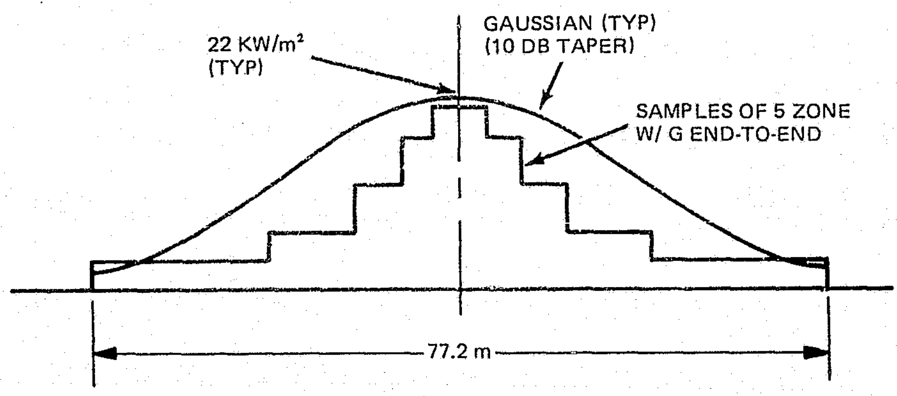
6.2.2.2 Configuration. The linear waveguide experiment is a key technology step leading to development of the full scale antenna shown in Figure 6-22. The antenna would be mechanically pointed at an earth-based receiving rectenna to within 1 arc min. Precise steering (1 arc sec) of the beam is accomplished by electronically phase shifting the signal between antenna subarrays such as the 18-m x 18-m square subarrays shown in Figure 6-22. In order to eliminate objectional sidelobes on the transmitted signal, the power density profile is varied across the face of the antenna aperture as a Gaussian distribution. A more practical arrangement would quantize the smooth curve into steps or zones. The example shown in Figure 6-22 has 10 zones of uniform power density, with a 22 kW/sq m peak value of power density at the antenna center. This value is the expected upper limit before the structural thermal integrity of the aluminum or Gr/Ep waveguides and support structure is exceeded.

The experimental linear array is configured to demonstrate typical elements of the ultimate antenna with a similar Guassian distribution, utilizing klystrons. Because klystrons (46 kW/Tube) were used for this linear waveguide experiment, the Gaussian distribution was divided into five rather then ten zones to minimize the total OCDA solar array power requirements, but still results in the relatively high power requirements shown in Figure 6-24.

The proposed linear array consists of discrete lengths of slotted waveguide. Each length of waveguide represents a sample of antenna taken from each power density zone of a hypothetical five zone antenna. Each length is three waveguides wide and long enough to achieve the required power density using the 46-kW klystron operated at half power. When placed end-to-end, these lengths result in a linear array 77.2-m long. The power density characteristics of this arrangement are shown in Figure 6-23 with the far field signal pattern shown in Figure 6-25.

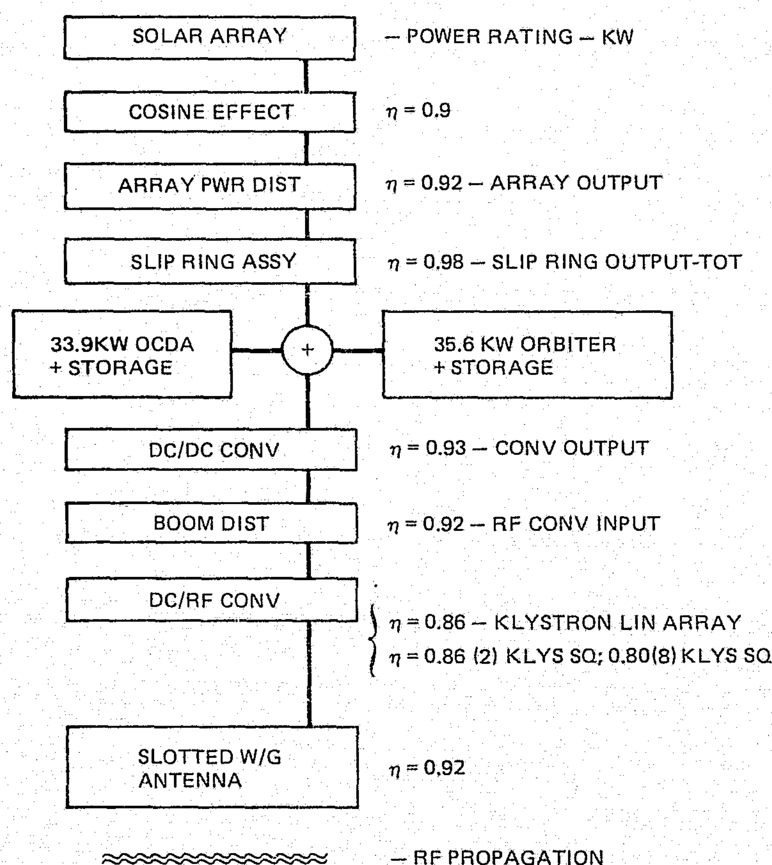
Two candidate klystron configurations are shown in Figure 6-26. The configurations differ primarily in the shape and orientation of the heat radiating surfaces. The lower configuration would be applicable to the linear array experiment. The upper configuration with the radiation reshaped to lie parallel with the waveguide tube axis has been proposed for use on large square arrays. The klystrons used in the linear array experiment are operated at half power (23 kW) to lower the experiment power requirements. A klystron efficiency of 86% is assumed.

The overall configuration of the proposed experiment is shown in Figure 6-27. The antenna consists of lengths of slotted waveguide, three sections wide, fed by a lateral waveguide. The klystrons are flange mounted to the ends of the lateral waveguides. The array is mounted on the rotating boom structure of the OCDA, on the side opposite the manipulator/traveler rails. Initial alignment of the waveguide antenna will be accomplished by adjusting the waveguide support brackets, using an optical alignment system as reference. The control modules, which provide input and beam steering information to the klystrons, are mounted below the waveguide antenna. The array equipment is mounted on the boom on pickup points along the continuous boom caps, which allows for the



10 KLYSTRONS - RF OUTPUT 230 KW
POWER DENSITY PROFILE FOR KLYSTRON LINEAR ARRAY

Figure 6-23 10 Klystrons - RF Output 230 KW Power Density Profile for Klystron Linear Array



POWER, KW	
LIN ARRAY	SQ ARRAY
471.3	455.5
424.2	409.9
390.2	377.1
382.5	369.5
291.0	279.0
267.0	257.4
230.0	212.0
212.0	195.0

Figure 6-24 Missions and Power Requirements, Linear and Square Array Tests

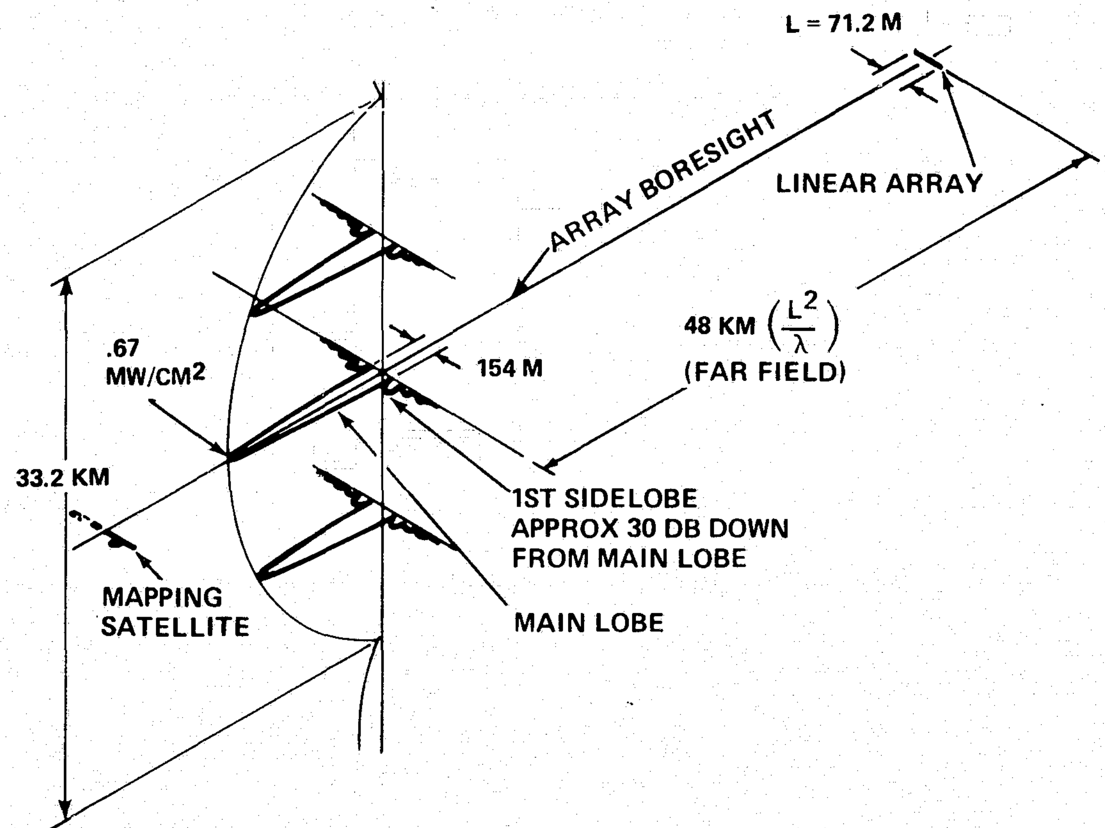
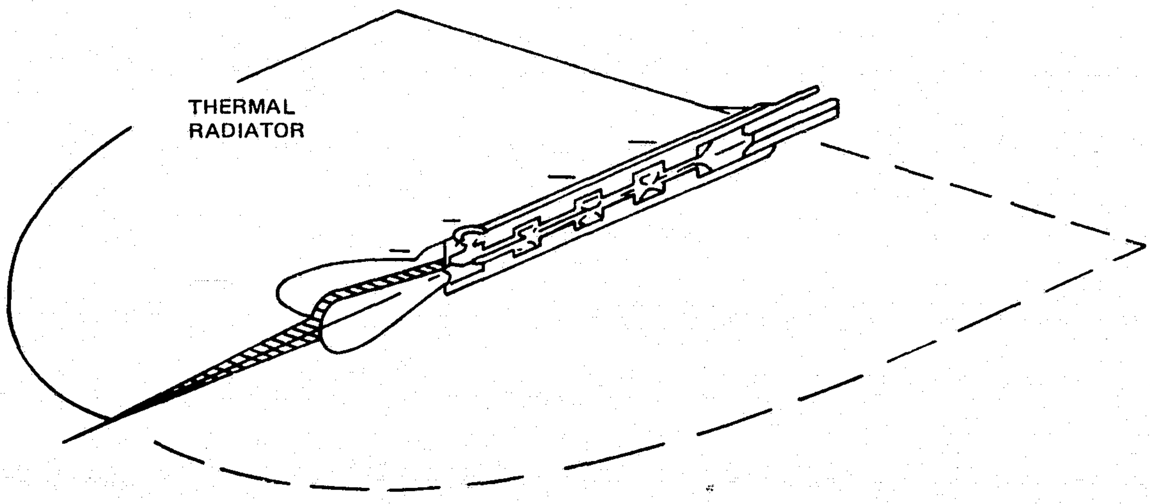


Figure 6-25 Far Field Signal Pattern 77-m Linear Array



- 50 KW KLYSTRON

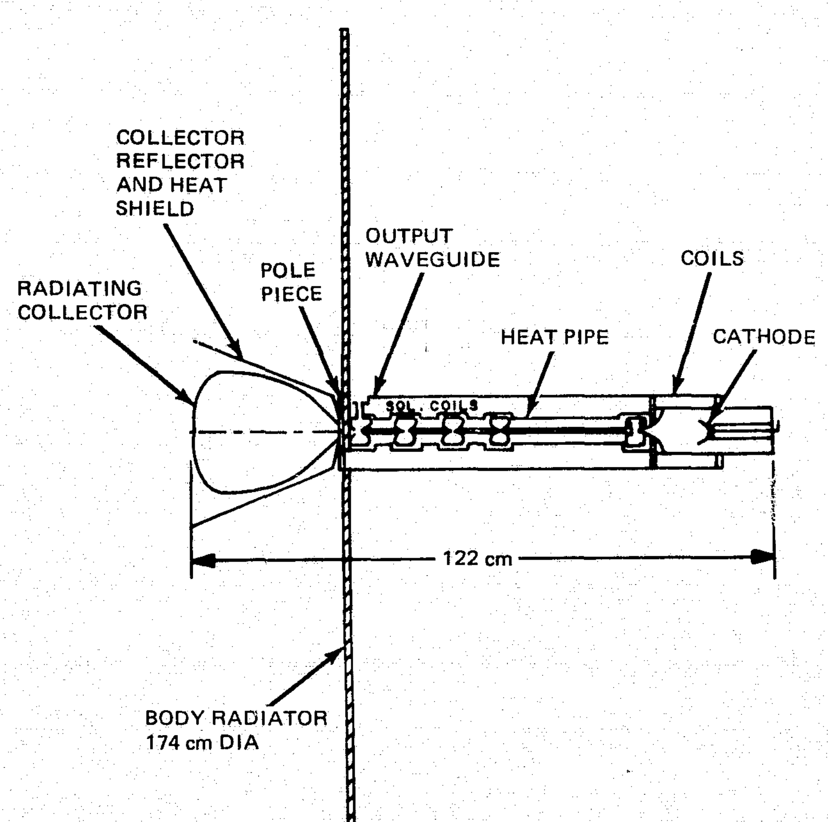


Figure 6-26 Two Configurations of Heat Rejecting Radiator Surfaces

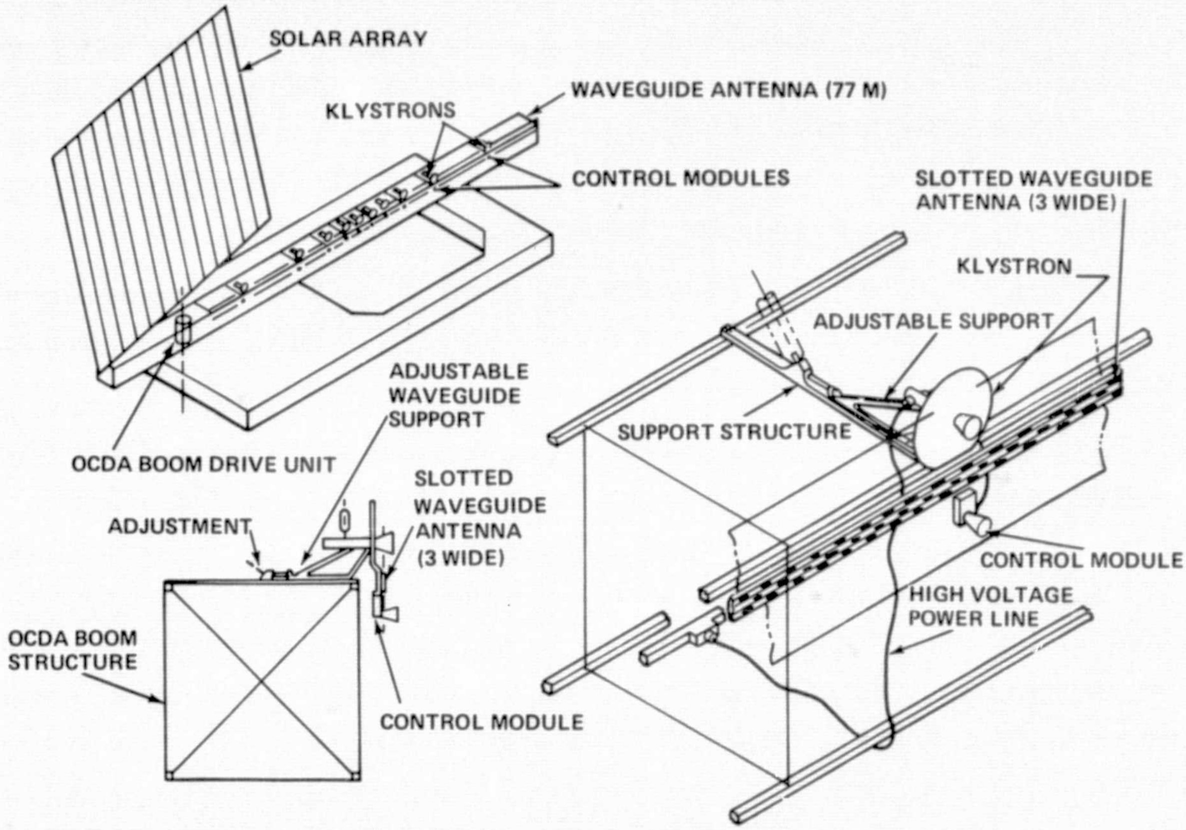


Figure 6-27 Linear Array Configuration/Assembly (Klystron)

irregular klystron spacing required to achieve the desired power distribution. Electrical power, both high and low voltage is drawn from connections on the power bus running along the length of the boom.

An option to mapping the beam with a co-orbital satellite is to track a ground base. An analysis was performed to determine the structural deflection of the OCDA boom due to the rotation acceleration as the boom tracks a hypothetical ground station. The rotational acceleration of the boom is shown in Figure 6-28. The peak acceleration is 31×10^{-5} radian/sec.^{2}. The resulting deflection of the boom was evaulated, using a finite element model. It should be noted that the angular acceleration was regarded as a rigid body acceleration with no regard to dynamic effects. Figure 6-29 shows the structural finite element model and Figure 6-30 shows loading and deflections. The tip deflection is 3.73 cm, most of which is due to local deflection at the support, the "bow" of the boom measured at the cord from end to end is .32 cm. This analysis indicated the feasibility of measuring rf performance on the ground rather than using a mapping satellite.

6.2.2.3 Construction Operations. Assembly operations for the linear waveguide are shown in Table 6-26. Thirty five hours and thirty minutes have been alloted, leaving ample time for construction operations and initial tests.

6.2.2.4 Orbital Tests. The test objectives and requirements are defined in Table 6-27 for the linear waveguide activity, Mission 2 of Program Scenario 2, SPS photovoltaic development. As indicated in item 1 of the Test Requirements column, klystrons are used as the DC to rf conversion units in contrast to amplitrons used in Program Scenario 1. Since both the klystron and amplitron are viable contenders for the power propagation function, the data base obtained during this experiment will include klystron performance and operational data, in addition to the linear array power distribution and phase control characteristics.

Figure 6-31 depicts the major phases of the linear array tests. For example, the Shuttle manipulator would be used for logistics purposes extracting waveguide sections from the cargo bay and placing them in the OCDA boom's traveler for transportation to the assembly location on the boom. A cherry picker with an articulated manipulator is used to assemble the individual waveguides on the boom structure. Installation alignment tests are conducted utilizing optical/laser equipment and servo driven screw jacks. The pictorial system schematic shows the klystron attachment to the waveguides, the ground signal reference antenna, the control/command data link and the high voltage control and distribution system. Since further studies must be conducted to determine whether

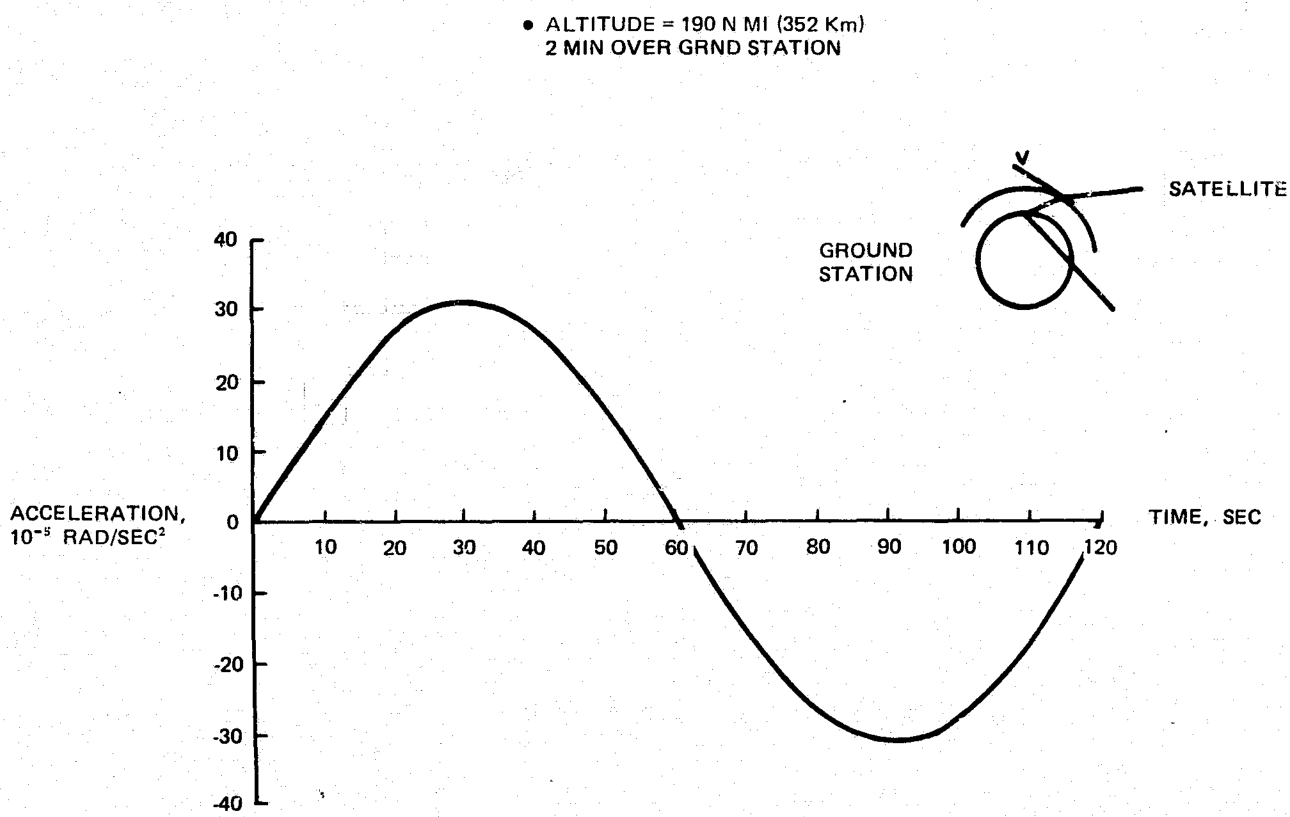


Figure 6-28 Rotary Joint Acceleration Profile

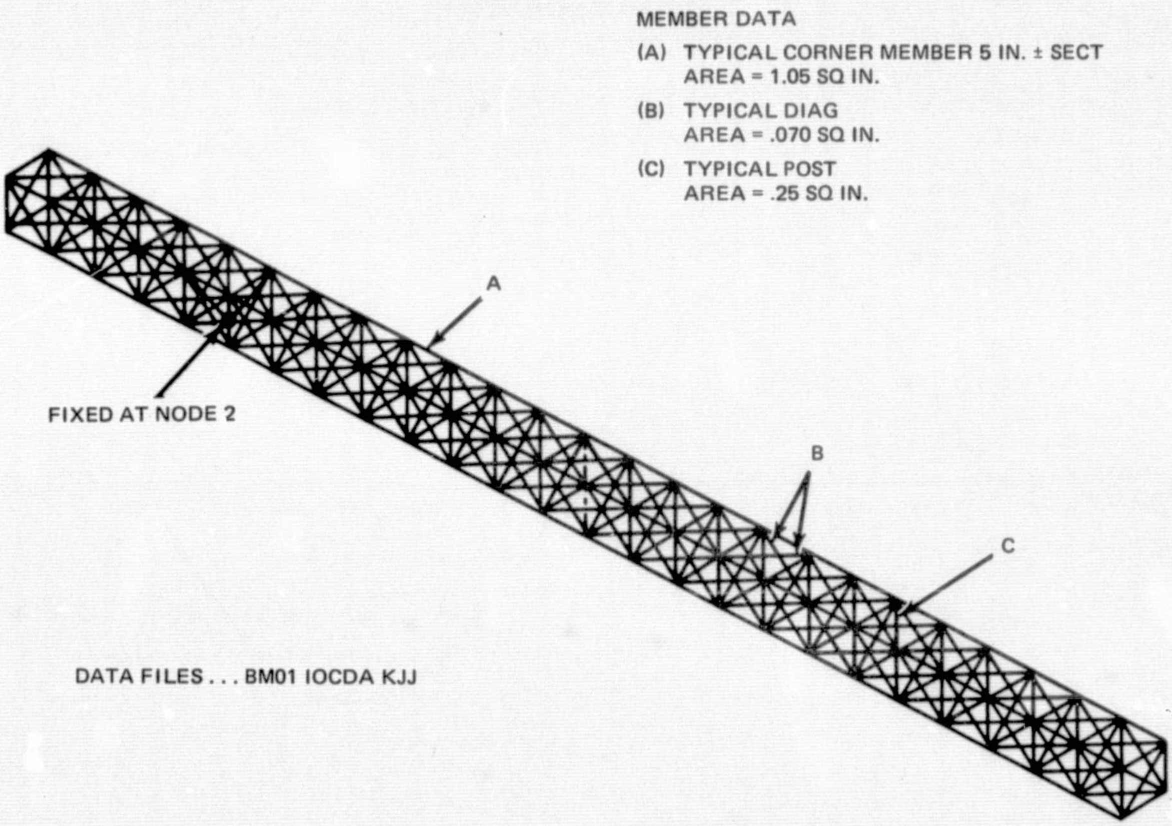


Figure 6-29 OCDA Boom Finite Element Model

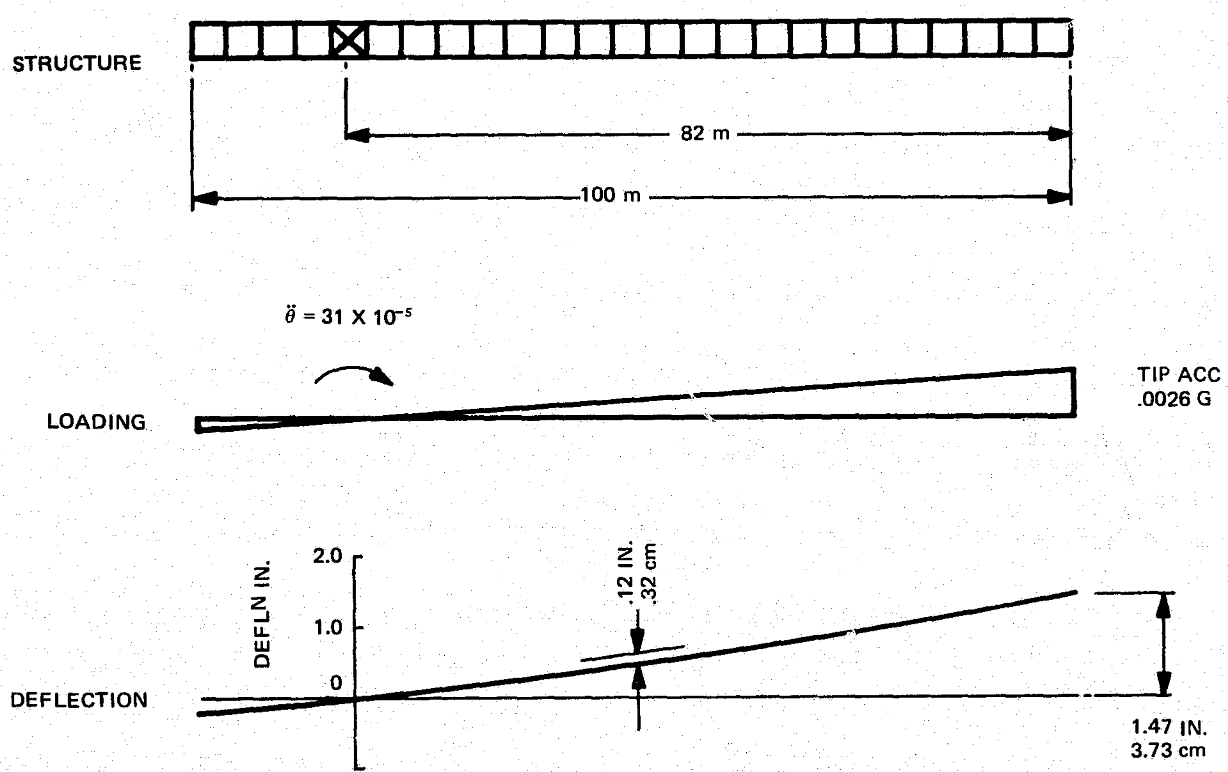
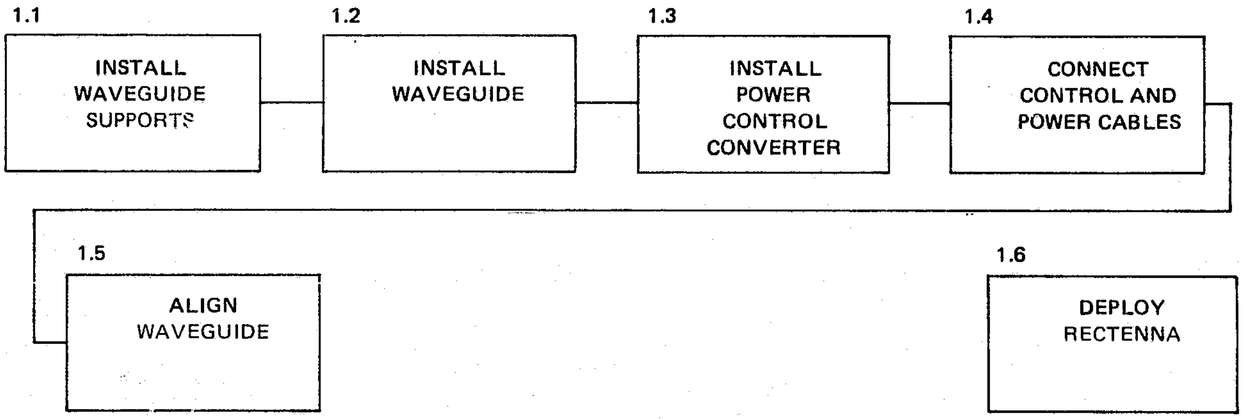


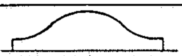
Figure 6-30 OCDA Boom Lateral Deflection

Table 6-26 Functional Operations Scenario – Function 1.0 Linear Waveguide



TIME HR:MIN	OPERATIONS	REMARKS
(11:00)	INSTALL WAVEGUIDE SUPPORTS (11)	
:05	REMOVE SUPPORT ASSY FROM P/L BAY	CHERRY PICKER
:05	TRANSLATE TO INSTALLATION LOCATION	
:05	POSITION SUPPORT ASSY	
:15	ATTACH SUPPORT ASSY TO BOOM	
(11:40)	INSTALL WAVEGUIDE (10)	
:05	REMOVE SECTIONS FROM P/L BAY	
:05	TRANSLATE TO INSTALLATION LOCATION	
:05	POSITION WAVEGUIDE SECTION	
:10	ATTACH WAVEGUIDE	
:10	COUPLE WAVEGUIDE SECTIONS	
(1:30)	INSTALL POWER CONTROL/CONVERTER	
:05	REMOVE CONVERTER FROM P/L BAY	40 KVDC SUPPLY
:05	POSITION ON BOOM STRUCTURE	
:20	ATTACH TO BOOM	
1:00	CONNECT POWER CABLES	
(3:20)	CONNECT CONTROL AND POWER CABLES	
:05	CONNECT CONTROL CABLES TO WAVEGUIDE SWITCHES	
:05	CONNECT POWER CABLES TO KLYSTRONS	
(5:40)	ALIGN WAVEGUIDE	
:30	INSTALL ALIGNMENT REFERENCE UNIT	
:10	ACTIVATE ALIGNMENT SYSTEM	
5:00	CALIBRATE/ADJUST ALIGNMENT	
(2:20)	DEPLOY RECTENNA	
:30	ACTIVATE SUBSYSTEMS	RELEASED
:15	ERECT SATELLITE	PRIOR TO OCDA
1:00	DEPLOY RECTENNA ARMS	DOCKING
:30	CHECKOUT SATELLITE	
:05	RELEASE SATELLITE	
35:30	TOTAL FOR CONSTRUCTION 1 SHUTTLE FLIGHT	

Table 6-27 Orbital Construction Experiment Definition – SPS Photovoltaic Development – Power Transmission

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
THERMAL CYCLING ON WAVEGUIDES AND PHASE CONTROL	1. DETERMINE ORBITAL ASSEMBLY RATE INCLUDING INITIAL ALIGNMENT REQUIREMENT 20 MIN/SECTION - SECTION INCLUDES WAVEGUIDE, KLYSTRON CONTROL MODULE AND ALIGNMENT ACTUATOR 2. OVERALL ALIGNMENT OF ARRAY REQUIREMENT ALIGNMENT 1 MM/M TIME 45 MIN 3. DETERMINE GND POWER DISTRIBUTION (BEAM MAPPING) REQUIREMENT  - GUASION DISTRIB WITH 10 DB TAPER 4. DETERMINE PHASE CONTROL CHARACTERISTICS REQUIREMENTS ORBIT - 350 KM GND SIGNAL-TBD DBW PHASE CONTROL 1 ARC SECOND	1. MANIPULATORS FOR INSTALLATION 2. LASER ALIGNMENT INSTRUMENTATION 3. TRANSMITTERS, RECEIVER AND SIGNAL MEASURING EQUIPMENT 4. HIGH RESOLUTION RADAR/ TRANSPONDERS FOR TRACKING OCDA 5. TELEMETRY TO TRANSMIT OCDA AND WAVEGUIDE PERFORMANCE PARAMETERS 6. FREE FLYER TO PROVIDE ORBITAL MAPPING 7. GND TEST RECTENNA RANGE AT ISOLATED LOCATION SUCH AS	THE PROPOSED TESTS OF THE LINEAR ARRAY ANTENNA WILL PROVIDE INFORMATION ON THE MAJOR ISSUES (POWER DISTRIBUTION AND PHASE CONTROL AT LEO WHICH CAN BE EXTRAPOLATED TO PROVIDE A GOOD UNDERSTANDING OF THE PERFORMANCE AND ENVIRONMENTAL PROBLEMS TO BE EXPECTED AT GEO FOR A 5 GW ORBIT SPS FACILITY. SPECIFICALLY THE PROPAGATION CHARACTERISTICS OF THE GROUND PILOT CONTROL BEAM THROUGH THE ATMOSPHERE AND THE POWER DENSITY DISTRIBUTION OF THE MAIN BEAM OUT TO THE FIRST LOBE. TRADES WILL HAVE TO BE MADE RELATIVE TO GND INSTRUMENTATION VS FREE FLYER TO CONDUCT EXPERIMENTS.

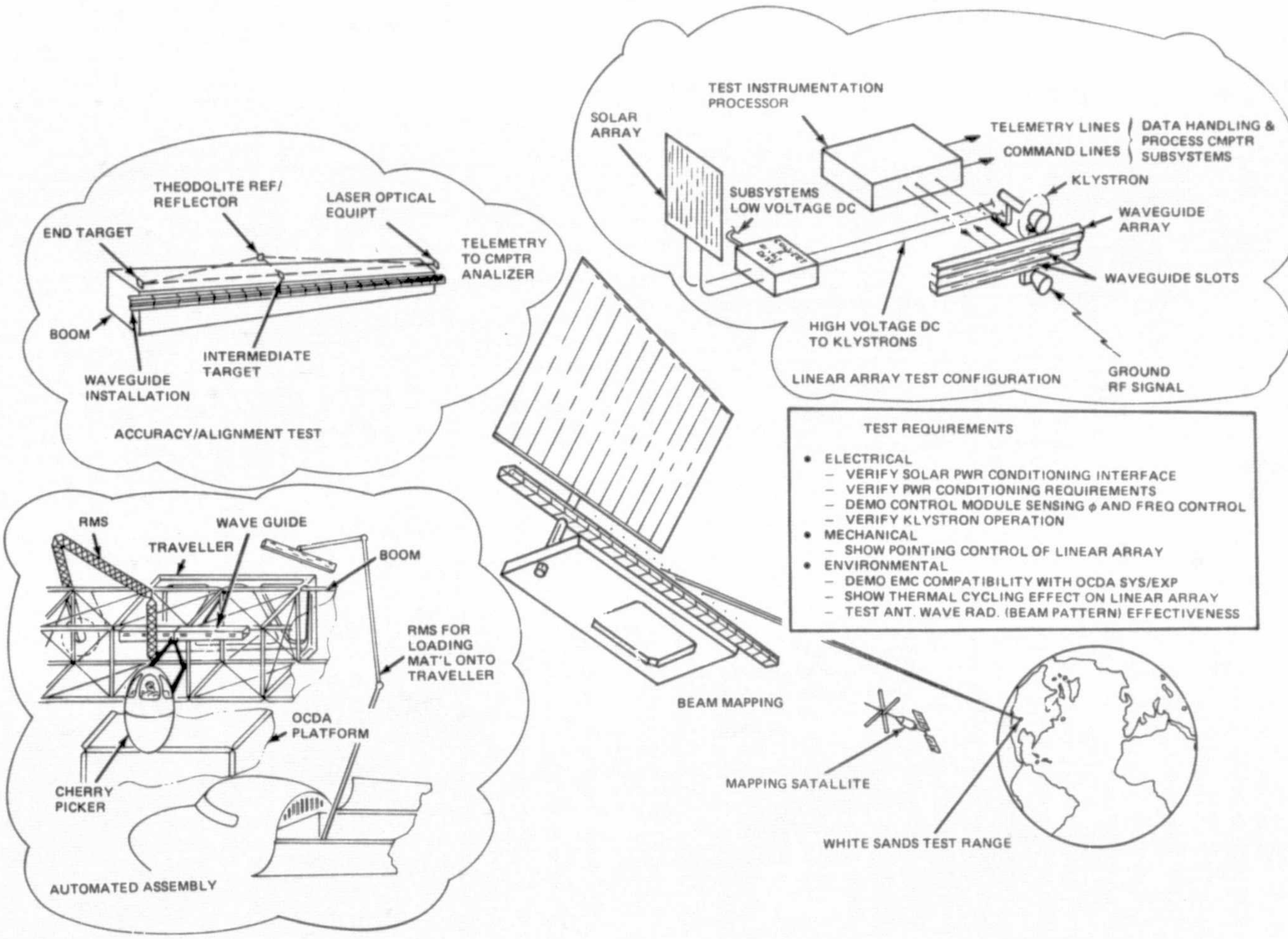


Figure 6-31 OCDA/Linear Array Antenna Experiment

ground and/or orbital mapping will be required, both a free flying mapping satellite and a ground test range are shown in Figure 6-31.

The test scenario includes a power up and check-out of the high voltage conversion and distribution system, the voltage control and protection circuits and the phase control subsystem. Check-out of the onboard equipment is conducted in parallel with check-out of the beam mapping satellite remotely from either the OCDA or from the ground control center. When all systems are "go" the beam mapping and experiments are conducted. Besides antenna patterns, rf signal levels and waveguide loss measurements; voltage, current and temperature measurements will be taken throughout the high voltage distribution system to verify its performance. The remote instrumentation onboard the orbiter and on the ground will monitor the parameters throughout the various LEO sunlight conditions.

Table 6-28 is a list of the mission peculiar equipment and the estimated mass for each item.

6.2.3 Mission 3 - Microwave Square Array (Thermal Tests)

A key issue associated with SPS microwave transmission is the ability of the transmitting antenna to handle the thermal gradients associated with the high rf power densities without distortion which would adversely affect the antenna performance. As indicated in Figure 6-22 the center elements are fed by klystron DC to rf converters to produce a power density of 22 kW/sq m. This technogical issue is therefore the prime drive in establishing the mission objectives and test requirements for the 6-m x 6-m square array experiment.

6.2.3.1 Mission Objectives and Requirements. The mission objectives and test requirements were selected to establish the thermal gradients that are generated in the waveguide structure by high energy inputs (22 kW/sq m) in the LEO sun/shade environment. Other factors that are verified in this experiment are the installation techniques, transmission characteristics including energy distribution pattern and power transmissi on, the performance of the high voltage conversion system, performance of the klystrons, and the effects of thermal cycling on the waveguide structure and system operation. The mission objectives and test requirements are summarized as:

Mission Objectives

- Verify array thermal gradients at 22 kW/sq m power density
- Verify automatic installation techniques
- Verify microwave power transmission

Table 6-28 Linear Waveguide Mass

ELEMENT	MASS	
	LB	KG
• CHERRY PICKER	(4807)	(2187)
– STRUCT MECH	2187	998
– TRUCK	1250	568
– BUBBLE SYSTEM		
• CONTROLS	175	79
• ECLS	100	45
• BUBBLE HATCH	1095	497
• KLYSTRON EXPERIMENT PECULIAR	(11247)	(5106)
– TUBES	1068	485.3
– WAVEGUIDES	32	14.5
– CONTROL ELECTRONICS	1736	788
– MECHANICAL	285	129
– POWER DISTRIBUTION	8126	3689
• ORBITAL TEST EQUIPMENT	(2192)	(996)
– FREE FLYER S/C	1720	781
– EXPERIMENT PECULIAR STRUCTURE	457	208
– EXPERIMENT PECULIAR ELECT.	15	7.0
TOTAL	18246	8284

- Verify high voltage power distribution system performance
- Measure thermal cycling effect.

Test Requirements

- Determine orbital assembly rates
- Determine alignment accuracy 1 mm/m required
- Measure temperature variation of each array element
- Measure power transmission efficiency and radiation pattern
- Determine efficiency of high voltage distribution system and rf generators
- Provide operations data on LEO construction and test activities.

6.2.3.2 Configuration. A deployable structure is used for the subarray, thereby putting the emphasis on the assembly of the components rather than on the assembly of the support structure. Figure 6-32 shows the steps required to mount the subarray on the boom. The folded antenna subarray is removed from the orbiter payload bay and transported to the OCDA platform for deployment. The antenna system is mounted to the OCDA boom structure near the boom drive unit. A prepackaged structure is taken from the Shuttle cargo bay and deployed. The expanded structure is then fastened to the cap members of the boom structure at four points providing a rigid support for the antenna array. Subarrays are then fastened to the front face of the structure. Each subarray is a complete unit with slotted waveguide antenna, klystrons and waveguide manifolding. Each subarray is attached at three places to the node points of the support structure grid. This method of attachment minimizes thermal environment effects and fits well with the geometry of the OCT-TET support structure. The three pickup points are adjustable to allow the subarrays to be aligned to the required flatness.

Figure 6-33 summarizes the trade conducted to size the array. The square microwave antenna was sized to produce the largest array that would fit within the capability of the Option 2 (500 kW) solar array. The center subarray was configured to operate at 22 kW/sq m power density to demonstrate the thermal and rf conditions anticipated on the full size MPTS antenna. The center subarray also demonstrated functioning of the klystron rf converter at full power operation (46 kW).

The center subarray size is then multiplied by the area required to handle 46 kW at a power density of 22 kW/sq m, using one, two, three, etc., klystrons in that subarray. The surrounding subarrays are powered at a low level to provide a step in power density.

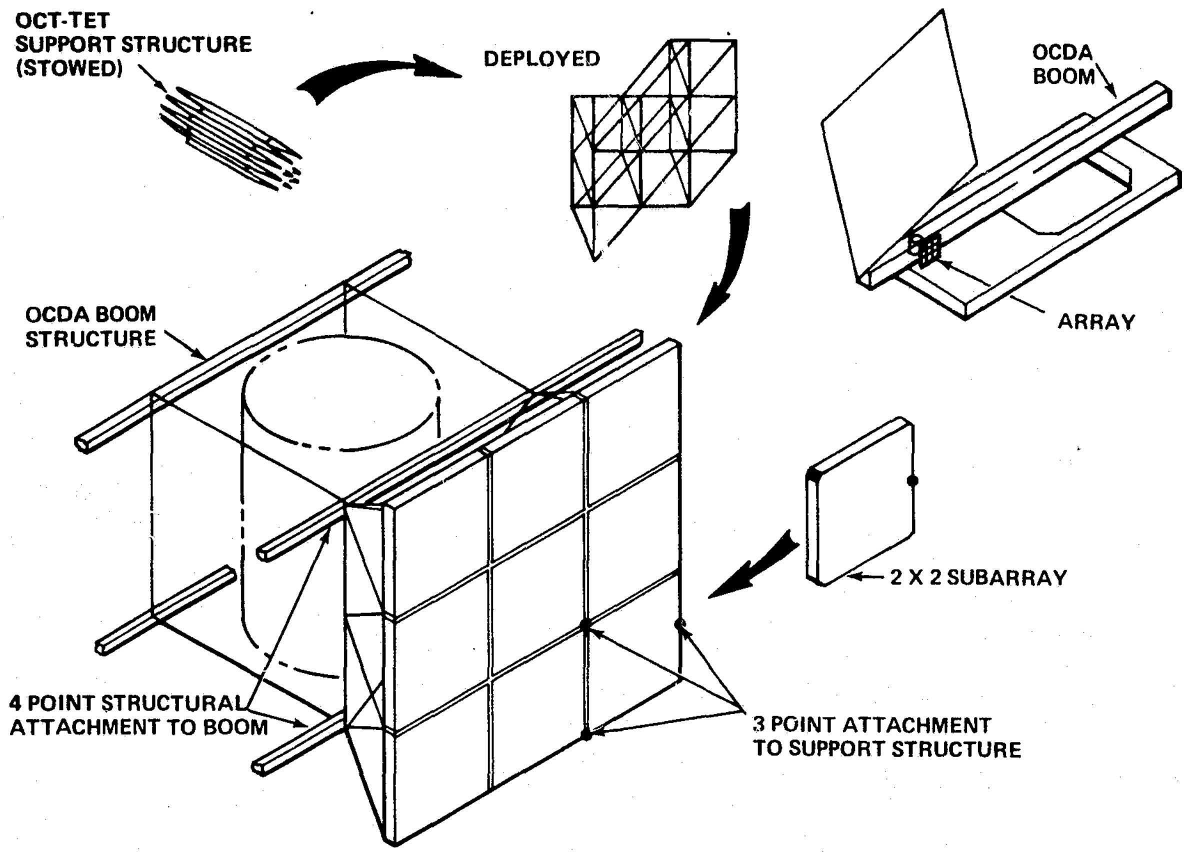


Figure 6-32 OCDA Microwave Experiment Square Array

NO. FULL POWER TUBES IN CENTER SUBARRAY	SUBARRAY SIZE (22 KW/M^2)	POWER DIST. (1 = 46 KW)	TOTAL POWER (KW) RF OUT	TOTAL POWER (KW) $\eta_1 = .86$, $\eta_{1/3} = .8$ DC IN	SOLAR ARRAY REQD* (KW)
1	1.4 M SQ	1/3 1/3 1/3 / 1/3 ① 1/3 / 1/3 1/3 1/3	166	203	285
2	2 M SQ	1/3 1/3 1/3 / 1/3 ② 1/3 / 1/3 1/3 1/3	212	257	456
3	2.4 M SQ	1/3 1/3 1/3 / 1/3 ③ 1/3 / 1/3 1/3 1/3	285	310	531

WITHIN 500 KW ARRAY

Figure 6-33 Microwave Square Antenna (Sizing)

One-third power was assumed to be the lowest practical level at which a klystron could be operated. Each of the surrounding subarrays is powered by one klystron at one-third power.

The table summarizes the results of several configurations which fit the above conditions. The array chosen has a subarray of 2-m square, using two klystrons in the center at full power and a klystron in each of the surrounding subarrays at reduced power. The total solar array required to operate this system (along with the housekeeping requirements of the vehicle) is 456 kW, within the Program 2 array (500 kW).

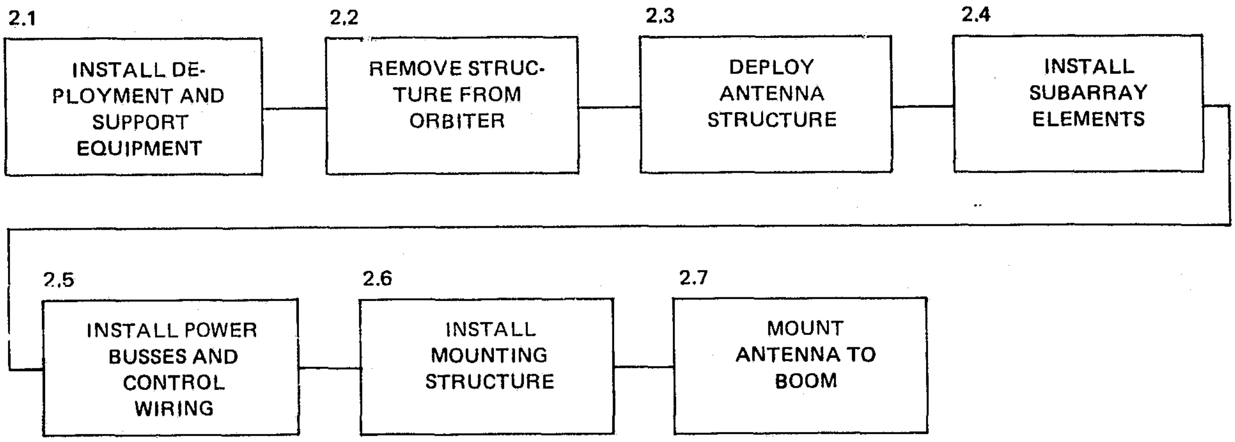
6.2.3.3 Construction Operations. Table 6-29 is a functional operations scenario and contains an estimation of the time (32 hr) to construct the subarray antenna and one Shuttle flight to support operations. The OCT-TET antenna support structure is brought up to the OCDA in the orbiter payload bay. Here it is mounted to a deployment fixture, then deployed and attached to a stabilizing fixture. The orbiter RMS is used to remove the subarray microwave elements from orbiter and mounts them on the boom traveller for transportation to the subarray structure. A cherry picker at the assembly site is used to mount the subarray elements to the structure and align the elements. After the elements have been installed, the subarray is removed from the platform attachment fixtures, flipped over and remounted. A cherry picker now installs power control boxes and power cables on the structure and completes the electrical connections. Subarray mounting structure is attached to the boom and the subarray is attached to it. Power and control cable connections are made to complete the installation.

6.2.3.4 Orbital Tests. The test requirements for the microwave antenna are shown in Table 6-30.

The tests will include the following:

- Install, align and check alignment of 6-m x 6-m array elements
- Record and analyze video tape and film of all operations
- Turn on and C/O high voltage distribution system
- Power up and C/O klystron rf generators
- Analyze variation in thermal gradients with variations in klystron power levels
- Turn on and C/O satellite instrumentation
- Transmit to beam mapping satellite and measure pattern, power and RFI
- Recycle tests at various sunlight and eclipse conditions.

Table 6-29 Functional Operations Scenario – Microwave Square Antenna



TIME HR:MIN	OPERATIONS	REMARKS
(1:15)	INSTALL DEPLOYMENT AND STABILITY FIXTURE	
:15	REMOVE DEPLOYMENT FIXTURE AND POSITION ON PLATFORM	
:15	MOUNT DEPLOYMENT FIXTURES	
:30	REMOVE STABILIZING FIXTURES AND POSITION ON PLATFORM	
:30	MOUNT STABILIZING FIXTURES	
(:45)	REMOVE STRUCTURE FROM ORBIT	
:15	ATTACH RMS MANIPULATOR TO STRUCTURE PKG.	
:15	LIFT CLEAR OF PAYLOAD BAY	
:15	TRANSPORT TO PLATFORM	
(:50)	DEPLOY ANTENNA STRUCTURE	
:15	ATTACH STRUCTURE PACKAGE TO DEPLOYMENT FIXTURE	4.5 m LONG
:05	DEPLOY ANTENNA AND VERIFY LOCKS	
:30	ATTACH STABILIZING FIXTURES	
(12:45)	INSTALL SUBARRAY ELEMENTS	
1:30	REMOVE PANELS IN SEQUENCE FROM ORBITER	ATTACHMENT FIX. REQUIRED 9 ELEMENT PANELS
2:15	TRANSPORT ELEMENTS TO ANTENNA	
4:30	POSITION PANELS & INSTALL ALIGNMENT SCREWS	
2:15	COURSE ADJUST ELEMENTS	
2:15	FINE ALIGN ANTENNA PLANARITY	
(13:00)	INSTALL POWER BUSSES AND CONTROL WIRING	
:15	RELEASE DEPLOYMENT AND STABILIZING FIXTURES	
:05	ROTATE ANTENNA 180°	BOOM CHERRY PICKER
:45	ATTACH SUPPORT FIXTURES	
4:30	MOUNT POWER CONTROL BOXES	
2:15	CONNECT POWER CABLES	
1:00	DEPLOY POWER DISTRIBUTION CABLING	
2:15	CONNECT CABLING TO POWER CONTROL BOXES	
2:00	INSTALL CONTROL WIRING	
(1:45)	INSTALL MOUNTING STRUCTURE	
:30	REMOVE AND DEPLOY MOUNTING STRUCTURE (2)	
:15	TRANSPORT TO PLATFORM	
:30	ATTACH TO ANTENNA STRUCTURE	
:30	INSTALL POWER AND CONTROL CABLING	

Table 6-29 Functional Operations Scenario – Microwave Square Antenna (Continued)

TIME HR:MIN	OPERATIONS	REMARKS
(1:30) :15 :15 :30 :30	MOUNT ANTENNA TO BOOM RELEASE DEPLOYMENT AND STABILIZING FIXTURES MANEUVER ANTENNA TO BOOM AND POSITION ATTACH ANTENNA TO BOOM CONNECT POWER AND CONTROL CABLING	
32:00	TOTAL FOR CONSTRUCTION 1 SHUTTLE FLIGHT	

Table 6-30 Orbital Construction Experiment Definition – SPS Photovoltaic Development - Option 2 Microwave Antenna – Power Transmission

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
ASSEMBLY OF SUBARRAYS, THERMAL CYCLING AND POWER TRANSMISSION EVALUATION.	1. DETERMINE ORBITAL ASSEMBLY RATE. REQUIREMENT: TBD MIN/SECTION 2. DETERMINE OVERALL ALIGNMENT OF 6 X 6 ARRAY REQUIREMENT: 1 mm/m 3. DETERMINE ANTENNA PATTERN DISTRIBUTION AND VERIFY PHASE CONTROL WITH BEAM MAPPING SATELLITE RANGE: 48 Km 4. DETERMINE POWER TRANSFER EFFICIENCY WITH BEAM MAPPING SATELLITE RANGE: 8 Km POWER DELIVERED: 10-20 WATTS DC 5. DETERMINE SUBARRAY THERMAL INTERACTION REQUIREMENT: 500°F MAX	1. CHERRYPICKERS FOR SUB-ARRAY INSTALLATION. 2. LASER ALIGNMENT INSTRUMENTATION. 3. BEAM MAPPING SATELLITE FOR PATTERN VERIFICATION AND PILOT BEAM GENERATION. 4. TELEMETRY TO TRANSMIT OCDA AND SUBARRAY PARAMETERS. 5. THERMAL MEASUREMENT INSTRUMENTATION	A COMPLETE OPERATIONAL ANTENNA HAS NOT BEEN BUILT PREVIOUSLY. THEREFORE A SCALE MODEL IS REQUIRED TO VERIFY TECHNIQUES OF INSTALLING SUBARRAYS TO THE REQUIRED PLANARITY AND INSTALLING POWER DISTRIBUTION SYSTEM. EFFICIENCY OF POWER TRANSMISSION AND BEAM MAPPING FROM ORBIT TO ORBIT REQUIRES A DEMONSTRATION FOR AN SPS DEVELOPMENT DECISION.

This test scenario lists the major events required to conduct the thermal beam mapping and power transmission experiment. A beam mapping satellite is used to map the beam and measure the transmitted power possible with a typical slotted line 2-dimensional transmitting antenna. The satellite antenna will be located at approximately 1500 m to duplicate the power density present in the ultimate SPS ground rectenna. Although the ionospheric losses will not be duplicated in the co-orbit power transmission experiment utilizing the free flyer, the overall power transmission and reception characteristics of typical antenna elements will be verified.

Table 6-31 is a list of the mission peculiar equipment and the estimated mass for each item.

6.2.4 Mission 4 - 20-m Beam Fabrication

Current literature on large space structures for various applications, i.e., SPS, large antenna and orbital industrial plants generally agreed on the utilization of 20-m deep beams as one of the fundamental SPS building block elements. The 20-m x 246.5-m test specimen discussed in the following section will be used to verify the production and structural properties of large 20-m beam elements which is typical of the size used on a 5 GW SPS.

6.2.4.1 Mission Objective and Requirements. The objectives of Mission 4 are aimed at verifying the producibility of 20-m beam elements. This is a pivotal experiment in providing the technological base required to construct large structures for the SPS. The test requirements translate the mission objectives into verification requirements which will measure the production rate, the quality of the product including straightness and structural integrity, and measure the effects of the LEO thermal environment on the 20-m beam elements. Composites will be used to construct the 20-m beam test specimens. Specific objectives and requirements include:

Mission Objectives - Verify:

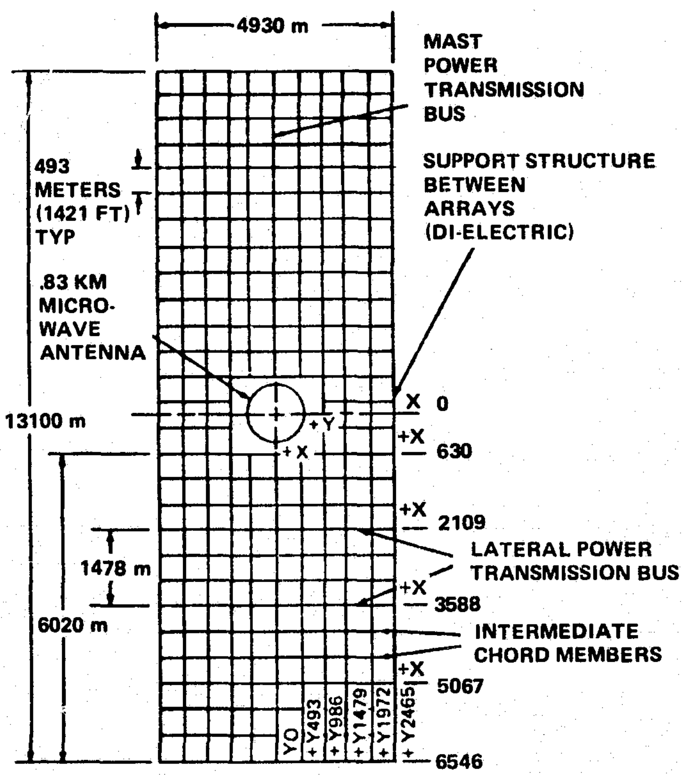
- Producibility of 20-m beam elements
- Structural integrity of beam elements
- Fab module performance
- Operational procedures.

Test Requirements - Determine:

- Fabrication rate; 1ft/min. required
- Dimensional/straightness accuracy

Table 6-31 Microwave Antenna Mass

ELEMENT	MASS	
	LB	KG
INTERFACE FIXTURES/JIGS	(69)	(20.5)
DEPLOYMENT FIXTURE	11	5
PIVOT SUPPORT (2)	48	11
SUPPORT EQUIPMENT		
SUBARRAY PICK-UP TOOL	10	4.5
TRANSMIT ANTENNA	(7153)	(3247)
• PRIMARY STRUCTURE	10	4.54
• SUBARRAY/ELEMENT MECH INT.	577.1	262
• RF CONVERTERS	1282	582
• PHASE CONTROL ELECT.	4326	1964
• POWER DISTRIBUTION	734	333
• WAVEGUIDES	223.7	101.5
• ROTARY JOINT INTERFACE	–	–
TOTAL	7222	3268



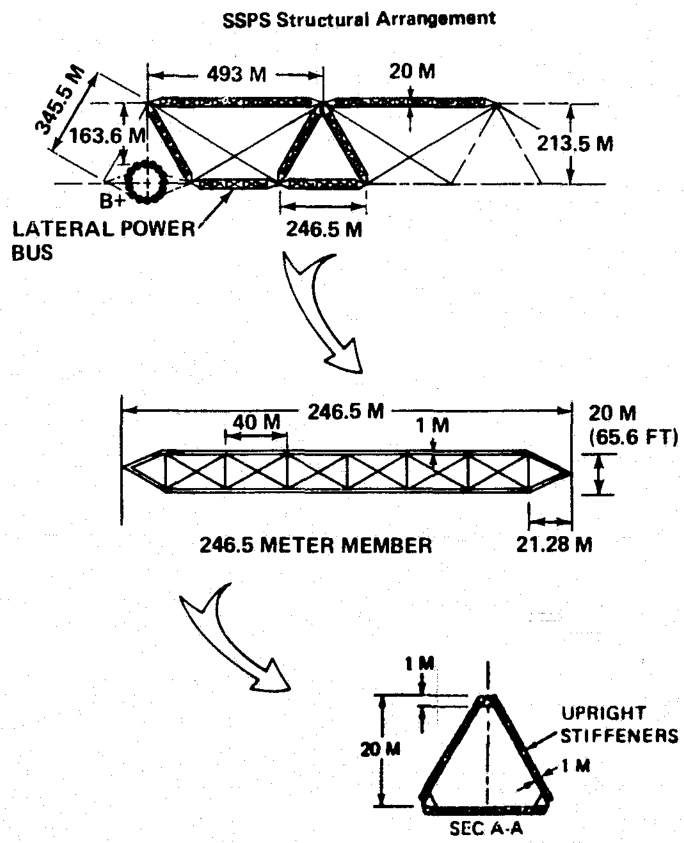


Figure 6-34 20 m Test Specimen

- Machine performance, i.e., roller forces, feed rates, control system, etc.
- Temperature delta of various truss members
- Effects of LEO temperature variations
- Structural integrity
- Natural frequency.

6.2.4.2 Configuration. Figures 6-34 through 6-38 illustrate the relationship of the test specimen to a typical SPS structure, the basic elements of the test beam and the equipments required to fabricate the test specimen. Figure 6-34 indicates the relationship of the 246.5-m x 20-m test specimen to the basic 493-m building block element used to construct the 13100-m x 4930-m SPS structure. The building block structure used to construct the test specimen, shown in Figure 6-35, consists of a 1-m deep by 40-m long triangular cross section truss fabricated from composites material. The shear carrying members consist of verticals and diagonals in each of three planes.

To support the 20-m fabrication test objectives and requirements, a fabrication module concept introduced in the NASA Space-Based Solar Power Conversion and Delivery System Study (NAS 8-31308) was selected for our OCDA experiment. The 20-m beam fabrication module arrangement is shown in Figure 6-36. The configuration consists of a 58-m long structural frame assembly which is an assembly of Shuttle delivered prepackaged deployable structures. The frame assembly provides mounting and support for 4 1-m composite beam fabrication modules, swing arms, carriages and other module components shown in Figure 6-37. Figure 6-38 shows the cable rigging equipment for installing diagonals.

The 20-m fabrication module/OCDA arrangement is shown in Figure 6-39. The module is attached to platform nodals and is located on the platform side opposite of the rotating solar array. This location of the module does not restrict the OCDA boom rotation and does not require an increase in platform length, though this configuration does require the platform to increase 8 m in width.

To assemble and erect the 20-m fabrication module (factory) on the OCDA additional manipulators a track system is required due to the limitations (reach and location) of the OCDA rotating boom manipulators. The factory manipulator support structure (deployables) is attached to the platform nodal points and located adjacent to the fabrication module.

6.2.4.3 Construction Operations. Table 6-32 contains top level functions for the fabrication of the 20-m beam. Construction operations associated with each function and estimated

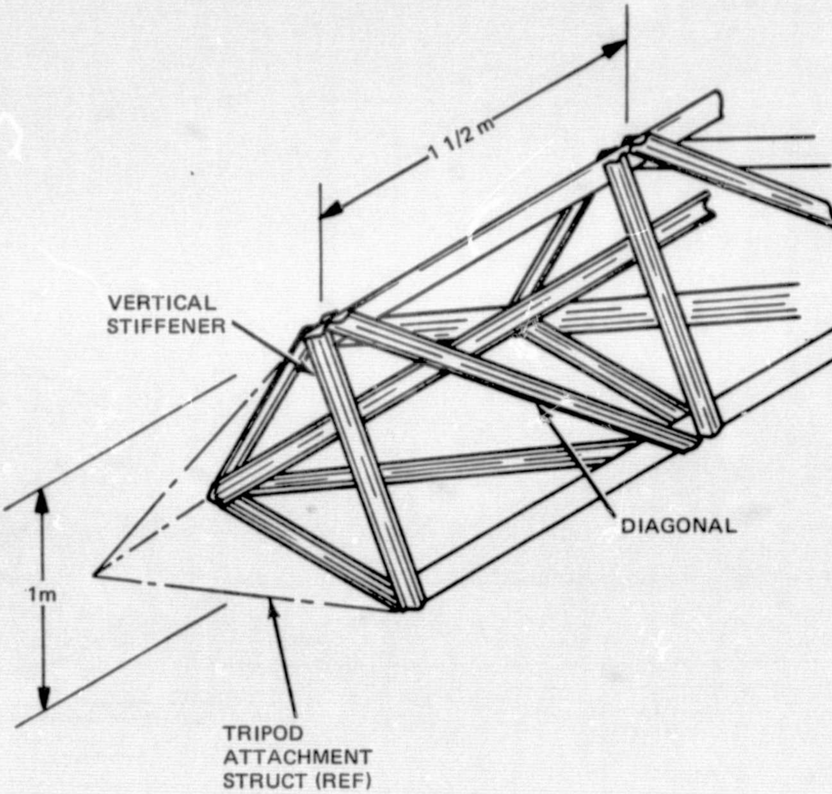


Figure 6-35 Building Block Truss, 1-m Deep

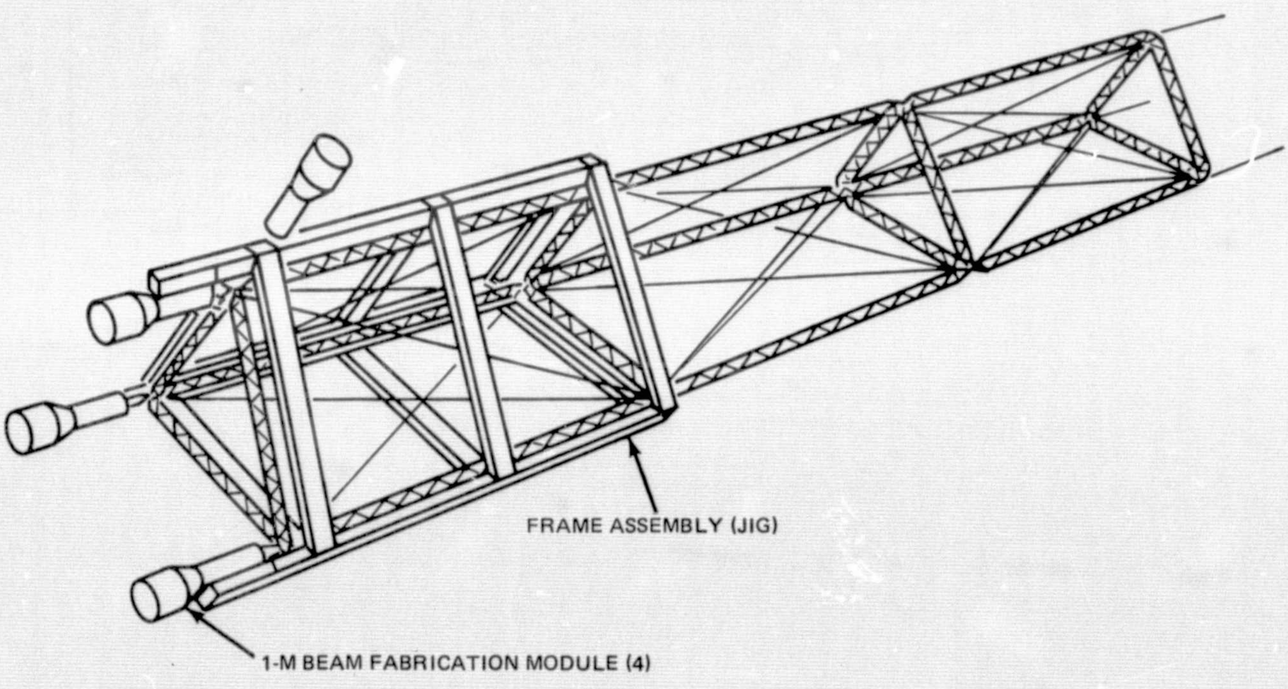
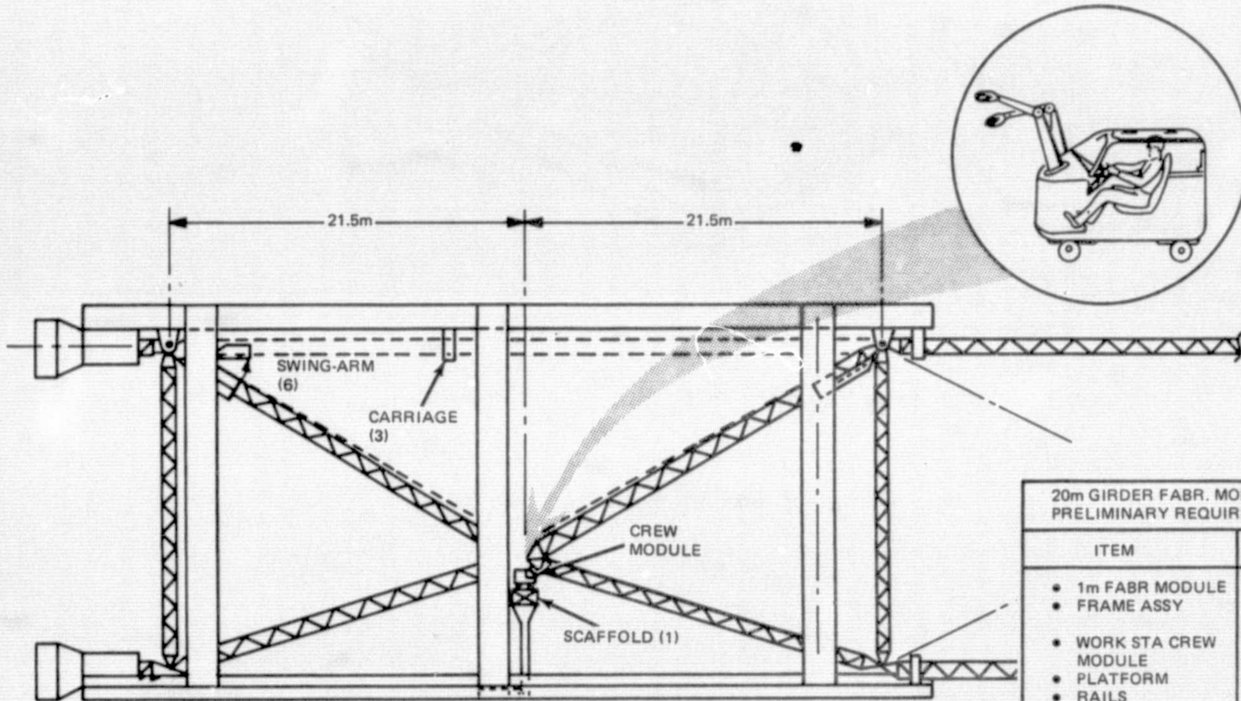
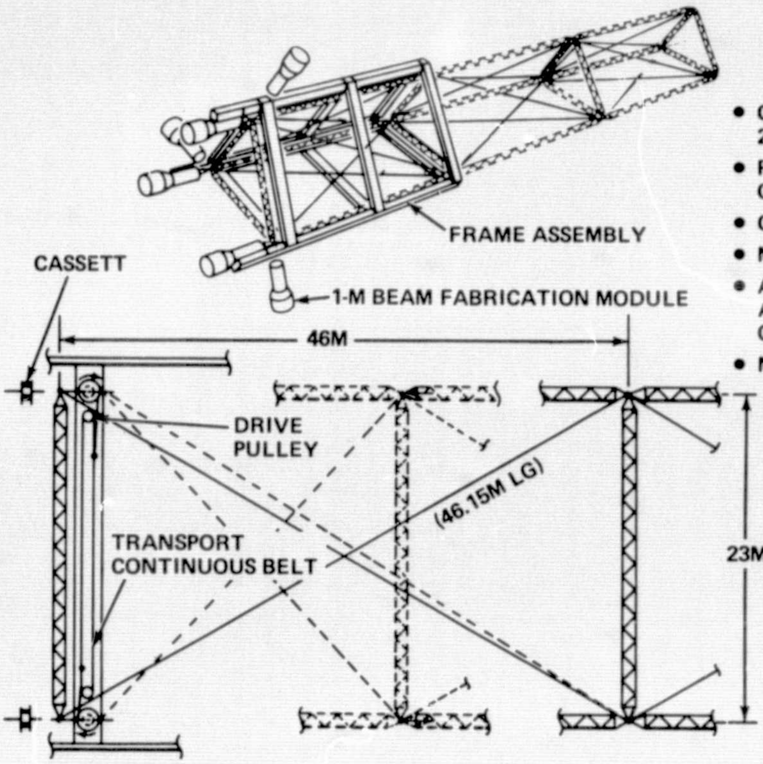


Figure 6-36 20-m Girder Fabrication Module



20m GIRDER FABR. MODULE PRELIMINARY REQUIREMENTS	
ITEM	NUMBER
• 1m FABR MODULE	4
• FRAME ASSY	1
• WORK STA CREW MODULE	3
• PLATFORM	3
• RAILS	3
• SCAFFOLD	1
• CARRIAGE	3
• SWING ARM	6
• ALIGN FIXT	3
• PRETENSION TOCL	3
• CABLE RIGGING DEVICE	3
CREW TASKS	
• ATTACH BATTENS	
• ATTACH & PRELOAD CABLES	
• ATTACH APEX POINTS	
• MONITOR, SERVICE, & REPAIR 1m FABR MODULE	

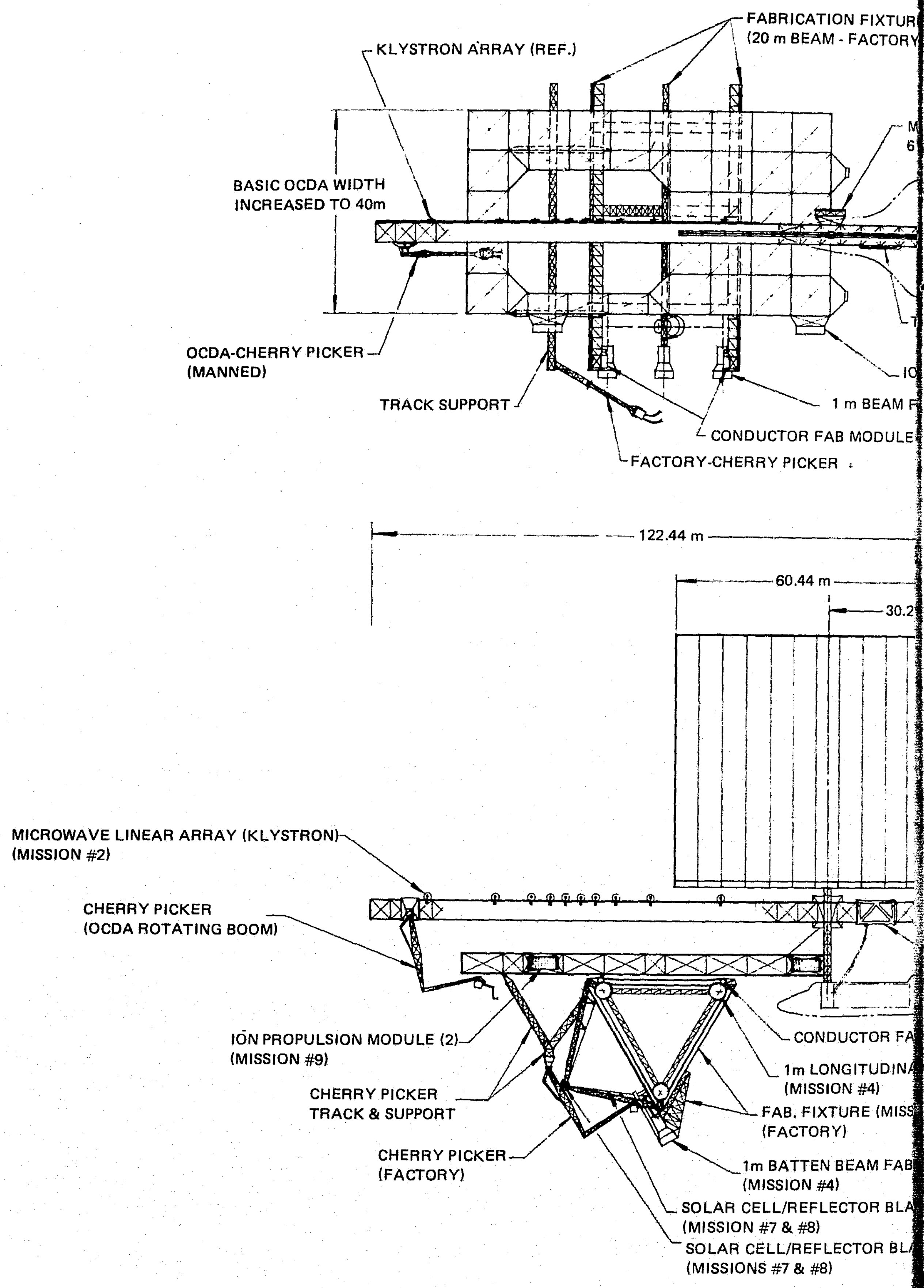
Figure 6-37 20-m Beam Fabrication Module Apex Assembly



CHARACTERISTICS

- CONTINUOUS BELT SYSTEM MOUNTS ON 20M BEAM FRAME MODULE
- PROVIDES FOR VERTICAL TRANSLATION OF FREE ENDS OF CABLES
- CABLES SUPPLIED FROM CASSETTS
- MOTION OF 20M BEAM DEPLOY CABLES
- ATTACHING & TENSIONING ACCOMPLISHED BY CHERRY PICKER OPERATIONS.
- MASS: 45 KG

Figure 6-38 Cable Rigging



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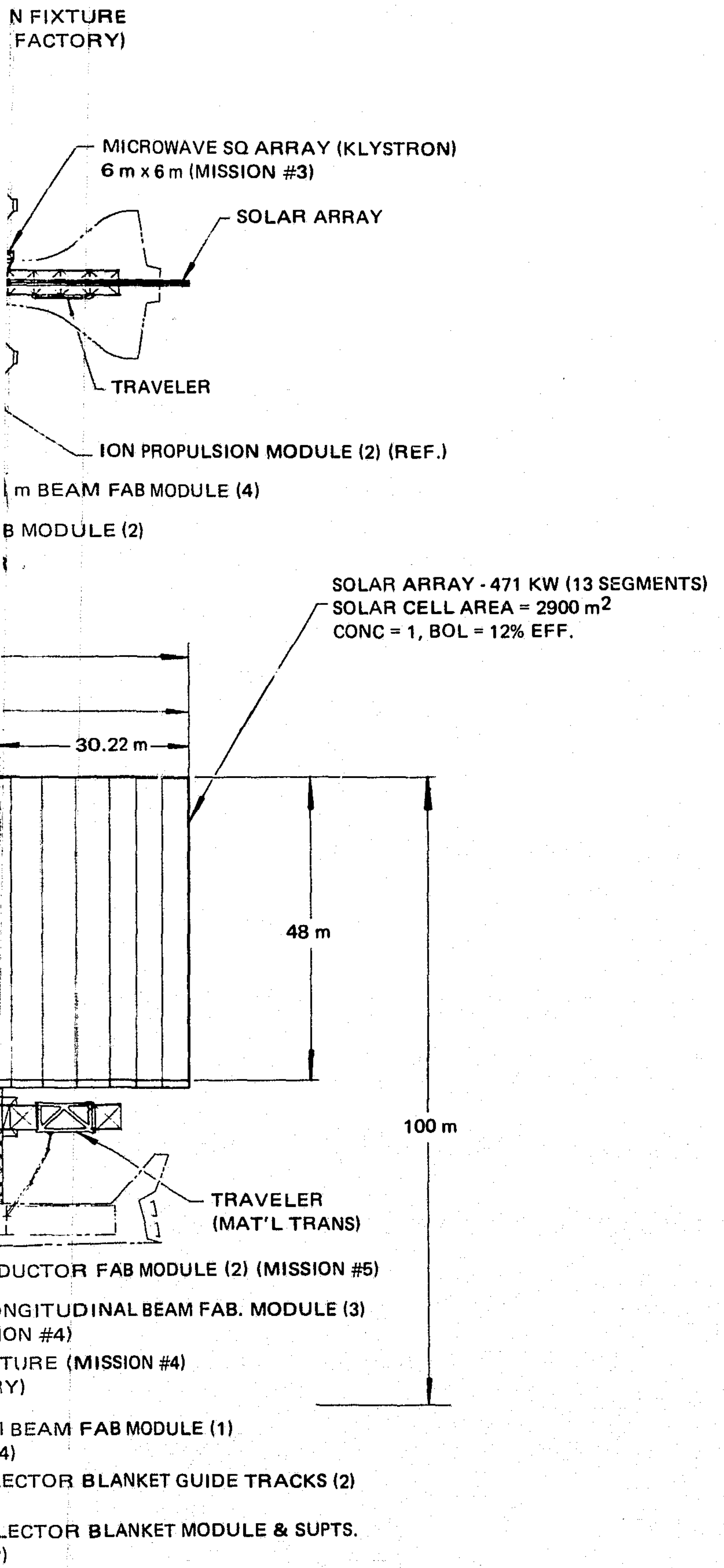

NOTES:

1. TO PROVIDE POWER FOR KLYSTRON LINEAR ARRAY TEST (MISSION #2) THE BASIC OCDA SOLAR ARRAY ($2592m^2$) IS REPLACED WITH A $2900m^2$ 471 KW ARRAY.
2. THE BASIC OCDA PLATFORM WIDTH (32m) IS INCREASED TO 40m TO ACCOMMODATE THE 20m BEAM FAB. TEST (MISSION #4)
3. MANNED CHERRY PICKER REPLACES STS (RMS) MANIPULATOR ON OCDA ROTATING BOOM FOR ALL MISSIONS.

0 5 10 20 30 40

SCALE - METERS

Figure 6-39 Program Scenario 2 Mission 4 — 20-m Beam Fabrication

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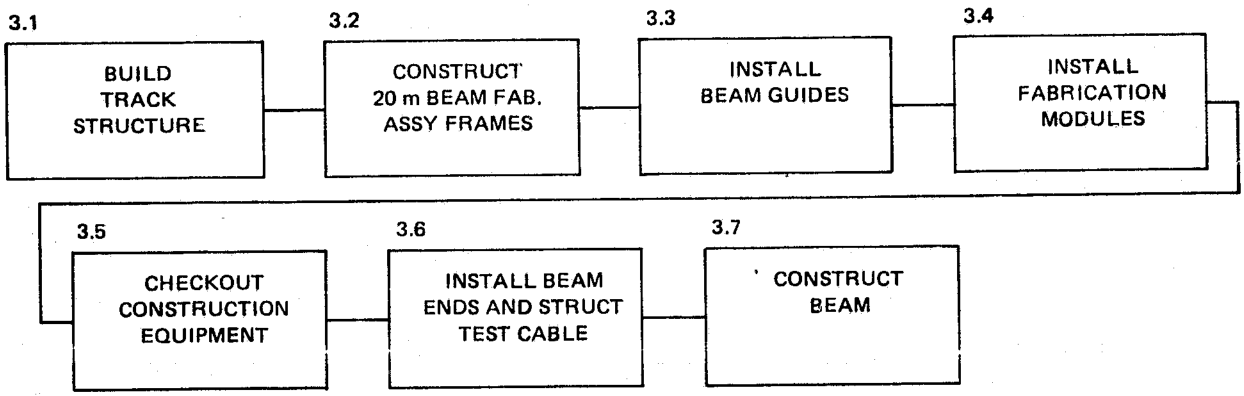
Table 6-32 Functional Operations Scenario – Function 3.0 20 m Beam Fabrication



TIME HR:MIN	OPERATIONS	REMARKS
(12:30)	BUILD TRACK STRUCTURE	
2:00	INSTALL FRAME LEG PLATFORM ATTACHMENTS (4)	
1:00	MOUNT TRACK ASSEMBLY FIXTURE TO PLATFORM	
:45	DEPLOY TRACK STRUCTURE (3 SECTIONS)	
:45	ASSEMBLE TRACK	
1:00	INSTALL CHERRY PICKERS	
:30	RELEASE TRACK ASSEMBLY FIXTURE AND MANEUVER TO OPPOSITE SIDE	BOOM CHERRY PICKER
:30	MOUNT TRACK SUPPORT FIXTURE TO PLATFORM	
1:00	DEPLOY TRACK SUPPORT LEGS (4)	
2:00	INSTALL LEGS AND CABLES TO PLATFORM AND TRACK STRUCTURE (4)	
:30	INSTALL POWER CABLING	
:30	CHECKOUT CHERRY PICKER OPERATION	
2:00	ERECT TRACK SUPPORT STRUCTURE AND SECURE	TRACK CHERRY PICKERS
(17:30)	CONSTRUCT 20 m BEAM FABRICATION ASSY FRAMES	
3:00	INSTALL FRAME ATTACHMENT SUPPORTS (6)	BOOM CHERRY PICKERS
1:30	INSTALL A FRAME ASSY JIG IN PLATFORM	TRACK CHERRY PICKERS
2:15	DEPLOY A FRAME BEAMS (9)	
1:30	ASSEMBLE A FRAMES (3)	
3:00	REMOVE A FRAMES FROM JIG AND ATTACH TO SUPPORT (3)	
1:30	DEPLOY LONGERONS (6)	
3:00	ATTACH LONGERONS TO A FRAMES (6)	
1:00	INSTALL STIFFENING STAYS (12)	
(16:30)	INSTALL BEAM GUIDES	
6:00	MOUNT CARRIAGE TRACK SUPPORT STRUCTURE	
6:00	INSTALL CARRIAGE TRACKS (18)	
3:00	INSTALL BEAM CARRIAGES (6)	
1:30	INSTALL CABLE RIGGING CONTINUOUS BELT	
(23:00)	INSTALL FABRICATION MODULES	
12:00	MOUNT FAB. MODULE SUPPORT STRUCTURE	
8:00	INSTALL FAB & CONDUCTOR MODULES AND ALIGN (6)	2 FLIGHTS
1:30	CONNECT ELECTRICAL POWER CABLES	
1:00	MOUNT END FITTING SCAFFOLD ATTACHMENT	
1:00	INSTALL SCAFFOLD	

Table 6-32 Functional Operations Scenario — Function 3.0 20 m Beam Fabrication (Continued)

TIME HR:MIN	OPERATIONS	REMARKS
(8:00)	INSTALL SOLAR BLANKET & REFLECTOR DISPENSERS AND INSTALLERS	
1:00	MOUNT SOLAR BLANKET DISPENSER ATTACHMENT	
2:00	MOUNT REFLECTOR BLANKET DISPENSERS ATTACHMENT	
2:00	INSTALL DISPENSERS (2)	
2:00	MOUNT BLANKET INSTALLER ATTACHMENT SUPPORTS (4)	
1:00	INSTALL BLANKET INSTALLERS AND CONNECT POWER	
(10:30)	CHECKOUT CONSTRUCTION EQUIPMENT	
2:30	INSTALL MATERIAL CASSETTES TO FAB AND CONDUCTOR MODULES	1 FLIGHT 1 m/MIN.
1:30	OPERATE EACH MODULE	
1:30	VERIFY BEAM ALIGNMENT	
1:00	VERIFY CARRIAGE OPERATION	
1:30	VERIFY CABLE RIGGING	
1:30	VERIFY JOINT MODULE OPERATION	
1:30	VERIFY CONDUCTOR MODULE OPERATION	
(7:30)	INSTALL BEAM ENDS AND STRUCT TEST CABLE	
3:00	FAB. TRIPOD STRUCTURE AND INSTALL END FITTINGS	
3:00	ASSEMBLE TRIPOD TO BEAM END (2)	
1:00	INSTALL CABLE ATTACHMENT FITTINGS	
:30	ATTACH STRUCTURE TEST CABLE	
(22:30)	CONSTRUCT BEAM (246.5 m LONG)	
:45	FABRICATE FIRST SECTION	
1:30	FAB. AND INSTALL LATERAL FRAMES	
1:30	INSTALL AND TENSION STAYS (6)	
3:45	FABRICATE SECOND THRU SIXTH SECTION	
7:30	FAB. AND INSTALL LATERAL FRAMES	
7:30	INSTALL & TENSION STAYS	
118:30	TOTAL FOR CONSTRUCTION FOUR SHUTTLE FIGHTS	

time to complete the construction are listed. Other operations that are not specifically part of this experiment but follow in sequence after the beam has been constructed are included for convenience in this scenario. They are the conductor fabrication module installation solar blanket and the reflector dispenser installation. As indicated in the Table, 118 1/2 hours are projected for the construction scenario.

6.2.4.4 Orbital Tests. The test objectives and requirements associated with the 20-m beam fabrication are indicated in Tables 6-33 and Figure 6-40. The tests will satisfy the Demo/Test objective, space fabrication of a building block structure for the development of solar power satellite systems. The test objectives discussed under Test Rational (Table 6-33) address the producibility and integrity of space fabricated structural members.

Table 6-34 lists some of the parameters considered in choosing the test article against the nominal 5 GW SPS pilot plant discussed in NASA Study report Contract No NAS 8-31308 dated 30 June 1975 which was used as the design reference point. Option 2 was chosen because it provides information on one of the design reference beam lengths in composites. Composites were selected rather than Al 2219-T6 (design reference) because expected temperature gradients will cause potentially severe distortions and internal stress using aluminum structure.

Figure 6-40 illustrates a scenario for conducting the 20-m beam structural tests. The test scenario includes erection and dimensional checks of the fixture, check-out of the individual fabrication modules, and initial tests to establish the synchronization of the individual fabrication modules. Truss element dimensional accuracy and straightness will be tested throughout the production process to determine the repeatability of the fabrication process. A concept in which the OCDA rotating boom is used to hold the completed 246.5 m structure for a compression test is also shown. Compression loads are applied using an actuator turnbuckle arrangement. The beam could be enclosed in a cylindrical steel mesh for safety during the destructive tests. The boom manipulator is also used to support the beam for vibration tests. Preliminary analysis indicates the manipulator could be used as a shaker to provide the .2 to .5 cps forcing function.

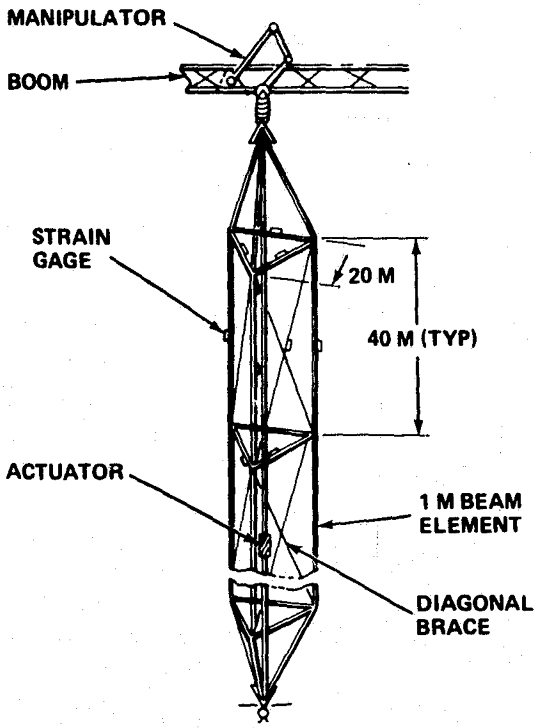
Table 6-35 is a list of the mission peculiar equipment and the estimated mass for each item.

6.2.5 Mission 5 - Conductor Installation

Conductor installation for the SPS systems is a critical operation because of the many miles of conductor involved, and the high voltage and currents which the conductor must eventually carry. The activities described in the following sections will provide some of

Table 6-33 Orbital Construction Experiment Definition – SPS Photovoltaic Development, Program Scenario 2 – Structures

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
BUILDING BLOCK STRUCT FAB AND/OR DEPLOY - FABRICATE 20 m BEAMS FOR SPS PRIMARY STRUCT	1. VERIFY SYNCHRONIZATION OF MACHINES REQUIRED TO BUILD 20 m BEAMS REQUIREMENT 1 FT/MIN 2. VERIFY DIMENSIONAL ACCURACY REQUIREMENT 1 FT/100 FT 3. VERIFY INDIVIDUAL MACHINE OPERATING PARAMETERS, I.E., PINCH UP FORCES, SPEED OF CONTROL SYSTEM PLUS OVERALL SENSING AND SYNCHRONIZATION SYSTEM REQUIREMENTS MACHINE OPS ROLLER FORCES-TBD FEED RATES-TBD LINEAR FEED-TBD SENSING AND CONTROL 4. DETERMINE ASSEMBLY TIMES FOR 20 m BEAMS REQUIREMENTS ASSEMBLY RATE - 1 m/MIN 5. DETERMINE EFFECTS OF LEO TEMP VARIATION ON FAB, BEAM INTEGRITY AND STRAIGHTNESS EXPECTED -50° TO -200°F Δ 100°F BETWEEN UPPER AND LOWER CAPS 6. BEAM COLUMN MATERIAL - COMPOSITES LENGTH - 246.5 m 7. STRUCTURAL INTEGRITY TESTS REQUIREMENTS COMPRESSION - LOAD TO ULTIMATE IN 20 LB STEPS STARTING AT 1000 LB VIBRATION - MEASURE LATERAL AND VERTICAL AXIS NATURAL FREQUENCY .2 TO .5 CPS EXPECTED	1. TELEMETRY SYSTEM FOR SPACE FAB MACHINE PARAMETERS 2. OPTICAL ALIGNMENT SYSTEM (LASER) 3. VIDEO EQUIPMENT TO RECORD AND MEASURE ASSEMBLY RATES 4. SPACE FAB PRODUCTION RATE SENSORS	THE OBJECTIVE IS TO VERIFY THE ABILITY TO GANG 1 m SPACE FAB MACHINES (DEVELOPED ON SORTIE MISSIONS) TOGETHER TO PRODUCE 20 m BEAMS WHICH WILL BE USED FOR THE PILOT SPS PHOTOVOLTAIC SOLAR ARRAY. MAJOR THRUST WILL INCLUDE ALIGNMENT, SYNCHRONIZATION AND CONTROL OF MACHINES REQUIRED TO PRODUCE 20 m BEAM COLUMNS. VERIFICATION OF INDIVIDUAL MACHINE OPERATING PARAMETERS PLUS OVERALL FABRICATION AND ASSEMBLY RATES. THESE TEST RESULTS WILL VERIFY THE PRODUCEABILITY OF 20 m BEAMS AND IDENTIFY THE CRITICAL AREAS AS A PRECURSOR TO PRODUCTION OF LARGE SPACE STRUCTURES. THE STRUCTURAL INTEGRITY OF THE SPACE PRODUCED BEAMS WILL ALSO BE VERIFIED.



TEST SCENARIO

- DETERMINE PRODUCIBILITY
  - ERECTION OF FAB RIG
  - C/O & SYNC OF FAB MODS
- MEASURE FAB RATE
  - TRUSS ELEMENT
  - END FITTINGS
- MEASURE ACCURACY
  - DIMENTIONAL
  - STRAIGHTNESS
- VERIFY STRUCTURAL INTEGRITY
  - JOINTS
  - COMPLETE 246 M BEAM
- EVALUATE THERMAL EFFECTS
  - RECORD TEMP VARIATION
  - WARPING
  - INDUCED LOADS
  - STRAIGHTNESS
  - LONG PERIOD EFFECTS
- OPS ANALYSIS OF VIDEO TAPES AND FILM

Figure 6-40 20-m Beam Test Description

Table 6-34 Solar Array 20-m Structural Tests

SPS SOLAR ARRAY STRUCTURAL MEMBER DESIGN REQUIREMENTS	5 GW SPS NOMINAL	OCDA TEST REQUIREMENTS		
		OPTION 1	OPTION 2	OPTION 3
SIZE OF PRIMARY STRUCT. MEMBERS	246.5 m X 20 m 493 m X 20 m *1479 m X 213 m	246.5 m X 20 m	246.5 m X 20 m	369.4 m
MATERIAL	AL 2219 - T6	2219 - T6	GRAPHITE EPOXY	GRAPHITE EPOXY
WEIGHT	1.08 LB/m	1.08 LB/m	.864 LB/m	.864 LB/m
E	10.5×10^6 Psi	10.5×10^6 Psi	8×10^6 Psi	8×10^6 Psi
ρ	$.103$ LB/m^3	$.103$ LB/m^3	$.06$ LB/IN.^{3}	
AXIAL LOAD FOR 1479 m X 213 m BEAM	1932 LB			
STRUCTURAL TESTS				
• AXIAL LOADS		X	X	X
• LATERAL VIBRATION		X	X	X
• LONGITUDINAL VIBRATION		X	X	X
• ENVIRONMENTAL TEMP		X	X	X
• EFFECTS				

OPTION 2 RECOMMENDED FOR TEST

Table 6-35 20-m Beam Fabrication

ELEMENT	MASS	
	LB	KG
• FRAME ASSEMBLY (1)	(3657)	
– MAIN STRUCTURE	1527	693
– PLATFORM	300	136
– RAILS	170	123
– SCAFFOLD	400	181
– CARRIAGE	300	136
– PRETENSION DEVICE	20	9
– POWER DIST. AND CONTROL	300	136
– SWING ARMS	330	150
– ALIGN FIXTURE	180	82
– LIGHTING	30	14
– CABLE RIGGER	100	45
• FABRICATION MODULE (6)	33000	14982
• CREW MODULE	6000	2724
• SPECIAL MANIPULATORS	–	–
• MATERIAL	4300	1952
TOTAL	46957	21318

the pertinent verification data required. The 597-m long conductor with a .04-cm x 78.5-cm cross section will be loaded to slightly over the 795 amps/sq cm, duplicating the current density of the ultimate SPS conductor. A separate test will evaluate conductor performance at 40 kV. This will provide data relative to the losses, heating and proper isolation of SPS conductors.

6.2.5.1 Mission Objectives and Requirements. Meeting the mission objectives and test requirements listed below will verify the ability to synchronize conductor production and installation with the 20-m beam fabrication. It will also verify the conductor's ability to carry high currents (795 amps/sq cm) without producing local hot spots at the joints or creating electromagnetic torques and/or current flows which would interfere with the production process or create other problems. High voltage effects, i.e., local plasma effects, isolation from adjoining structure, and electrostatic surface charges, would be investigated during this activity. Thermal effects on the overall production process and the electrical properties of the conductor would also be established. Specific objectives include:

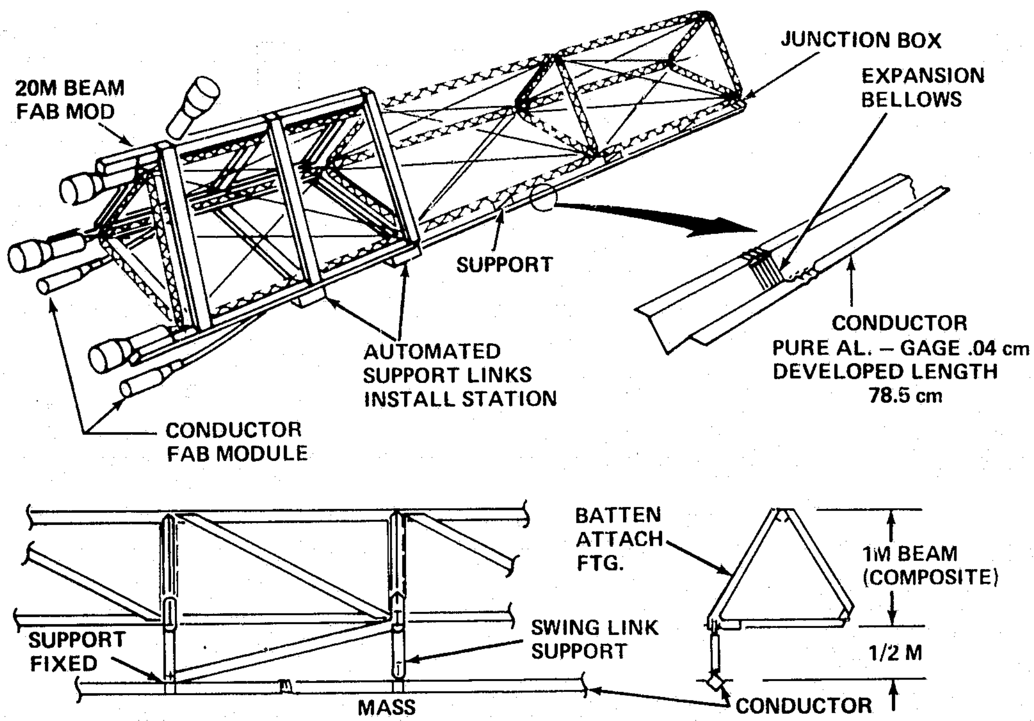
Mission Objectives - Verify:

- Synchronization of conductor and 20-m beam fabrication process
- Conductor current carrying capability
- High voltage isolation

Test Requirements - Determine:

- Compatability of conductor/20-m beam fab
- Fabrication rate
- Structural accuracy of 20-m beam/conductor combination
- Effects of high current (795 amps/sq cm) flow
- High voltage (40 kV) isolation
- Thermal cycle effects.

6.2.5.2 Configuration. Figure 6-41 illustrates how the conductor installation will be synchronized with the fabrication of the 20-m beam. The upper left-hand drawing shows how conductor fabrication modules are incorporated into the 20-m fabrication fixture so that they can be synchronized with the 20-m fabrication modules. As the 20-m truss



	MASS LB	MASS KG	POWER REQD
FAB MOD & SUPPORT HDWR	2650	1203	290 KW

Figure 6-41 Conductor Installation

elements are manufactured, the conductor elements are also fabricated. The conductor is scaled down from a full scale SPS. It is based on a minimum weight conductor with high current density capability and, therefore, large surface area for heat rejection. The conductor configuration employs a deep V trough for stiffness with expansion bellows between a fixed and swing link support. This permits the conductor to expand independently of the 1-m composite support beam. The supports are attached at the battens of the 1-m beam and can be spaced at intervals which will satisfy the dynamic requirements.

The installation requires two conductor fabrication modules with automated support link installation stations. Junction boxes are used to join the lateral and longitudinal conductors at the 20-m beam tripod.

6.2.5.3 Construction Operations. Conductor installation is a single function, so it was not practical to include a separate scenario in this section. However, the operations associated with conductor installation are listed in Table 6-32 in logical sequence, during construction of the 20-m beam.

6.2.5.4 Orbital Tests. Tables 6-36 and 6-37 provide the test objectives and requirements for a power bus representative of the ultimate SPS reference design. Of prime concern is the ability to synchronize the fabrication and the mounting of the bus with fabrication of the 20-m beam elements. The ability of the conductor to pass the high currents without undue distortion or the creation of local hot spots and the ability of the installation to operate at high voltages are also primary objectives. The latter could be aggravated by local plasma concentrations caused by the by-products of the attitude control and station keeping propulsion systems. Also of interest is the structural integrity of the conductor. Table 6-37 summarizes the results of trades conducted in arriving at the recommended test requirements. An analysis similar to that conducted for Scenario 1 was conducted using the increased OCDA experiment power available (500 kW) to determine the conductor size.

Initial calculations, Option 1 column of Table 6-37 indicated that the current density desired, 795 amps/sq cm, could not be attained even with the 2.5 kAmp available from the 500 kW solar array, if the cross sectional area of the ultimate SPS conductor was used. Option 2 indicates that the gauge of the material (conductor thickness) has to be reduced to .01 cm to achieve the 795 amp/sq cm current density for a span of 312 cm. This is impractical because the .01-cm gauge is too thin - roughly equivalent to heavy duty aluminum foil. Option 3 in which the current density of 795 amps/sq cm is achieved

Table 6-36 Orbital Construction Experiment Definition — SPS Photovoltaic Development, Scenario 2 — Power Distribution

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
INSTALL INTEGRATED STRUCTURE/BUS SYS - SPACE FAB NON STRUCTURAL DC SOLAR ARRAY BUS	1. VERIFY ORBITAL FAB AND ASSEMBLY RATE FOR SOLAR ARRAY SCALED DOWN BUS. REQUIREMENTS MATERIAL - AL6101 @ $3\mu\Omega$ cm^2/cm CROSS SECT AREA .629 cm^2 FAB RATE 1 FT/MIN ASSEMBLY RATE 10 MIN/SECT. 2. VERIFY CONDUCTIVITY OF ASSEMBLY REQUIREMENTS I_D (CURRENT DENSITY) = 795 I/cm^2 3. CONDUCT HIGH VOLTAGE INSULATION BREAKDOWN TESTS REQUIREMENT ISOLATION = 40 KV 4. DETERMINE THERMAL CYCLE EFFECTS INCLUDING ALIGNMENT 5. DETERMINE OPERATIONAL PROBLEMS.	• VIDEO RECORDERS TO MEASURE FAB AND ASSEMBLY RATES • TEMP, VOLTAGE AND CURRENT INSTRU PLUS TELEMETRY • ALIGNMENT TOOLS	THE OBJECTIVE OF THIS TEST WILL BE TO MANUFACTURE AND INSTALL A TYPICAL SPS BUS SECTION TO EVALUATE PRODUCTION AND PERFORMANCE CHARACTERISTICS PRIOR TO BUILDING PILOT POWER PLANT. THIS EXPERIMENT WOULD UTILIZE 20 METER BEAMS IN ORDER TO REPRESENT TYPICAL SPS STRUCTURE FOR EVALUATION OF INSTALLATION AND THERMAL CYCLE CONSIDERATION. IT WOULD UTILIZE THE END CAP FAB UNIT TO PRODUCE THE CONDUCTOR.

Table 6-37 Solar Array Electrical Bus Test Requirements

SOLAR ARRAY POWER DESIGN PARAMETERS	5 GW SPS NOMINAL	OPTION 1	OPTION 2	OPTION 3
PWR AVAILABLE	5 GW	500 KW	500 KW	500 KW
SOLAR ARRAY DIST. VOLTAGE	40 KV	*200 V/40 KV	*200 V/40 KV	*200 V/40 KV
CURRENT	200 KA	2.5 KA	2.5 KA	2.5 KA
CONDUCTOR AREA, cm^2	12.5	12.5	3.14	3.14
GAUGE, cm	.04	.04	.01	.04
SPAN, cm	312	312	312	78.5
CURRENT DENSITY AMPS/cm^2	795	202	795	795
BUS LENGTH METERS		597 m	597 m	597 m
TESTS				
SPACE FAB			x[2]	x[1]
CURRENT CARRYING LOCAL HEATING		x[3]	x	x
HIGH VOLTAGE ISOLATION		x	x	x

OPTION 3 SELECTED FOR TEST

[1]END CAP FAB UNIT USED TO MFG CONDUCTOR SPA 25% OF NOMINAL
[2]CONDUCTOR GAUGE 25% OF NOMINAL
[3]CURRENT DENSITY $\in \approx$ 25% OF NOMINAL
*200 VDC AVAILABLE TO BE BOOSTED TO 40 KV FOR ISOLATION TESTS

using the .04 cm gauge material but with a conductor span of 78 cm rather than the SPS span of 312 cm is recommended. This provides:

- A current density of 795 amps/sq cm
- Utilization of the proper material - .04 cm (.015 in.) gauge Al.

The only significant parameter that is not duplicated is the conductor span which turns out to be 1/4 of the SPS design. This results in a fabrication installation which is smaller than the ultimate SPS unit. Stand-off insulators are mounted at offset distances that duplicates the ultimate SPS design for verifying the insulation and isolation arrangement. For high voltage tests needed to verify conductor isolation, the normal 200 kVDC OCDA voltage sources must be boosted to 40 kVDC using DC to DC conversion.

Test Scenario

- Determine producibility
  - Synchronization of cond/20-m beam fabrication modules
  - Synchronization of auto support link install station
  - Installation of junction boxes and system protection devices
- Measure fabrication of rate
  - The Conductor Fabricator
  - The attachment mechanism.
- Measure accuracy (dimensional and straightness)
- Measure effects of high current flow, e.g.,
  - Local hot spots
  - Voltage drops
- Measure high voltage effects, e.g.,
  - Local plasma effects
  - Support structure isolation
- Measure thermal effects, e.g.,
  - Integrity of structure
  - Power transfer characteristics.

The test scenario above verifies the sequence of events necessary to synchronize the fabrication and installation of the conductor with that of the 20-m beam elements and to test the installation electrical properties.

After the conductor fabricator initial setup, the check-out and production cycle is initiated, the fabrication/installation rates are measured and the beams/conductors are checked for straightness and dimensional accuracy. Upon completion of the conductor production phase, high currents and voltages will be applied to the installation to measure heating and insulation properties and to observe the dipole, plasma and electrostatic effects associated with the high currents and voltages. In addition to providing data on the phenomena associated with high voltages and currents, these test activities will provide verification on the methods used to connect and terminate high power conductors, the circuit protection devices and power switches used in this experiment.

Table 6-38 is a list of the mission peculiar equipment and the estimated mass of each item.

6.2.6 Mission 6 - Rotary Joint Installation

The SPS rotary joint must provide transfer of high voltage power as well as structurally support the large microwave antenna while minimizing friction disturbances at the rotary interface with the solar array. The OCDA activity of installing and testing a scaled SPS rotary joint will verify assembly and performance for one of the rotary joint concepts currently being considered. The rotary joint test article is a scaled down version of the ball joint concept included in the JSC report JSC 11568, Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts - Volume II, dated 31 August 1976.

6.2.6.1 Mission Objectives and Requirements. The mission objectives and test requirements outlined below verify the electrical, mechanical and structural performance of the rotary joint. The test requirements will verify the assembly rates involved in mating the preassembled rotary joint to the structure and the ability of the ball joint drive mechanism to provide the required rotation of pointing accuracy of 1 arc minute under load. Electrical tests will verify the slip ring brushes ability to transfer high currents (7.75 amps/sq cm) at the high voltage (40 kVDC). Becuase of the close tolerance of the moving mechanical parts, the ability of the rotary joint to function properly throughout the day-night temperature variations plus the temperature gradients generated by the high current flow is of particular interest in development of an operational rotary joint design.

Table 6-38 Conductor Installation

ELEMENT	MASS	
	LB	KG
• FRAME ASSEMBLY INTERFACE EQUIP.		
– CONDUCTOR FAB MODULE SUPPORTS	220	100
– GUIDES		
– SUPPORT LINKS INSTALL. STATION	N/A	N/A
– SWITCH BOX AND JUNCTION INSTALL. STATION	N/A	N/A
• CONDUCTOR FAB MODULE		
– FAB MODULE	2200	999
• SUPPORT EQUIPMENTS		
– SUPPORT LINK INSTALLER	230	104
– SWITCH BOX AND JUNCTION INSTALLER	N/A	N/A
• ORBITAL TEST EQUIPMENT	N/A	N/A
– DC TO DC CONVERTER		
TOTAL	2650	1203

Mission Objectives

- Evaluate rotary joint installation problems
- Verify performance in LEO environment
- Verify power transfer capability.

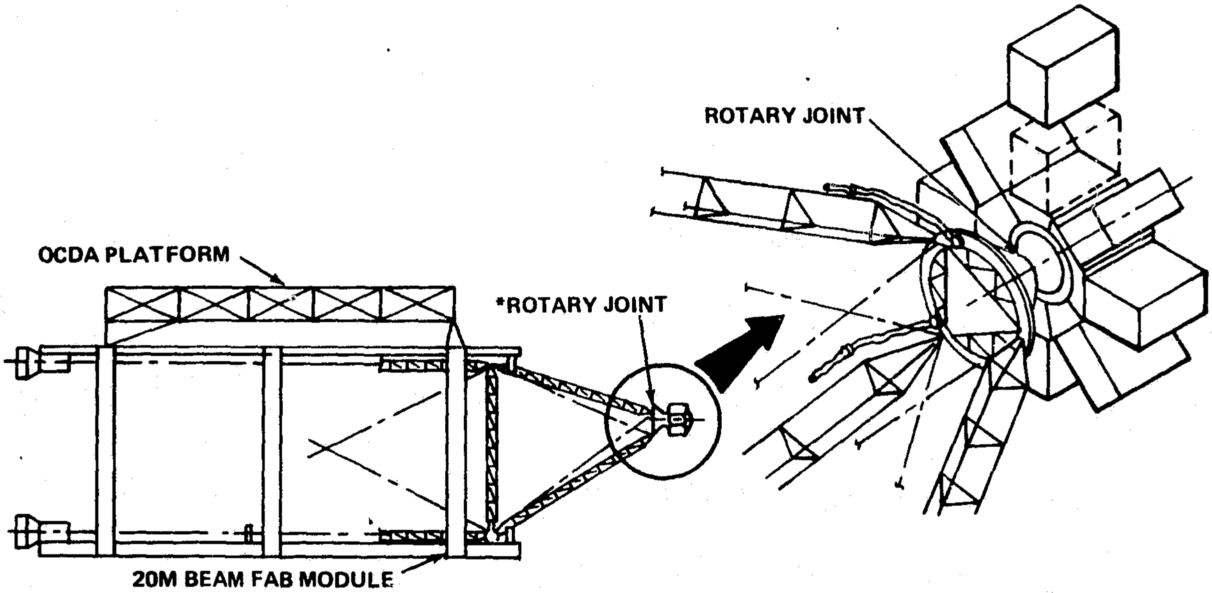
Test Requirements

- Determine assembly rates
- Determine operation of ball joint drive system (Rotation 15°/hr Elevation ± 10°)
- Determine high current transfer effects (7.75 amps/sq cm/brush)
- Determine high voltage effects (40 kV)
- Determine temperature variation of components for LEO environment
- Evaluate operational procedures.

6.2.6.2 Configuration. The rotary joint configuration used in Program 2 is shown in Figure 6-42. The three beam elements normally used for the apex fitting of the 20-m beam truss structure will serve as a tripod for attaching the rotary joint to the 20-m beam. The typical antenna load will be simulated by using an assembly which provides mechanical load to the rotary joint while housing the electircal load banks required for the high current and voltage tests. The tripod structural members used are identical to the 1-m deep battens fabricated for the 20-m deep structural elements.

6.2.6.3 Construction Operations. Table 6-39 lists the construction operations indicating that five hours are required for total rotary joint installation. Two hours are required for the actual assembly of the rotary joint to the tripod and three hours are needed to install the load banks used in the high current and voltage tests.

6.2.6.4 Orbital Tests. Table 6-40 and 6-41 list the rotary joint test objectives and requirements. The primary concern is the rotary joint's ability to transfer electrical power, provide a structural connection between mating structures and proper rotation of the joint. Of special interest will be the performance of the close tolerance assemblies during variations in the thermal environment. The rotary joint described in JSC 11568 section IV - C-8 was used as the nominal 5-GW SPS design. Table 6-41 lists the prime



MASS REQUIREMENTS

ELEMENT	LB	KG
• ROTARY JOINT AND MAST	6195	2813
• ORBITAL TEST EQUIPMENT	459	208

POWER REQUIREMENTS

291 KW AT 40 KV FOR HI VOLT TESTS

313 KW AT 200 V FOR CURRENT TESTS

*REFERENCE JSC 11568

Figure 6-42 Rotary Joint Configuration

Table 6-39 Functional Operations Scenario – Function 5.0 Rotary Joint Installation

5.1 INSTALL ROTARY JOINT — 5.2 INSTALL CURRENT LOAD BANK — 5.3 INSTALL VOLTAGE LOAD BANK

TIME HR:MIN	OPERATIONS	REMARKS
(2:00)	INSTALL ROTARY JOINT	
:15	TRANSFER JOINT FROM P/L BAY TO TRANSPORTER	ORBITER RMS
:05	TRANSPORT TO BOOM CHERRY PICKER	
:10	TRANSFER JOINT TO TRACK CHERRY PICKER	
1:00	POSITIONS AND FASTEN JOINT TO BEAM END	
:30	CONNECT ELECTRICAL POWER CABLES	
(1:00)	INSTALL CURRENT LOAD BANK	
:30	TRANSFER LOAD BANK FROM P/L BAY TO JOINT	
:30	POSITION AND FASTEN LOAD TO JOINT	
(2:00)	INSTALL VOLTAGE LOAD BANK	
:30	DISCONNECT CURRENT LOAD AND REMOVE FROM JOINT	
:30	TRANSFER CURRENT LOAD TO P/L BAY	
:30	TRANSFER VOLTAGE LOAD BANK FROM P/L BAY TO JOINT	
:30	POSITION AND FASTEN LOAD TO JOINT	
5:00	TOTAL FOR CONSTRUCTION 1 SHUTTLE FLIGHT	

Table 6-40 Orbital Construction Experiment Definition – SPS Photovoltaic Development – Power Distribution

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
INSTALL ROTARY POWER TRANSFER DEVICE - INSTALL ROTARY JOINT VERIFY MECHANICAL AND ELECTRICAL INTEGRITY	1. VERIFY INSTALLATION OF ROTARY JOINT REQUIREMENT INSTALLATION AND VISUAL INSP 2 HRS 2. VERIFY OPERATION OF BALL JOINT DRIVE AND SUSPENSION SYSTEM REQUIREMENT ROTATION 15°/HR ±.5°/MIN ELEVATION ±10° 3. VERIFY POWER TRANSFER REQUIREMENT DISTRIBUTION SYSTEM 40 KV HI VOLTAGE TEST 7.75 A/cm² - CURRENT DEN. PER BRUSH TESTS 4. VERIFY TEMPERATURE DISTRIBUTION AND VARIATIONS DURING OPERATION IN LEO ENVIRONMENT REQUIREMENT TEMP VARIATIONS -50° TO -200°F 5. MEASURE TEMP OF DRIVE MECHANISM OUTER RACE, INNER RACE, BRUSHES	• VIDEO AND TIMING EQUIPMENT FOR VERIFYING INSTALLATION PROCEDURES AND TIMES • BALL JOINT DRIVE AND BALL JOINT INSTRUMENTATION FOR MEASURING BALL JOINT DRIVE SERVO-OPERATION, ANTENNA ROTATION, TEMPERATURES OF BALL JOINT BRUSHES, SERVO STRUCTURE, VOLTAGE, AND CURRENTS. • TELEMETRY SYSTEM	THE OBJECTIVE OF THIS TEST IS TO SIMULATE THE INSTALLATION OF ROTARY JOINT ASSEMBLY ON THE SPS SOLAR ARRAY AND ANTENNA TO EVALUATE THE POTENTIAL PROBLEMS ASSOCIATED WITH THE INSTALLATION OF CLOSE TOLERANCE ASSEMBLIES OF SPECIAL INTEREST WILL BE THE PERFORMANCE DURING THE VARIATION IN THE LEO THERMAL ENVIRONMENT, I.E., BINDING, JITTER, ABNORMAL HEATING AND POWER TRANSFER. THIS TEST WILL BE PERFORMED AFTER GROUND TESTS HAVE DEFINED THE NORMAL OPERATING PARAMETERS AND MEASURED THE OUTGASSING CHARACTERISTICS OF THE MATERIALS USED ESPECIALLY FOR THE BRUSHES. THE HIGH VOLTAGE TESTS WILL BE CONDUCTED USING A KLYSTRON DUMMY ANTENNA LOAD. THE CURRENT DENSITY TEST WILL BE CONDUCTED USING A 500 KW LOAD BANK.

Table 6-41 Solar Array Rotary Joint Test Requirements

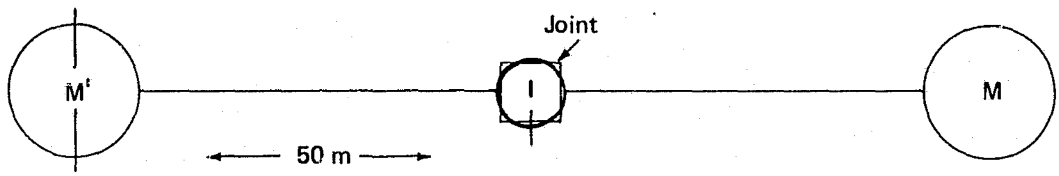
SPS ROTARY JOINT DESIGN PARAMETERS	5 GW SPS NOMINAL DESIGN	OCDA 500 KW ARRAY	
		OPTION 1	OPTION 2
ROTARY BALL JOINT OUTER DIAMETER	7.6 mD	3 mD	3 mD
POWER TRANSFER	40 KV 250 KA	200 V 2.5 KA	200 V 2.5 KA
BRUSHES	5000	800	50*
AREA (CROSS SECT) cm^2	64.5	64.5	64.5
CURRENT DENSITY AMPS/cm^2	.78	.05	.78
CONDUCTOR R /m AL	2.9×10^{-8}	2.9×10^{-8}	2.9×10^{-8}
POWER LOSS W/m	1824	.18	.18
ROTATION	15°/HR	15°/HR	15°/HR
DIAMETER	500 m	50 m	
MASS (M)	5.25×10^6 KG	$.63 \times 10^6$ KG	
INERTIA (I)	3.28×10^{11} KG m^2	3.15×10^9 K	
TORQUE ON JOINT			
NEW TON METERS	1200	-------------	**11.50
LBS INCHES	106020.45	-------------	101.75
*NUMBER OF ACTIVE BRUSHES **COUNTER RATIONAL TORQUE			
TESTS			
• SPACE INSTALLATION		X	X
• CURRENT CARRYING			X
• THERMAL		X	X
• MECHANICAL (ROTATION)		X	X

OPTION 2 RECOMMENDED FOR TEST

parameters for the nominal design in the first column. Keeping the mass density constant and scaling the mass and moment of inertia by the following factors:

- $L_s = .3947$ Length Scaling Factor
- $M_s = .0615$ Mass Scaling Factor
- $I_s = .0096$ Inertia Scaling Factor

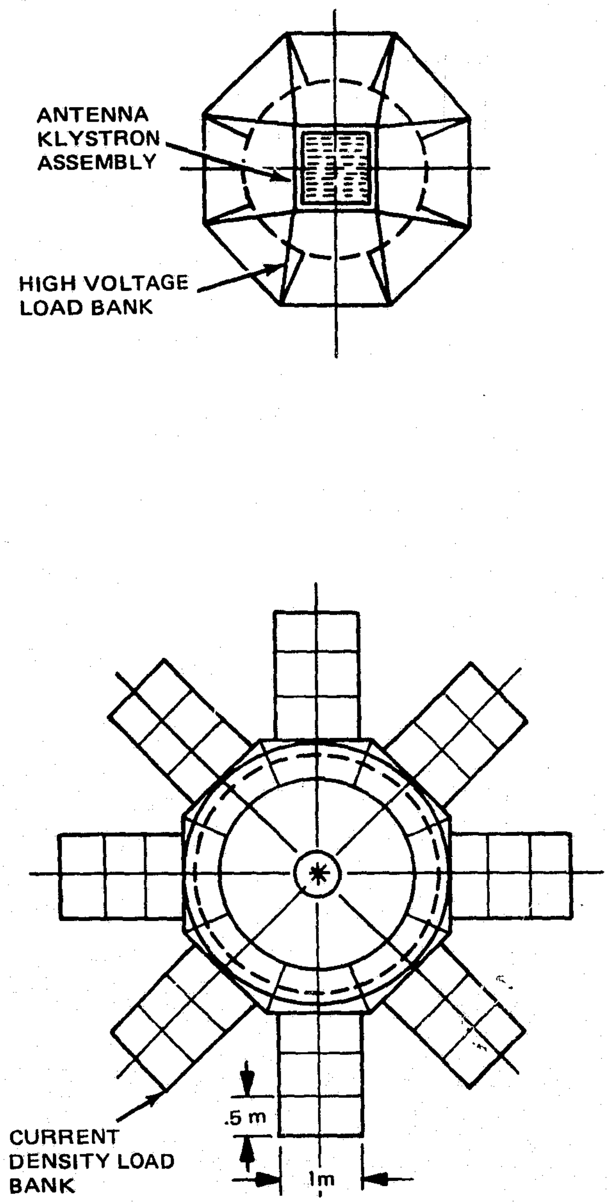
$I_1 = M_1 R_1/4^2$ (I for a disk) to represent the nominal antenna moment of inertia with $M_1 = 5.25 \times 10^6$ kg and R = 500 m, I is 3.28×10^{11} kg. Utilizing the scaling factors and assuming a test configuration inertia $I_2 = 2\ M_2\ R_2^2$ based on the configuration shown in the sketch below



Provides a $M_2 = 6.3 \times 10^6$ kg = 1.386×10^6 lb required for a scaled down representation of the ultimate SPS design. Since it would take several flights (65,000 lb payload capability) just to deliver the mass, this approach was discarded in favor of utilizing a small mass in conjunction with a counter torque brake to simulate a torque of 1200 Newton meters (N-m) during rotation of the SPS joint. The scaled down torque is about 11.50 N-m or 101.75 in. lb. This can be readily achieved with a simple brake arrangement.

The power transfer tests can simulate the same current density as expected in the ultimate SPS rotary joint (.78 amp/sq cm) by energizing 50 of the 800 brushes designed into the scaled down rotary joint. The question of isolating the 50 current-carrying brushes from the remaining 750 brushes (required for structural reasons) remains an issue to be resolved.

Option 2 of Table 6-41 represents the test parameters, while figure 6-43 shows the two types of loads used for the electrical tests of the rotary joint and a test scenario describing the sequence of test events. Attachment of the rotary joint to the structure and installation of the plug-in load banks to the rotary joint is accomplished using the cherry picker. Electrical hook-up will be automatically accomplished as the load banks and power connections are mated to the rotary joint. Continuity and power on functional tests will also be accomplished remotely from the orbiter.



TEST SCENARIO

- DETERMINE PRODUCIBILITY
  - FIXED STRUCTURE
  - MOVABLE STRUCTURE
  - ELECTRICAL HOOK UP AND C/O
- MEASURE MECHANICAL PERFORMANCE
  - ROTATION 15°/HR
  - ELEVATION ± 10° TRAVEL; POSITION 1 ARC SEC
  - SMOOTH OPERATION NO BINDING OR JITTER
  - THERMAL EFFECTS ON PERFORMANCE
- MEASURE POWER TRANSER
  - TEMP RISE/HOT SPOTS (7.75 AMPS/BRUSH)
  - LOCAL ARCING (40 KV DC)
  - COMBINED ROTATION/POWER TRANSFER EFFECTS
- EVALUATE THERMAL CYCLE EFFECTS ON OPS
  - MECHANICAL
  - ELECTRICAL
- EVALUATE OPS PROBLEMS
  - SAFETY
  - C/O AND MAINTENANCE

Figure 6-43 Rotary Joint Test Description

For the mechanical tests (rotation and elevation) a simple brake arrangement will be used to simulate the design reference gravity gradient and dynamic unbalance torques since it is not practical to simulate the 1000-m diameter design reference antenna with a mass of 5.25×10^6 kg and an inertia of 3.28×10^6 kg. In order to duplicate the 7.95 amp/sq cm high current density through the brushes, approximately 5% of the total number of brushes required for structural purposes will be used to transfer the available power. For the high voltage tests, all of the brushes will be used to transfer the available power. The full rated current density tests will verify the thermal gradients resulting from the high current flows. The high voltage tests will verify the conductor isolation, joint arching within the brush assembly and adjacent structure throughout the travel of the moving parts.

Table 6-42 lists the mission peculiar equipment and the estimated mass of each item.

6.2.7 Mission 7 - Solar Blanket Installation

The purpose of this mission is to verify that the solar blanket installation can be synchronized with the fabrication of the 20-m beam elements without affecting the integrity or power output of the solar array.

6.2.7.1 Mission Objectives and Requirements. To meet mission objectives, it is required to verify installation of a solar cell blanket on a 20-m beam section. The principal issue in this activity is to verify that the solar blanket installation can be synchronized with fabrication of the 20-m beam so that the completed beam includes the solar cell blanket.

As indicated below, the test will verify the blanket installation through a detailed inspection and an electrical integrity test.

The mission objectives and associated test requirements are:

Mission Objectives

- Verify synchronization of solar cell blanket installation and 20-m beam fabrication
- Verify electrical integrity of installed solar cell blanket.

Test Requirements

- Determine compatibility of blanket installation and 20-m beam fabrication
- Inspect blanket installation (flatness, wrinkle free)
- Determine out power (measurements within 1% of ground values)
- Evaluate operational problems.

Table 6-42 Rotary Joint Installation Mass

ELEMENT	MASS	
	LB	KG
• INTERFACE FIXTURES/JIGS	N/A	N/A
• ROTARY JOINT/MAST	(6195)	(2810)
– ROTARY BALL JOINT	3150	1430
– MAST STRUCTURE	112	50
– POWER DISTRIBUTION	2933	1330
• SUPPORT EQUIPMENT		
– CABLE TENSION DEVICE	N/A	N/A
– ALIGNMENT OPTICS	N/A	N/A
– SCAFFOLD	N/A	N/A
• ORBITAL TEST EQUIPMENT	(458.8)	(208.5)
– LOAD BANK (LOW VOLTAGE)	352	160
– KLYSTRON (HI VOLTAGE)	106.8	48.5
– DC TO DC CONVERTER	N/A	N/A
TOTAL	6654	3019

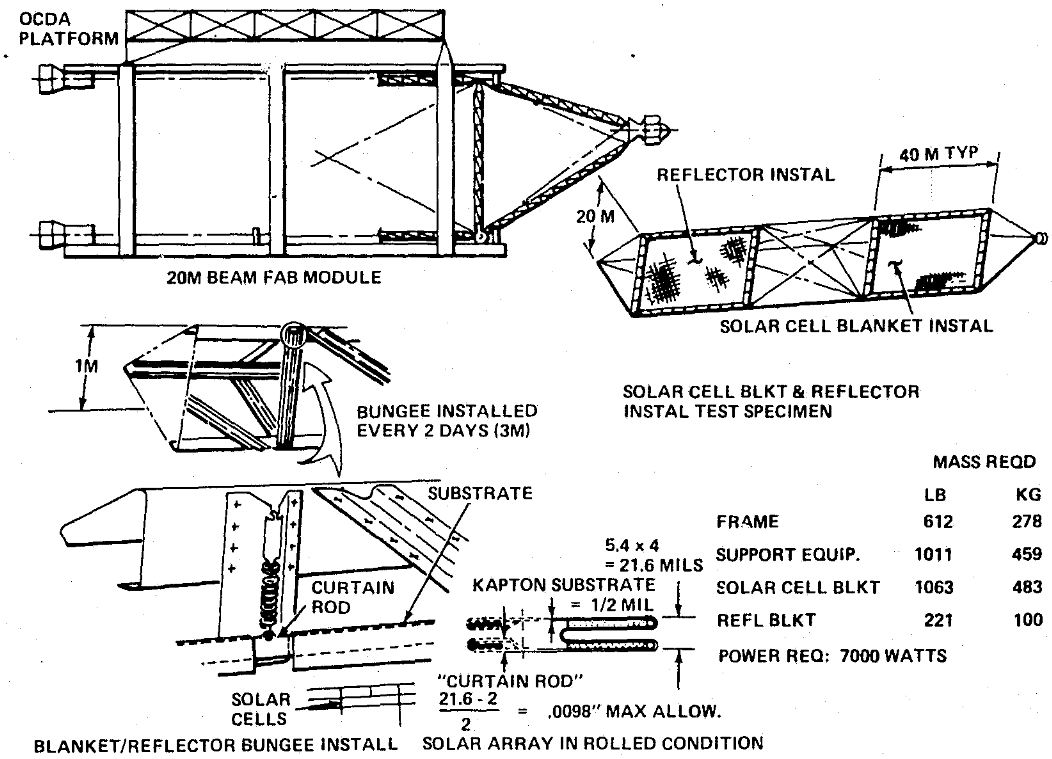
6.2.7.2 Configurations. To meet the test objections and requirements of the solar cell blanket installation activity, a test article 23 m wide by 40 m long has been selected for installation in one 40-m bay of a 20-m deep triangular structural element as shown in Figure 6-44. The solar cell blanket is suspended from the 20-m girder (1-m deep beam caps) by bungees as shown in Figure 6-44. This approach was taken to maintain flatness and eliminate the extreme stresses that would be induced into the beam caps if the blanket was rigidly attached during light/dark thermal cycling. The blanket configuration provides a reinforced edge (curtain rod) for attachment of the bungees to the blanket. The 23-m x 40-m blanket is folded and rolled onto a module for Shuttle delivery to the OCDA.

The 20-m girder fabrication module frame assembly (jig) is modified to provide support of the blanket module as shown in Figure 6-45. Installing the solar cell blanket during fabrication of the 20-m structure consists of unrolling the blanket in synchronization with the fabrication of the structure. As the blanket is unrolled, assembly of the bungees to the blanket is accomplished utilizing the bungees stowed in a cassette (2) mounted adjacent to the blanket module; each of the assembled bungees is then picked up by a guide track which is used to unwrap the blanket and deliver the blanket edge to its proper structural interface where a bungee installer attaches the blanket to the structure.

6.2.7.3 Construction Operations. The solar blanket construction operations are included in Table 6-32, 20 meter beam fabrication because they are synchronized with the beam fabrication operations. The blanket installation equipment could be installed in a single 8 hour shift.

6.2.7.4 Orbital Tests. Table 6-43 provides a listing of the solar array blanket test objectives and requirements. The primary objective for this mission is to verify the ability to synchronize the blanket installation with the fabrication of the 20-m beam elements. The blankets are unrolled and guided to the structural elements, and the sides of the blankets are attached to the structure automatically by the bungee installer. The cherry picker with an articulated manipulator is used to stitch the ends of the mating surfaces together. This sequence will be synchronized with the fabrication of the 20-m elements. The beam fabrication modules will be stopped while the stitching operation is in progress.

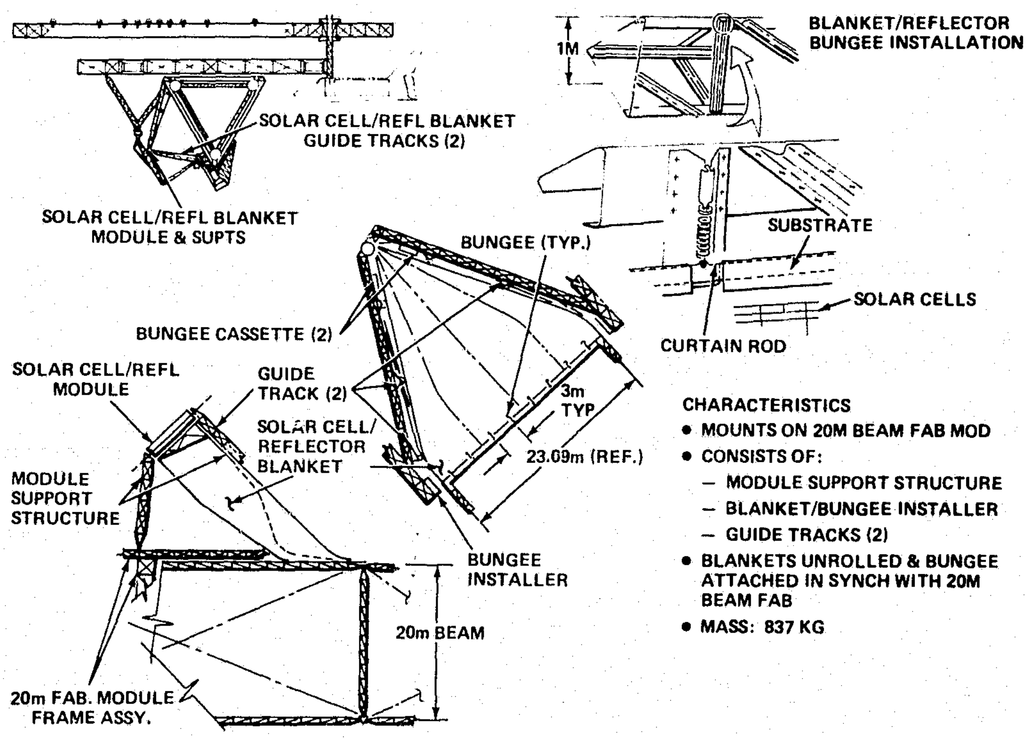
In addition to a meticulous inpsection of the blanket, developed during ground simulation, voltage and current measurements will be condutced. The criteria will be based on the results of ground measurements, with orbital power measurement requirements held to 1% of ground power measurements.



	MASS REQD LB	MASS REQD KG
FRAME	612	278
SUPPORT EQUIP.	1011	459
SOLAR CELL BLKT	1063	483
REFL BLKT	221	100

POWER REQ: 7000 WATTS

Figure 6-44 Solar Blanket and Reflector Installation



CHARACTERISTICS
- MOUNTS ON 20M BEAM FAB MOD
- CONSISTS OF:
  - MODULE SUPPORT STRUCTURE
  - BLANKET/BUNGEE INSTALLER
  - GUIDE TRACKS (2)
- BLANKETS UNROLLED & BUNGEE ATTACHED IN SYNCH WITH 20M BEAM FAB
- MASS: 837 KG

Figure 6-45 Solar Cell/Reflector Blanket Installation

Table 6-43 Orbital Construction Experiment Definition – SPS Photovoltaic Development, Scenario 2 – Solar Array

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
ARRAY TO STRUCTURE INSTALLATION - INSTALL 40 m X 23 m SOLAR CELL BLANKET CONFIGURATION WITH AN OUTPUT OF APPROXIMATELY 125 KW	1. VERIFY INSTALLATION OF SOLAR CELL BLANKET ROLLS REQUIREMENT: SOLAR CELL BLANKET INSTALLATION TO BE SYNCHRONIZED WITH 20 m BEAM FABRICATION 2. SOLAR CELL CIRCUIT PROTECTION AND DISTRIBUTION SYSTEM INSTALLATION AND OPERATION TO BE VERIFIED. REQUIREMENT: 125 KW @ 200 VDC 625 AMPS @ SOLAR ARRAY OUTPUT. OUTPUT POWER (CURRENT AND VOLTAGE) MEASUREMENTS WITHIN 1 PERCENT OF GROUND TEST RESULTS AS EXTRAPOLATED TO AMO.	VIDEO EQUIPMENT FOR RECORDING AND TIMING SOLAR ARRAY CONFIGURATION INSTALLATION VOLTAGE AND CURRENT PICKUPS TO MEASURE THESE PARAMETERS FOR THE TEST SOLAR ARRAY DISTRIBUTION SYSTEM POINTS. TELEMETRY AND DATA MANAGEMENT SYSTEM. 125 KW LOAD BANK (~1/4 OF ROTARY JOINT LOAD BANK)	THE OBJECTIVE OF THIS MISSION IS TO VERIFY THE ABILITY TO SYNCHRONIZE THE SOLAR ARRAY AND REFLECTOR BLANKETS INSTALLATION WITH THE FABRICATION OF THE 20 m BEAMS. THIS EXPERIMENT WILL INCLUDE THE VERIFICATION OF THE INSTALLATION. VOLTAGE/CURRENT TESTS WILL BE USED TO CHECK FOR DEGRADATION IN THE SOLAR ARRAY DUE TO PACKAGING, LAUNCH AND DEPLOYMENT

Table 6-44 Solar Blanket Installation Mass

ELEMENT	MASS	
	LB	KG
• FRAME ASSEMBLY ADDITIONS	(612)	(278)
– SUPPORT-BLANKET MODULE	342	155
– SUPPORT-GUIDE TRACK	50	23
– BLANKET/BUNGEE ASSY STATION	110	50
– BLANKET BUNGEE INSTALL STATION	110	50
• SUPPORT EQUIPMENT	(1011)	(459)
– SHIP AND DISPENSING MODULE	221	100
– GUIDE TRACK-BLANKET DEPLOY	625	384
– BUNGEE CASSETTE	55	25
– BLANKET BUNGEE INSTALLER	110	50
• SOLAR CELL BLANKET (23 m x 40 m)	1063	483
TOTAL	1623	737

Test Scenario

- Determine producibility of:
  - Positioning of blanket roll on rig
  - Initial rollout of blanket with manipulator
  - Attachment to crossmember on 20-m beam
- Synchronization of operations
  - Automatic installation of bungees
  - Stitching to structure at end of blanket
- Inspection of installation
  - Flatness
  - Wrinkle free
- Integrity electrical tests
  - Open CKT - voltage
  - Short CKT - current
  - Nominal load (volts and amps)

  } Within 1% of GRD Test Values
- Analyze video tape of each operation.

The test scenario indicates the steps required to set up the solar blanket and make the initial attachment to the 20-m beam cross sections, as well as synchronization of the automatic bungee installation machine with fabrication of the 20-m beam. The inspections will have to check for flatness. This could be accomplished with an optical tool using the boom as a reference plane which would plot the variations in distance from the boom to the blanket surface. Electrical tests would consist of open circuit voltage measurements, short circuit current measurements and voltage and current measurements with a nominal load on the solar blanket electrical bus. This blanket could also be configured to provide approximately 20 kVDC to check some of the problems associated with high voltage collection and distribution systems.

Table 6-44 is a list of the mission peculiar equipment and the estimated mass of each item.

6.2.8 Mission 8 - Reflector Installation

The purpose of this mission is to verify that the fragile reflector blanket installation can be synchronized with the fabrication of 20-m beam elements without affecting the integrity or reflectivity of the blankets.

6.2.8.1 Mission Objectives and Requirements. The mission and test objectives listed below will verify the ability to synchronize the installation of solar reflectors with the fabrication of 20-m structural beams. The machines and techniques for attaching the reflectors to the structural beam members are the same as those required for the solar blanket installation described for Mission 7.

Mission Objectives

- Verify synchronization of reflector blanket installation and 20-m beam fabrication
- Verify integrity of installed solar cell blanket.

Test Requirements

- Determine compatibility of blanket installation and 20-m beam fabrication
- Inspect blanket installation (flatness, reflectivity)
- Evaluate operational problems.

6.2.8.2 Configuration. To support the reflector installation test objectives and requirements, a test article 23-m wide by 40-m long has been selected for installation in one 40-m bay of a 20-m deep triangular structural article.

The reflector is suspended from the 1-m beam caps of the 20-m girder by bungees to maintain reflector flatness. Figure 6-44 shows the reflector configuration.

The reflector blankets provides a reinforced edge (curtain rod) for attachment of the bungee to the reflector. The reflector is folded and rolled into a module for Shuttle delivery to the OCDA.

The reflector blanket module is supported in the 20-m girder fabrication module frame assembly at the same station and support structure established for the solar cell blanket module as shown in Figure 6-45. Installing the reflector blanket during fabrication of the 20-m structure follows the same scenario as that of the solar cell blanket installation. The reflector is unrolled in synchronization with the structure fabrication; bungees are assembled to the reflector blanket and, in turn, each bungee is picked up by the guide track which unwraps the folded blanket and delivers the blanket edge to its proper structural interface where the bungee installer attaches the reflector to the structure.

6.2.8.3 Construction Operations. The construction operations for the reflector installation are included in Table 6-32 for the 20-m beam fabrication scenario.

6.2.8.4 Orbital Tests. The test objectives and requirements for the reflector installation are listed in Table 6-45. Of prime concern will be synchronization of the structural beam fabrication modules with the automatic machines used to clip the sides of the reflector blankets to the structure, and the cherry picker/articulated manipulator used to stitch the ends of mating reflector blankets together. The task will be to synchronize the operations so that the very thin aluminized mylar ($>$ .5 mils) will not tear or crinkle during installation while achieving the required assembly rates of 5 hours for each 40-m section. No performance tests are planned for the installation. Instead, a meticulous inspection of the reflector blanket will be conducted based on ground developed procedures to check the flatness; also, reflectivity tests will be conducted.

The test scenario includes a test sequence for the installation of reflector blankets and their verification. Verification that reflector blankets were not damaged during the installation will be accomplished through a detailed inspection of the blankets for damage, a flatness check (similar to that conducted for the solar cell blankets) and reflectometer tests. Portable reflectometers utilizing a filtered xenon light source, a thermopile detector and the associated optics required to measure the energy reflected by the blanket will be used to check for damage. All inspections and quantitative tests will utilize ground data on the same blanket to establish installation quality.

Test Scenario

- Determine producibility
  - Positioning of blanket roll on rig
  - Initial roll out of blanket with manipulator
  - Attachment to crossmember on 20-m beam
- Synchronization of operations
  - Automatic installation of bungees
  - Stitching to structure at end of blanket

Table 6-45 Orbital Construction Experiment Definition - SPS Photovoltaic Development, Program Scenario 2 — Solar Array

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
REFLECTOR INSTALLATION SYNCHRONIZE INSTALLATION OF 40 m X 23 m REFLECTOR WITH THE 20 m BEAM FABRICATION	1. VERIFY THE INSTALLATION OF THE SOLAR ARRAY REFLECTOR REQUIREMENT: REFLECTOR INSTALLATION TO BE SYNCHRONIZED WITH BEAM FABRICATION. INSTALLATION ASSEMBLY RATE 1 FT/MIN 2. INSPECT REFLECTOR INSTALLATION FOR FLATNESS AND SMOOTHNESS (WRINKLE-FREE) REQUIREMENT: FABRICATE TO AN ACCURACY OF 1 FT/1000 FT FOR BEAM FAB OPERATION AND 5 HR FOR COMPLETING 40 m BLANKET INSTALLATION INCLUDING END STITCHING OPERATION.	VIDEO EQUIPMENT FOR RECORDING AND TIMING SOLAR ARRAY CONCENTRATOR INSTALLATION LASER/OPTICAL EQUIPMENT TO MEASURE ACCURACY AND FLATNESS OF INSTALLATION	THE PROPOSED TESTS WILL VERIFY THE ASSEMBLY PROCEDURES AND THE SYNCHRONIZATION OF THE BEAM FAB MODULES AND THE CHERRY PICKER/MANIPULATOR AND OTHER MACHINES REQUIRED TO INSTALL THE REFLECTOR BLANKETS.

- Inspection of installation
  - Flatness
  - Reflectometer tests
- Evaluate video tape of each operation.

Table 6-46 is a list of the mission peculiar equipment and the estimated mass of each item.

6.2.9 Mission 9 - High Performance Transfer Stage Installation

The need to develop new high performance propulsion systems to transfer payloads from one orbit to another is a key issue in the development of the SPS. This mission activity provides performance data on one of the leading propulsion system candidates, the ion engine.

6.2.9.1 Mission Objectives and Requirements. The mission objectives require verification of the installation and performance of high thrust ion engines utilized for orbital maneuvers. The tests will verify installation times, operations and sequencing of various thruster combinations and the reaction of the OCDA to the net thrust developed.

Mission Objectives - Verify:

- Integration of electric propulsion system to large flexible structure
- Maneuvering capability.

Test Requirements - Determine:

- Installation rate/problems
- Control system operation
- Interaction of thrusters/flexible structure
- Power and fuel consumption
- Orbit maneuver performance.

6.2.9.2 Configuration. Figure 6-46 illustrates the installation of two ion propulsion units on the edge of the OCDA. Thses units are located equidistant from the center of mass of the OCDA configured with a 64-m x 77-m solar array and 33826 kg of construction equipment. The total mass is 106693 kg.

Table 6-46 Reflector Installation Mass

ELEMENT	MASS LB	MASS KG
• FRAME ASSEMBLY		
– SUPPORT MIRROR MODULE		
– SUPPORT GUIDE TRACK	N/A	
– MIRROR/BUNGEE ASSEMBLY STATION		
– MIRROR BUNGEE INSTALL. STATION		
• SUPPORT EQUIPMENT	(221)	(100)
– SHIP AND DISPENSING MODULE	221	100
– GUIDE TRACK BLANKET		
– DEPLOY	N/A	
– BUNGEE CASSETTE		
– MIRROR BUNGEE INSTALLED		
• MIRROR BLANKET (23 m x 40 m)	(44)	20
TOTAL	265	120

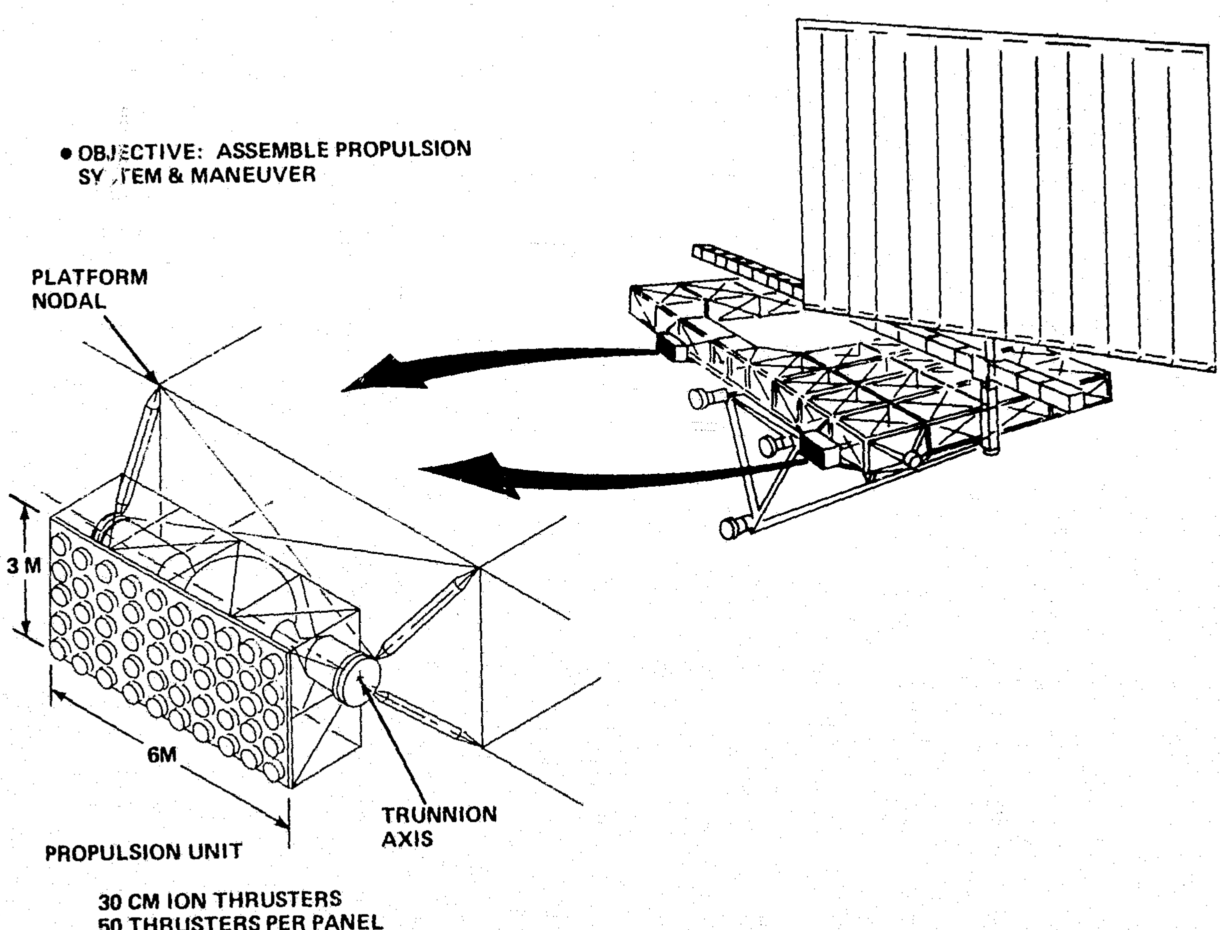


Figure 6-46 High Performance Transfer Stage Installation

The propulsion units are configured with deployable support members which attach to the OCDA platform edge nodal points. Each unit utilizes a 3-m x 6-m bank of fifty 30-cm ion thrusters with a 2.5-m diameter argon fuel tank (7250 kg). Thrust vector control is accomplished by a motor driven set of trunnions. The units with support members folded are designed to fit within the orbiter payload bay.

The approach used for sizing the propulsion system was to assume the unit would be used to transfer the OCDA from LEO to GEO. GEO transfer data is summarized in table 6-47 and Figures 6-47, 6-48 and 6-49. The solar array (801 kW BOL) was reduced 25% to account for degradation during a trip through the Van Allen belts. At this power level the system T/Mo is restricted to 2 x 10^{-4} N/kg resulting in a 355-day trip time.

6.2.9.3 Construction Operations. The two construction functions associated with the transfer stage installation are shown on Table 6-48. Four hours are assumed for assembly. A third function "Service Transfer Stage Assembly" is the removal and replacement of the transfer stage and takes longer than the original installation, because the used unit is stowed in the orbiter payload bay.

6.2.9.4 Orbital Tests. This mission addresses propulsion requirements for maneuvering beyond normal station keeping. Propulsion units are sized for transferring the OCDA with a 64-m x 77-m solar array and 33826 kg of construction equipment aboard from LEO to GEO. These electric propulsion units will be preassembled and mounted at the edge nodal points of the OCDA. Each unit will utilize a bank of 30-cm ion thrusters (argon fuel) and power from OCDA solar array. The units will employ trunnions for thrust vector control.

The objective of this mission is to demonstrate the integration of electrical propulsion devices to a large structure, and to test propulsion/control/flexible structure interaction during maneuvers. The propulsion units are sized for transfer to GEO to leave open the option of testing system performance through the Van Allen Belts.

The test scenario defines the major test sequences required to install and evaluate the operation of the high performance ion thruster engines. Test will include a remotely controlled automatic checkout of the firing sequence and control logic. These will be followed by short term and long duration maneuvers to check for structure-to-thruster reactions and recording of the pertinent parameters, i.e., position, attitude and acceleration of the OCDA plus the specific impulse, thrust developed and propellant consumed.

Table 6-47 OCDA GEO Transfer Data

$\frac{T}{m_o}$	$I_{SP_{OPT}}$	$m_{P/L}$ (Kg)	$\frac{m_{P/L}}{m_o}$	m_o	T (N)	$P = \frac{T I_{SP} g}{2n}$	NO. ENGINES	m_{STAGE} (Kg)	TRIP TIME
10^{-3}	1500	74,000	0.35	211,428	211.4	2378 KW	1057	137,428	45 DAYS
$5X10^{-4}$	3100	74,000	0.54	137,037	68.5	1593 KW	343	63,037	100 DAYS
10^{-4}	5100	74,000	0.86	86,046	8.6	329 KW	43	12,046	470 DAYS

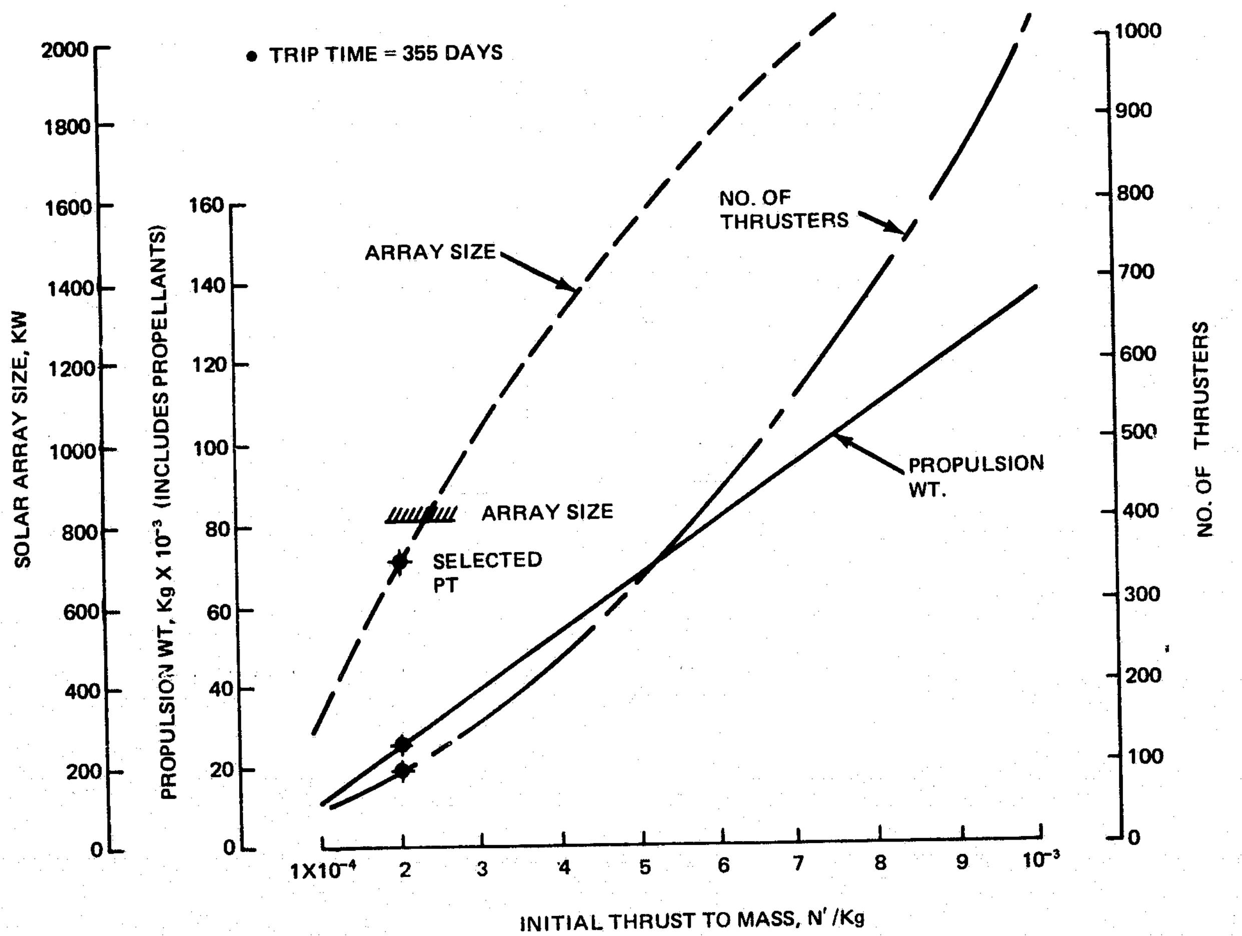
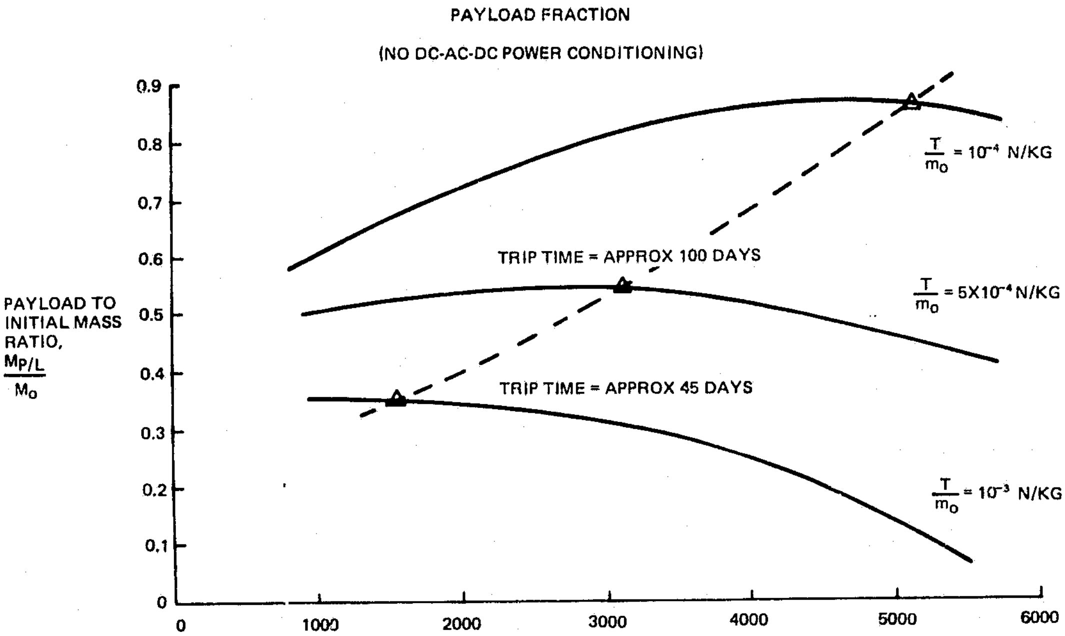


Figure 6-47 OCDA GEO Transfer - System Sizing



$$\frac{M_{P/L}}{m_o} = 1 - \frac{T}{m_o}\left[\frac{I_{sp}g}{2\eta K_1} + \frac{t_1 + \frac{K_2}{K_3 g}}{I_{sp}g}\right]$$

I_{sp} SPECIFIC IMPULSE ~ SEC

K_1 = SOLAR ARRAY CONVERSION FACTOR = 45.1 W/KG
K_2 = ENGINE FACTOR = 100 Kg/m^2
K_3 = 9.75 X 10^{-6} Kg - SEC/m^3
T_1 = TRIP TIME (SEC); η = .65

Figure 6-48 OCDA GEO Transfer — System Sizing

- LOW THRUST TRANSFER TIMES (NO PLANE CHANGE)

$$T_1 = \left(\frac{m_f}{m_o}\right)\left(\frac{m_o}{T}\right) I_{sp}g \cdot \frac{.1}{86400}$$

$$\frac{m_f}{m_{o_1}} = 1 - \exp -\frac{1}{I_{sp}g}\left(\sqrt{\frac{\mu}{r_o}} - \sqrt{\frac{\mu}{r_1}}\right)$$

μ = 3.99 X 10^{14} m^3/Sec^2
r_o = 6.78 X 10^6 m (200 m.MiAlt)
r_1 = 42.16 X 10^6 m (19.323 m.MiAlt)
m_f = PROPELLANT MASS (KG)
m_o = INITIAL MASS (KG)
T = THRUST (N)
g = 9.75 m/Sec^2

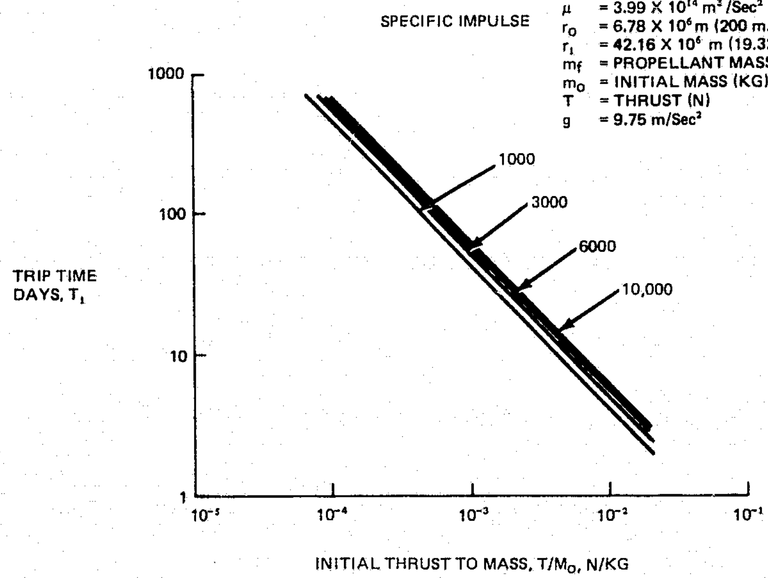
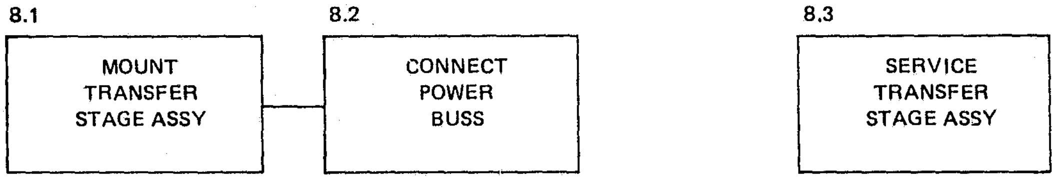


Figure 6-49 OCDA GEO Transfer — System Sizing

Table 6-48 Functional Operations Scenario – Function 8.0 High Performance Transfer Stage Installation and Maneuvers



TIME HR:MIN	OPERATIONS	REMARKS
(3:30)	MOUNT TRANSFER STAGE ASSEMBLY (2)	
:15	REMOVE TRANSFER STAGE ASSY FROM PAYLOAD BAY	
:15	DEPLOY ATTACHMENT STRUCTURE	
:15	TRANSFER TO INSTALLATION SITE	
1:00	MOUNT THRUSTER ASSY TO PLATFORM	
(:30)	CONNECT POWER BUSS (2)	
:15	WELD TRANSFER STAGE BUS TO OCDA POWER BUS	POWER CABLES PREVIOUSLY INSTALLED IN PLATFORM
4:00	TOTAL FOR CONSTRUCTION 1 SHUTTLE FLIGHT	
(4:30)	SERVICE TRANSFER STAGE ASSEMBLY (2)	
:15	CUT POWER BUS	
1:00	DISCONNECT STRUCTURE ATTACHMENT	
:15	TRANSFER ASSEMBLY TO P/L BAY	
:30	COLLAPSE ATTACHMENT STRUCTURE	
:15	STOW USED ASSEMBLY IN P/L BAY	

Table 6-49 High Performance Transfer Stage Installation Mass

ELEMENT	MASS	
	LB	LB
• INTERFACE FIXTURES	1000	454
• SUPPORT EQUIPMENT	NONE	
• PROPULSION	(67,990)	(30,868)
DRY	36,050	16,367
PROPELLANT	31,940	14,501
TOTAL	68,990	31,322

Test Scenario

- Verify installation producibility
  - Prepare ion thruster modules for installation
  - Mount each module
- Check out control system
  - Ignition power to thrusters
  - Vector control circuits
- Determine performance parameters
  - Specific impulse developed
  - Thrust developed
  - Power required
  - Propellant consumption
- OPS analysis.

Table 6-49 is a list of the mission peculiar equipment and the estimated mass of each item.

6.2.10 Mission Operations Summary

This section summarizes those elements which are common to the follow-on activities described in the previous sections. These include support equipment, electrical power, manpower and accomplishments. Together with the discussion of the individual missions contained in the proceeding pages, they provide a comprehensive data base on candidate OCDA activity required to verify critical issues associated with photovoltaic SPS systems as well as, provide a permanent construction capability for building many large structures in space.

6.2.10.1 Equipment Mass. Table 6-50 provides a summary list of the prime mission equipment along with estimates of the mass. One mission, the high performance transfer stage, exceeds the Shuttle capability for a single flight.

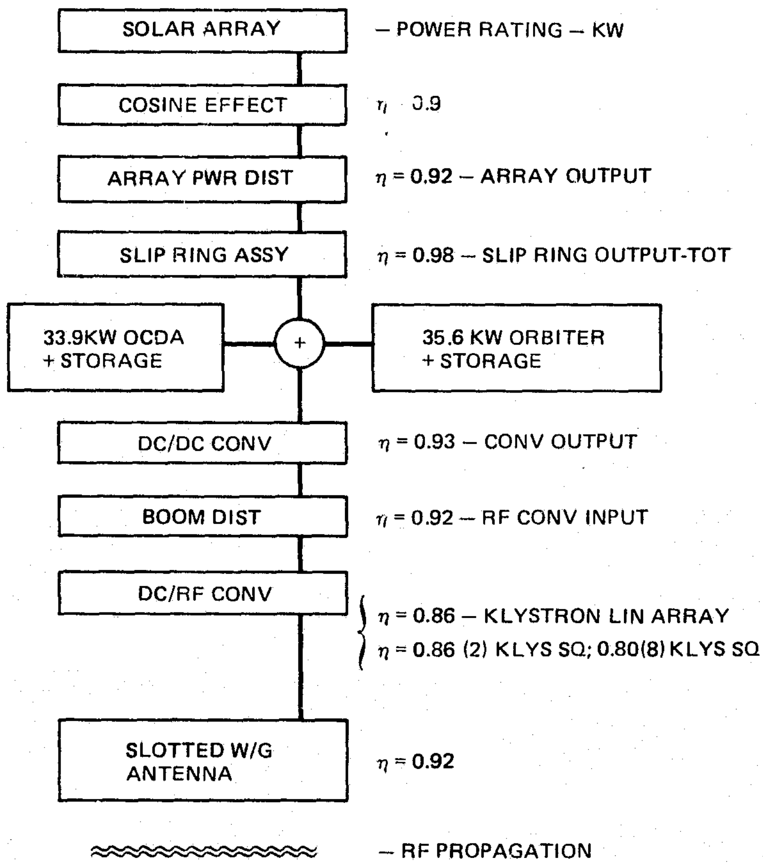
6.2.10.2 Electric Power. Power requirements for Program 2 are established by the needs of construction or test activities of the missions. Some test activities are actually construction operations, e.g., producing beams after the assembly fixture has been built. The preparations for implementing tests were found to require much less power than the test. Two tests that need the highest power were analyzed to establish solar array requirements.

Figure 6-50 shows the power transmission efficiency chain for all the major equipment for Mission 2, linear array tests and Mission 3, square array tests. A listing of the

Table 6-50 Mission Peculiar Equipment Mass Estimate, Program Scenario 2 – SPS Photovoltaic Development by Element

MISSION	ELEMENT	MASS LB	MASS KG
2. MW LINEAR ARRAY		(18,246)	(8289)
	CHERRY PICKER	4807	2187
	KLYSTRON EXPERIMENT	11247	5106
	ORBITAL TEST EQUIPMENT	2192	996
3. MW SQUARE ARRAY		(7232)	(3272)
	INTERFACE FIXT/JIGS	69	20.5
	SUPPORT EQUIP	10	4.5
	TRANSMIT ANTENNA	7153	3247
4. 20 m BEAM FAB		(35,957)	(16,324)
	FRAME ASSEMBLY	3657	1660
	FAB MODULES	22,000	9988
	CREW WORK MODULES	6000	2724
	MATERIALS	4300	1952
	OPS (4 FLT)		
5. CONDUCTOR INSTALLATION		(2650)	(1203)
	FRAME ASSEMBLY DELTA	220	100
	CONDUCTOR FAB MODULE	2200	999
	SUPPORT EQUIPMENT	230	104
	OPS (1 FLT)		
6. SOLAR BLANKET INSTALLATION		(2686)	(1220)
	FRAME ASSEMBLY DELTA	612	278
	SUPPORT EQUIPMENT	1011	459
	SOLAR CELL BLANKET	1063	483
	OPS (1 FLT)		
7. REFLECTOR INSTALLATION			
	FRAME ASSEMBLY DELTA	N/A	N/A
	SUPPORT EQUIPMENT	221	100
	REFLECTOR BLANKET	44	20
	OPS (0 FLT)*		
8. ROTARY JOINT INSTALLATION		(6654)	(3021)
	INTERFACE FIXT/JIGS	N/A	N/A
	ROTARY JOINT/MAST	6195	2813
	ORBITAL TEST EQUIP	459	208
	OPS (1 FLT)		
9. HIGH PERFORMANCE TRANSFER STAGE INSTALLATION AND MANEUVERS		(68,990)	(31,322)
	INTERFACE STRUCT	1000	454
	SUPPORT EQUIP	NONE	NONE
	PROPULSION	67,990	30,868
	OPS (2 FLT)		

*SAME FLIGHT AND SOLAR BLANKET INSTALLATION



POWER, KW	
LIN ARRAY	SQ ARRAY
471.3	455.5
424.2	409.9
390.2	377.1
382.5	369.5
291.0	279.0
267.0	257.4
230.0	212.0
212.0	195.0

Figure 6-50 Missions and Power Requirements, Linear and Square Array Tests

power required to provide an rf output of 212 kW for the linear array shows that the solar array must generate 471.3 kW. Table 6-51 lists the power needs for Mission 4, 20-m fabrication. The solar array must provide 162.8 kW of power to meet all power needs simultaneously. The linear array power needs of 471.3 kW obviously drive the solar array requirements.

6.2.10.3 Manpower. Table 6-52 is a list of number of manhours required for construction and test, and the flights required for each of the nine missions. The greatest manpower effort is needed for the initial OCDA placement. Fabrication of the 20-m beams requires the same number of flights as the OCDA placement mission, not because of manpower requirements but because of transportation requirements. On this mission cherry picker and associated framework are transported on the first flight, the fabrication modules are transported on the second flight, and the beam building rig and all other associated equipment and material are transported on the third flight.

6.2.10.4 Objectives Accomplished. The information provided in Table 6-53 provides an overall assessment of how well the follow-on activities studied meet the demonstration objectives formulated at the start of the study.

A rating system, e.g., 25%, 50%, 75% and 100%, was used to discriminate between missions. This helps to rate mission suitability in instances where similar objectives are addressed but the demonstration articles differ in scale and/or construction complexity. The methodology assigned a value to each mission in two steps. First, values were assigned to each mission within the scenario. Then, similar missions for any two program scenarios (e.g., 1 and 2) were compared and the ratings adjusted on a comparative basis. For example, the 2-MW solar array Fabrication mission (Mission 7 of Scenario 1) was compared against the individual solar blanket and mirror installations (Missions 7 and 8, respectively, of Scenario 2). The solar array (Mission 7 of Scenario 1) scored appreciably higher than the solar blanket and mirror installation (Missions 7 and 8 of Scenario 2) because of the difference in scope and scale utilized in the 2-MW solar array which is a total test of a solar conversion system construction.

6.3 PROGRAM SCENARIO 3 - ANTENNA DEVELOPMENT

Two antenna construction missions were planned for Program Scenario 3. The first is the construction of a 100-m parabolic reflector used as a radiometer which is assembled in a series of radials and circumferentials. The second antenna is the construction of a multi-beam communications antenna which uses the "bootlace" lens concept. It is constructed by assembling deployable hexagonal units containing all the dielectric elements.

Table 6-51 Power Requirements for Mission 4, 20-m Beam Fabrication

EQUIPMENT	AVERAGE POWER, KW PRODUCTION RATE AT 1 FT/MIN	
1 m FAB MODULES (4)	5.52	
CHERRY PICKER (1)	2.07	
DISPENSER (1)	0.3	
CARRIAGES (3)	4.5	
CONDUCTOR FAB (1)	1.0	
LIGHT SIDE SUBTOTAL		13.4
LOSSES		1.2
LIGHTING	44.3	
DARK SIDE SUBTOTAL (SLIP RING)	57.7	
LOSSES	5.0	
TOTAL DARK SIDE	62.7	
BATTERY RECHARGE		48.0
HOUSEKEEPING		33.9
ORBITER SUPPORT		35.6
LIGHT SIDE TOTAL (SLIP RING)	132.1	
LOSSES		30.7
SOLAR ARRAY POWER		162.8

Table 6-52 Program Scenario 2 Operations Summary

MISSION	CONSTRUCTION MAN HOURS	TEST MAN HOURS	SHUTTLE FLIGHTS
1. OCDA PLACEMENT	500	0	3
2. LINEAR WAVEGUIDE	190	90	1
3. MW SQUARE ARRAY	160	90	1
4. 20M BEAM FAB	230	150	4
5. CONDUCTOR INSTAL	50	30	1
6. ROTORY JOINT INSTAL	30	30	1
7. SOLAR BLANKET INSTAL	30	20	1
8. REFLECTOR INSTAL	30	10	1
9. ORBIT TRANSFER	90	TBD	1
		TOTAL	14

Table 6-53 Program 2 Mission Suitability Correlation Matrix

PROBLEM AREA	DEMO/TEST OBJECTIVE FOR PROGRAM SCENARIO 2	MISSION SUITABILITY										
		DEMO NEED WT.	MISSION									% OBJ MET
			1	2	3	4	5	6	7	8	9	
STRUCTURES	1) BUILDING BLOCK STRUCT FAB AND/OR DEPLOY	6	50			75			75	75		75
	2) JOINT ASSEMBLY PROCEDURES	8	75						50	50		75
	3) MAN/MACHINE/INTERACTION	8	50						50	50		50
	4) LARGE ELEMENT MATING	9	75			0			25	25		75
	5) SECONDARY STRUCTURE INSTALLATION	8	50						50	50		50
	6) MEASURE PRODUCTIVITY	6	50						50	50		50
	7) ATTITUDE CONTROL DURING CONSTRUCTION	7	100			100			50	50		100
	8) THERMAL CYCLING DURING CONSTRUCTION	6	100	75		100			75	75		100
	9) ACCURACY & INTEGRITY TESTS	8	50	75		100			50	50		100
	10) STRUCTURAL REPAIR	7	50			50			50	50		50
	11) STRUCTURE/CONTROL/INTERACTION	7				50			25	25		50
SOLAR ARRAY	1) CONSTRUCTION & DEPLOYMENT	8	25						50			50
	2) LOW COST, HIGH EFFICIENT SPACE FAB BLANKET	8	0						0			0
	3) ARRAY TO STRUCT INSTALLATION	7	25						50			50
	4) CONCENTRATOR INSTALLATION	7	0						0	50		50
	5) THERMAL CYCLE	6	50						50			50
	6) FAULT-ISOLATION & REPAIR	7	50						25			50
POWER DISTRIBUTION	1) INSTALL INTEGRATED STRUCTURE/BUS SYSTEM	5	50				75	100	25			50
	2) INSTALL DEDICATED SYSTEM WITH SWITCH GEAR & CIRCUIT PROTECTION	5	50				50	25	25			50
	3) INSTALL STORAGE SYSTEM	5	100				0	0	0			100
	4) INSTALL POWER CONDITIONING UNITS	7	100				0	0	0			100
	5) INSTALL ROTARY POWER TRANSFER DEVICE	8	75				0	100	0			100
	6) HI VOLTAGE OPERATION	8	0				100	100	0			100
	7) LEAKAGE PREDICTION	7	25				75	75	0			75
	8) FAULT ISOLATION & REPAIR	7	50				75	75	25			75
POWER TRANSMISSION	1) DC TO RF CONVERSION IN STEPS	8	0	50	75							75
	2) INTEGRATED PROOF OF CONCEPT	10	0	50	50							0
	3) THERMAL CYCLING TESTS ON WAVE GUIDES & PHASE CONTROL	6	0	100	100							100
	4) IONOSPHERE TESTS	4	0	0	0							
	5) GEO PERFORMANCE (HI VOLTAGE & START)	8	0	0	0							
	6) LIFE TESTS	4	0	0	0							
	7) DEMO TRANSMISSION TO GROUND	8	0	25	0							0
PROPULSION	1) INSTALL PROPULSION UNIT FOR ATTITUDE CONTROL & STATION KEEPING	7	100								100	100
	2) VERIFY EFFECTS OF EXHAUST PRODUCTS	3	50								75	75
	3) FAULT ISOLATION & REPAIR	5	50								75	75
STABILIZATION & CONTROL	1) CONTROL OF LARGE FLEXIBLE BODIES USING CENTRALIZED & DISTRIBUTED SYSTEMS	7	50								50	50
	2) SURFACE CONTOUR CONTROL	8	0								0	0
	3) POINT 1 LARGE MASS RELATIVE TO 2ND	7	25								0	25
	4) STATIONKEEPING	7	100								50	100
	5) FAULT ISOLATION & REPAIR	5	50								50	50
REFLECTOR MIRROR FACETS	1) PLACEMENT & INSTALLATION	8	0									
	2) POINTING & CONTROL ON FLEXIBLE BODY	8	0									
	3) FAULT ISOLATION & REPAIR	5	0									
RADIATORS	1) POSITIONING & ASSEMBLY OF RADIATOR ELEMENTS	8	0									
	2) CONSTRUCT GAS TIGHT JOINTS	6	0									
	3) FAULT ISOLATION & REPAIR	4	0									
THERMAL CAVITY	1) POSITIONING & ASSEMBLY	8	0									
	2) GAS TIGHT JOINTS	6	0									
	3) CAVITY PERFORMANCE THROUGH CONSTRUCTION	8	0									
	4) CONTROL WITH ROTATING MACHINERY	8	0									
LARGE MIRROR SURFACE	1) POSITIONING & ASSEMBLY	8	0									
	2) CONTOUR CONTROL	8	0									
	3) EFFICIENCY MEASUREMENT	5	0									
	4) LIFE TESTING	4	0									
ASSEMBLY OPERATIONS	1) INITIAL PLACEMENT OF CONSTRUCTION PLATFORM	8	100	0	0	0	0	0	0	0	0	100
	2) SITE LOGISTICS	7	50	75	75	75	75	75	75	75	75	75
	3) RESUPPLY & STORAGE	6	50									75
	4) HABITATION	4	0	0	0	0	0	0	0	0	0	0
	5) SITE COMMUNICATIONS	5	100	50	50	50	50	50	50	50	50	100
	6) SITE LIGHTING	5	100	100	100	100	100	010	100	100	50	100
	7) RADIATION SAFETY (GEO)	6	0	0	0	0	0	0	0	0	0	0
	8) PRODUCTIVITY GOALS	8	50	50	75	75	75	50	75	75	25	75
	9) REMOTE CONTROLLED MANIPULATORS	7	75	75	25	75	25	50	50	50	0	75
	10) SPARE FABRICATION (AUTO ASSEMBLY)	8	0	0	25	100	25	0	75	75	0	100
	11) USE OF EVA	6	75	50	25	50	75	50	50	50	50	75
	12) FAULT ISOLATION & REPAIR OF CONSTRUCTION EQUIPMENTS	6	75	75	75	75	75	75	75	75	75	75
PROCESSES	1) FASTENER OPTIONS (WELD, BOND, ETC)	7	50	25	25	50	50	25	75	50	75	75
	2) FAB IN METALLICS & NON METALLICS	6	25	0	0	100	50	0	0	0	0	100
	3) VAPOR DEPOSITION FOR REPAIR	8	0	0	0	0	0	0	0	0	0	0
MISSION OPS	1) COMMUNICATIONS	5	50	100	100	100	100	100	100	100	100	100
	2) REMOTE CONTROL FROM GROUND	8	0	50	75	0	0	0	0	0	0	75
	3) MISSION PLANNING	4	25	25	75	25	25	25	50	25	50	75
ANTENNAS	1) RIB STRUCTURE FABRICATION	6	0	0	0	0						
	2) ACTIVE CONTOUR CONTROL	8	0	0	0	0						
	3) WIRING INSTALLATION	5	0	0	0	0						
	4) LENS PANEL INSTALLATION	7	0	0	0	0						

0 MEETS NO PCT OF OBJECTIVE
25 MEETS LOW PCT OF OBJECTIVE
50 MEETS 1/2 OF OBJECTIVE
75 MEETS HI PCT OF OBJECTIVE
100 MEETS ALL OF OBJECTIVE

Eight Shuttle flights are required in addition to the three needed to construct the basic OCDA to build the radiometer antennas; three more flights are required to build the communication antenna. Table 6-54 is a projected flight schedule.

It was found that a program centered around the construction of prototype large antenna will cost in the neighborhood of $1.2B excluding the cost of transporting the end-item to its mission orbit.

6.3.1 Mission 1-OCDA Placement

Mission 1, consisting of three flights, is used to assemble and prepare the orbital construction facility. The operations required on each of the three flights to achieve operational readiness are discussed in Section 3.

6.3.2 Mission 2 - 100-m Radiometer

The 100-m radiometer described in this section will not only provide useful thermal emission data on the earth's atmosphere and surface, but will also verify the operational procedures required to fabricate and assemble large reflector antennas in space. The radiometer structure, except for the erectable mast, is fabricated on the OCDA. After assembly, the antenna is completely checked out while attached to the OCDA to facilitate minor adjustments to the system, including calibration of the low noise receivers, receiver-horn alignment and verification of software used to process the information. A free flying satellite with low-power transmitters will be used at a range of 200 km to verify the performance of the radiometer and provide the data required to make the final adjustments.

6.3.2.1 Mission Objectives and Requirements. Analysis of future radiometer requirements indicate the need for a 400-m diameter antenna that operates at 30 GHz. A 100-m diameter antenna was selected as a first step towards this goal. A 100-m antenna is potentially beyond the practical limitations of deployable antennas and at the lower end of the spectrum of space erectable antennas. The lessons learned and technology developed for the 100-m antenna would be directly applicable to the larger antennas. The Shuttle payload bay limits the central hub of the antenna structure to a diameter of 4.3 m. The goal is to assemble a radiometer antenna within the practical constraints of the OCDA which would also measure as much of the microwave radiation involved in the natural emissions of terrestrial bodies with a reasonable degree of resolution. The specific microwave spectrum of interest listed below is based on NASCR-2621 report.

Frequency (f)	Wavelength (λ)	Source	Resolution
1-10 GHz	.3 - .03 m	Soil moisture	.2 km
10 GHz	.03 m	Dynamic ocean surface	100 km
5 GHz	.06 m	Ocean surface	5-150 km
1 GHz	.3 m	Salinity	<5
3-30 GHz	.1 - .01 m	Sea ice	.2
30 GHz	.01 m	Storm cells	2

The Option 2 design shown in Table 6-55 provides a good compromise between the practical limits of the OCDA construction base, the orbiter transport and the frequency regime of interest. It uses 94 ribs, each with a flange of .125 m to achieve the .25-cm RMS surface accuracy, and a practical limit with respect to the 13.5 m hub circumference available. Together with the 16 circumferentials, this design will optimize the radiometer gain within the practical OCDA/orbiter constraints. The degradation in resolution due to inaccuracies in the reflector shape will also be minimized. The contour error will be within $\lambda/50$ for frequencies up to 2.5 GHz and $\lambda/10$ for frequencies up to 12 GHz. The resolution of .59 km for the design selected is based on the OCDA orbit of 198 n mi. Resolution was calculated based on the relationship derived in NASA CR-2621:

$$r = 1.25 \times \frac{\lambda}{D} R$$

where: r = resolution
λ = wavelength
D = diameter of parabola
R = range

The 10 GHz design (Option 1) was discarded based on the practical consideration of rib size necessary to stay within the hub circumference limits. The .61 GHz design (Option 3) was discarded because it did not provide as good coverage of the frequency spectrum of interest as the 2.5 GHz (Option 2).

6.3.2.2 Concept Definition. The Mission 2 article is a 100-m diameter parabolic reflector designed to operate at a frequency of 2.5 GHz with an RMS surface accuracy of $\frac{\lambda}{\delta} = 50$ and a focal length-to-diameter (f/d) equal to 0.5. The antenna design concept is based on design data taken from OCDS reference No. 41 "Design Concepts and Parametric Studies of Large Area Structures," NASA Contract NAS 1-13178. In this report a multiring concept similar to the device shown in Figure 6-51 was analyzed for surface accuracy. The parabolic surface is formed by a series of concentric conical frustra. The support structure is comprised of a series of radial ribs and circumferentials. To augment this design approach, an active contour control device (thermal expander) has been added to

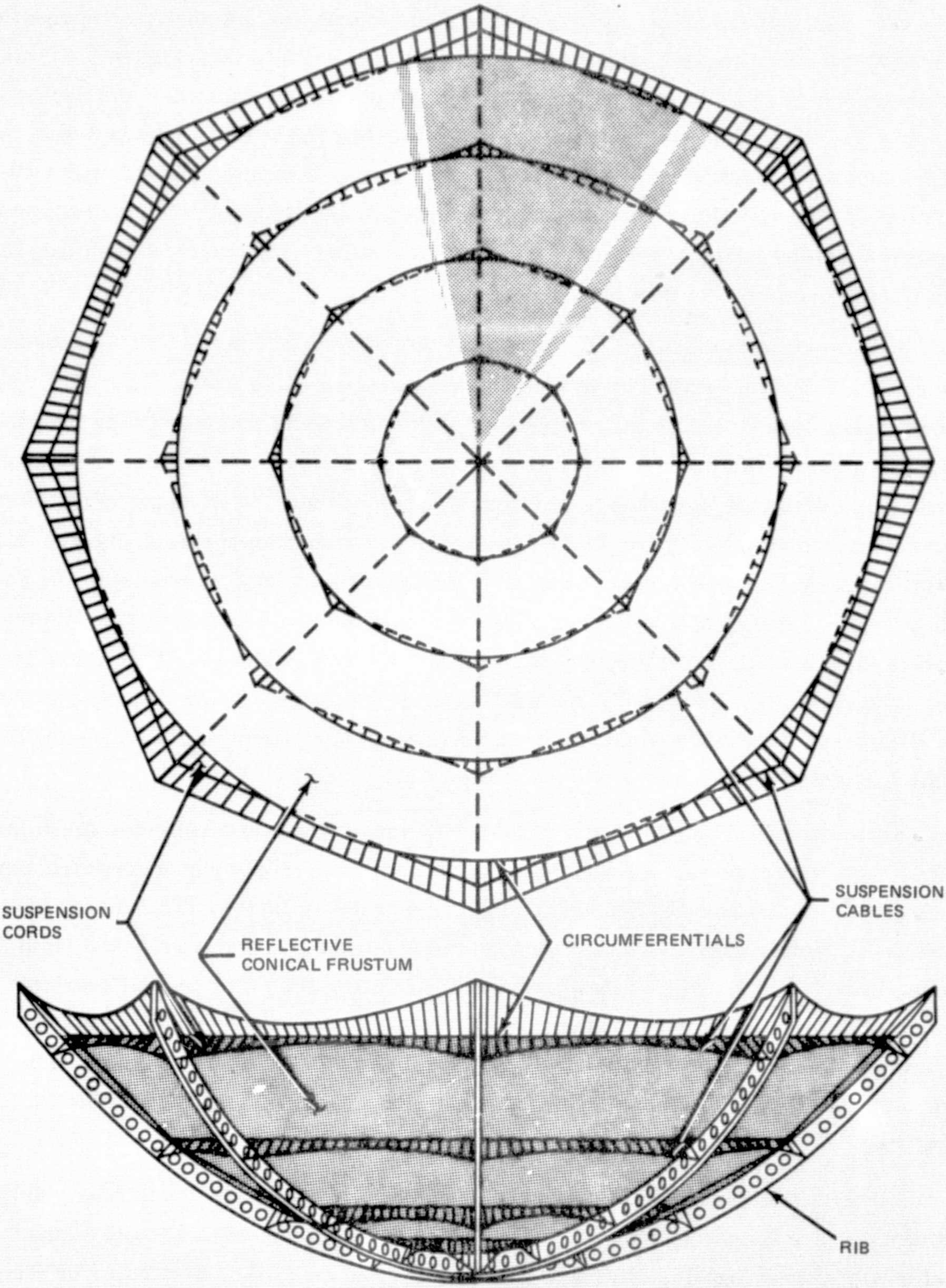
Table 6-54 Program Scenario 3 Shuttle Flights

MISSION	FLIGHTS-CALENDAR YEAR	
	1984	1985
1. OCDA PLACEMENT	ΔΔΔ	
2. 100 M RADIOMETER	ΔΔΔΔΔΔΔΔ	
3. 61 m MULTI-BEAM COMMUNICATIONS ANTENNA		ΔΔΔ

Table 6-55 Radiometer Parabolic Reflector Requirements

PARABOLIC REFLECTOR DESIGN PARAMETERS	PARABOLA DESIGN REFS	OCDA OPTIONS		
		1	2	3
OPERATIONAL FREQUENCY (F, GHz)	.61-30	10 GHz	2.5 GHz	.6 GHz
RESOLUTION, R (Km)	2.3-.046 Km	.138 Km	.51 Km	2.1 Km
CONTOUR ERROR, σ		.06 cm	.24 cm	.75 cm
AVAILABLE PAYLOAD DIA (m)	16 m BASED ON HLLV-CLASS 4	4.3 m	FOR SHUTTLE ORBITER	
MAX HUB CIRCUMFERENCE (m)	50.27 m	13.5 m	13.5 m	13.5 m
RIB I BEAM FLANG (m)	—	.112 m	.125 m	.25 m
NO. OF RIBS	60	120	94	47
NO. OF CIRCUMFERENTIALS	10	32	16	9
ANTENNA D (m)	400 m	100 m	100 m	100 m
TESTS				
• PRODUCIBILITY				
– FABRICATION RATES		X	X	X
– CONTOUR ERROR		X	X	X
– STRUCT. NATURAL FREQ.		X	X	X
• PERFORMANCE				
– SYSTEMS C/O		X	X	X
– ANTENNA PATTERN		X	X	X
– PRE OPERATIONAL PERFORMANCE TESTS		X	X	X
• OPERATIONAL				
– SOIL MOISTURE	X	X	X	
– SALINITY	X	X	X	
– OCEAN SURFACE	X	X	X	X
– STORM CELLS	X			
– DYNAMIC OCEAN SURFACE	X	X		
– SEA ICE	X			

SELECTED (→ option 2)



*(REF. NO. 41-NASA CONTRACT NAS 1-13178)

Figure 6-51 Multiring Reflector Concept

maintain the parabolic contour of the flexible reflector (mesh) surface. This active contour control system is controlled by a laser sensing contour mapping automatic compensation system. The radiometer configuration consists of a core module (see Figure 6-52) which houses and supports the subsystem module, a central mast stow cannister and deploy mechanism, the tip module and the antenna hub. Attached to the core module hub is the reflector surface support structure consisting of 16 circumferentials and 94 radial ribs. The number of ribs and circumferentials needed to meet the RMS surface accuracy was determined using the reference design data shown in Figure 6-53 and 6-54 resulting in the antenna characteristics shown in Figure 6-55.

6.3.2.3 Construction Operations. To construct the radiometer on the OCDA, a manned cherry picker operating on the 108-m long OCDA boom is used to mount the radial rib (composite) fabrication module to the upper platform side nodal points with the prepackaged deployable support structure. In addition, a 10-m long deployable extension structure which supports a 2-m diameter turntable is attached to the upper and lower nodal points of the platform edge as shown in Figure 6-56. The construction sequence starts with the attachment of the Shuttle delivered prepackaged core module (tip module interface) to the assembly fixture (turntable); then the composite radial rib produced by the fabrication module is attached to the hub of the core module, the turntable is then indexed 3.82° to the adjacent rib location, the rib is installed and the circumferentials are added. This sequence is then repeated until all of the 94 ribs and 16 circumferentials are assembled, completing the reflector support structure.

The contour control devices are attached and the prepackaged reflector mesh is installed, completing the parabolic reflector. After contour alignment tests are completed, the OCDA boom is then rotated 325° to the backside of the reflector. The cherry picker engages the subsystem module of the core module and the reflector is released from the turntable, the boom rotates the reflector outboard to clear the platform and reorients the antenna which is then reattached to the turntable at the subsystem module interface. The next step is to deploy the center mast (50 m) establishing the antenna, $\frac{F}{D} = 0.5$. The configuration is now ready for antenna pattern and system performance tests via the subsatellite.

Top level functions are identified, and associated construction operations including time estimates are listed in Table 6-56. The construction time estimate and a rough cut at orbiter payload bay packing (size and mass) is used to establish the number of Shuttle flights required for input to cost data.

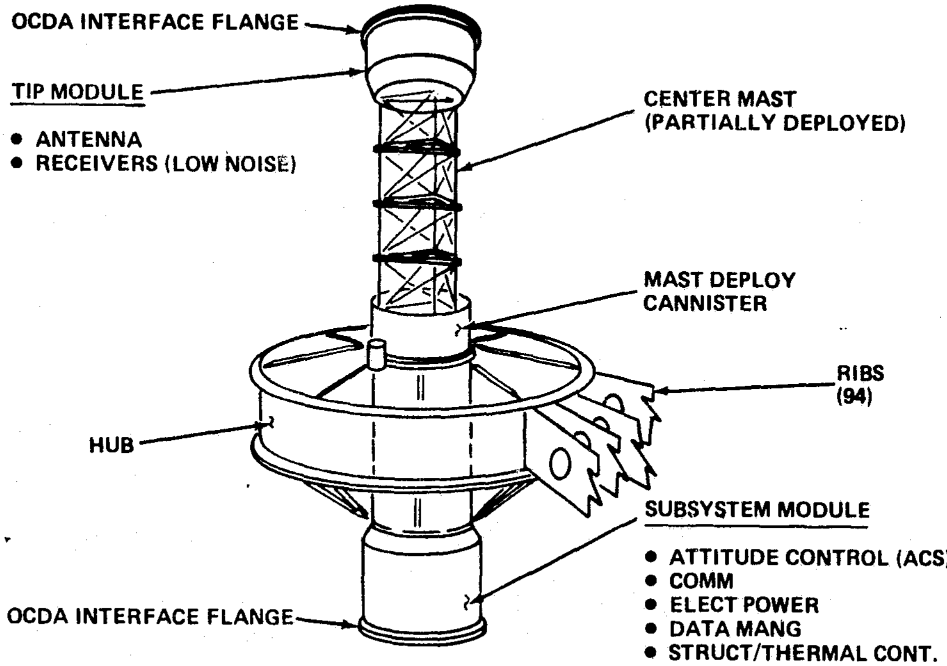
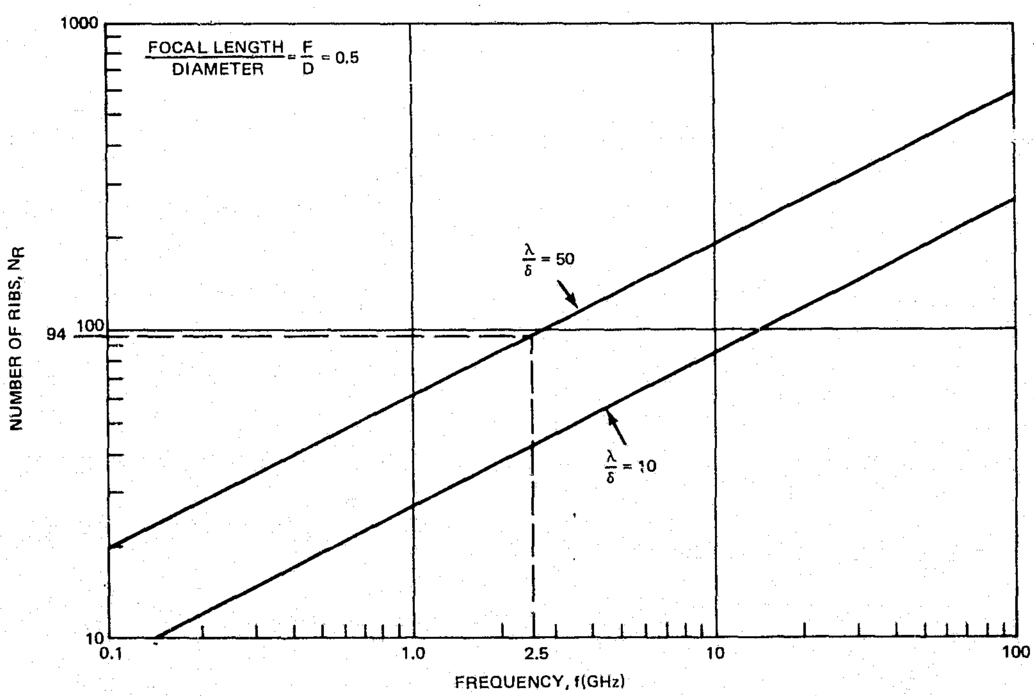


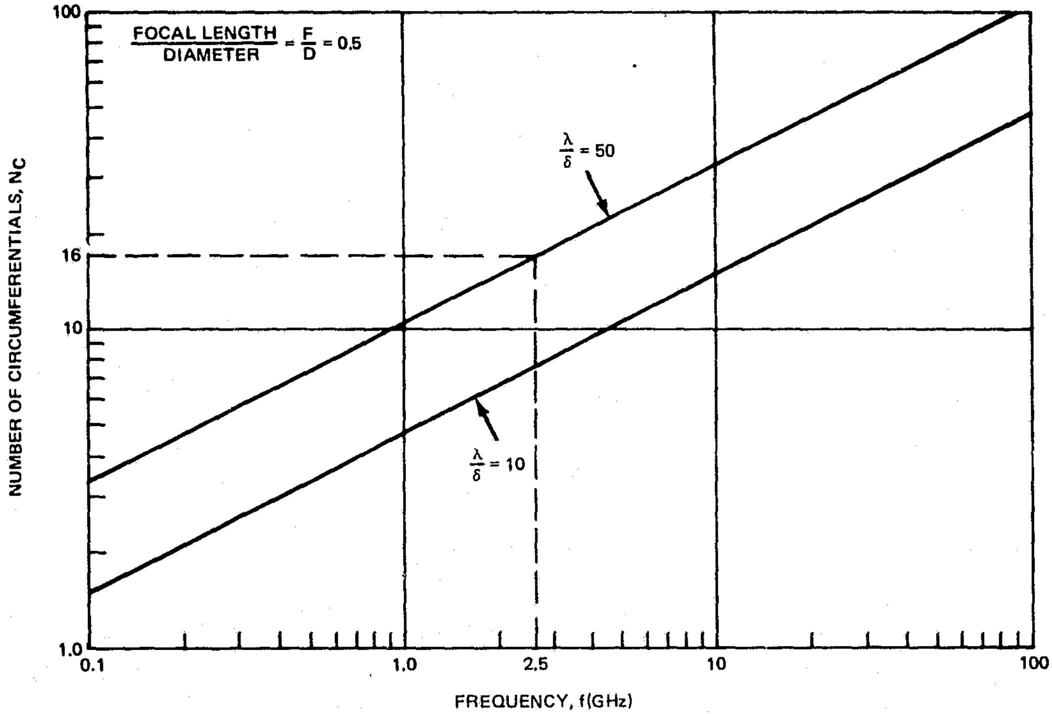
Figure 6-52 Core Module Hub and Center Mast Configuration



• NUMBER OF RIBS REQUIRED FOR A 100-m DIAMETER MULTIRIB PARABOLOIDAL REFLECTOR TO OPERATE AT VARIOUS FREQUENCIES WHILE LIMITING SURFACE DEVIATIONS TO 1/50 AND 1/10 OF THE CORRESPONDING WAVELENGTHS.

(REF. NO. 41 - NASA CONTRACT NAS 1-13178)

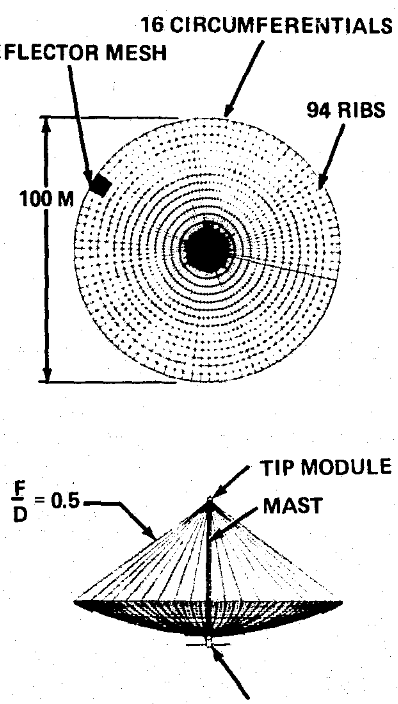
Figure 6-53 Ribs Required for a 100-m Reflector



- NUMBER OF CIRCUMFERENTIALS REQUIRED FOR A 100-METER DIAMETER MULTIRIB PARABOLOIDAL REFLECTOR TO OPERATE AT VARIOUS FREQUENCIES WHILE LIMITING SURFACE DEVIATIONS TO 1/50 AND 1/10 OF THE CORRESPONDING WAVELENGTHS.

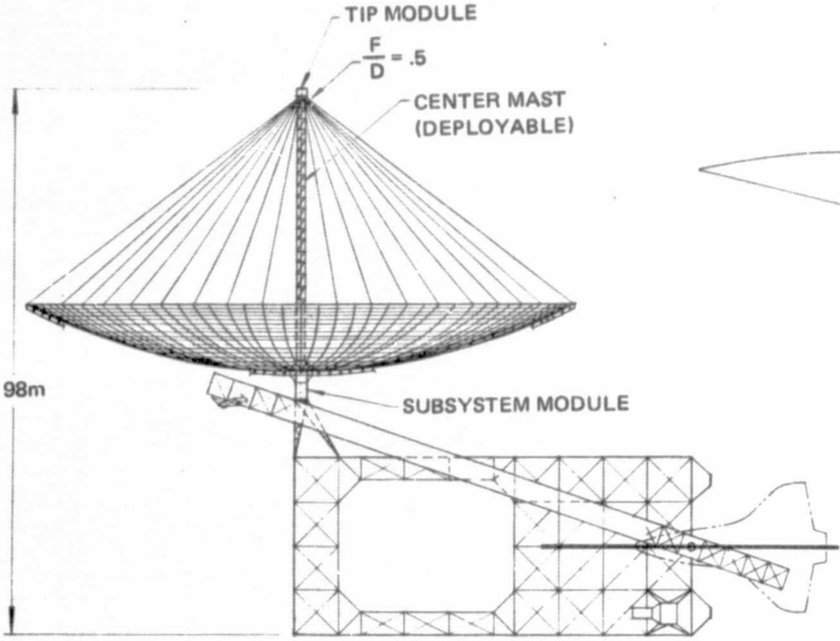
(REF. NO. 41 - NASA CONTRACT NAS 1-13178)

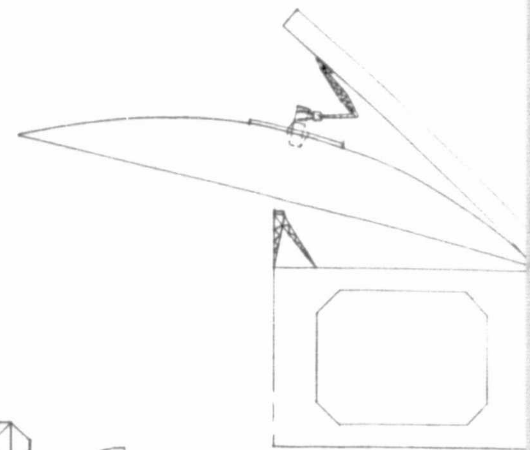
Figure 6-54 Circumferentials Required for a 100-m Reflector



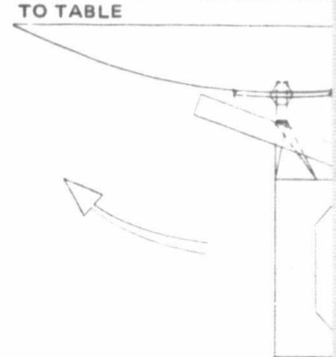
ELEMENT		MASS ESTIMATE Kg		LBM
• ANTENNA	(6238)		(13755)	
– SURFACE MESH		200		441
– STRUCTURE				
o CIRCUMFERENTIALS		460		1,014
o RIBS		3,778		8,330
– HUB		600		1,323
– MAST		200		441
– MECHANICAL SYST		1,000		2,205
• SUBSYSTEMS	(965)		(2128)	
– STRUCTURE/THERMAL CONTROL		200		441
– ATTITUDE CONT (ACS)		40		88
– COMM		200		441
- ELECT POWER		180		397
– DATA MANG (DM)		315		695
– SENSORS		30		66
TOTAL	(7203)		(15883)	

Figure 6-55 100-m Radiometer Configuration



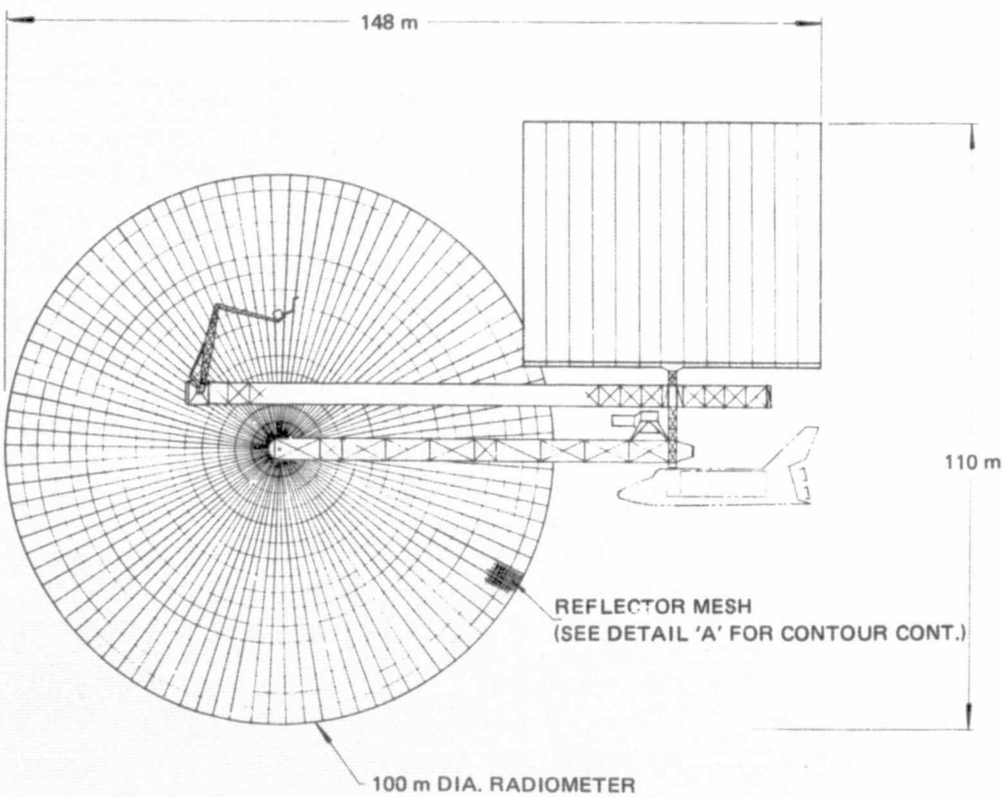


(E) AFTER COMPLETION OF CONST
ALIGNMENT TEST OF PARABOI
OCDA BOOM ROTATED TO BAC
ANTENNA CHERRY PICKER EN
MODULE REMOVES ANT FROM
RE-ORIENTS ANTENNA & RE-A
TO TABLE



(F) WITH ANTENNA MOUNTED TO FIXTURE CENTER MAST IS DEPLOYED TO ESTABLISH THE ANTENNA $\frac{F}{D}$ = .5

(G) CONFIGURATION READY FOR ANTENNA PATTERN & SYSTEM PERFORMANCE TEST VIA SUB-SATELLITE



FOLDOUT FRAME \

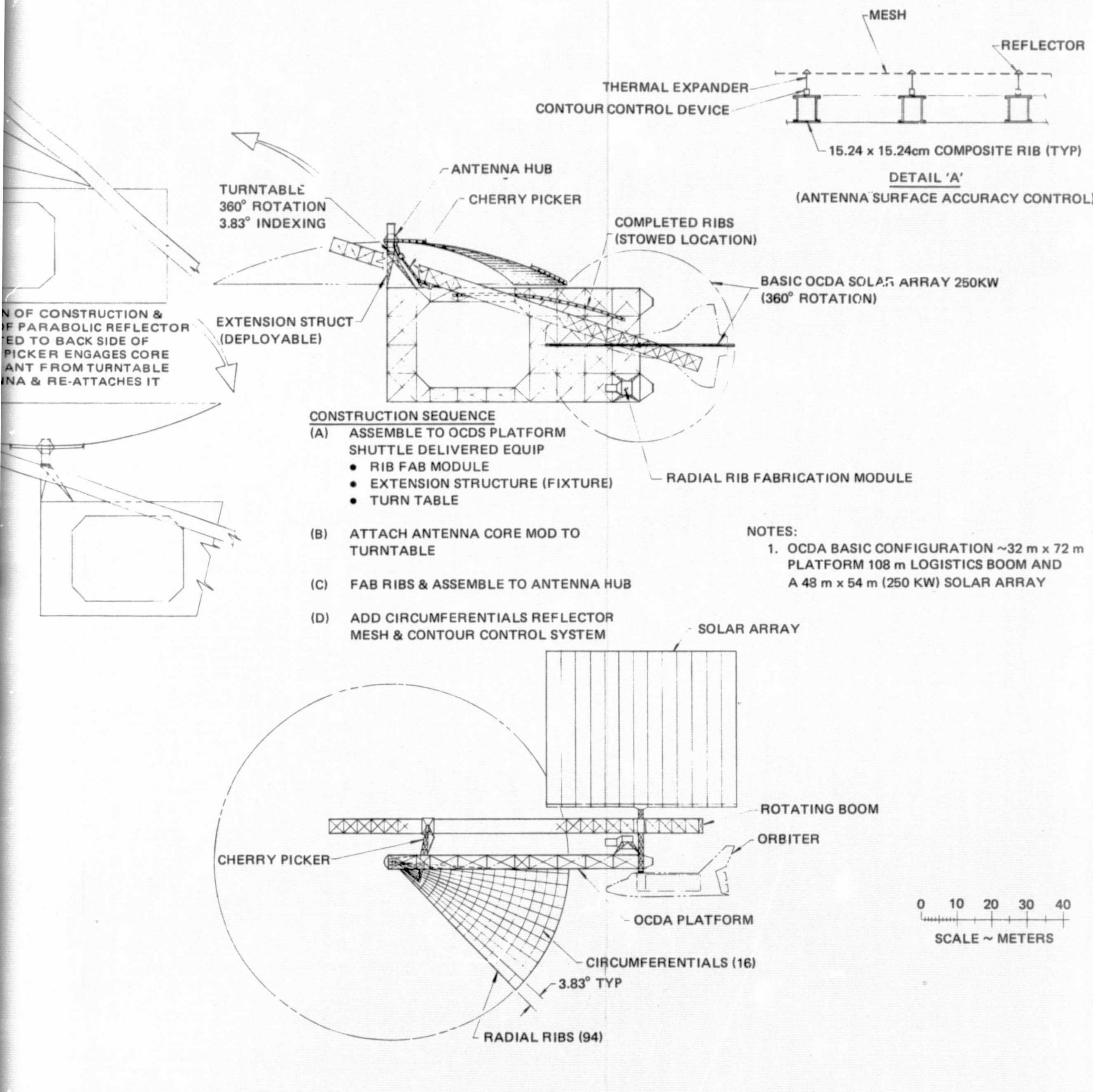
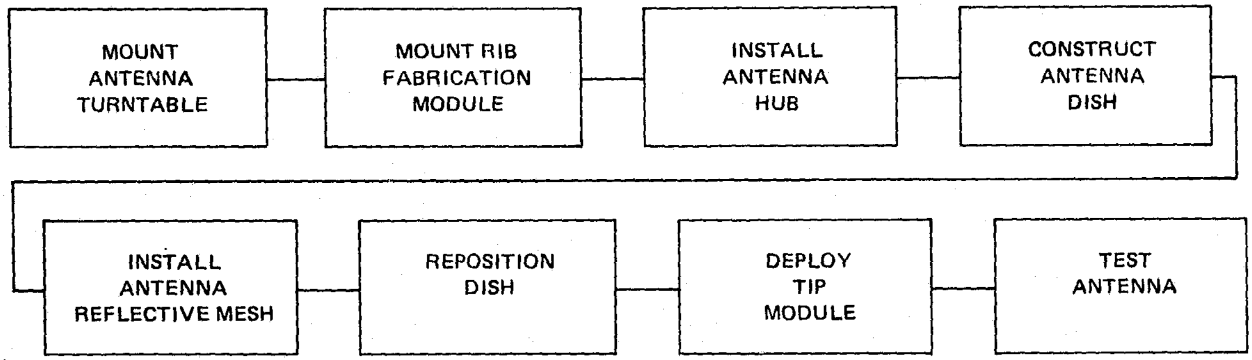


Figure 6-56 Program Scenario 3 – Mission 2 - 100-m Radiometer

Table 6-56 Functional Operations Scenario — Radiometer Antenna Construction



TIME HR:MIN	OPERATIONS	REMARKS
(5:00)	MOUNT ANTENNA TURNTABLE	
:30	DEPLOY TURNTABLE SUPPORT STRUCTURE (4)	
:30	ATTACH STRUCTURE TO TURNTABLE	
:40	INSTALL STAYS (8)	
:20	REMOVE TURNTABLE FROM TRANSPORTATION FIXTURE	
2:00	ATTACH TURNTABLE TO PLATFORM AND TENSION STAYS	NO PLATFORM
1:00	CONNECT POWER CABLES, C/O CLAMP OPS AND INDEXING	FIXTURES
		REQUIRED
(5:30)	MOUNT RIB FABRICATION MODULE	
:30	REMOVE AND DEPLOY FAB MOD SUPPORT STRUCTURE	
1:00	ATTACH STRUCTURE TO PLATFORM	
2:00	INSTALL FAB MOD ON PLATFORM	
:30	CONNECT POWER CABLES	
:30	INSTALL MATERIAL DISPENSERS	
1:00	C/O FAB MODULE OPS	
(1:00)	INSTALL ANTENNA HUB	
:20	ATTACH BOOM MANIPULATOR TO HUB	
:10	RELEASE HUB HOLD-DOWN	
:30	REMOVE HUB AND POSITION ON TURNTABLE	
--	ACTUATE TURNTABLE HUB	
(188:30)	CONSTRUCT ANTENNA DISH STRUCTURE	
:30	INSTALL MATERIAL DISPENSERS (186)	15 MIN EACH
47:00	MANUFACTURE RIBS (94)	30 MIN EACH
:15	REMOVE AND STOW DISPENSERS	
23:30	POSITION RIBS TO HUB	PARALLEL OPS
23:30	FASTEN RIBS TO HUB	
8:00	INDEX HUB (93)	5 MIN/INDEX
128:00	INSTALL CIRCUMFERENTIALS (16 X 92)	FIXED LENGTH
1:20	INSTALL STITCH CIRCUMFERENTIALS	5 MIN EACH
4:00	ADJUST CIRCUMFERENTIAL TENSION	
(616:00)	INSTALL ANTENNA REFLECTIVE MESH	
31:00	LOAD DISPENSER (94)	DISPENSER LO
284:00	MOUNT THERMAL TENSIONERS (1504)	LOAD/RIB
24:00	CONNECT POWER AND CONTROL CABLES TO S/S MODULE	CONNECTED TO
8:00	REMOVE REFLECTIVE MESH SPOOL DISPENSER (24) AND MOUNT SPOOLS TO HUB (24)	TENSIONERS
12:00	DEPLOY MESH GORES ATTACH TO RIB END & HUB (24)	
6:00	ZIPPER GORES TOGETHER (23)	
251:00	ATTACH CONTOUR TENSION TIES (1504)	10 MIN EACH
8:00	REMOVE AND STOW SPOOLS (24)	LOCATORS IN MESH

Table 6-56 Functional Operations Scenario — Radiometer Antenna Construction (Continued)

TIME HR:MIN	OPERATIONS	REMARKS
(1:00) 1:00	DEPLOY TIP MODULE STAYS UNREEL STAYS (6) FROM TIP MOD. AND ATTACH TO DISH	
(2:00)	REPOSITION DISH POSITION BOOM TO BACKSIDE OF DISH ATTACH MANIPULATOR TO HUB RELEASE HUB HOLD-DOWN CLAMPS SWING BOOM/DISH CLEAR OF PLATFORM TURN DISH OVER REINSTALL HUB TO TURNTABLE	
(1:15) :15 1:00	DEPLOY TIP MODULE DEPLOY CENTER MAST TENSION MAST STAYS	
(260:00)	TEST ANTENNA CONNECT POWER AND CONTROL CABLES AND TEST ANTENNA	SUBSYSTEM MODULE
1080:00	45 DAYS, 8 FLTS (7 DAYS/FLT.)	

Table 6-57 Orbital Construction Experiment Definition — Antenna Development, Program Scenario 3 (Radiometer Mission 2) — Large Mirror (RF Reflector Surface)

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
• FABRICATION OF LARGE ANTENNA STRUCTURE • ASSEMBLY OF LARGE PARABOLIC STRUCTURE • CONTOUR CONTROL AND MEASUREMENT OF LARGE PARABOLIC RF REFLECTOR SURFACE • PERFORMANCE MEASUREMENT • OPERATIONAL	• FABRICATE RADIOMETER RIBS (5 FT/MIN). CONTOUR ERROR OF BEAMS .2 cm/m • ASSEMBLE THE RADIOMETER STRUCTURE • DETERMINE NATURAL FREQUENCY OF RADIOMETER • DETERMINE AND ADJUST INITIAL CONTOUR ±1 cm ERROR AT EACH SUSPENSION CABLE ADJUSTMENT • DETERMINE PERFORMANCE OF ACTIVE CONTOUR CONTROL DEVICE (±1 cm) • C/O OF SUBSYSTEMS • CALIBRATION OF LOW NOISE RECEIVERS • MEASURE SENSITIVITY TO PROGRAMMED MICROWAVE EMISSIONS • MEASURE ANTENNA PATTERN • DETERMINE SCANNING ANGLE (100°) • DETERMINE OPERATIONAL PERFORMANCE CHARACTERISTICS	• LASER REFLECTOMETER SYSTEM • ACCELEROMETERS AND ASSOCIATED INSTRUMENTATION • RADIOMETER C/O STA ON-BOARD SHUTTLE • CALIBRATION EMITTERS INSTALLED ON PARABOLA PERIMETER • MMS SATELLITE OUTFITTED FOR RADIOMETER PERFORMANCE TESTS.	IN SPACE FABRICATION OF RADIOMETER STRUCTURE, ASSEMBLY AND OPERATION OF 100-m RADIOMETER WILL PROVIDE THE TECHNOLOGY VERIFICATION REQUIRED TO BUILD THE REFERENCE DESIGN (400 m) RADIOMETER. THE 100-m RADIOMETER WILL ALSO PROVIDE VALUABLE DATA ON SOIL MOISTURE, SALINITY AND OCEAN SURFACE INFORMATION.

Over one-half of the operation time to assemble the radiometer antenna is associated with the installation of the antenna reflective mesh. The mounting of many tensioners (1504) to the antenna structure and the subsequent attachment of reflective mesh tension ties is planned as a series operation requiring two crewmen to perform the task. Therefore, three shift operations were planned for this job. Test operations similarly need two crewmen, therefore, three shifts were again planned.

6.3.2.4 Orbital Tests. The mission objectives and related test requirements are identified in Table 6-57. The requirements range from construction and performance verification to long term operational requirements which will provide data on soil moisture, salinity and weather information.

The test scenario will include evaluation of the rib fabrication units, i.e., production rates, roller pinch forces and synchronization of the various automatic processes. Dimensional accuracy checks will be conducted on the ribs to check the performance of fabrication units as well as the repeatability of the units. Following assembly of the radiometer, an actuator will be mounted at the interface of the parabola and the turntable, and the frequency response of the radiometer will be checked. These construction and operational checks will be followed by an extensive check-out of all onboard systems. The low noise receiver will be calibrated using standard RF emitters on the peripheral edge of the antenna. The data processing and the software will be exercised by processing known input data; the radiometer attitude control and telemetry data link will be checked out while the radiometer is still attached to the OCDA.

Following this onboard check-out period, the antenna will be checked out via a sub-satellite as shown in Figure 6-57. The Multimission Modular Spacecraft currently being developed could be used for this purpose. Following this check-out, the radiometer would be transferred to the desired high inclination orbit to start its operational data gathering long-term mission.

6.3.3 Mission 3 - 61-m Multi-Beam Antenna

This mission demonstrates the orbital assembly and test of a bootlace lens, multi-beam communications satellite. It ultimately would be positioned in geostationary orbit to provide highly directional beams that receive and transmit signals to and from 256 locations in the United States. The construction and testing contained herein is limited to the OCDA orbital altitude of 190 n mi.

6.3.3.1 Mission Objectives and Requirements. The primary objective is the construction and testing of a large bootlace lens antenna. The antenna is intended to provide a large a

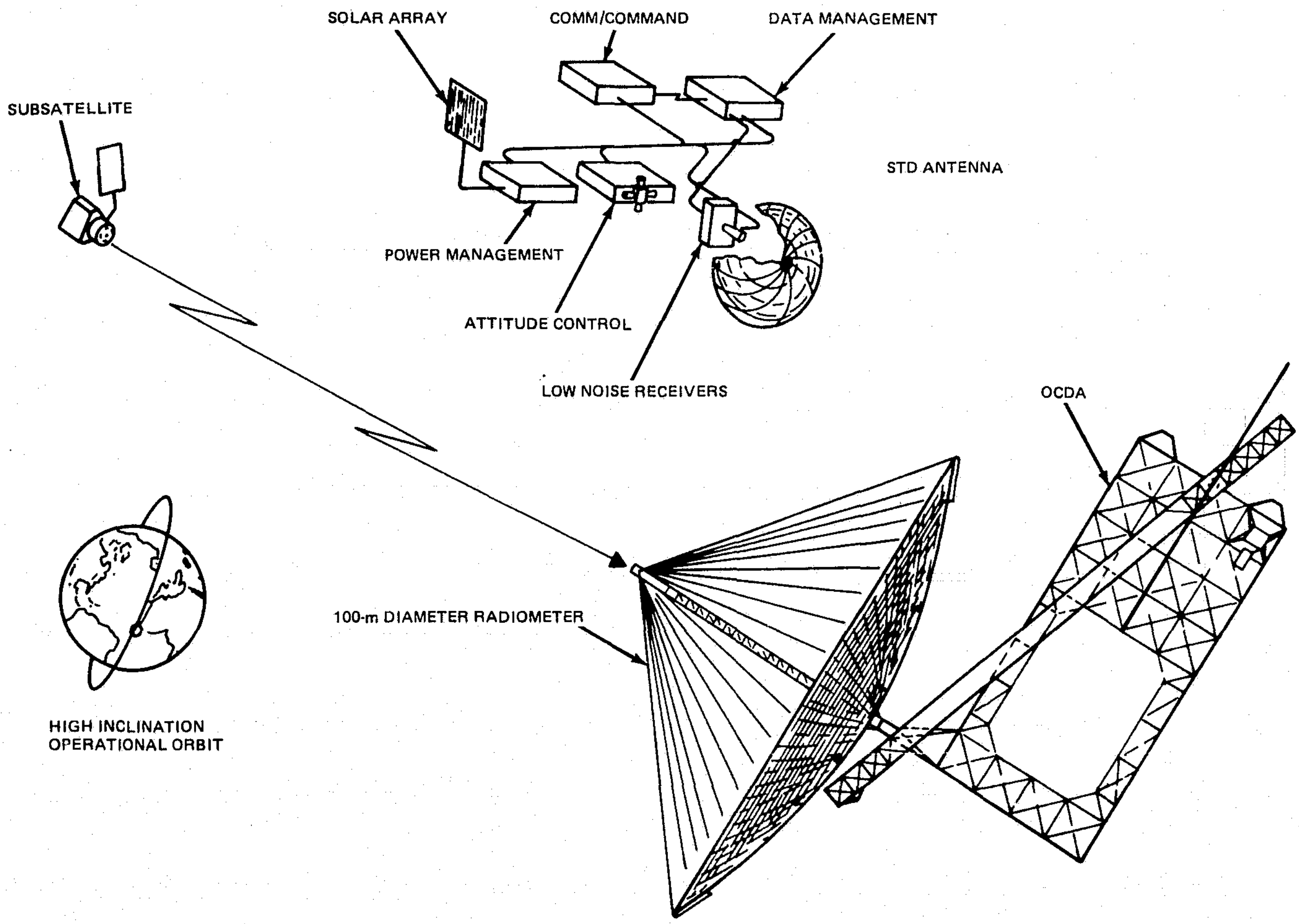


Figure 6-57 Test Setup Schematic

number of narrow beams over the United States composed of 256 fixed beams shown in Figure 6-58. A previous Grumman study of this type of antenna concluded that the ground resolution of the beam should be a diameter of 60 n mi (Ref. 103). The relationship between the beam size and the required antenna diameter is shown in Figure 6-59 and illustrates that an antenna diameter of 61-m is required.

The antenna converts a spherical feed side wave into a planer phased radiation pattern that formats a narrow beam as the signal passes through the aperture. This lens effect can be achieved by using any of the aperture cross sections shown in Table 6-58. Of primary consideration in choosing the lens configuration is the need to pack the components into the cargo bay of the Shuttle and the need for structural rigidity in the completed antenna lens. The configuration chosen represents a minimum volume shape that presents a spherical surface to the fed side signal. Because of its shell construction, this design achieves rigidity without the need of great section thicknesses.

6.3.3.2 Concept Definition. The multi-beam communications antenna is a large (61-m diameter) bootlace lens. It is intended to be operated in a geostationary orbit to provide a public sector communications link between any two points in the United States. The antenna produces 256 fixed beams and 16 scanning beams to provide continuous coverage. In comparison to the existing Intelsat IV, which must interface with a large ground antenna (30 m) to complete the communications link, the multi-beam lens is a very large antenna with large gain, enabling the ground user equipment to be much smaller and less sophisticated.

The vehicle configuration used in the study of Mission 3 is shown in Figures 6-60 and 6-61. The major features of the vehicle is a large lens aperture, a subsystem module, three long struts and a solar array.

The lens structure consists of panels, generally of hexagonal shape, connected together to form a spherical shell as illustrated in Figure 6-62. The panels are sized to allow efficient packing in the Shuttle cargo bay (4.5-m diameter). The lens structure is made up of the equivalent of 226 panels, partial panels being required to complete the circular shape of the aperture. Adjacent panels are held together with an interface connection plate and three fasteners. Each connection plate is fitted with a retroreflector on the feed side of the lens structure to assist in the subsequent alignment and conformation analysis. The completed lens is then fitted with a rim around the outside to stiffen the shell and provide an attachment for the support struts. The rim is a preformed member made of thin material that can be elastically flattened and rolled up to enhance Shuttle stowage. The aperture is completed with the addition of the support strut fittings (3) and the tension ties.

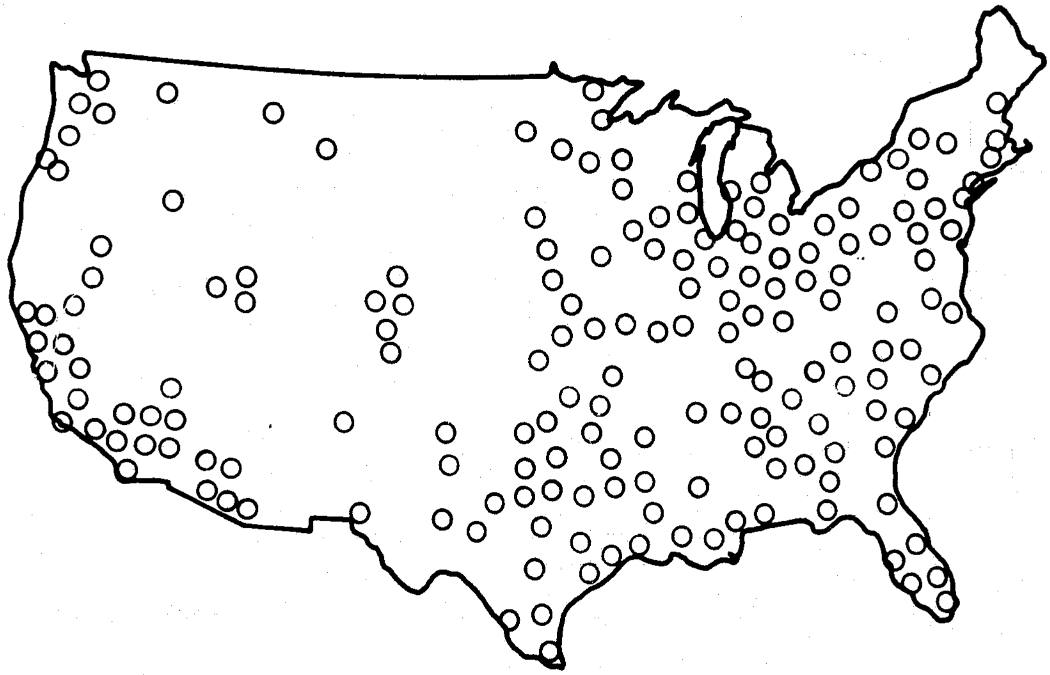


Figure 6-58 An Arrangement of Fixed Beams

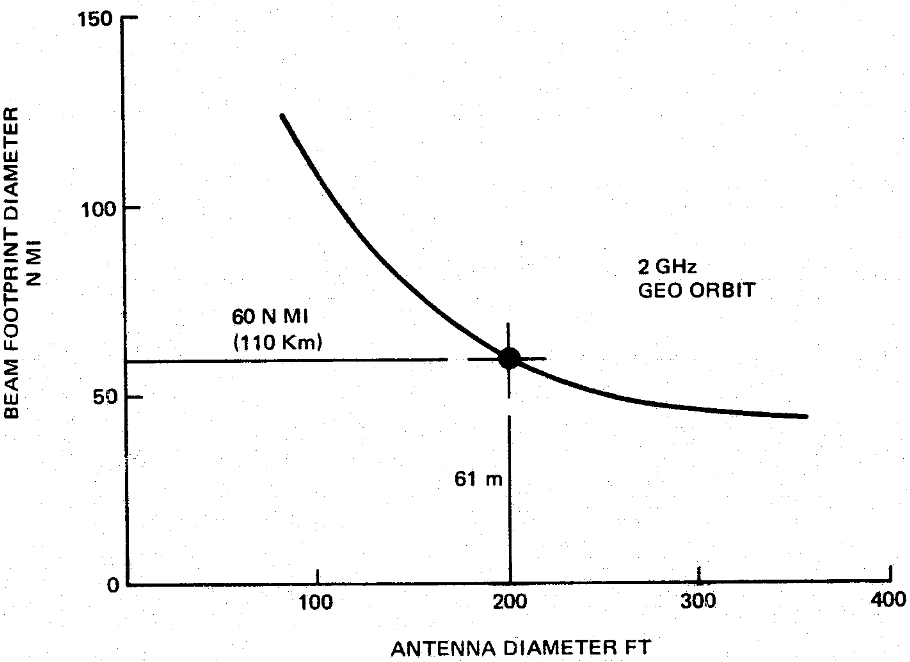
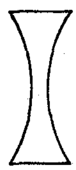
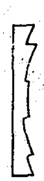
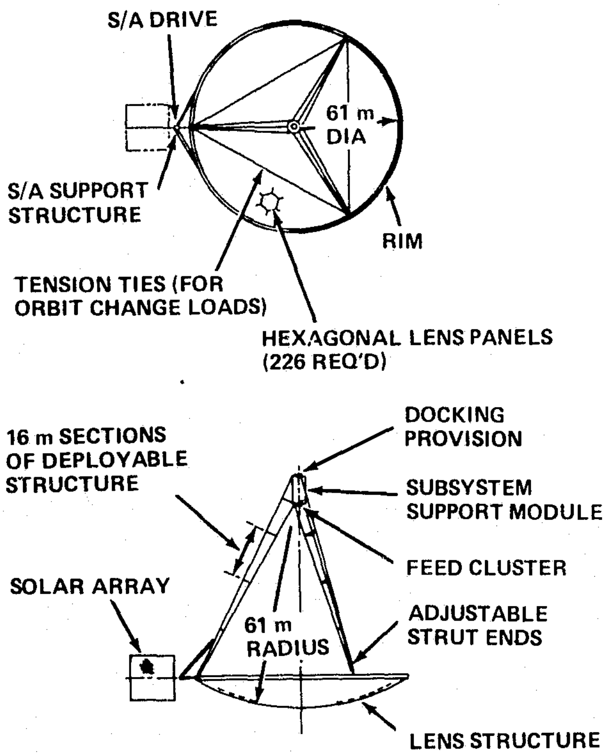


Figure 6-59 Ground Resolution vs Antenna Size

Table 6-58 Candidate Shapes for Bootlace Lens

LENS CONFIGURATIONS (IN ORDER OF ELECTRICAL PREFERENCE)		REMARKS
DOUBLE CONCAVE		• SPHERICAL PICKUP SURFACE MINIMIZES "COMA LOBE" • PICKUP AND RADIATING SURFACES HAVE PHASE ERROR CORRECTION • VERY HIGH VOLUME (MANY STS FLIGHTS REQUIRED)
PLANO CONCAVE		• SPHERICAL PICKUP SURFACE MINIMIZES "COMA LOBE" • FLAT RADIATING SURFACE PRODUCES MINIMUM INCIDENCE ANGLE OVER LENS SURFACE AND SCAN ANGLE • HIGH VOLUME (MANY STS FLIGHTS REQUIRED)
CONVEX CONCAVE		• SPHERICAL PICKUP SURFACE MINIMIZES "COMA LOBE" • MINIMUM VOLUME (FEW FLIGHTS REQUIRED) • RIGID (SHELL) CONSTRUCTION ← SELECTED FOR STUDY
PLANO		• FLAT RADIATING SURFACE PRODUCES MINIMUM INCIDENCE ANGLE OVER LENS SURFACE AND SCAN ANGLE • HIGH VOLUME (THICK) OR EXTERNAL STRUCTURE (THIN) REQUIRED FOR STRUCTURAL RIGIDITY
ZONED		• BANDWIDTH RESTRICTED • ZONED CORRUGATIONS DEGRADE CARGO BAY PACKING • HIGH VOLUME (THICK) OR EXTERNAL STRUCTURE (THIN) REQUIRED FOR STRUCTURAL RIGIDITY



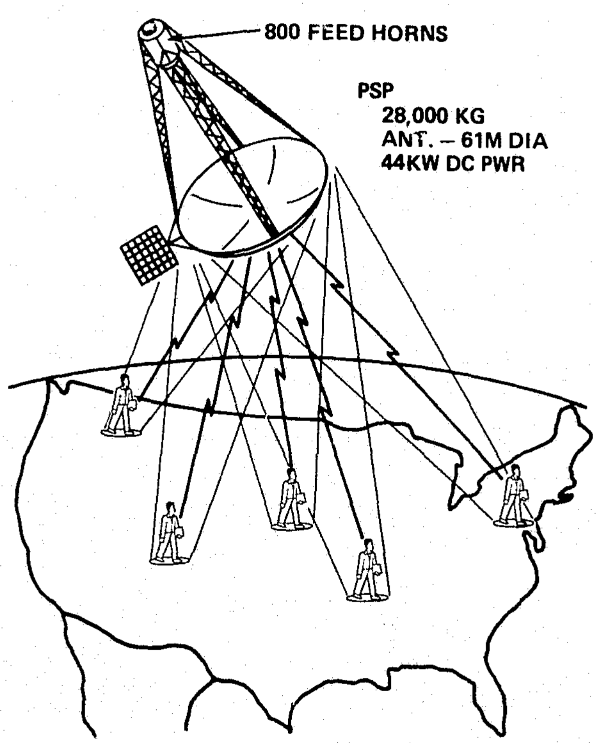
ELECTRICAL POWER REQUIREMENTS

	POWER (WATTS)
COMMUNICATIONS ELECTRONICS	43,785
TT&C	65
FLIGHT CONTROL	50
PROPULSION	20
THERMAL CONTROL	40
ELECTRICAL POWER & INTEGRATION	20
TOTAL	43,980

MASS PROPERTIES

	LBM	Kg
• ANTENNA APERTURE		
– LENS PANELS	19,460	8,825
– APERTURE RIM	2,063	936
• FEED SUPPORT STRUCTURE	1,875	850
• SUBSYSTEM MODULE		
– STRUCTURE	125	57
– FEED/DIPLEXER ASSEMBLY	156	71
– COMMUNICATIONS ELECTRONICS	563	255
– TT&C	37	17
– FLIGHT CONTROL	147	67
– PROPULSION	87	39
– THERMAL CONTROL	63	29
– ELECTRICAL POWER & INTEGRATION	2,125	964
• SOLAR ARRAY	750	340
• PROPELLANT	280	127
TOTAL	27,731	12,577

Figure 6-60 Multi-Beam Communications Antenna General Arrangement



CHARACTERISTICS

- FREQUENCY: 2 GHz
- NUMBER OF BEAMS: 256 FIXED, 16 SCANNING
- RESOLUTION (FROM GEO): 110 KM (FIXED BEAM), 222 KM (SCANNING BEAM)
- BANDWIDTH: 33 MHz

FUNCTIONS

- PERSONAL COMMUNICATION: 1000 CHANN'LS/BEAM
- POLICE COMMUNICATION: 10 CHANN'LS/BEAM
- VOTING/POLLING: 1000* CHANN'LS/BEAM
- DISASTER CONTROL: 10 CHANN'LS/BEAM

*TIME SHARED

Figure 6-61 Multi-Beam Communication Antenna General Characteristics

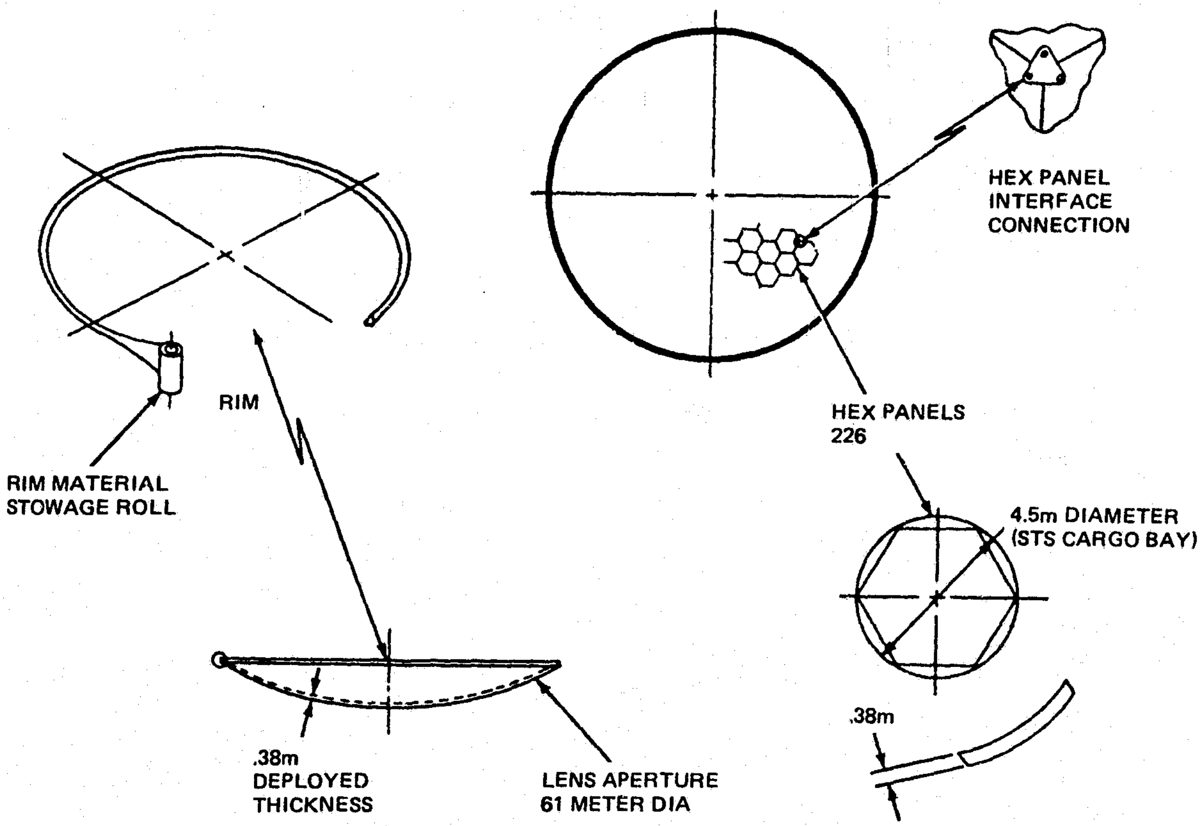


Figure 6-62 Lens Aperture Structure Design Concept

The tension ties relieve the rim and lens panels of the spreading load induced by the geometry of the support struts during acceleration from low earth to geostationary orbit.

The lens panels are of non-metallic honeycomb sandwich construction. Both the feed side and earth side of the panels contain many small antenna elements (664 per panel). Each antenna consists of a crossed dipole on the feed side (a photoetched conductive material on the outer surface of the feed side face sheet) with a conductive layer on the opposite face sheet serving as a ground plane. The thickness of the sandwich provides the correct spacing between the antenna and ground plane. A delay line element runs from the crossed dipole on the feed side to a similar dipole on the earth side. The delay line element is a flexible dielectric, having conductive paths deposited on the surface. The delay line elements constitute the "bootlace" element of the bootlace lens. Each element is designed to produce a signal delay appropriate for its distance from the boresight of the antenna. The arrangement of the various components of the lens panels is illustrated in Figure 6-63. The hex lens panels are designed to allow folding the earth side honeycomb panel to enhance Shuttle packing. Upon removal from the cargo bay, the panel will be deployed, giving the correct spacing between delay line elements. The panel spacing (0.3 m) was chosen to give sufficient delay line length to permit the required delay effect for a 30.5-m radius antenna system.

The support structure struts consist of end-to-end sections of deployable structure. The structural configuration used (see Figure 6-64) is similar to the Grumman A13 deployable structure used for the OCDA platform structure. Assembly of the strut structure is accomplished in a manner similar to the end-to-end assembly of the OCDA boom sections. The struts are fitted with a terminal connection at the lens end of the strut to allow adjustment.

6.3.3.3 Construction Operations. Components for the antenna will be delivered to the OCDA by the Shuttle on racks carried in the cargo bay. An arrangement for stowing the required components for the 61-m multi-beam communications antenna is illustrated in Figure 6-65 (Grumman Space Station Analysis Study Report NSS-SS-RE007). The arrangement shows that two Shuttle flights will be sufficient to deliver the required antenna components to the OCDA for assembly.

The racks will be removed, and utilizing the boom traveler, carried to the far end of the OCDA platform. Hex-shaped panels containing the bootlace elements will be attached to form the spherical shell making up the lens aperture. Connectors at the apex intersections of the panels provide structural attachment. A cherry picker will be used to handle the components and connectors. The lens structure will be assembled on a turntable

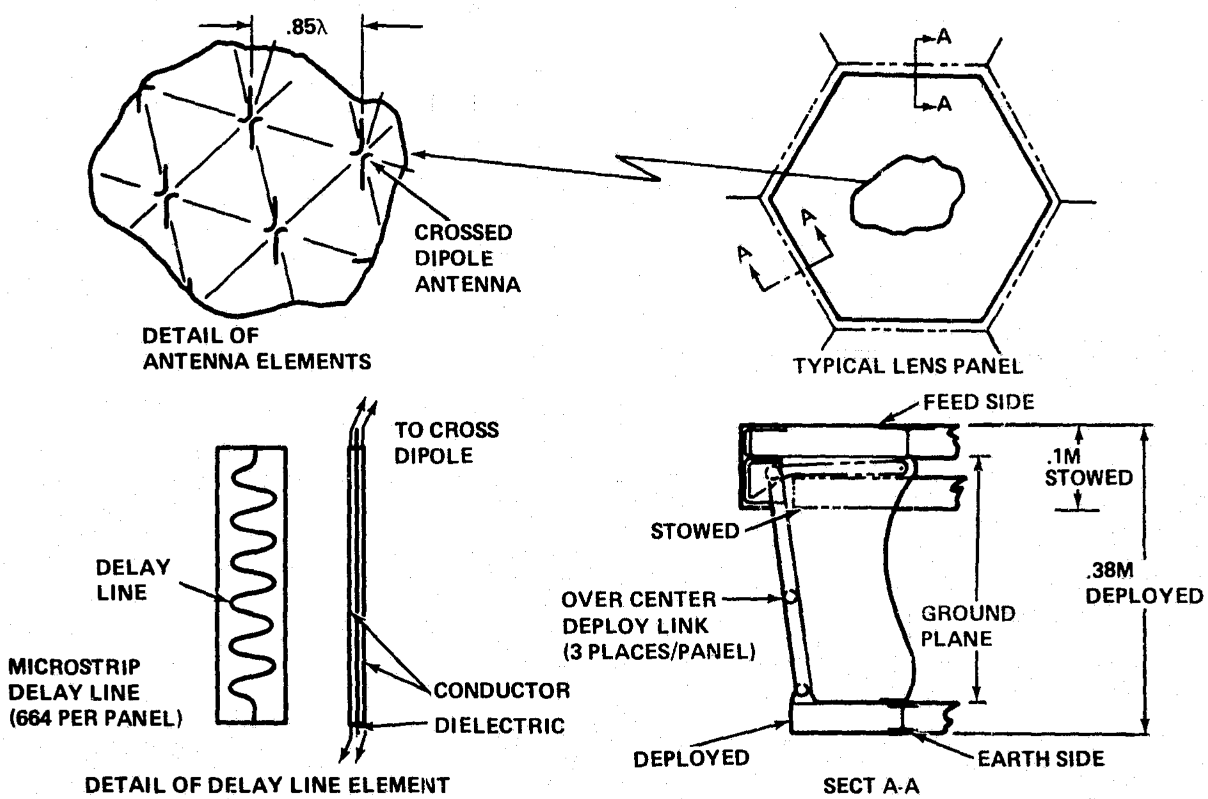
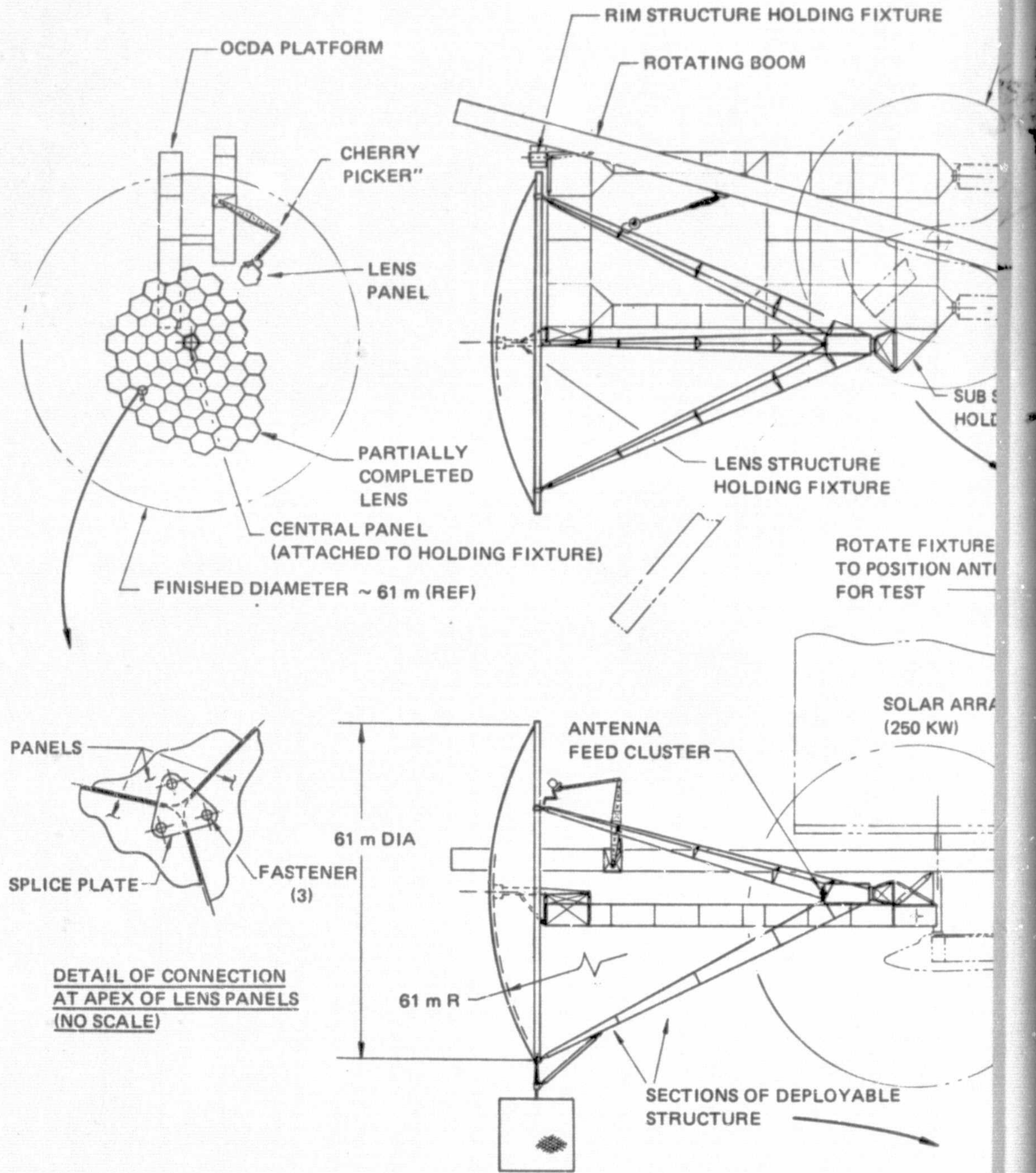
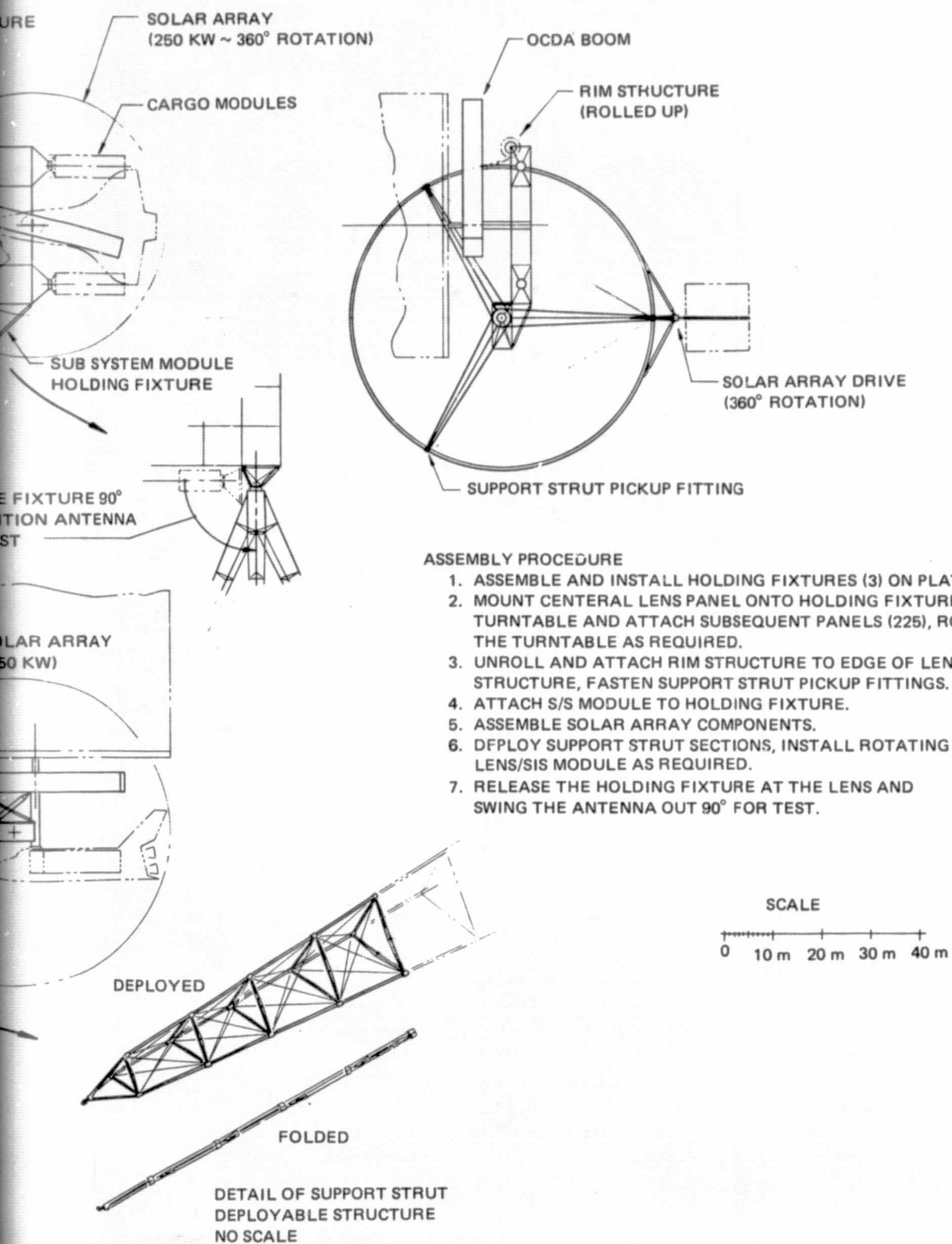


Figure 6-63 Lens Bootlace Element Design Concept



FOLDOUT FRAME



ASSEMBLY PROCEDURE

1. ASSEMBLE AND INSTALL HOLDING FIXTURES (3) ON PLATFORM.
2. MOUNT CENTERAL LENS PANEL ONTO HOLDING FIXTURE TURNTABLE AND ATTACH SUBSEQUENT PANELS (225), ROTATING THE TURNTABLE AS REQUIRED.
3. UNROLL AND ATTACH RIM STRUCTURE TO EDGE OF LENS STRUCTURE, FASTEN SUPPORT STRUT PICKUP FITTINGS.
4. ATTACH S/S MODULE TO HOLDING FIXTURE.
5. ASSEMBLE SOLAR ARRAY COMPONENTS.
6. DEPLOY SUPPORT STRUT SECTIONS, INSTALL ROTATING LENS/SIS MODULE AS REQUIRED.
7. RELEASE THE HOLDING FIXTURE AT THE LENS AND SWING THE ANTENNA OUT 90° FOR TEST.

Figure 6-64 Program Scenario 3 – Mission 3 - Multi-Beam Antenna

FOLDOUT FRAME 2

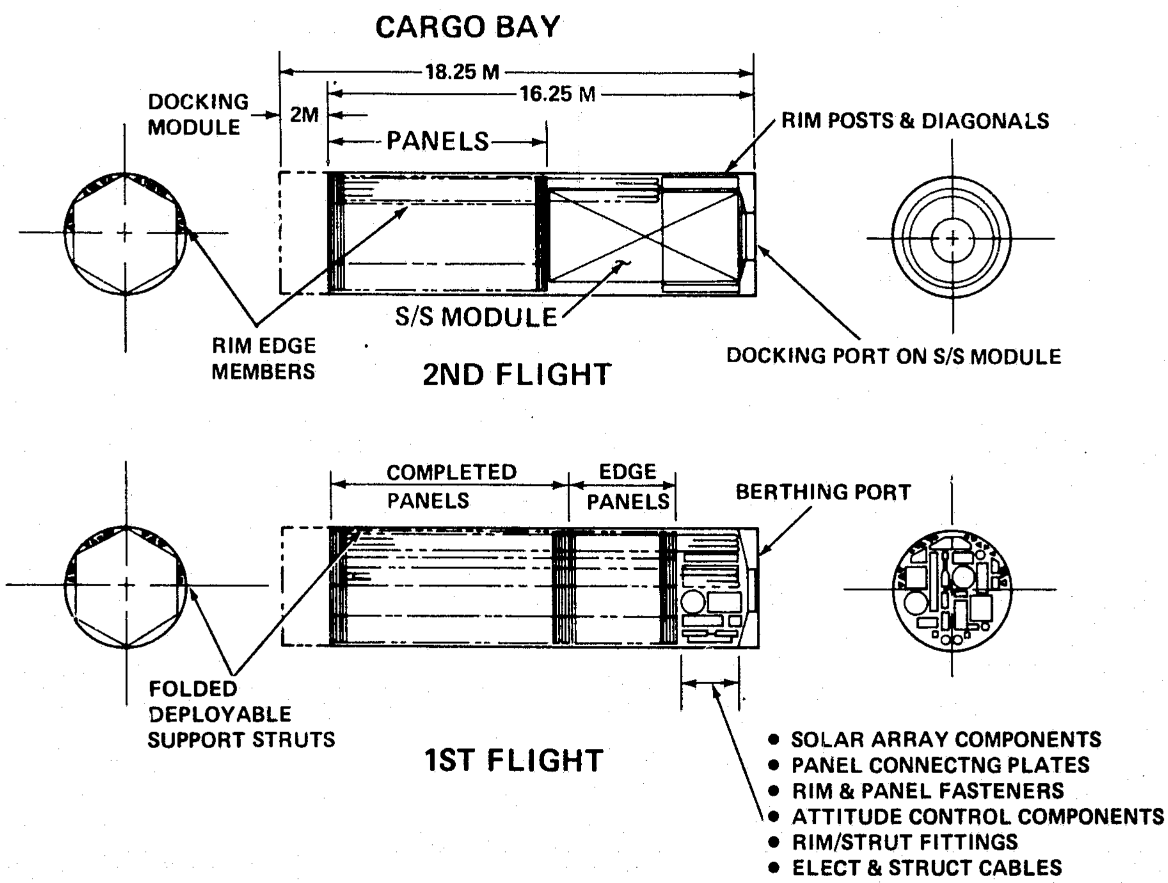


Figure 6-65 Multi-Beam Communications Antenna Shuttle Packing

fixture attached to the OCDA platform structure. The turntable will be rotated as required to bring the work area within easy reach of the boom mounted cherry picker. The rim material is applied and fastened to the edge of the completed lens. Sections of prepackaged structure are deployed and attached end-to-end to form the support struts. The construction phase of this activity is shown in Figure 6-64.

The subsystems module is brought up fully assembled within the Shuttle cargo bay. The module contains the antenna feed system, the transponder electronics, and the remaining subsystems required to make the multi-beam antenna self sufficient. The subsystem module is equipped with a docking provision on one end to allow attachment of a vehicle for orbit change maneuvers and to allow handling during construction and testing.

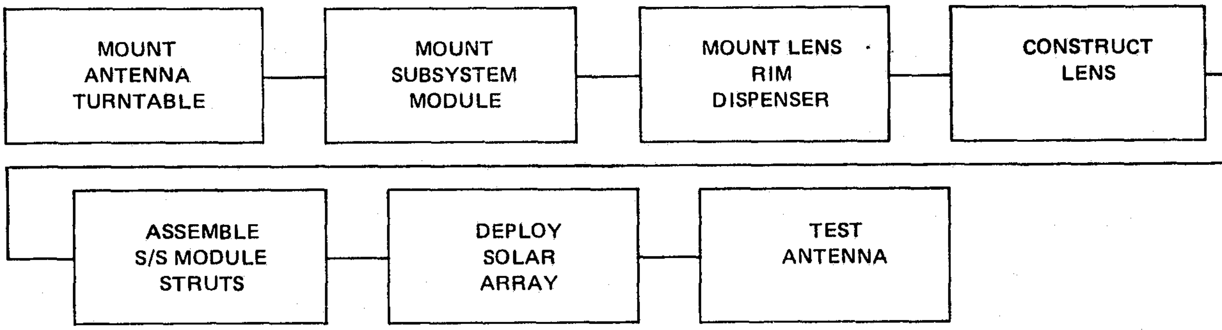
The support struts are installed between the subsystem module and the lens rim. The ends of the support struts are adjustable to align the axis of the lens to the feed focal point.

Table 6-59 lists the functions, operations, and an estimate of the time to construct and test the antenna. The major block of time is associated with construction of the antenna lens. This lens is constructed outward from the center by adding panels as the lens is rotated. The need for four Shuttle flights to construct and test the antenna is based on two shifts of three crewman during construction and three shifts of two crewmen during testing.

6.3.3.4 Orbital Tests. Several types of tests are required to verify the constructional phase of the antenna and evaluate its performance. Table 6-60 lists the test objectives, requirements, equipment and support rationale. A pictorial representation of several tests is given in Figure 6-66. These tests are as follows:

- Antenna Aperture Surface Contour and Roughness Test - A gimbal mounted rangefinder is positioned at the feed center point. Retroreflective devices (corner reflectors) on the lens panel connectors allow the rangefinder to measure the distance to each panel apex. The radial location of each retroreflective device can be measured by azimuth and altitude angles measured at the gimbal. Structural distortions are defined in two ways: axial components (displacement along the boresight of the lens) and radial components (perpendicular to the boresight). The acceptable limit for these components are 15-cm axial and 3.75-cm radial.
- Subsystems Check-Out - The multi-beam antenna contain subsystems that provide communications transponding capability attitude control and power. The bulk of the subsystems are located in the subsystems module at the feed end of the satellite. When the antenna is attached to the OCDA, the antenna subsystems will interface with a test console in the orbiter.

Table 6-59 Functional Operations Scenario — Bootlace Lens Antenna Construction



TIME HR:MIN	OPERATIONS	REMARKS
(5:00)	MOUNT ANTENNA TURNTABLE	
:45	DEPLOY TURNTABLE SUPPORT STRUCTURE (6)	
:45	ATTACH STRUCTURE TO TURNTABLE	
:30	INSTALL STAYS (4)	
:30	REMOVE TURNTABLE FROM TRANSPORTATION FIXTURE	
1:30	ATTACH TURNTABLE TO PLATFORM AND TENSION STAYS	
1:30	CONNECT POWER CABLES, C/O CLAMP OPS AND INDEX	
(4:00)	MOUNT SUBSYSTEM MODULE	
:30	DEPLOY S/S MODULE SUPPORT STRUCTURE	
:30	ATTACH STRUCTURE TO PLATFORM	
:30	ALIGN STRUCTURE TO ANTENNA TURNTABLE	
:30	CONNECT POWER CABLES AND C/O DOCKING INTERFACES	
1:00	REMOVE S/S MOD FROM TRANS FIX AND DOCK TO PLATFORM	
1:00	C/O SUBSYSTEMS AND AZIMUTH ACTUATOR	
(2:30)	MOUNT LENS RIM DISPENSER	
:30	DEPLOY DISPENSER SUPPORT STRUCTURE	
:30	ATTACH STRUCTURE TO PLATFORM	
1:30	TRANSPORT DISPENSER AND ATTACH TO SUPPORT STRUCT	
:30	CONNECT POWER CABLE	
(182:00)	CONSTRUCT LENS	
:30	LOAD LENS PANELS (2) ON TRAVELLER AND TRANSPORT	226 PANELS
1:00	POSITION LENS PANEL TO HUB AND FASTEN	REQUIRED
:30	ATTACH LENS PANEL TO HUB PANEL	TEMPORARY
:10	DEPLOY PANELS (2) AND INDEX HUB	POSITIONING
56:00	LOAD LENS PANELS (22) AND TRANSPORT	BEAM REQUIRED
112:00	ATTACH PANELS TO FORM LENS (224)	PARALLEL OPS
39:00	DEPLOY PANELS (224) AND INDEX HUB	
29:00	FEED RIM FROM DISPENSER AND FASTEN TO PANELS	96 ATTACH
3:00	MOUNT STRUT ADAPTERS (3)	POINTS
2:00	MOUNT SOLAR ARRAY FITTINGS (2)	
(10:00)	ASSEMBLE S/S MODULE STRUTS	
1:00	DEPLOY STRUT SECTIONS (4) AND TRANSPORT	
1:00	ASSEMBLE STRUT ON PLATFORM	
:45	POSITION STRUT AND ATTACH TO LENS AND S/S MODULE	
5:30	REPEAT ABOVE TWICE	
1:00	ALIGN S/S TO LENS	ADJUST STRUT
:45	INSTALL AND ADJUST TENSION TIES (3)	

Table 6-59 Functional Operations Scenario – Bootlace Lens Antenna Construction (Continued)

TIME HR:MIN	OPERATIONS	REMARKS
(7:00)	SOLAR ARRAY DEPLOYMENT	
:15	DEPLOY STRUTS (3)	
:45	ATTACH STRUT TO S/A DRIVE	
1:00	ASSEMBLE STRUTS TO LENS RIM	
1:00	ASSEMBLE SOLAR PANEL SUPPORT STRUCTURE	4 ELEMENTS
2:00	MOUNT STRUCTURE TO S/A DRIVE AND POWER CONN	
:30	DEPLOY S/A ELEMENTS (4)	
:30	INSTALL POWER CABLE	
1:00	C/O SOLAR ARRAY	
(260:00)	TEST ANTENNA	
470:00	4 FLIGHTS (7 DAYS/FLIGHT)	

Table 6-60 Orbital Construction Experiment Definition – Antenna Development, Program Scenario 3 – Multi-Beam Antenna Mission 3

DEMO/TEST OBJECT	TEST REQUIREMENTS	TEST EQUIP. REQUIRED	TEST RATIONALE
• ASSEMBLY OF LARGE BOOTLACE LENS STRUCTURE	• ASSEMBLY OF BOOTLACE LENS APERTURE • DEPLOYMENT OF STRUT STRUCTURE	• LASER REFLECTOMETER SYSTEM • CHECKOUT STATION ON-BOARD SHUTTLE	A LARGE MULTI-BEAM COMMUNICATIONS ANTENNA HAS NEVER BEEN LAUNCHED INTO GEOSTATIONARY ORBIT THAT WILL MEET THE REQUIREMENTS OF EXPANDING SERVICE TO MANY USERS WITH SMALL TERMINALS. ASSEMBLY/CONSTRUCTION TECHNIQUES AND ON ORBIT PERFORMANCE EVALUATION OF LARGE COMMUNICATIONS ANTENNAS ARE PRECURSOR TECHNOLOGY STEPS LEADING TO EXPANDED WORLD WIDE PUBLIC SERVICE SATELLITES.
• MEASUREMENT OF DEFLECTIONS IN BOOTLACE LENS APERTURE	• CHECKOUT OF SUBSYSTEMS • MEASURE ANTENNA PATTERN	• FREE FLYER SATELLITE TO MAP RADIATION PATTERN	
• PERFORMANCE MEASUREMENT	• DETERMINE OPERATIONAL PERFORMANCE CHARACTERISTICS	• ACCELEROMETERS AND ASSOCIATED INSTRUMENTATION	
• OPERATIONAL	• DETERMINE NATURAL FREQUENCY OF BOOTLACE LENS ANTENNA • FEED/APERTURE ALIGNMENT • AXIAL (<15 cm) AND RADIAL (<4cm) DISTORTION MEASUREMENTS OF LENS APERTURE		

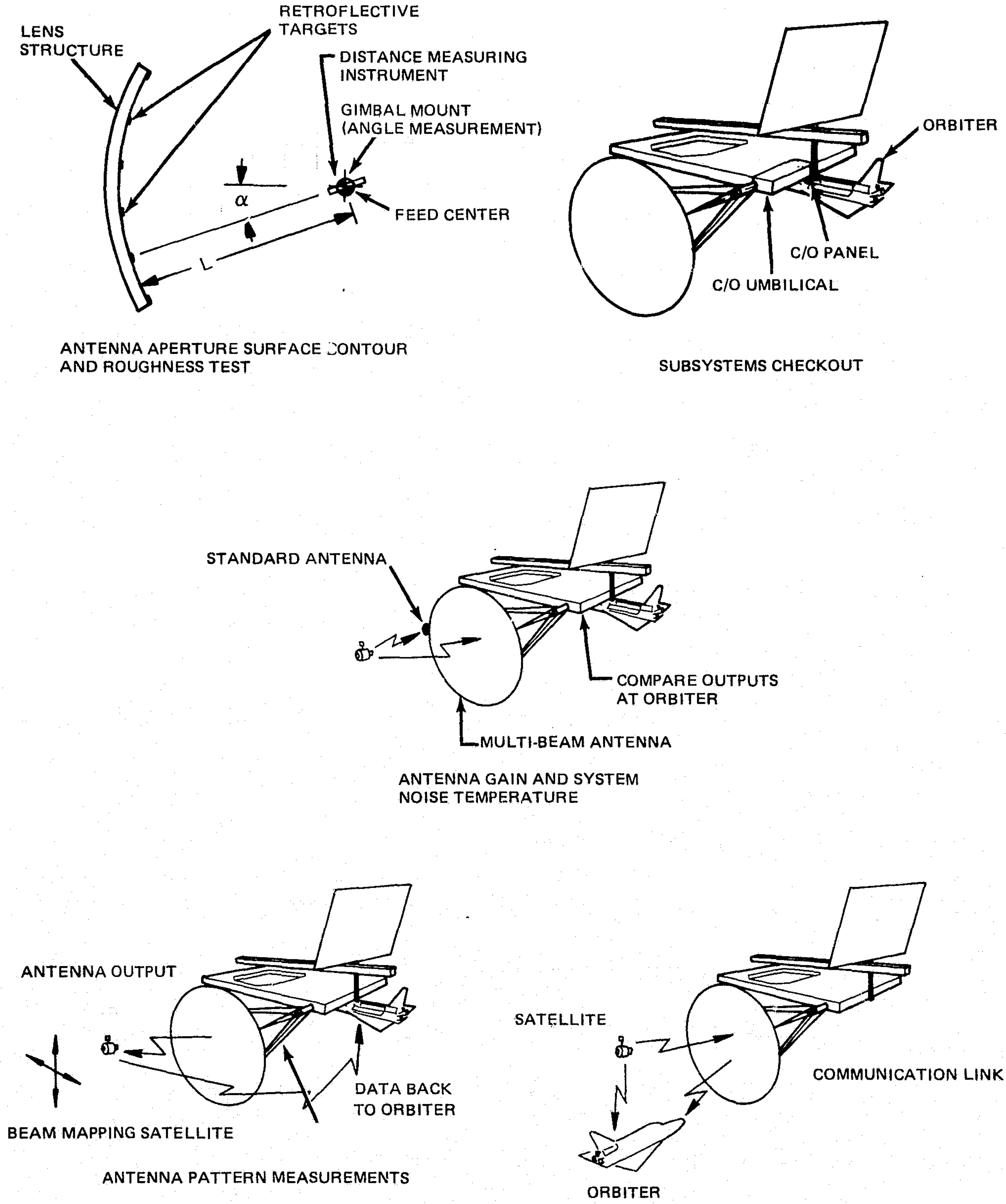


Figure 6-66 Multi-Beam Antenna Test Configurations

- Antenna Pattern Measurements - Antenna pattern measurements will be made with the use of a co-orbital free flying signal mapping satellite. The satellite will be positioned in the far field (further than 50 km) of the antenna. An RF axial beam signal will be emitted from the multi-beam antenna. The mapping satellite will measure the radiation pattern as it is maneuvered relative to the beam axis, transmitting the data back to the docked orbiter for storage. After sufficient samples have been taken, the data may be used to determine the entire pattern of the antenna's radiation.

- Antenna Gain and System Noise Temperature - The measurement of the absolute antenna gain of the multi-beam antenna will be accomplished by comparing a received signal level with that received by a calibrated standard gain antenna at the same frequency. A signal will be transmitted from the mapping satellite received at the multi-beam antenna which is reduced by an attenuator, and a reference level is obtained with a power meter. The power meter is preceded by an attenuator to provide a convenient reference level. The multi-beam antenna receiver is then switched to a standard gain horn with the attenuator network out of the circuit and a new reference reading is obtained. The attenuator is then adjusted until a reading corresponding to the first is obtained. The gain of the multi-beam antenna is the arithmetic sum of the standard gain horn gain and the attenuator network setting. The noise temperature measurement of the multi-beam antenna is accomplished by the comparison of RF noise level as received by the antenna with a calibrated standard noise generator. An accurately calibrated nitrogen cold load and a room temperature load are utilized to measure receiver noise. The antenna noise temperature is then measured and the total system noise temperature (in degrees Kelvin) is obtained by adding the two measurements. The ratio gain/temperature can then be obtained by subtracting in db the temperature from the antenna gain.

- Communication Link - In normal operation the multi-beam antenna will receive a signal from one location and, after some signal manipulation, retransmit the signal down to another location, completing a communication link. A communication link test that will allow a quantitative performance of the antenna utilizes a free flying satellite and the orbiter to simulate both ends of the link. The mapping satellite will be instrumented with a data transmitter that radiates a digital message to the orbiter via the multi-beam lens antenna. The data transmitted and received by both users (mapping satellite and orbiter) is compared for bit error rate detection. The test is repeated for various user locations and signal levels.

6.3.4 Operations Summary

6.3.4.1 Equipment Mass. Mass estimates for the radiometer and communication antennas are contained in Tables 6-61 and 6-62. The communication antenna is twice as heavy as the radiometer primarily due to the weight of the lens panels. Both antennas have solar arrays, however, as the communication antenna is much smaller than the radiometer, the weight allocation is included in the communication antenna EPS estimate. The calculated valves for support and orbital test equipment is the same for both antenna.

6.3.4.2 Electrical Power. The power required by the OCDA to support antenna construction activities is listed in Table 6-63 and 6-64, and in both instances the basic OCDA solar array 250 kW is adequate. Considerable power is required to operate the communications antenna as shown in Table 6-65, but as it is 24% of the construction requirements, it does not impact on the basic OCDA. The radiometer power required is 100% of the communication antenna needs.

6.3.4.3 Manpower. The manpower required was determined by simply taking the number of crew needed for each task and multiplying by the time, then totaled. It should be noted that it was assumed that one crewman is available to perform orbiter related tasks and this requirement is not included in the table.

Manpower and Flights Required

Mission	Construction Man-hours	Experiment Man-hours	Shuttle Flights
1. OCDA	500	--	3
2. 100-m Radiometer Antenna	1640	520	8
3. 61-m Multi-Beam Communication Antenna	630	520	4

6.3.4.4 Objectives Accomplished. We analyzed the extent to which the proposed tests or activities demonstrated the stated objective. Table 6-65 contains the results of this analysis. Engineering judgment was used to determine the extent to which demonstration objectives are met by individual missions, using the following criteria:

- 25% meets a low percentage of the objective
- 50% meets 1/2 of the objective
- 75% meets a high percentage of the objective
- 100% meets all of the objectives.

Table 6-61 Radiometer Mass Estimate

ELEMENT	MASS KG	MASS LBM
ANTENNA	(6238)	(13755)
• SURFACE MESH	200	441
• STRUCTURE		
– CIRCUMFERENTIALS	460	1,014
– RIBS	3,778	8,330
• HUB	600	1,323
• MAST	200	441
• MECHANICAL SYST	1,000	2,205
SUBSYSTEMS	(965)	(2128)
• STRUCTURE/THERMAL CONTROL	200	441
• ATTITUDE CONT (ACS)	40	88
• COMM	200	441
• ELECT POWER	180	397
• DATA MANG (DM)	315	695
• SENSORS	30	66
INTERFACE FIXTURES	1,000	2203
SUPPORT EQUIPMENT	4,779	10527
ORBIT TEST EQUIPMENT	826	1819
TOTAL	13808	30932

Table 6-62 Communication Antenna Mass Estimate

ELEMENT	MASS KG	MASS LBM
ANTENNA APERTURE		
• LENS PANELS	19460	8825
• APERTURE RIM	2063	936
• FEED SUPPORT STRUCTURE	1875	850
SUBSYSTEM MODULE		
• STRUCTURE	125	57
• FEED/DIPLEXER ASSEMBLY	156	71
• COMMUNICATIONS ELECTRONICS	563	255
• TT&C	37	17
• FLIGHT CONTROL	147	67
• PROPULSION	87	39
• THERMAL CONTROL	63	29
• ELECTRICAL POWER & INTEGRATION	2125	964
• SOLAR ARRAY	750	340
• PROPELLANT	280	127
INTERFACE FIXTURES	1500	3303
SUPPORT EQUIPMENT	4779	10527
ORBIT TEST EQUIPMENT	826	1819
TOTAL	34,836	76,639

Table 6-63 Radiometer Power Requirements

EQUIPMENT	AVERAGE POWER, KW	
FABRICATION MODULE (5 FT/MIN)	15.0	
ROTATING FIXTURE	4.9	(75.5 PEAK)
ALIGNMENT EQUIPMENT	0.2	
COMMUNICATION EQUIPMENT	0.5	
CHERRY PICKER	2.1	(5.0 PEAK)
LIGHT SIDE SUBTOTAL		22.7
LOSSES		1.9
LIGHTING	36.3	
DARKSIDE SUBTOTAL (SLIP RING)	59.0	
LOSSES	15.13	
TOTAL DARKSIDE	64.13	
BATTERY RECHARGE	→	49.1
HOUSEKEEPING		33.9
ORBITER SUPPORT		35.6
LIGHTSIDE TOTAL (SLIP RING)		143.2
LOSSES		33.4
SOLAR ARRAY POWER		176.6

Table 6-64 Communications Antenna Power Requirements

EQUIPMENT	AVERAGE POWER, KW-	
ROTATING FIXTURE	20.9	
ALIGNMENT EQUIPMENT	0.2	
COMMUNICATION EQUIPMENT	0.5	
CHERRY PICKER	2.1	
LIGHT SIDE SUBTOTAL		23.7
LOSSES		2.1
LIGHTING	41.0	
DARK SIDE SUBTOTAL (SLIP RINGS)	64.7	
LOSSES	5.6	
TOTAL DARKSIDE	70.3	
BATTERY RECHARGE	→	53.8
HOUSEKEEPING		33.9
ORBITER SUPPORT		35.6
LIGHTSIDE TOTAL (SLIP RINGS)		149.1
LOSSES		34.6
SOLAR ARRAY POWER		183.7

Table 6-65 Program 3 Mission Suitability Matrix

PROBLEM AREA	DEMO/TEST OBJECTIVE	MISSION SUITABILITY										
		DEMO NEED WT.	MISSION 1	2	3	4	5	6	7	8	9	% OBJ MET
STRUCTURES	1) BUILDING BLOCK STRUCT FAB AND/OR DEPLOY	6	50	0	0							50
	2) JOINT ASSEMBLY PROCEDURES	8	75	50	50							75
	3) MAN/MACHINE/INTERACTION	8	50	75	50							75
	4) LARGE ELEMENT MATING	9	75	50	50							50
	5) SECONDARY STRUCTURE INSTALLATION	8	50	50	50							50
	6) MEASURE PRODUCTIVITY	6	50	100	75							100
	7) ATTITUDE CONTROL DURING CONSTRUCTION	7	100	100	100							100
	8) THERMAL CYCLING DURING CONSTRUCTION	6	100	100	100							100
	9) ACCURACY & INTEGRITY TESTS	8	50	50	50							50
	10) STRUCTURAL REPAIR	7	50	50	50							50
	11) STRUCTURE/CONTROL/INTERACTION	7	50	50	50							50
SOLAR ARRAY	1) CONSTRUCTION & DEPLOYMENT	8	25	0	0							25
	2) LOW COST, HIGH EFFICIENT SPACE FAB BLANKET	8	0	0	0							0
	3) ARRAY TO STRUCT INSTALLATION	7	25	0	0							25
	4) CONCENTRATOR INSTALLATION	7	0	0	0							0
	5) THERMAL CYCLE	6	50	0	0							50
	6) FAULT-ISOLATION & REPAIR	7	50	0	0							50
POWER DISTRIBUTION	1) INSTALL INTEGRATED STRUCTURE/BUS SYSTEM	5	50	0	0							50
	2) INSTALL DEDICATED SYSTEM WITH SWITCH GEAR & CIRCUIT PROTECTION	5	50	0	0							50
	3) INSTALL STORAGE SYSTEM	5	100	0	0							100
	4) INSTALL POWER CONDITIONING UNITS	7	100	0	0							100
	5) INSTALL ROTARY POWER TRANSFER DEVICE	8	75	0	0							75
	6) HI VOLTAGE OPERATION	8	0	0	0							0
	7) LEAKAGE PREDICTION	7	25	0	0							25
	8) FAULT ISOLATION & REPAIR	7	50	0	0							50
POWER TRANSMISSION	1) DC TO RF CONVERSION IN STEPS	8	0	0	0							0
	2) INTEGRATED PROOF OF CONCEPT	10	0	0	0							0
	3) THERMAL CYCLING TESTS ON WAVE GUIDES & PHASE CONTROL	6	0	0	0							0
	4) IONOSPHERE TESTS	4	0	0	0							0
	5) GEO PERFORMANCE (HI VOLTAGE & START)	8	0	0	0							0
	6) LIFE TESTS	4	0	0	0							0
	7) DEMO TRANSMISSION TO GROUND	8	0	0	0							0
PROPULSION	1) INSTALL PROPULSION UNIT FOR ATTITUDE CONTROL & STATION KEEPING	7	100	50	50							100
	2) VERIFY EFFECTS OF EXHAUST PRODUCTS	3	50	50	50							50
	3) FAULT ISOLATION & REPAIR	5	50	50	50							50
STABILIZATION & CONTROL	1) CONTROL OF LARGE FLEXIBLE BODIES USING CENTRALIZED & DISTRIBUTED SYSTEMS	7	50	0	0							0
	2) SURFACE CONTOUR CONTROL	8	0	0	0							0
	3) POINT 1 LARGE MASS RELATIVE TO 2ND	7	25	25	25							25
	4) STATIONKEEPING	7	100	100	100							100
	5) FAULT ISOLATION & REPAIR	5	50	50	50							50
REFLECTOR MIRROR FACETS	1) PLACEMENT & INSTALLATION	8	0	0	0							0
	2) POINTING & CONTROL ON FLEXIBLE BODY	8	0	0	0							0
	3) FAULT ISOLATION & REPAIR	5	0	0	0							0
RADIATORS	1) POSITIONING & ASSEMBLY OF RADIATOR ELEMENTS	8	0	0	0							0
	2) CONSTRUCT GAS TIGHT JOINTS	6	0	0	0							0
	3) FAULT ISOLATION & REPAIR	4	0	0	0							0
THERMAL CAVITY	1) POSITIONING & ASSEMBLY	8	0	0	0							0
	2) GAS TIGHT JOINTS	6	0	0	0							0
	3) CAVITY PERFORMANCE THROUGH CONSTRUCTION	8	0	0	0							0
	4) CONTROL WITH ROTATING MACHINERY	8	0	0	0							0
LARGE MIRROR SURFACE	1) POSITIONING & ASSEMBLY	8	0	0	0							0
	2) CONTOUR CONTROL	8	0	0	0							0
	3) EFFICIENCY MEASUREMENT	5	0	0	0							0
	4) LIFE TESTING	4	0	0	0							0
ASSEMBLY OPERATIONS	1) INITIAL PLACEMENT OF CONSTRUCTION PLATFORM	8	100	0	0							100
	2) SITE LOGISTICS	7	50	75	75							75
	3) RESUPPLY & STORAGE	6	50	75	75							75
	4) HABITATION	4	0	0	0							0
	5) SITE COMMUNICATIONS	5	100	100	100							100
	6) SITE LIGHTING	5	100	100	100							100
	7) RADIATION SAFETY (GEO)	6	0	0	0							0
	8) PRODUCTIVITY GOALS	8	50	100	100							100
	9) REMOTE CONTROLLED MANIPULATORS	7	75	75	75							75
	10) SPARE FABRICATION (AUTO ASSEMBLY)	8	0	100	100							100
	11) USE OF EVA	6	75	75	75							75
	12) FAULT ISOLATION & REPAIR OF CONSTRUCTION EQUIPMENTS	6	75	75	75							75
PROCESSES	1) FASTENER OPTIONS (WELD, BOND, ETC)	7	50	100	50							100
	2) FAB IN METALLICS & NON METALLICS	6	25	100	100							100
	3) VAPOR DEPOSITION FOR REPAIR	8	0	0	0							0
MISSION OPS	1) COMMUNICATIONS	5	50	100	75							100
	2) REMOTE CONTROL FROM GROUND	8	0	75	75							75
	3) MISSION PLANNING	4	25	75	75							75
ANTENNA CONSTRUCTION	1) RID STRUCTURE FABRICATION	6	0	100	100							100
	2) ACTIVE CONTOUR CONTROL	8	0	100	0							100
	3) CONTROL ACTUATOR & HARNESS INSTALLATION	5	0	100	0							100
	4) LENS PANEL INSTALLATION	7	0	0	100							100

The OCDA construction accomplished 29 of 76, or 38% of the objectives. The 29 figure is obtained by adding the partial and full compliances. For example, the structures technical area has a total of 7 compliances of a possible 11 objectives.

6.4 LIGHTING REQUIREMENTS

Calculation of lighting requirements is influenced by many subjective factors, i.e.:

- What areas should be lighted?
- What should be the light intensity for these areas?
- What are the practical considerations, i.e., coverage factors, utilization factors, lamp configurations, etc.
- What efficiency factor (lumens/watt) should be used?

Various OCDA work areas were lit at different levels based on the planned activity and a conservative calculation approach utilized.

The beam-lumens design approach was selected from among the various industrial design methods investigated because it more closely approximates the OCDA application. Other industrial methods, such as the point-by-point or lumens-per-foot method are applicable to design of large indoor areas since they account for room characteristics as well as the distribution, efficiency, number and location of the light sources (Luminaire Characteristics). The beam-lumen method is used for floodlighting of outdoor areas and/or structures. Data used throughout the following text was obtained from the IES Lighting Handbook, Fifth Edition, dated 1972; NASA General Specification - Lighting, Manned Spacecraft and Related Flight Crew Equipment, Functional Design Requirements for, SC-L-0002, dated July 1972; and various industrial technical lighting bulletins.

Although final lighting design analysis conducted during the detailed design phase (Phase B/C) for a specific mission will include many layouts, aiming diagrams and additional calculations, the following relationships provide a preliminary estimate of lighting power requirements:

$$N = \frac{A_L \times C_F}{B_A} \qquad (1) \qquad\qquad N = \frac{F_C \times A_L}{M \times U \times B_L} \qquad (2)$$

where: N = Number of floodlights required

C_F = Coverage factor

A_L = Area to be lighted

B_A = Beam spot area

F_C = Footcandles required

M = Maintenance factor

U = Utilization factor

B_L = Beam lumens for specific flood light selected

These two formulas are calculated individually: (1) providing an estimate of the number of floods (N) based on the beam spot coverage and (2) providing an estimate of N based on the beam lumens available. The N selected will be the larger of the two calculations with the floodlight beam angles being selected providing the nimum difference between the two results (1) and (2).

In equation (1) the beam spot coverage (B_A) is a function of the floodlight beam angle, the beam aiming angle and the perpendicular distance between the source and the surface to be covered. Figure 6-67 illustrates the coverage as a function of these parameters. The coverage factor (C_F) is really a safety factor which defines the number of directions that each point in the lighted area should be illuminated from to minimize shadows and avoid large dark patches if one or two luminaires should fail. Figure 6-68 illustrates this point and Table 6-66 is a copy of the typical recommended C_F for industrial application from the referenced documents. Area lighted (A_L) is self explanatory.

In equation (2) the maintenance factor (M) allows for dirt and normal lamp degradation. Because of the space dirt-free environment, an M of 1 is assumed. For normal earth environment industrial applications M is assumed to be about .7. The utilization factor (U) is the ratio of lumens effectively lighting the area to beam lumens available. It accounts for beam overhang (see Figure 6-69). Since well over half the floodlight can be aimed so that the lumens fall within the desired area, an overall utilization factor of .75 has been assumed. The foot candles (F_C) were determined by subdividing the areas to be lighted as a function of the planned activity for the various missions and using the applicable suggested F_C for that activity. Table 6-67 tabulates the F_C used for each activity area compared to the related industry activity.

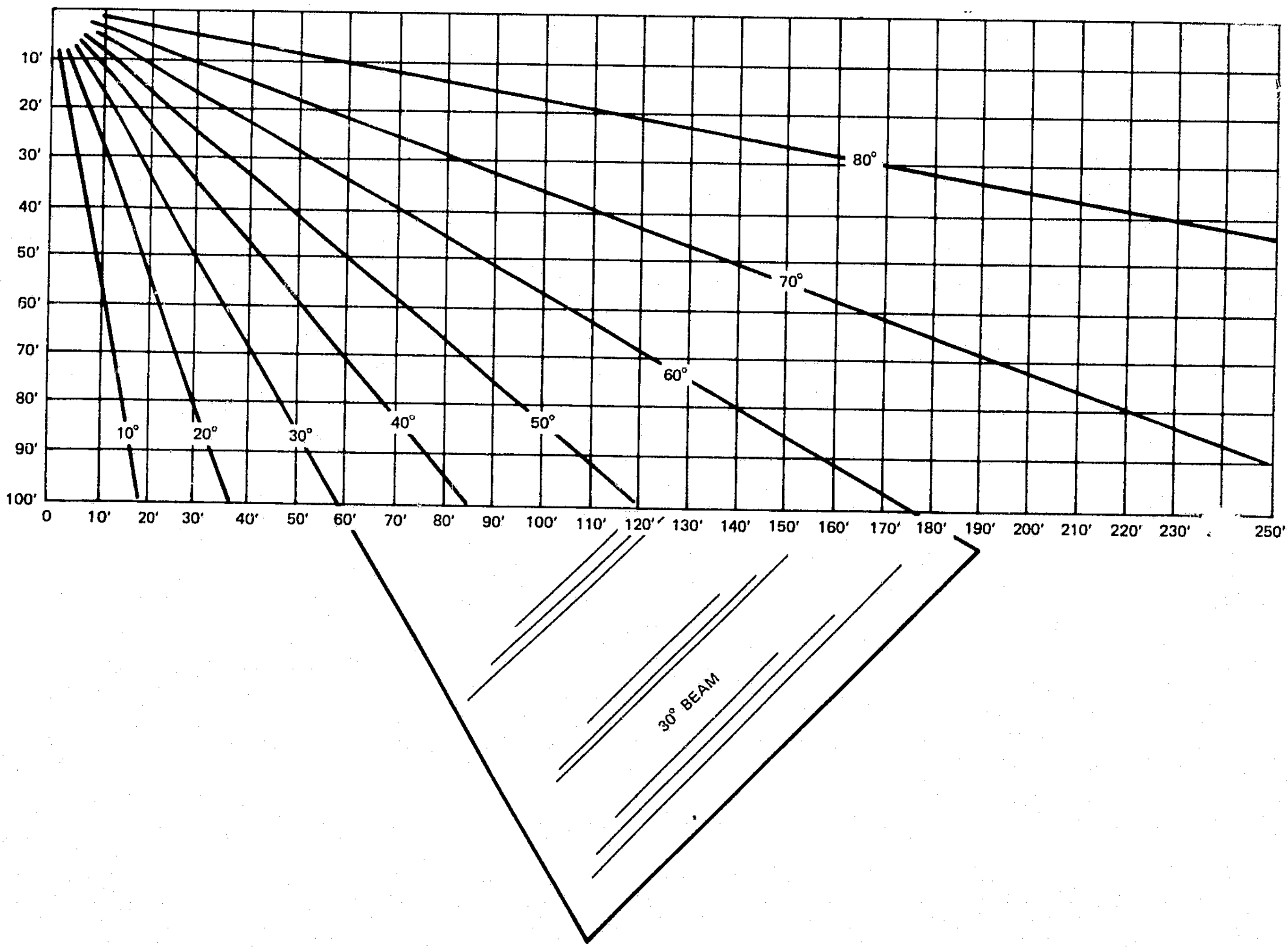


Figure 6-67 Coverage as a Function of Beam Angle, Aiming and Distance

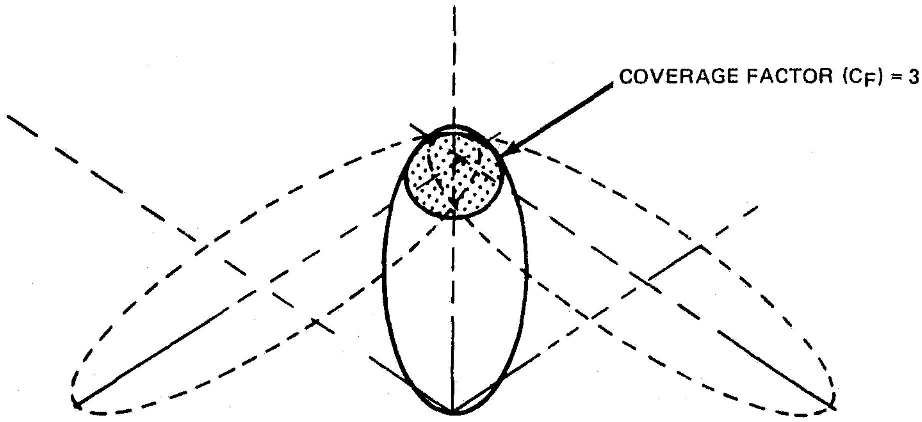


Figure 6-68 Flood Light Aiming Pattern

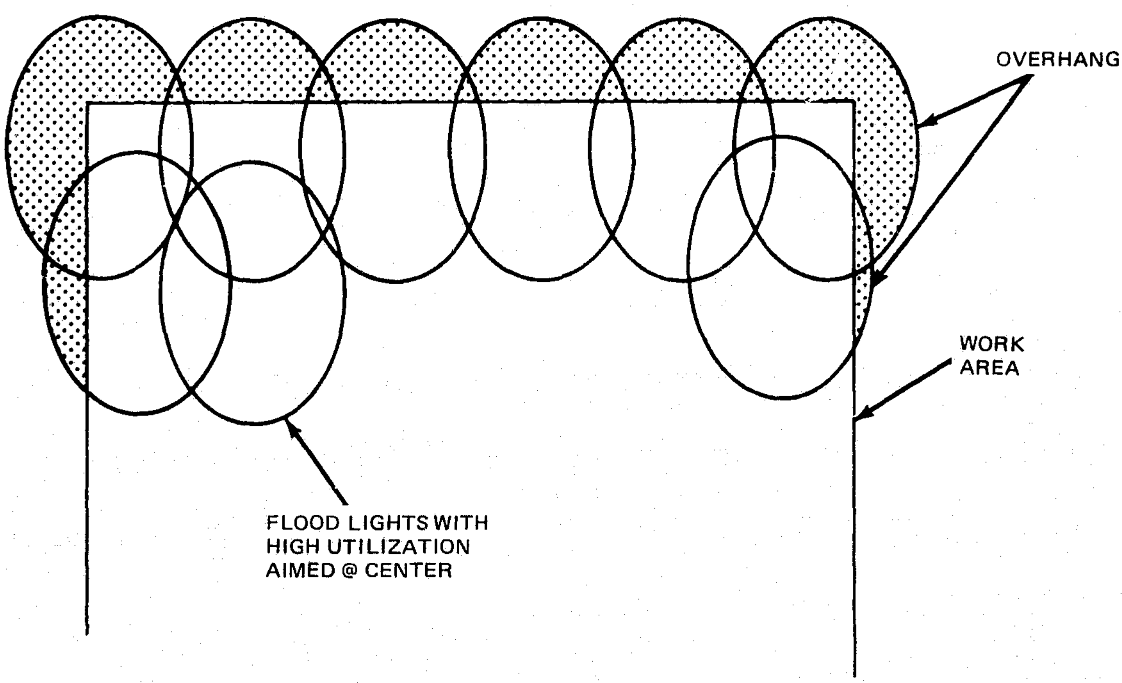


Figure 6-69 Flood Light Utilization Pattern

Table 6-66 Typical Recommended Footcandle Levels and Coverage Factors for Floodlighting Systems

LOCATION	FOOTCANDLES	MINIMUM COVERAGE FACTOR
BUILDINGS—AVERAGE SURROUNDINGS.	10–30	2
CONSTRUCTION WORK	20	3–4
FENCES (PROTECTIVE)	0.2	1–2
SERVICE STATION YARDS.	5–10	3–4
LOADING PLATFORMS	20	3–4
PARKING LOTS	1–5	2
PROTECTIVE LIGHTING—ACTIVE AREAS	5–20	2
SHIPYARDS—CONSTRUCTION.	5–30	3–4
SIGNS, POSTER BOARDS	20–100	1–2
TREES, MONUMENTS	5–50	1–2

Table 6-67 OCDA Illumination vs Industry Practice For Various Activities

ACTIVITY AREA ILLUMINATION LEVELS	ILLUMINATION (FT C)	RECOMMENDED LEVELS OF ILLUMINATION FOR VARIOUS APPLICATIONS (IES LIGHTING HANDBOOK)
	150	DRAFTING ROOMS
	100	GENERAL MANUFACTURING
CHERRY PICKER LIGHTING →	50	STRUCTURAL STEEL FABRICATION
	30	CONFERENCE ROOMS, LOBBYS
	20	CORRIDORS, HALLWAYS
SMALL AREA ACTIVITY → LIGHTING	10	BUILDING CONSTRUCTION, RECREATIONAL SPORTS
LARGE AREA ACTIVITY → LIGHTING	5	STORAGE, THEATER AND DANCING AREAS
OCDA BOOM LIGHTING →	1	PARKING AREAS
	.2	PROTECTIVE LIGHTING (OPEN AREAS)

Results

Figures 6-70 through 6-73 provide the results of the lighting analysis for the radiometer antenna, bootlace antenna, 2-MW solar array fabrication and 20-m beam fabrication missions:

- Pictorial representation of the various lighted areas
- The intensity (F_C) selected for each area
- The power determined from equations (1) and (2) for each area
- Total lighting power for mission construction and assembly phase.

A sample set of calculations for the radiometer antenna are tabulated below:

Radiometer Antenna Construction

OCDA Beam Fabrication Area -

10 ft candles at 40 ft for 10 m x 10 m

Assume $C_F = 2$, $B_L = 45°$

$$(1)\ N = \frac{A_L \times C_F}{B_A} = \frac{10.76 \times 10^2 x2}{B_A} = \frac{21.52x10^2}{B_A}$$

15°	30°	50°	
253	1141	4464	B_A (sq ft)
8.5	1.8	.48	N

$$(2)\ N = \frac{F_C \times A_L}{(M)(U)(B_L)} = \frac{10x10.76x10^2}{(1)\ (.75)\ B_L} = \frac{10.76x10^3}{.75B_L}$$

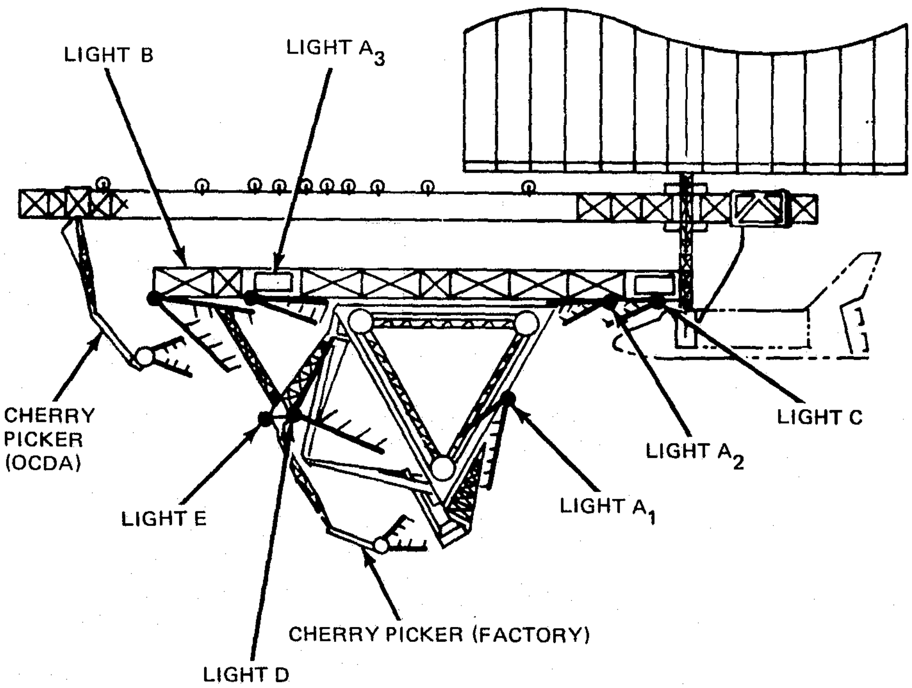
1000	750	750	Watts/Lamp
6500	6500	7000	B_L
2.2	2.2*	2.04	N

Based on using three 30° lights at 750 Watts

Power required = 2.25 kW

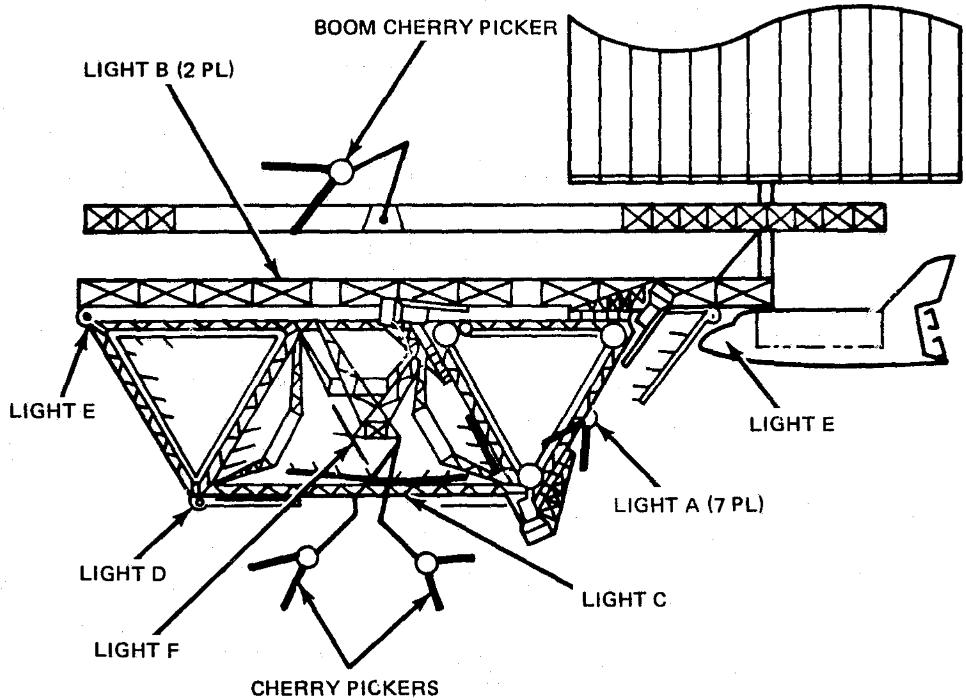
*Next integer (3) selected

Table 6-68 and 6-69 provide samples of the tables used to determine spot size and beam lumens, respectively, from the available commercial bulletins. The efficiency, lumens/watt, of the standard incandescent floodlights used in the calculations, Table 6-69, range from 8-12 lumens/watt. Utilizing greater efficiency lamps, (i.e., 20 lumens/watt ref Table 6-75), would significantely reduce the power requirements. This emphasizes the fact that the detailed design phases (B, C & D) should include a lighting optimization effort: aiming diagrams, evaluation of coverage factors and design of the specific luminaires to be used. The results of the current analysis provide a conservative projection of lighting power required.



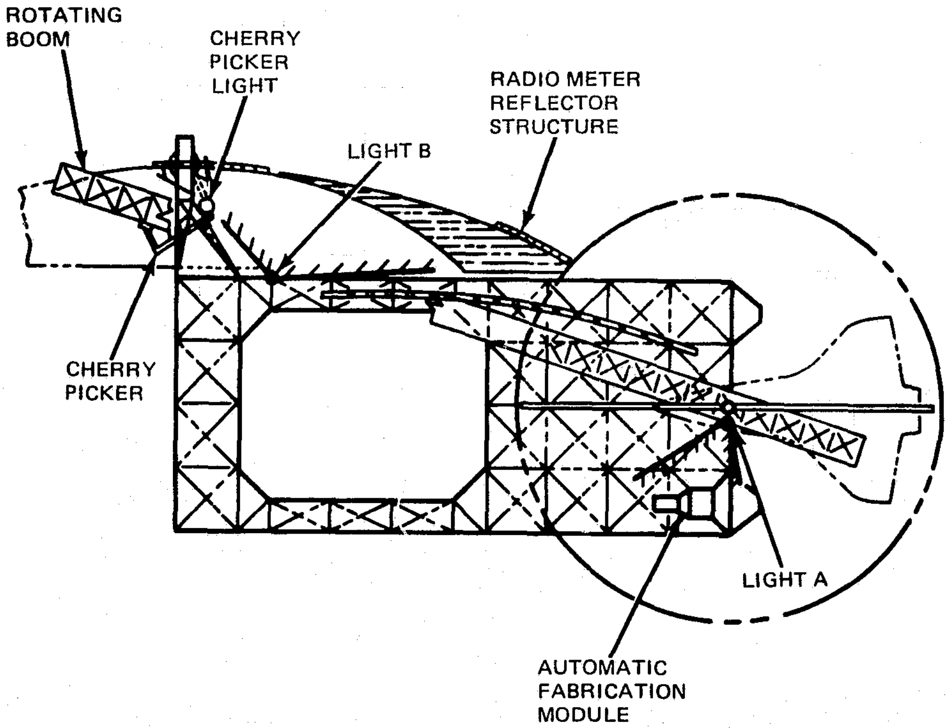
LIGHT	INTENSITY (FT C)	REGION OF ILLUMINATION	ELECTRIC POWER REQ'D
A	10	BEAM FABRICATION AREA (4 PL)	4 kW
B	5	GENERAL WORK AREA (58 x 32 m)	14.25 kW
C	10	CONDUCTOR LINK WORK STATION	3 kW
D	10	SOLAR BLANKET/REFLECTOR AREA	3 kW
E	1	FACTORY CP TRACK PATH	1 kW
CHERRY PICKERS (2)	50	CP WORK AREAS	18 kW
		TOTAL	43.25 kW

Figure 6-70 Lighting Requirements for 20-m Beam Construction



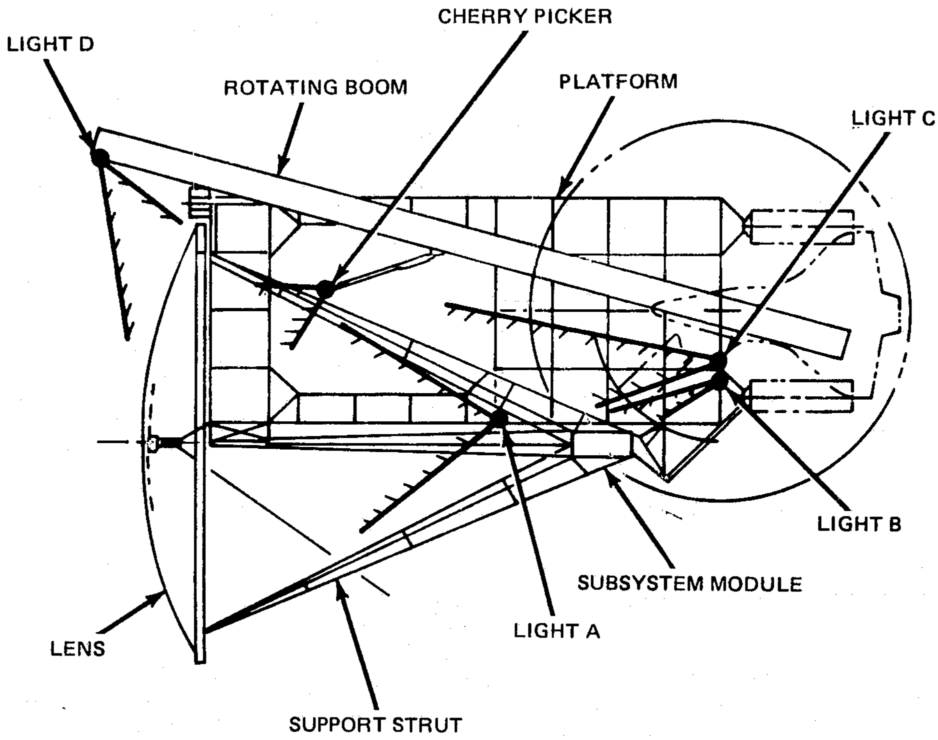
LIGHT	INTENSITY (FT c)	REGION OF ILLUMINATION	ELECTRIC POWER REQUIRED
A	10	BEAM FABRICATION AREAS (7 PL)	7 kW
B	10	CONDUCTOR LINK WORK STA. (4)	6 kW
C	10	TROUGTH WORK STA (2 X 70 m)	4.6 kW
D	10	SOLAR BLANKET/REFLECTOR AREA	9 kW
E	5	GENERAL WORK AREA (58 X 65 m)	28.5 kW
F	1	FACTORY CP TRACK PATH	1 kW
CHERRY PICKERS (3)	50	CP WORK AREAS (3)	27 kW
		TOTAL	83.1 kW

Figure 6-71 Lighting Requirements for 2 MW Solar Array Construction



LIGHT	INTENSITY (FT C)	REGION OF ILLUMINATION	ELECTRIC POWER REQ'D
A	10	BEAM FABRICATION AREA	2.25 kW
B	5	INSIDE SURFACE OF REFLECTOR STRUCTURE (36 x 75 m)	24 kW
CHERRY PICKER	50	CP WORK AREA	9 kW
		TOTAL	35.25 kW

Figure 6-72 Lighting Requirements for 100-m Radiometer Construction



LIGHT	INTENSITY (FT C)	REGION OF ILLUMINATION	ELECTRIC POWER REQ'D
A	5	INSIDE OF LENS	21 kW
B	50	SUBSYSTEM MODULE	3 kW
C	5	INBOARD SUPPORT STRUT	4 kW
D	10	OUTSIDE EDGE OF LENS	7 kW
CHERRY PICKER	50	CP WORK AREA	9 kW
		TOTAL	44 kW

Figure 6-73 Lighting Requirements for Multi-Beam Antenna Construction

Table 6-68 Spot Sizes – Floodlight Beams

	15° BEAM NARROW				30° BEAM MEDIUM				50° BEAM BROAD			
Distance D	Aiming Angle	SPOT AREA Sq. Ft.	L Ft.	W Ft.	Aiming Angle	SPOT AREA Sq. Ft.	L Ft.	W Ft.	Aiming Angle	SPOT AREA Sq. Ft.	L Ft.	W Ft.
	0°	5.4	2.6	2.6	0°	22.5	5.4	5.4	0°	68.3	9.3	9.3
	10°	5.7	2.7	2.7	10°	23.7	5.5	5.4	10°	72.2	9.7	9.5
	15°	6.1	2.8	2.7	15°	25.2	5.8	5.6	15°	77.6	10.2	9.7
	20°	6.6	3.0	2.8	20°	27.6	6.1	5.7	20°	86.0	10.9	10.1
	25°	7.3	3.2	2.9	25°	31.0	6.6	6.0	25°	98.8	11.9	10.6
	30°	8.5	3.5	3.0	30°	36.0	7.3	6.3	30°	118	13.4	11.2
10 Ft.	35°	10.0	4.0	3.2	35°	43.3	8.3	6.7	35°	147	15.6	12.0
	40°	12.3	4.5	3.5	40°	54.2	9.6	7.2	40°	195	18.8	13.2
	45°	15.8	5.4	3.8	45°	71.3	11.5	7.9	45°	279	23.8	14.9
	50°	21.1	6.5	4.1	50°	99.8	14.4	8.8	50°	418	32.7	17.5
	55°	30.4	8.3	4.7	55°	152	19.1	10.1	55°	871	[illegible]	21.8
	60°	17.2	11.1	5.4	60°	259	27.3	12.1	60°	2651	107	31.5
	65°	81.6	16.0	6.5	65°	545	44.8	15.5	65°			
	70°	168	25.9	8.3	70°	1809	100	23.0	70°			
	0°	12.3	3.9	3.9	0°	50.6	8.0	8.0	0°	154	14.0	14.0
	10°	12.8	4.1	4.0	10°	53.3	8.3	8.2	10°	162	14.5	14.2
	15°	13.6	4.2	4.1	15°	56.7	8.7	8.3	15°	175	15.2	14.6
	20°	14.8	4.5	4.2	20°	62.0	9.2	8.6	20°	193	16.3	15.1
	25°	16.5	4.8	4.4	25°	69.8	9.9	8.9	25°	222	17.9	15.8
	30°	19.0	5.3	4.6	30°	81.1	11.0	9.4	30°	265	20.1	16.8
15 Ft.	35°	22.5	5.9	4.8	35°	97.5	12.4	10.0	35°	331	23.3	18.1
	40°	27.7	6.8	5.2	40°	122	14.4	10.8	40°	439	28.1	19.8
	45°	35.6	8.0	5.6	45°	160	17.3	11.8	45°	628	35.7	22.3
	50°	47.6	9.8	6.2	50°	224	21.7	13.2	50°	1008	49.0	26.2
	55°	68.5	12.4	7.0	55°	341	28.6	15.2	55°	1961	76.4	32.7
	60°	106	16.7	8.1	60°	582	41.0	18.1	60°	5965	161	47.2
	65°	184	21.0	9.7	65°	1226	67.2	23.2	65°			
	70°	378	38.8	12.4	70°	4070	150	34.5	70°			
	0°	21.8	5.3	5.3	0°	90.0	10.7	10.7	0°	273	18.6	18.6
	10°	22.8	5.4	5.3	10°	94.8	11.1	10.9	10°	289	19.4	19.0
	15°	24.2	5.7	5.5	15°	101	11.5	11.1	15°	310	20.3	19.5
	20°	26.3	6.0	5.6	20°	110	12.2	11.5	20°	314	21.7	20.1
	25°	29.4	6.4	5.8	25°	124	13.3	11.9	25°	395	23.8	12.1
20 Ft.	30°	33.8	7.1	6.1	30°	144	14.6	12.5	30°	471	26.8	22.4
	35°	40.	7.9	6.5	35°	173	16.6	13.3	35°	588	31.1	24.1
	40°	49.2	9.1	6.9	40°	217	19.2	14.3	40°	780	37.5	26.5
	45°	63.3	10.7	7.5	45°	285	23.1	15.7	45°	1116	47.7	29.8
	50°	84.6	13.1	8.3	50°	399	28.9	17.6	50°	1792	65.3	34.9
	55°	122	16.6	9.3	55°	606	38.2	20.2	55°	3486	102	43.6
	60°	189	22.2	10.8	60°	1035	54.6	24.1	60°	10604	215	62.9
	65°	327	32.0	13.0	65°	2179	89.6	31.0	65°			
	70°	672	51.8	16.5	70°	7236	200	46.1	70°			

Table 6-69 Approximate Beam Lumens of Typical Enclosed Floodlighting Luminaires with Lamps at Rated Voltage

15° BEAM (NEMA TYPE 1) (NARROW)		30 - 35° BEAM (NEMA TYPE 3) (MEDIUM)		50 - 60° BEAM (NEMA TYPE 4) (BROAD)	
FLOODLIGHT LAMP-WATTS	BEAM LUMENS	GENERAL SERVICE LAMP-WATTS	BEAM LUMENS	GENERAL SERVICE LAMP-WATTS	BEAM LUMENS
250	1300–1700	500	3900–4800	500	4200–5000
500	3000–4000	750	6500–8100	750	7000–8500
1000	6500–8500	1000	9000–11000	1000	9500–12000
1500	11000–14000	1500	15000–17500	1500	16500–18000

Table 6-70 Beam Lumen Output for High Efficiency Lamps (20 Lumens/Watt)

BEAM ANGLE					
15°		30/35°		50/60°	
LAMP POWER, WATTS	BEAM LUMENS	LAMP POWER, WATTS	BEAM LUMENS	LAMP POWER WATTS	BEAM LUMENS
250	2480	500	7445	500	8015
500	5725	750	12400	750	13360
1000	12400	1000	17180	1000	18135
1500	21000	1500	28635	1500	31500

Section 7

IMPACT OF FOLLOW-ON ACTIVITIES

7.1 STRUCTURE

The configuration layout requirements for the follow-on programs that emphasized SPS technology advancement (Programs 1 and 2) and large antenna construction (Program 3) result in the plan-form needs summarized in Figure 7-1. Both Programs 1 and 2 require larger platform sizes than the baseline to accommodate the 20-m deep truss girder fabrication equipments. Both require a platform width of at least 40 m, and Program 1 requires a platform length of 96 m to accommodate the added fixtures needed to build the 2 MW solar array. Because a larger platform is required, the rotating boom must be extended 8 m for platform assembly operations. See Figure 7-2 for a composite of the structure modifications. The baseline platform and rotating boom sizes are adequate for constructing the 100-m diameter radiometer and the 61-m diameter multi-beam communications antenna.

7.2 ELECTRICAL POWER

The study of follow-on missions indicates that the 250 kW OCDA solar array may not be adequate. Figure 7-3 summarizes the major power requirements. The 250 kW was found adequate to perform construction operations, but is too low to conduct SPS related microwave testing. In Program 1 the microwave linear array mission requires an array rated at 290 kW (BOL). The solar array requirements increase to 471 kW for the Program 2 in which the linear array test is performed with klystrons. The Program 3 power requirements of 180 kW is needed because the assembly operations during the dark period of the orbit require an estimated 40 kW for lighting.

The power requirements for conducting the 20-m beam fabrication experiments in Programs 1 and 2 are also relatively high. Even with modest lighting, which illuminates a 15 sq m area around the apex of the beam being assembled at 10 ft-candles, and 1 ft-candle general illumination for safety, the lighting requirements are as high as 75 kW. Power requirements also vary with the number and speed of the fabrication modules used, and could push total mission peculiar power requirements as high as 113 kW. When added to OCDA housekeeping power and shuttle support power, this can push the solar array requirement to 306 kW.

	BASELINE OCDA	PROGRAM 1	PROGRAM 2	PROGRAM 3
REQUIREMENT	32 m, 72 m	40 m, 96 m	40 m, 72 m	32 m, 72 m
PLATFORM DIMENSIONS				
• LENGTH, m	72	96	72	72
• WIDTH, m	32	40	40	32
• DEPTH, m	4	4	4	4
BOOM LENGTH, m	108	116	108	108
MASS, Kg (DRY)	28,958	37,261	31,040	28,958

Figure 7-1 Layout Requirements

- LENGTHEN BOOM
- ADD PLATFORM WIDTH FOR BEAM FABRICATION
- EXTEND PLATFORM LENGTH FOR SOLAR COLLECTOR ASSEMBLY
- UTILIZE CHERRY PICKER FOR CONSTRUCTION

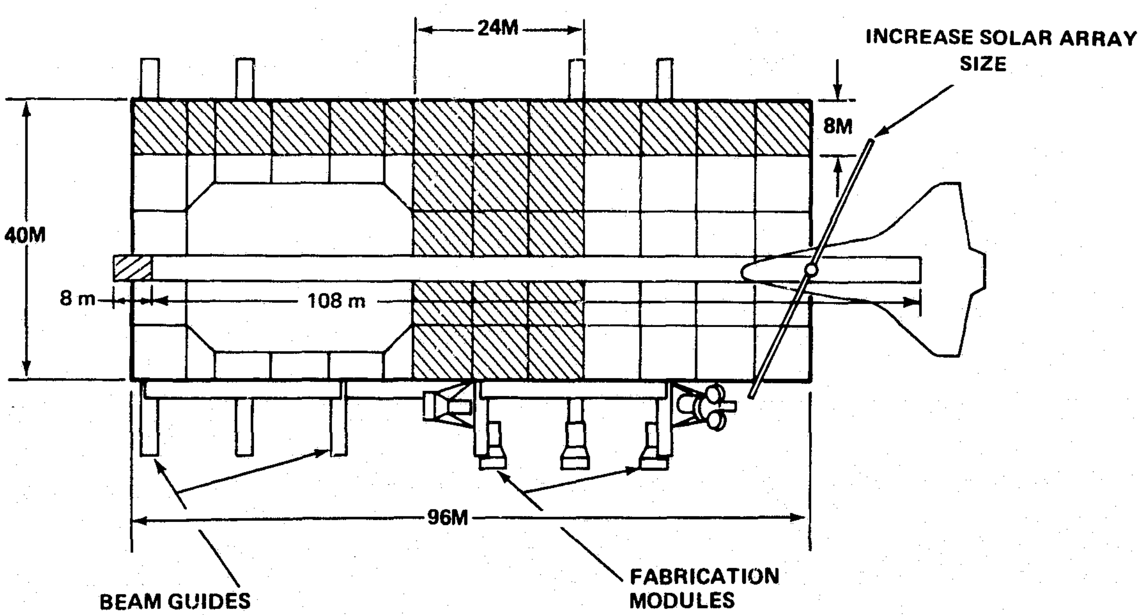


Figure 7-2 Basic OCDA Structure Modifications

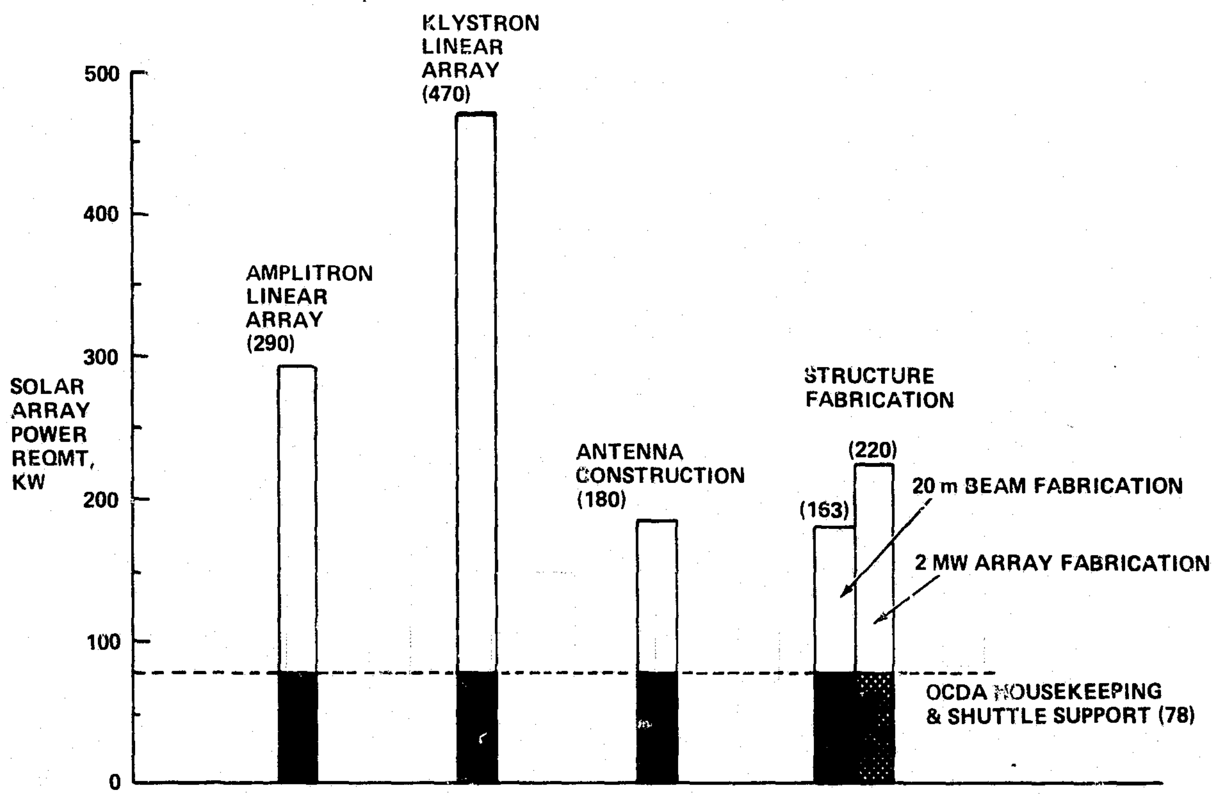
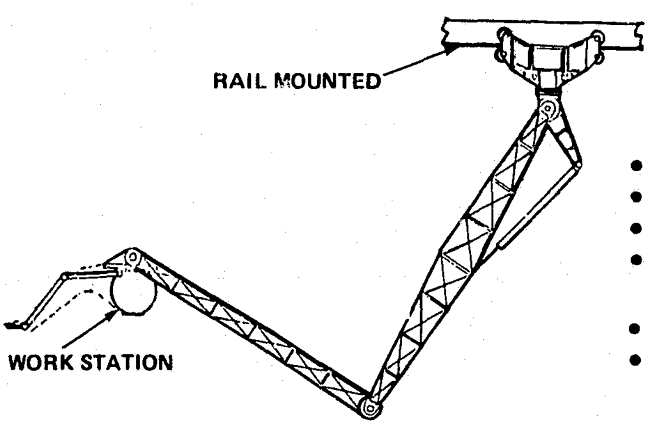


Figure 7-3 OCDA Solar Array Power Requirements

7.3 PLATFORM LOGISTICS AND ASSEMBLY

The boom and traveler have high utilization during the SPS and antenna construction demonstration. Many follow-on construction tasks are more complex than those required to build the basic OCDA, also a number of tasks are repetitious and time consuming. Therefore, in order to accomplish work tasks expeditiously, we decided to replace the boom manipulator with a cherry picker Figure 7-4 for the purposes of this study.

The cherry picker work station may be configured as a pressurized, shirt-sleeve environment bubble or a suited (EVA) operated work platform (open or closed). Each configuration has advantages and disadvantages and is independent of the basic utility of a manned manipulator. For the purpose of costing, the pressurized bubble has been selected.



CHARACTERISTICS

- UNIVERSAL TOOL – COMMON TO ALL EXPERIMENTS
- MAX REACH – 30 M (STATIONARY)
- RAIL MOUNTED FOR EXTENDED REACH
- WORK STATION
  - PRESSURIZED OR EVA
- MASS 2,950 KG (DRY)
- POWER REQ'D 2 KW AVG

*REF–SPACE STATION SYSTEM STUDY NAS 8-31993

Figure 7-4 Cherry Picker Manned Manipulator

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Section 8

COST SUMMARY AND ANNUAL FUNDING

Cost estimates for three OCDA programs were prepared with the aid of the SPACE cost model. This model is also being utilized in the Space Station Systems Analysis Study for NASA/MSFC. The SPACE model generates DDT&E, PRODUCTION, and OPERATIONS cost data for space systems and then spreads these data, according to a preselected beta distribution, function, to obtain annual funding profiles.

8.1 COSTING GROUNDRULES

The groundrules and assumptions used for obtaining costs for the final report of the OCDA study were as follows:

- Cost estimates are reported in constant mid-year 1977 dollars.
- Cost estimates are commensurate with program definition at the time of the estimate, the relative level of study effort, and with the understanding that the estimates are only for preliminary planning and tradeoff study purposes.
- Cost estimates exclude NASA institutional costs, such as base support contractor personnel costs, civil service personnel salaries and allowances, and administrative support technical services.
- Costs exclude contractor fee.
- NASA furnished Shuttle, costs of $19.5M per flight in mid-fiscal year 1977 dollars are used.
- Configurations costed are at their "most likely" weight (contingency excluded).
- The emphasis is on relative costs rather than on absolute costs.
- The cost estimates are developed and documented in consonance with the latest JSC approved Work Breakdown Structure (WBS) and WBS dictionary.
- The cost estimates assume no dedicated flight test hardware and/or major ground test articles.
- All flight crew and training costs not included in the per flight Shuttle costs are excluded from the total program costs.

- It is assumed for funding purposes that the first available funding will begin at the start of fiscal year 1980.
- It is assumed for scheduling purposes that the first OCDA launch will be January, 1984.
- Costs for this study are derived using the following criteria as a base:
  - Thruput cost estimates prepared by Aerospace Industry, and/or government agencies.
  - Cost Estimating Relationships (CERs), cost factors, and best judgement estimates obtained in consonance with knowledgeable engineering personnel are used in obtaining the remaining costs.
- The CERs that are used are either from Aerospace Industry and/or government agencies, or are formulated from historical data stored in the Grumman data bank.
- The cost of GFE equipment, such as the Beam Fabrication Machine and docking module are not included in the estimate, but the cost, if any, of modifying GFE to meet the requirements of this program is included.
- Excluded are costs for logistics/facilities, flight operations and controls interface equipment.

Figure 8-1 presents the "total program" cost summary for Programs 1, 2 and 3.

8.2 PROGRAM 1

Figure 8-2 presents the basic OCDA costs, excluding all mission hardware and initial spares.

Figure 8-3 presents the annual funding requirements for Program 1. The peak annual funding is $620M and it occurs in 1984. The solar array fabrication incurs the highest peak annual funding, which is more than the peak annual funding for all the other missions taken together. The relatively high solar array cost derives from the fabrication cost of solar blankets which is based on present day technology.

Figure 8-4 is a reproduction of the SPACE computer list of input data for Program 1. This listing identifies how the cost of any specific WBS item was estimated and what the input was. The unit measure column indicates whether an item was estimated parametrically on the basis of weight, square meters, etc., or whether its cost estimate was done

	PROGRAM 1	PROGRAM 2	PROGRAM 3
BASIC OCDA COST, $M	337	447	337
MISSION EQUIP COST, $M	1202	654	619
TRANSPORTATION, $M	312	273	273
TOTAL, $M	1851	1374	1229

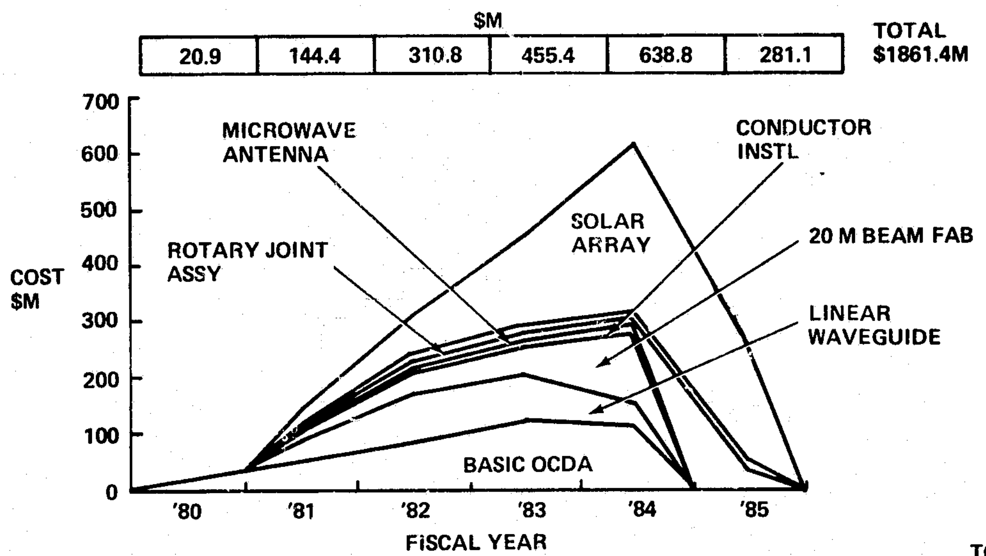
NOTES:
- 1977 $
- BASIC OCDA AND MISSION EQUIPMENT COSTS INCLUDE GSE AND INITIAL SPARES

Figure 8-1 Total Program Cost Summary

ELEMENT	COST, $M DDT&E	COST, $M 1ST UNIT
CORE MODULE/MAST	(13.11)	(18.85)
• STRUCTURE	3.04	.76
• DOCKING RING	0	1.47
• COMM/DATA HDL	.82	2.70
• ELECTRICAL POWER	5.82	8.40
• ACS	3.42	5.53
PLATFORM	(50.62)	(20.74)
• STRUCT/MECH	37.92	9.48
• POWER DISTRIBUTION	3.55	2.21
• PROPULSION	4.14	1.08
• ACS	5.00	5.00
• COMM ANT (WB COMM)	0	.03
• DOCK RINGS (2)	0	2.94
ROTATING BOOM/MANIP	(41.36)	(17.42)
• STRUCT/MECH	22.64	5.66
• PWR DISTRIBUTION	5.97	3.72
• MANIP/CARRIAGE	0	3.46
• TRAVELLER	4.51	.78
• ROTARY JOINT	8.25	3.80
SOLAR ARRAY	(23.04)	(79.34)
• STRUCT/MECH	.69	1.52
• SOLAR BLKTS/DEPL MECH	18.81	76.69
• PWR DISTRIBUTION	3.54	1.13
TOTAL SUBSYSTEMS	(128.13)	(136.35)
PROGRAM MANAGEMENT	15.36	11.97
SYSTEM ENGR & INTEGRATION	12.68	12.35
GSE	12.81	.90
SUBTOTAL	330.55	
SHUTTLE COSTS	58.5	
TOTAL	389.05*	

* Initial Spares Excluded

Figure 8-2 Basic OCDA Costs



MISSION							TOTALS, $M
1. BASIC OCDA	20.9	51.5	82.0	123.1	118.6		396.1
2. LINEAR WAVEGUIDE		33.0	79.2	79.6	46.3		238.0
3. 20 m BEAM FAB		15.6	41.5	51.8	118.6		227.5
4. CONDUCTOR INSTAL		3.7	9.4	10.5	23.4		47.0
5. MICROWAVE ANTENNA		5.2	11.5	20.4	19.3	39.0	95.4
6. ROTARY JOINT ASSEMBLY		6.0	14.7	18.3	18.1	26.5	83.6
7. SOLAR ARRAY FAB		29.4	72.6	151.7	294.5	215.6	763.8

Figure 8-3 Program 1 Annual Funding Requirements

***** NOTES ON SPACE MODEL INPUTS *****

WHEN INPUTS ARE DOLLAR THRUPUTS COL. 1 IS FOR DDT&E, COL. 2 IS FOR PRODUCTION, COL. 3 IS FOR OPERATIONS
WHEN INPUTS ARE WTS SPECIFIED AS KG,KG COL. 1 IS FOR NON-REPLICATED WT, COL. 2 IS FOR TOTAL DRY WT.
WHEN INPUTS ARE WTS SPECIFIED AS KG COL. 1 IS FOR TOTAL DRY WT.
WHEN INPUTS ARE SPECIFIED AS KG,SM,KG COL. 1 IS FOR NON-REPLICATED EPS WT(LESS ARRAY), COL. 2 IS FOR ARRAY AREA IN SQ. METERS,
COL. 3 IS FOR TOTAL DRY WT. OF EPS(LESS ARRAY)

OCDA-P1 INPUTS---- MODE

WBS	COST ELEMENT	UNIT MEAS	INPUT1	INPUT2	INPUT3	INPUT4	SHIPSET QTY	GRD TST	COMN/COMPLEX DDT&E	COMN/COMPLEX FSUN	STATE OF DEV DDT&E	STATE OF DEV FSUN
1.1.3.1	STRUCTURE	KG	143.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.3.2	DOCKING MODULE	KG	145.10	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.3.3	COMM&DATA HNDLG.	DLR	0.825	2.700	0.0		1	0.0				
1.1.3.4	ELECTRICAL POWER	DL2,KG2	0.04	1.18	386.80	1209.10	1	0.0	1.00	1.00	1.00	1.00
1.1.3.6	ATT. CONTROL	DLR	3.419	5.526	0.0		1	0.0				
1.1.4.1	STRUCTURE	KG	3870.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.2	POWER DISTR.	KG	2233.10	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.3	PROPULSION	KG	20.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.4	ATT. CONTROL	DLR	5.000	5.000	0.0		1	0.0				
1.1.4.5	ANTENNAS	DLR	0.0	0.030	0.0		1	0.0				
1.1.5.1	STRUCTURE	KG	1972.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.2	POWER DISTR.	KG	4393.70	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.3	MANIPULATOR	KG,DL2	438.10	0.0	0.06	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.4	TRAVELLER	KG	64.90	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.5	ROTARY JOINT	DLR	8.250	3.800	0.0		1	0.0				
1.1.6.1	STRUCTURE	KG	268.90	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.2	SOLAR BLANKET	SM	192.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.4	POWER DISTR.	KG,KG	768.30	23.60	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.5	TILT MECHANISM	KG	15.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.7.1	MMU	KG	102.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.4.1	STRUCT/MECH	KG	998.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.4.2	TRUCK	KG	568.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.12.2.4.3.1	CONTROLS	KG	79.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.12.2.4.3.2	ECLS	DLR	1.000	0.500	0.0		1	0.0				
1.12.2.4.3.3	BUBBLE HATCH	KG	497.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.6.1	RF CONVERTERS	DLR	2.700	0.187	0.0		1	0.0				
1.1.12.2.6.2	WAVEGUIDES	KG	16.93	0.0	0.0	0.0	1	0.0	1.00	0.80	1.00	1.00
1.1.12.2.6.3	PHS CONTRL ELECT	DLR	14.200	10.127	0.0		1	0.0				
1.1.12.2.6.4	MECHANICAL	KG,DL	259.00	4.49	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.6.5	PWR. DISTR.	T,T,KG	30.80	2.93	1474.00	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.7.1	FREE FLYER S/C	DLR	3.700	7.400	0.0		1	0.0				
1.1.12.2.7.2	EXP PEC STRUCT	DLR	0.100	0.300	0.0		1	0.0				

Figure 8-4 Program 1 — SPACE Cost Model-Inputs

1.1.12.2.7.3	EXP PEC ELTNS	KG	7.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.1	PRIME STRUCTURE	KG	693.00	0.0	0.0	0.0	1	0.0	0.80	0.80	1.00	1.00
1.1.12.3.4.2	PLATFORM	KG	136.00	0.0	0.0	0.0	1	0.0	0.50	0.60	1.00	1.00
1.1.12.3.4.3	RAILS	KG	77.00	0.0	0.0	0.0	1	0.0	0.30	0.10	1.00	1.00
1.1.12.3.4.4	SCAFFOLD	KG	181.00	0.0	0.0	0.0	1	0.0	0.30	0.10	1.00	1.00
1.1.12.3.4.5	CARRIAGE	KG	45.33	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.6	CABLE RIGGER	KG	15.00	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.7	PRETENSION D*V*F	KG	3.00	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.8	PWR DISTRIBUTION	KG	45.33	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.9	SWING ARMS	KG	50.00	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
.1.12.3.4.11	ALIGNERS	KG	82.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.3.5	FAB. MODULES	KG	2497.00	0.0	0.0	0.0	6	0.0	1.00	1.00	1.00	1.00
1.1.12.3.6	CREW WORK MODULE	DLR	28.200	7.800	0.0		1	0.0				
1.1.12.3.7	MATERIAL	KG	1952.00	0.0	0.0	0.0	1	0.0	0.50	1.00	1.00	1.00
1.1.12.4.4.1	CO FAB MOD-SUPTS	KG	100.00	0.0	0.0	0.0	1	0.0	0.20	0.20	1.00	1.00
1.1.12.4.5	FABRIC. MODULES	KG	999.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.4.6.1	SUPPORT LNK INS	KG.KG	34.00	71.60	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.5.4.1	DEPLOYMENT FIX	KG	5.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.5.4.2	PIVOT SUPPORT	KG	22.00	0.0	0.0	0.0	1	0.0	0.10	0.10	1.00	1.00
1.1.12.5.5	SUPPORT EQUIP	KG	4.50	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.5.6.1	PRIMARY STRUCT.	KG	18.00	0.0	0.0	0.0	1	0.0	0.50	0.50	1.00	1.00
1.1.12.5.6.2	SAR/ELE MECH INT	DL.KG	1.30	25.88	0.0	0.0	50	0.0	1.00	1.00	1.00	1.00
1.1.12.5.6.3	RF CONVERTERS	DLR	3.000	1.135	0.0		1	0.0				
1.1.12.5.6.4	PHS CONTRL ELECT	DLR	7.100	10.490	0.0		1	0.0				
1.1.12.5.6.5	POWER DIST.	DL.KG	8.20	449.00	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.5.6.6	WAVEGUIDES	DL.SM	0.75	8.08	0.0	0.0	50	0.0	1.00	1.00	1.00	1.00
1.1.12.6.4.1	ROTY JTS D/L FIX	KG	191.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.6.5.1	ROTY JT (ODAPT)	DLR	4.900	2.500	0.0		1	0.0				
1.1.12.6.5.2	ROTY JT (BALL)	DLR	11.600	5.100	0.0		1	0.0				
1.1.12.6.5.3	MT STR (D/L-SO)	KG	485.00	0.0	0.0	0.0	1	0.0	0.90	0.80	1.00	1.00
1.1.12.6.5.4	MT STR TRNS I TR	KG	279.00	0.0	0.0	0.0	1	0.0	0.30	0.30	1.00	1.00
1.1.12.6.5.5	POWER DISTR.	KG	2665.00	0.0	0.0	0.0	1	0.0	0.30	0.30	1.00	1.00
1.1.12.7.5.2	SOLR CL BLKT MOD	KG	45.40	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.7.5.3	CONCTR BLKT MOD	KG	37.20	0.0	0.0	0.0	2	0.0	1.00	1.00	1.00	1.00
1.1.12.7.5.4	SOLR/CONCTR B IN	KG	204.10	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.7.5.5	CABLE RIGGER	KG	45.37	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.7.5.6	PRETENSION DEVIC	DLR	1.700	0.210	0.0		3	0.0				
1.1.12.7.6.1	STRUCTURE/MECH.	KG	3722.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.7.6.2	SOLAR CELL BLKT	SM	8487.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.7.6.3	CONCTR BLKT	KG	511.33	0.0	0.0	0.0	3	0.0	0.10	0.10	1.00	1.00
1.2.4	SHUTTLE	DLR	0.0	0.0	312.000		1	0.0				

OTHER INPUTS

END ITEM QUANTITY = 1
PERCENT LEARNING = 0.750
REFERENCE YEAR = 1977.
INFLATION FACTOR = 0.0

Figure 8-4 Cont

off line and entered as a thruput. The four columns at the right side are for various contingency adjustments, such as commonality, complexity, and off-the-shelf availability.

Figure 8-4 is a reproduction of the SPACE cost model output for Program 1. Clarifying notes are printed on both the input and output tables to minimize misinterpretation.

8.3 PROGRAM 2

Figure 8-5 presents the annual funding requirements for Program 2. The peak annual funding is $400M and it occurs in 1984. The basic OCDA cost is higher than in Program 1 because the Solar Array in Program 2 is twice the size of the array in Program 1.

Figure 8-6 is a reproduction of the SPACE cost model input data and Figure 8-6 is the detailed output. As in Program 1, the input data unit measure column indicates how the cost of a given WBS item was estimated. If the unit measure is in kilograms, for example, the cost of that WBS item was obtained from a weight-related cost estimating relationship, CER. Conversely, if the unit measure is in dollars, the estimate was prepared off line and entered as a thruput.

8.4 PROGRAM 3

Figure 8-7 presents the annual funding requirements for Program 3. The peak annual funding is $420M and it occurs in 1984.

Figure 8-8 is a reproduction of the SPACE cost model input data and Figure 8-8 is the detailed output. As in Program 1, the input data unit measure column indicates how the cost of a given WBS item was estimated. If the unit measure is in kilograms, for example, the cost of that WBS item was obtained from a weight-related cost estimating relationship (CER). Conversely, if the unit measure is in dollars, the estimate was prepared off line and entered as a thruput.

**** NOTES ON SPACE MODEL OUTPUT ****

FIRST UNIT COST IS TOTAL PER SHIPSET
PRODUCTION COST IS TOTAL FOR THE NUMBER OF END ITEMS SPECIFIED

OCDA-P1 GENERAL COST OUTPUT (MILLIONS OF 1977. CONSTANT DOLLARS)

WBS	COST ELEMENT	DDT&E: ENG DES AND DEV	DDT&E: GRD TEST HDWR	DDT&E: TOTAL	PRODUCTION: FIRST UNIT	PRODUCTION: VEHICLE PROD	PRODUCTION: INITIAL SPARES	PRODUCTION: TOTAL	OPERATIONS: OPER ACT.	OPERATIONS: OPER SPARES	OPERATIONS: TOTAL	TOTAL
1.0	ORB CONS DM PROJ	761.93	0.0	761.93	741.69	741.69	35.87	777.56	312.00	0.0	312.00	1851.49
1.1	ORB CONS DM ART.	168.98	0.0	168.98	161.58	161.58	6.86	168.44	0.0	0.0	0.0	337.42
1.1.1	PROJ. MGMT	15.36	0.0	15.36	11.97	11.97	0.0	11.97	0.0	0.0	0.0	27.33
1.1.2	SE & I	12.68	0.0	12.68	12.35	12.35	0.0	12.35	0.0	0.0	0.0	25.04
1.1.3	CORE SYSTEM	13.11	0.0	13.11	18.85	18.85	0.94	19.80	0.0	0.0	0.0	32.90
1.1.3.1	STRUCTURE	3.04	0.0	3.04	0.76	0.76	0.04	0.80	0.0	0.0	0.0	3.84
1.1.3.2	DOCKING MODULE	0.0	0.0	0.0	1.47	1.47	0.07	1.54	0.0	0.0	0.0	1.54
1.1.3.3	COMM&DATA HNDLG.	0.82	0.0	0.82	2.70	2.70	0.13	2.83	0.0	0.0	0.0	3.66
1.1.3.4	ELECTRICAL POWER	5.82	0.0	5.82	8.40	8.40	0.42	8.82	0.0	0.0	0.0	14.64
1.1.3.6	ATT. CONTROL	3.42	0.0	3.42	5.53	5.53	0.28	5.80	0.0	0.0	0.0	9.22
1.1.4	PLATFORM	50.62	0.0	50.62	20.74	20.74	1.04	21.78	0.0	0.0	0.0	72.40
1.1.4.1	STRUCTURE	37.92	0.0	37.92	9.48	9.48	0.47	9.95	0.0	0.0	0.0	47.88
1.1.4.2	POWER DISTR.	3.55	0.0	3.55	2.21	2.21	0.11	2.32	0.0	0.0	0.0	5.88
1.1.4.3	PROPULSION	4.14	0.0	4.14	1.08	1.08	0.05	1.14	0.0	0.0	0.0	5.28
1.1.4.4	ATT. CONTROL	5.00	0.0	5.00	5.00	5.00	0.25	5.25	0.0	0.0	0.0	10.25
1.1.4.5	ANTENNAS	0.0	0.0	0.0	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.03
1.1.4.6	LOG. DOCK PORT	0.0	0.0	0.0	2.94	2.94	0.15	3.08	0.0	0.0	0.0	3.08
1.1.5	ROTATING BOOM	41.36	0.0	41.36	17.42	17.42	0.87	18.29	0.0	0.0	0.0	59.65
1.1.5.1	STRUCTURE	22.64	0.0	22.64	5.66	5.66	0.28	5.94	0.0	0.0	0.0	28.58
1.1.5.2	POWER DISTR.	5.97	0.0	5.97	3.72	3.72	0.19	3.90	0.0	0.0	0.0	9.87
1.1.5.3	MANIPULATOR	0.0	0.0	0.0	3.46	3.46	0.17	3.64	0.0	0.0	0.0	3.64
1.1.5.4	TRAVELLER	4.51	0.0	4.51	0.78	0.78	0.04	0.82	0.0	0.0	0.0	5.33
1.1.5.5	ROTARY JOINT	8.25	0.0	8.25	3.80	3.80	0.19	3.99	0.0	0.0	0.0	12.24
1.1.6	SOLAR ARRAY	23.04	0.0	23.04	79.34	79.34	3.97	83.31	0.0	0.0	0.0	106.35
1.1.6.1	STRUCTURE	0.69	0.0	0.69	1.52	1.52	0.08	1.60	0.0	0.0	0.0	2.29
1.1.6.2	SOLAR BLANKET	18.73	0.0	18.73	74.45	74.45	3.72	78.17	0.0	0.0	0.0	96.90
1.1.6.3	MAST-CANN-NEGS	0.0	0.0	0.0	2.21	2.21	0.11	2.32	0.0	0.0	0.0	2.32
1.1.6.4	POWER DISTR.	3.54	0.0	3.54	1.13	1.13	0.06	1.19	0.0	0.0	0.0	4.72
1.1.6.5	TILT MECHANISM	0.08	0.0	0.08	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.11
1.1.9	GSE	12.81	0.0	12.81	0.90	0.90	0.04	0.94	0.0	0.0	0.0	13.75
1.1.12	EXPT. REQ. EQ'MT	592.95	0.0	592.95	580.11	580.11	29.01	609.12	0.0	0.0	0.0	1202.06
1.1.12.2	LINEAR WAVEGUIDE	175.83	0.0	175.83	40.69	40.69	2.03	42.72	0.0	0.0	0.0	218.55
1.1.12.2.1	PROJ. MGMT.	15.98	0.0	15.98	3.01	3.01	0.15	3.16	0.0	0.0	0.0	19.15
1.1.12.2.2	SE & I	13.20	0.0	13.20	3.11	3.11	0.16	3.27	0.0	0.0	0.0	16.46
1.1.12.2.4	CHERRY PICKER	75.77	0.0	75.77	6.43	6.43	0.32	6.75	0.0	0.0	0.0	82.52
1.1.12.2.4.1	STRUCT/MECH	27.66	0.0	27.66	2.39	2.39	0.12	2.51	0.0	0.0	0.0	30.17
1.1.12.2.4.2	TRUCK	19.84	0.0	19.84	1.48	1.48	0.07	1.55	0.0	0.0	0.0	21.39
1.1.12.2.4.3	BUBBLE SYSTEM	28.27	0.0	28.27	2.56	2.56	0.13	2.69	0.0	0.0	0.0	30.97
1.12.2.4.3.1	CONTROLS	8.94	0.0	8.94	0.75	0.75	0.04	0.78	0.0	0.0	0.0	9.72
1.12.2.4.3.2	ECLS	1.00	0.0	1.00	0.50	0.50	0.02	0.52	0.0	0.0	0.0	1.52
1.12.2.4.3.3	BUBBLE HATCH	18.34	0.0	18.34	1.32	1.32	0.07	1.38	0.0	0.0	0.0	19.72
1.1.12.2.6	AMPL. EXP. PEC.	53.64	0.0	53.64	19.46	19.46	0.97	20.44	0.0	0.0	0.0	74.08
1.1.12.2.6.1	RF CONVERTERS	2.70	0.0	2.70	0.19	0.19	0.01	0.20	0.0	0.0	0.0	2.90
1.1.12.2.6.2	WAVEGUIDES	0.59	0.0	0.59	0.12	0.12	0.01	0.12	0.0	0.0	0.0	0.72
1.1.12.2.6.3	PHS CONTRL ELECT	14.20	0.0	14.20	10.13	10.13	0.51	10.63	0.0	0.0	0.0	24.83
1.1.12.2.6.4	MECHANICAL	2.76	0.0	2.76	4.49	4.49	0.22	4.71	0.0	0.0	0.0	7.48
1.1.12.2.6.5	PWR. DISTR.	33.39	0.0	33.39	4.54	4.54	0.23	4.77	0.0	0.0	0.0	38.15
1.1.12.2.7	GRD TEST EQ'M'T	3.90	0.0	3.90	7.74	7.74	0.39	8.13	0.0	0.0	0.0	12.03
1.1.12.2.7.1	FREE FLYER S/C	3.70	0.0	3.70	7.40	7.40	0.37	7.77	0.0	0.0	0.0	11.47
1.1.12.2.7.2	EXP PEC STRUCT	0.10	0.0	0.10	0.30	0.30	0.01	0.31	0.0	0.0	0.0	0.41
1.1.12.2.7.3	EXP PEC ELTNS	0.10	0.0	0.10	0.04	0.04	0.00	0.04	0.0	0.0	0.0	0.15
1.1.12.2.9	GSE	13.33	0.0	13.33	0.93	0.93	0.05	0.98	0.0	0.0	0.0	14.31

Figure 8-4A Program 1 — SPACE Cost Model-Outputs

1.1.12.3	20 M BEAM FAB.	82.83	0.0	82.83	45.02	45.02	2.25	47.27	0.0	0.0	0.0	130.10
1.1.12.3.1	PROJ. MGMT.	7.53	0.0	7.53	3.33	3.33	0.17	3.50	0.0	0.0	0.0	11.03
1.1.12.3.2	SE & I	6.22	0.0	6.22	3.44	3.44	0.17	3.61	0.0	0.0	0.0	9.83
1.1.12.3.4	FRAME ASSEMBLY	23.38	0.0	23.38	4.42	4.42	0.22	4.64	0.0	0.0	0.0	28.01
1.1.12.3.4.1	PRIME STRUCTURE	8.13	0.0	8.13	2.03	2.03	0.10	2.13	0.0	0.0	0.0	10.27
1.1.12.3.4.2	PLATFORM	1.75	0.0	1.75	0.44	0.44	0.02	0.46	0.0	0.0	0.0	2.21
1.1.12.3.4.3	RAILS	0.57	0.0	0.57	0.05	0.05	0.00	0.05	0.0	0.0	0.0	0.62
1.1.12.3.4.4	SCAFFOLD	1.09	0.0	1.09	0.09	0.09	0.00	0.10	0.0	0.0	0.0	1.19
1.1.12.3.4.5	CARRIAGE	0.84	0.0	0.84	0.33	0.33	0.02	0.34	0.0	0.0	0.0	1.18
1.1.12.3.4.6	CABLE RIGGER	2.33	0.0	2.33	0.13	0.13	0.01	0.13	0.0	0.0	0.0	2.46
1.1.12.3.4.7	RETENSION D'V'T	0.90	0.0	0.90	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.93
1.1.12.3.4.8	PWR DISTRIBUTION	0.54	0.0	0.54	0.68	0.68	0.03	0.72	0.0	0.0	0.0	1.26
1.1.12.3.4.9	SWING ARMS	0.89	0.0	0.89	0.35	0.35	0.02	0.37	0.0	0.0	0.0	1.27
.1.12.3.4.11	ALIGNERS	6.34	0.0	6.34	0.28	0.28	0.01	0.30	0.0	0.0	0.0	6.63
1.1.12.3.5	FAB. MODULES	0.0	0.0	0.0	25.15	25.15	1.26	26.41	0.0	0.0	0.0	26.41
1.1.12.3.6	CREW WORK MODULE	28.20	0.0	28.20	7.80	7.80	0.39	8.19	0.0	0.0	0.0	36.39
1.1.12.3.7	MATERIAL	11.23	0.0	11.23	0.43	0.43	0.02	0.45	0.0	0.0	0.0	11.68
1.1.12.3.10	GSE	6.28	0.0	6.28	0.44	0.44	0.02	0.46	0.0	0.0	0.0	6.74
1.1.12.4	COND'R FAB/INSTN	19.88	0.0	19.88	7.26	7.26	0.36	7.63	0.0	0.0	0.0	27.51
1.1.12.4.1	PROJ. MGMT.	1.81	0.0	1.81	0.54	0.54	0.03	0.56	0.0	0.0	0.0	2.37
1.1.12.4.2	SE & I	1.49	0.0	1.49	0.56	0.56	0.03	0.58	0.0	0.0	0.0	2.08
1.1.12.4.4	FRM ASSY INT EQP	0.46	0.0	0.46	0.12	0.12	0.01	0.12	0.0	0.0	0.0	0.58
1.1.12.4.4.1	CD FAB MOD-SUPTS	0.46	0.0	0.46	0.12	0.12	0.01	0.12	0.0	0.0	0.0	0.58
1.1.12.4.5	FABRIC. MODULES	9.06	0.0	9.06	5.37	5.37	0.27	5.64	0.0	0.0	0.0	14.69
1.1.12.4.6	SUPPORT EQUIP	5.56	0.0	5.56	0.58	0.58	0.03	0.61	0.0	0.0	0.0	6.17
1.1.12.4.6.1	SUPPORT LNK INS	5.56	0.0	5.56	0.58	0.58	0.03	0.61	0.0	0.0	0.0	6.17
1.1.12.4.9	GSE	1.51	0.0	1.51	0.11	0.11	0.01	0.11	0.0	0.0	0.0	1.62
1.1.12.5	MICRO TRANS ANTA	27.81	0.0	27.81	27.38	27.38	1.37	28.75	0.0	0.0	0.0	56.56
1.1.12.5.1	PROJ. MGMT.	2.53	0.0	2.53	2.03	2.03	0.10	2.13	0.0	0.0	0.0	4.66
1.1.12.5.2	SE & I	2.09	0.0	2.09	2.09	2.09	0.10	2.20	0.0	0.0	0.0	4.29
1.1.12.5.4	INT FIXTRS/JIGS	0.26	0.0	0.26	0.04	0.04	0.00	0.05	0.0	0.0	0.0	0.30
1.1.12.5.4.1	DEPLOYMENT FIX	0.18	0.0	0.18	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.21
1.1.12.5.4.2	PIVOT SUPPORT	0.07	0.0	0.07	0.02	0.02	0.00	0.02	0.0	0.0	0.0	0.09
1.1.12.5.5	SUPPORT EQUIP	0.17	0.0	0.17	0.02	0.02	0.00	0.03	0.0	0.0	0.0	0.20
1.1.12.5.6	TRANSMIT ANTENNA	20.66	0.0	20.66	23.04	23.04	1.15	24.19	0.0	0.0	0.0	44.85
1.1.12.5.6.1	PRIMARY STRUCT.	0.31	0.0	0.31	0.08	0.08	0.00	0.08	0.0	0.0	0.0	0.39
1.1.12.5.6.2	SAR/ELC MECH INT	1.30	0.0	1.30	0.10	0.10	0.00	0.10	0.0	0.0	0.0	1.40
1.1.12.5.6.3	RF CONVERTERS	3.00	0.0	3.00	1.13	1.13	0.06	1.19	0.0	0.0	0.0	4.19
1.1.12.5.6.4	PHS CONTRL ELECT	7.10	0.0	7.10	19.49	19.49	0.97	20.46	0.0	0.0	0.0	27.56
1.1.12.5.6.5	POWER DIST.	8.20	0.0	8.20	2.20	2.20	0.11	2.31	0.0	0.0	0.0	10.51
1.1.12.5.6.6	WAVEGUIDES	0.75	0.0	0.75	0.04	0.04	0.00	0.04	0.0	0.0	0.0	0.79
1.1.12.5.9	GSE	2.11	0.0	2.11	0.15	0.15	0.01	0.16	0.0	0.0	0.0	2.26
1.1.12.6	ROTY JT/MT INSTA	48.20	0.0	48.20	15.15	15.15	0.76	15.91	0.0	0.0	0.0	64.11
1.1.12.6.1	PROJ. MGMT.	4.38	0.0	4.38	1.12	1.12	0.06	1.18	0.0	0.0	0.0	5.56
1.1.12.6.2	SE & I	3.62	0.0	3.62	1.16	1.16	0.06	1.22	0.0	0.0	0.0	4.83
1.1.12.6.4	INT FIXTRS/JIGS	3.79	0.0	3.79	0.95	0.95	0.05	0.99	0.0	0.0	0.0	4.78
1.1.12.6.4.1	ROTY JTS D/L FIX	3.79	0.0	3.79	0.95	0.95	0.05	0.99	0.0	0.0	0.0	4.78
1.1.12.6.5	ROTY JT/MAST	32.76	0.0	32.76	11.66	11.66	0.58	12.25	0.0	0.0	0.0	45.00

Figure 8-4A Cont

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1.1.12.6.5.1	ROTY JT (ADAPT)	4.90	0.0	4.90	2.50	2.50	0.12	2.62	0.0	0.0	0.0	7.52
1.1.12.6.5.2	ROTY JT (BALL)	11.60	0.0	11.60	5.10	5.10	0.25	5.35	0.0	0.0	0.0	16.95
1.1.12.6.5.3	MT STR (DAL-SO)	6.19	0.0	6.19	1.55	1.55	0.08	1.62	0.0	0.0	0.0	7.81
1.1.12.6.5.4	MT STR TRNS I TR	1.52	0.0	1.52	0.38	0.38	0.02	0.40	0.0	0.0	0.0	1.92
1.1.12.6.5.5	POWER DISTR.	8.55	0.0	8.55	2.14	2.14	0.11	2.24	0.0	0.0	0.0	10.79
1.1.12.6.9	GSE	3.65	0.0	3.65	0.26	0.26	0.01	0.27	0.0	0.0	0.0	3.92
1.1.12.7	SOLAR ARRAY FAB	238.39	0.0	238.39	444.62	444.62	22.23	466.85	0.0	0.0	0.0	705.24
1.1.12.7.1	PROJ. MGMT.	21.67	0.0	21.67	32.93	32.93	1.65	34.58	0.0	0.0	0.0	56.25
1.1.12.7.2	SE & I	17.89	0.0	17.89	33.99	33.99	1.70	35.69	0.0	0.0	0.0	53.59
1.1.12.7.4.1	HLDG FIXT & RN G	1.63	0.0	1.63	2.44	0.0	0.0	0.0	0.0	0.0	0.0	1.63
1.1.12.7.4.2	CARRIAGE	0.17	0.0	0.17	0.33	0.0	0.0	0.0	0.0	0.0	0.0	0.17
1.1.12.7.5	SUPPORT EQUIP	18.58	0.0	18.58	1.73	1.73	0.09	1.82	0.0	0.0	0.0	20.40
1.1.12.7.5.2	SOLR CL BLKT MOD	0.84	0.0	0.84	0.17	0.17	0.01	0.18	0.0	0.0	0.0	1.02
1.1.12.7.5.3	CONCTR BLKT MOD	0.73	0.0	0.73	0.22	0.22	0.01	0.23	0.0	0.0	0.0	0.96
1.1.12.7.5.4	SOLR/CONCTR B IN	10.85	0.0	10.85	0.62	0.62	0.03	0.65	0.0	0.0	0.0	11.50
1.1.12.7.5.5	CABLE RIGGER	4.47	0.0	4.47	0.33	0.33	0.02	0.34	0.0	0.0	0.0	4.81
1.1.12.7.5.6	PRETENSION DEVIC	1.70	0.0	1.70	0.40	0.40	0.02	0.42	0.0	0.0	0.0	2.12
1.1.12.7.6	SOLAR ARRAY	162.16	0.0	162.16	374.70	374.70	18.73	393.43	0.0	0.0	0.0	555.59
1.1.12.7.6.1	STRUCTURE/MECH.	36.81	0.0	36.81	0.82	0.82	0.04	0.86	0.0	0.0	0.0	37.67
1.1.12.7.6.2	SOLAR CELL BLKT	124.55	0.0	124.55	373.83	373.83	18.69	392.52	0.0	0.0	0.0	517.08
1.1.12.7.6.3	CONCTR BLKT	0.81	0.0	0.81	0.04	0.04	0.00	0.05	0.0	0.0	0.0	0.85
1.1.12.7.9	GSE	18.07	0.0	18.07	1.27	1.27	0.06	1.33	0.0	0.0	0.0	19.40
1.2	STS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	312.00	0.0	312.00	312.00
1.2.4	SHUTTLE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	312.00	0.0	312.00	312.00

Figure 8-4A Cont

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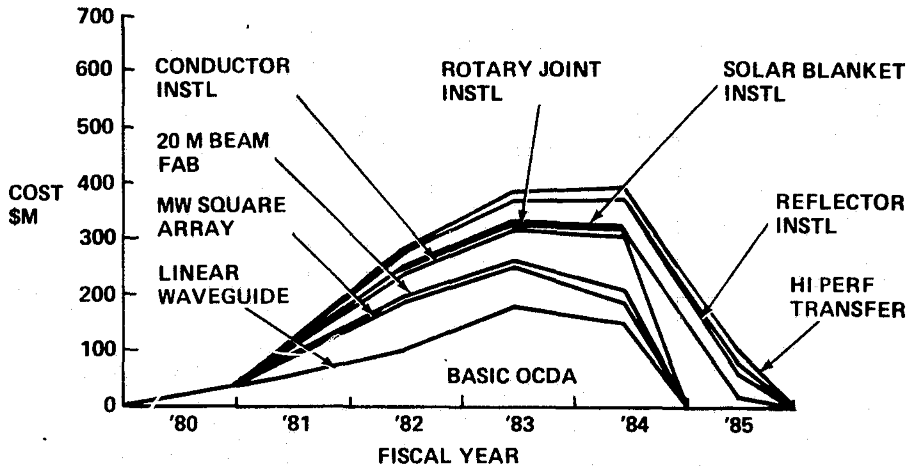
			$M			TOTAL
22.6	127.1	282.1	392.5	429.4	119.6	1373.3



MISSION							TOTALS $M
1. BASIC OCDA	22.6	55.8	101.5	176.0	149.1		505.0
2. LINEAR WAVEGUIDE		33.3	78.0	74.3	42.9		228.5
3. MW SQUARE ARRAY		5.2	13.2	15.2	25.3		58.9
4. 20 m BEAM FAB		15.6	41.5	51.8	99.1		208.0
5. CONDUCTOR INSTAL		3.7	9.4	10.5	23.4		47.0
6. ROTARY JOINT INSTAL		2.4	6.0	7.9	8.6	23.0	47.9
7. SOLAR BLANKET INSTAL		11.1	27.4	38.0	46.6	40.2	163.3
8. REFLECTOR INSTAL			.2	.4	.4	19.7	20.7
9. HI PERFORM TRANSFER			4.9	18.4	34.0	36.7	94.0

Figure 8-5 Program 2 Annual Funding Requirements

***** NOTES ON SPACE MODEL INPUTS *****

WHEN INPUTS ARE DOLLAR THRUPUTS COL. 1 IS FOR DDT&E, COL. 2 IS FOR PRODUCTION, COL. 3 IS FOR OPERATIONS
WHEN INPUTS ARE WTS SPECIFIED AS KG,KG COL. 1 IS FOR NON-REPLICATED WT. COL. 2 IS FOR TOTAL DRY WT.
WHEN INPUTS ARE WTS SPECIFIED AS KG COL. 1 IS FOR TOTAL DRY WT.
WHEN INPUTS ARE SPECIFIED AS KG,SM,KG COL. 1 IS FOR NON -REPLICATED EPS WT(LESS ARRAY), COL. 2 IS FOR ARRAY AREA IN SQ. METERS.
COL. 3 IS FOR TOTAL DRY WT. OF EPS(LESS ARRAY)

OCDA-P1 INPUTS---- MODE

WBS	COST ELEMENT	UNIT MEAS	INPUT1	INPUT2	INPUT3	INPUT4	SHIPSET QTY	GRD TST	COMN/COMPLEX DDT&E	COMN/COMPLEX FSUN	STATE OF DEV DDT&E	STATE OF DEV FSUN
1.1.3.1	STRUCTURE	KG	143.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.3.2	DOCKING MODULE	KG	145.10	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.3.3	COMM&DATA HNDLG.	DLR	0.825	2.700	0.0		1	0.0				
1.1.3.4	ELECTRICAL POWER	DL2,KG2	0.04	1.18	386.80	1209.10	1	0.0	1.00	1.00	1.00	1.00
1.1.3.6	ATT. CONTROL	DLR	3.419	5.526	0.0		1	0.0				
1.1.4.1	STRUCTURE	KG	3870.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.2	POWER DISTR.	KG	2233.10	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.3	PROPULSION	KG	20.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.4	ATT. CONTROL	DLR	5.000	5.000	0.0		1	0.0				
1.1.4.5	ANTENNAS	DLR	0.0	0.030	0.0		1	0.0				
1.1.5.1	STRUCTURE	KG	1972.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.2	POWER DISTR.	KG	4393.70	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.3	MANIPULATOR	KG,DL2	438.10	0.0	0.06	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.4	TRAVELLER	KG	64.90	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.5	ROTARY JOINT	DLR	8.250	3.800	0.0		1	0.0				
1.1.6.1	STRUCTURE	KG	258.90	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.2	SOLAR BLANKET	SM	192.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.4	POWER DISTR.	KG,KG	768.30	23.60	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.5	TILT MECHANISM	KG	15.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.7.1	MMU	KG	102.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.4.1	STRUCT/MECH	KG	998.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.4.2	TRUCK	KG	568.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.12.2.4.3.1	CONTROLS	KG	79.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.12.2.4.3.2	CCLS	DLR	1.000	0.500	0.0		1	0.0				
1.12.2.4.3.3	BUBBLE HATCH	KG	497.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.6.1	RF CONVERTERS	DLR	2.700	0.187	0.0		1	0.0				
1.1.12.2.6.2	WAVEGUIDES	KG	16.93	0.0	0.0	0.0	1	0.0	1.00	0.80	1.00	1.00
1.1.12.2.6.3	PHS CONTRL ELECT	DLR	14.200	10.127	0.0		1	0.0				
1.1.12.2.6.4	MECHANICAL	KG,DL	259.00	4.49	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.6.5	PWR. DISTR.	T,T,KG	30.80	2.93	1474.00	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.2.7.1	FREE FLYER S/C	DLR	3.700	7.400	0.0		1	0.0				
1.1.12.2.7.2	EXP PEC STRUCT	DLR	0.100	0.300	0.0		1	0.0				
1.1.12.2.7.3	EXP PEC ELTNS	KG	7.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.1	PRIME STRUCTURE	KG	693.00	0.0	0.0	0.0	1	0.0	0.80	0.80	1.00	1.00
1.1.12.3.4.2	PLATFORM	KG	136.00	0.0	0.0	0.0	1	0.0	0. .0	0.60	1.00	1.00

Figure 8-6 Program 2 — SPACE Cost Model-Inputs

1.1.12.3.4.3	RAILS	KG	77.00	0.0	0.0	0.0	1	0.0	0.30	0.10	1.00	1.00
1.1.12.3.4.4	SCAFFOLD	KG	181.00	0.0	0.0	0.0	1	0.0	0.30	0.10	1.00	1.00
1.1.12.3.4.5	CARRIAGE	KG	45.33	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.5	CABLE RIGGER	KG	15.00	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.7	PRETENSION D'V'T	KG	3.00	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.8	PWR DISTRIBUTION	KG	45.33	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.3.4.9	SWING ARMS	KG	50.00	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
.1.12.3.4.11	ALIGNERS	KG	82.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.3.5	FAB. MODULES	KG	2497.00	0.0	0.0	0.0	6	0.0	1.00	1.00	1.00	1.00
1.1.12.3.6	CREW WORK MODULE	DLR	28.200	7.800	0.0		1	0.0				
1.1.12.3.7	MATERIAL	KG	1952.00	0.0	0.0	0.0	1	0.0	0.50	1.00	1.00	1.00
1.1.12.4.3.1	CB FAB MOD-SUPTS	KG	100.00	0.0	0.0	0.0	1	0.0	0.20	0.20	1.00	1.00
1.1.12.4.5	FABRIC. MODULES	KG	999.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.4.5.1	SUPPORT LNK INS	KG,KG	34.00	71.60	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.5.4.1	DEPLOYMENT FIX	KG	5.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.5.4.2	PIVOT SUPPORT	KG	22.00	0.0	0.0	0.0	1	0.0	0.10	0.10	1.00	1.00
1.1.12.5.5	SUPPORT EQUIP	KG	4.50	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.5.6.1	PRIMARY STRUCT.	KG	18.00	0.0	0.0	0.0	1	0.0	0.50	0.50	1.00	1.00
1.1.12.5.6.2	SAR/ELE MECH INT	DL,KG	1.30	25.88	0.0	0.0	50	0.0	1.00	1.00	1.00	1.00
1.1.12.5.6.3	RF CONVERTERS	DLR	3.000	1.135	0.0		1	0.0				
1.1.12.5.6.4	PHS CONTRL ELECT	DLR	7.100	19.490	0.0		1	0.0				
1.1.12.5.6.5	POWER DIST.	DL,KG	8.20	449.00	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.5.6.6	WAVEGUIDES	DL,SM	0.75	8.08	0.0	0.0	50	0.0	1.00	1.00	1.00	1.00
1.1.12.6.4.1	ROTY JTS D/L FIX	KG	191.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.6.5.1	ROTY JT (ODAPT)	DLR	4.900	2.500	0.0		1	0.0				
1.1.12.6.5.2	ROTY JT (HALL)	DLR	11.600	5.100	0.0		1	0.0				
1.1.12.6.5.3	MT STR (D/L-SR)	KG	495.00	0.0	0.0	0.0	1	0.0	0.80	0.80	1.00	1.00
1.1.12.6.5.4	MT STR TRNS I TR	KG	279.00	0.0	0.0	0.0	1	0.0	0.30	0.30	1.00	1.00
1.1.12.6.5.5	POWER DISTR.	KG	2665.00	0.0	0.0	0.0	1	0.0	0.30	0.30	1.00	1.00
1.1.12.7.5.2	SOLR CL BLKT MOD	KG	45.40	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.7.5.3	CONCTR BLKT MOD	KG	37.20	0.0	0.0	0.0	2	0.0	1.00	1.00	1.00	1.00
1.1.12.7.5.4	SOLR/CONCTR B IN	KG	204.10	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.7.5.5	CABLE RIGGER	KG	45.37	0.0	0.0	0.0	3	0.0	1.00	1.00	1.00	1.00
1.1.12.7.5.6	PRETENSION DEVIC	DLR	1.700	0.210	0.0		3	0.0				
1.1.12.7.6.1	STRUCTURE/MECH.	KG	3722.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.7.6.2	SOLAR CELL BLKT	SM	8487.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.7.6.3	CONCTR BLKT	KG	511.33	0.0	0.0	0.0	3	0.0	0.10	0.10	1.00	1.00
1.2.4	SHUTTLE	DLR	0.0	0.0	312.000		1	0.0				

OTHER INPUTS

END ITEM QUANTITY = 1
PERCENT LEARNING = 0.750
REFERENCE YEAR = 1977.
INFLATION FACTOR = 0.0

Figure 8-6 Cont

ORIGINAL PAGE IS OF POOR QUALITY

**** NOTES ON SPACE MODEL OUTPUT ****

FIRST UNIT COST IS TOTAL PER SHIPSET
PRODUCTION COST IS TOTAL FOR THE NUMBER OF END ITEMS SPECIFIED

DCDA-P2 GENERAL COST OUTPUT (MILLIONS OF 1977. CONSTANT DOLLARS)

		DDT&E			PRODUCTION				OPERATIONS			
WBS	COST ELEMENT	ENG DES AND DEV	GRD TEST HDWR	TOTAL	FIRST UNIT	VEHICLE PROD	INITIAL SPARES	TOTAL	OPER ACT.	OPER SPARES	TOTAL	TOTAL
1.0	DRB CONS DM PROJ	627.70	0.0	627.70	452.24	452.24	20.71	472.95	273.00	0.0	273.00	1373.65
1.1	DRB CONS DM ART.	183.20	0.0	183.20	252.71	252.71	10.73	263.44	0.0	0.0	0.0	446.64
1.1.1	PROJ. MGMT	16.65	0.0	16.65	18.72	18.72	0.0	18.72	0.0	0.0	0.0	35.37
1.1.2	SE & I	13.75	0.0	13.75	19.32	19.32	0.0	19.32	0.0	0.0	0.0	33.07
1.1.3	CORE SYSTEM	13.11	0.0	13.11	18.85	18.85	0.94	19.80	0.0	0.0	0.0	32.90
1.1.3.1	STRUCTURE	3.04	0.0	3.04	0.76	0.76	0.04	0.80	0.0	0.0	0.0	3.84
1.1.3.2	DOCKING MODULE	0.0	0.0	0.0	1.47	1.47	0.07	1.54	0.0	0.0	0.0	1.54
1.1.3.3	COMM&DATA HNDLG.	0.82	0.0	0.82	2.70	2.70	0.13	2.83	0.0	0.0	0.0	3.66
1.1.3.4	ELECTRICAL POWER	5.82	0.0	5.82	8.40	8.40	0.42	8.82	0.0	0.0	0.0	14.64
1.1.3.6	ATT. CONTROL	3.42	0.0	3.42	5.53	5.53	0.28	5.80	0.0	0.0	0.0	9.22
1.1.4	PLATFORM	50.62	0.0	50.62	20.74	20.74	1.04	21.78	0.0	0.0	0.0	72.40
1.1.4.1	STRUCTURE	37.92	0.0	37.92	9.48	9.48	0.47	9.95	0.0	0.0	0.0	47.88
1.1.4.2	POWER DISTR.	3.55	0.0	3.55	2.21	2.21	0.11	2.32	0.0	0.0	0.0	5.88
1.1.4.3	PROPULSION	4.14	0.0	4.14	1.08	1.08	0.05	1.14	0.0	0.0	0.0	5.28
1.1.4.4	ATT. CONTROL	5.00	0.0	5.00	5.00	5.00	0.25	5.25	0.0	0.0	0.0	10.25
1.1.4.5	ANTENNAS	0.0	0.0	0.0	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.03
1.1.4.6	LDG. DOCK PORT	0.0	0.0	0.0	2.94	2.94	0.15	3.08	0.0	0.0	0.0	3.08
1.1.5	ROTATING BOOM	41.36	0.0	41.36	17.42	17.42	0.87	18.29	0.0	0.0	0.0	59.65
1.1.5.1	STRUCTURE	22.64	0.0	22.64	5.66	5.66	0.28	5.94	0.0	0.0	0.0	28.58
1.1.5.2	POWER DISTR.	5.97	0.0	5.97	3.72	3.72	0.19	3.90	0.0	0.0	0.0	9.87
1.1.5.3	MANIPULATOR	0.0	0.0	0.0	3.46	3.46	0.17	3.64	0.0	0.0	0.0	3.64
1.1.5.4	TRAVELLER	4.51	0.0	4.51	0.78	0.78	0.04	0.82	0.0	0.0	0.0	5.33
1.1.5.5	ROTARY JOINT	8.25	0.0	8.25	3.80	3.80	0.19	3.99	0.0	0.0	0.0	12.24
1.1.6	SOLAR ARRAY	33.82	0.0	33.82	156.68	156.68	7.83	164.51	0.0	0.0	0.0	198.33
1.1.6.1	STRUCTURE	1.18	0.0	1.18	2.59	2.59	0.13	2.72	0.0	0.0	0.0	3.89
1.1.6.2	SOLAR BLANKET	26.49	0.0	26.49	148.89	148.89	7.44	156.34	0.0	0.0	0.0	182.83
1.1.6.3	MAST-CANN-NEGS	0.0	0.0	0.0	3.11	3.11	0.16	3.27	0.0	0.0	0.0	3.27
1.1.6.4	POWER DISTR.	6.01	0.0	6.01	2.04	2.04	0.10	2.14	0.0	0.0	0.0	8.15
1.1.6.5	TILT MECHANISM	0.14	0.0	0.14	0.05	0.05	0.00	0.05	0.0	0.0	0.0	0.19
1.1.9	GSE	13.89	0.0	13.89	0.97	0.97	0.05	1.02	0.0	0.0	0.0	14.91
1.1.12	EXPT. REQ. EQ'MT	444.51	0.0	444.51	199.54	199.54	9.98	209.51	0.0	0.0	0.0	654.02
1.1.12.2	LINEAR WAVEGUIDE	177.22	0.0	177.22	30.24	30.24	1.51	31.75	0.0	0.0	0.0	208.97
1.1.12.2.1	PROJ. MGMT.	16.11	0.0	16.11	2.24	2.24	0.11	2.35	0.0	0.0	0.0	18.46

Figure 8-6A Program 2 – SPACE Cost Model-Outputs

1.1.12.2.2	SE & I	13.30	0.0	13.30	2.31	2.31	0.12	2.43	0.0	0.0	0.0	15.73
1.1.12.2.4	CHERRY PICKER	75.77	0.0	75.77	6.43	6.43	0.32	6.75	0.0	0.0	0.0	82.52
1.1.12.2.4.1	STRUCT/MECH	27.66	0.0	27.66	2.39	2.39	0.12	2.51	0.0	0.0	0.0	30.17
1.1.12.2.4.2	TRUCK	19.84	0.0	19.84	1.48	1.48	0.07	1.55	0.0	0.0	0.0	21.39
1.1.12.2.4.3	BUBBLE SYSTEM	28.27	0.0	28.27	2.56	2.56	0.13	2.69	0.0	0.0	0.0	30.97
1.12.2.4.3.1	CONTROLS	8.94	0.0	8.94	0.75	0.75	0.04	0.78	0.0	0.0	0.0	9.72
1.12.2.4.3.2	ECLS	1.00	0.0	1.00	0.50	0.50	0.02	0.52	0.0	0.0	0.0	1.52
1.12.2.4.3.3	BUBBLE HATCH	18.34	0.0	18.34	1.32	1.32	0.07	1.38	0.0	0.0	0.0	19.72
1.1.12.2.5	KLY'N EXP PEC	54.69	0.0	54.69	10.58	10.58	0.53	11.11	0.0	0.0	0.0	65.80
1.1.12.2.5.1	RF CONVERTERS	4.80	0.0	4.80	3.50	3.50	0.17	3.67	0.0	0.0	0.0	8.47
1.1.12.2.5.2	WAVEGUIDES	0.59	0.0	0.59	0.12	0.12	0.01	0.12	0.0	0.0	0.0	0.72
1.1.12.2.5.3	PHS CONTRL ELECT	14.20	0.0	14.20	1.40	1.40	0.07	1.47	0.0	0.0	0.0	15.67
1.1.12.2.5.4	MECHANICAL	1.71	0.0	1.71	2.49	2.49	0.12	2.61	0.0	0.0	0.0	4.33
1.1.12.2.5.5	PWR. DISTR.	33.39	0.0	33.39	3.07	3.07	0.15	3.22	0.0	0.0	0.0	36.61
1.1.12.2.7	ORB TEST EQ'M'T	3.90	0.0	3.90	7.74	7.74	0.39	8.13	0.0	0.0	0.0	12.03
1.1.12.2.7.1	FREE FLYER S/C	3.70	0.0	3.70	7.40	7.40	0.37	7.77	0.0	0.0	0.0	11.47
1.1.12.2.7.2	EXP PEC STRUCT	0.10	0.0	0.10	0.30	0.30	0.01	0.31	0.0	0.0	0.0	0.41
1.1.12.2.7.3	EXP PEC ELTNS	0.10	0.0	0.10	0.04	0.04	0.00	0.04	0.0	0.0	0.0	0.15
1.1.12.2.9	GSE	13.44	0.0	13.44	0.94	0.94	0.05	0.99	0.0	0.0	0.0	14.42
1.1.12.3	20 M BEAM FAB.	82.83	0.0	82.83	45.02	45.02	2.25	47.27	0.0	0.0	0.0	130.10
1.1.12.3.1	PROJ. MGMT.	7.53	0.0	7.53	3.33	3.33	0.17	3.50	0.0	0.0	0.0	11.03
1.1.12.3.2	SE & I	6.22	0.0	6.22	3.44	3.44	0.17	3.61	0.0	0.0	0.0	9.83
1.1.12.3.4	FRAME ASSEMBLY	23.38	0.0	23.38	4.42	4.42	0.22	4.64	0.0	0.0	0.0	28.01
1.1.12.3.4.1	PRIME STRUCTURE	8.13	0.0	8.13	2.03	2.03	0.10	2.13	0.0	0.0	0.0	10.27
1.1.12.3.4.2	PLATFORM	1.75	0.0	1.75	0.44	0.44	0.02	0.46	0.0	0.0	0.0	2.21
1.1.12.3.4.3	RAILS	0.57	0.0	0.57	0.05	0.05	0.00	0.05	0.0	0.0	0.0	0.62
1.1.12.3.4.4	SCAFFOLD	1.09	0.0	1.09	0.09	0.09	0.00	0.10	0.0	0.0	0.0	1.19
1.1.12.3.4.5	CARRIAGE	0.84	0.0	0.84	0.33	0.33	0.02	0.34	0.0	0.0	0.0	1.18
1.1.12.3.4.6	CABLE RIGGER	2.33	0.0	2.33	0.13	0.13	0.01	0.13	0.0	0.0	0.0	2.46
1.1.12.3.4.7	PRETENSION D'V'T	0.90	0.0	0.90	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.93
1.1.12.3.4.8	PWR DISTRIBUTION	0.54	0.0	0.54	0.68	0.68	0.03	0.72	0.0	0.0	0.0	1.26
1.1.12.3.4.9	SWING ARMS	0.89	0.0	0.89	0.35	0.35	0.02	0.37	0.0	0.0	0.0	1.27
.1.12.3.4.11	ALIGNERS	6.34	0.0	6.34	0.28	0.28	0.01	0.30	0.0	0.0	0.0	6.63
1.1.12.3.5	FAB. MODULES	0.0	0.0	0.0	25.15	25.15	1.26	26.41	0.0	0.0	0.0	26.41
1.1.12.3.6	CREW WORK MODULE	28.20	0.0	28.20	7.80	7.80	0.39	8.19	0.0	0.0	0.0	36.39
1.1.12.3.7	MATERIAL	11.23	0.0	11.23	0.43	0.43	0.02	0.45	0.0	0.0	0.0	11.68
1.1.12.3.10	GSE	6.28	0.0	6.28	0.44	0.44	0.02	0.46	0.0	0.0	0.0	6.74
1.1.12.4	COND'R FAB/INSTN	19.88	0.0	19.88	7.26	7.26	0.36	7.63	0.0	0.0	0.0	27.51
1.1.12.4.1	PROJ. MGMT.	1.81	0.0	1.81	0.54	0.54	0.03	0.56	0.0	0.0	0.0	2.37
1.1.12.4.2	SE & I	1.49	0.0	1.49	0.56	0.56	0.03	0.58	0.0	0.0	0.0	2.08
1.1.12.4.4	FRM ASSY INT EQP	0.46	0.0	0.46	0.12	0.12	0.01	0.12	0.0	0.0	0.0	0.58
1.1.12.4.4.1	CD FAB MOD-SUPTS	0.46	0.0	0.46	0.12	0.12	0.01	0.12	0.0	0.0	0.0	0.58
1.1.12.4.5	FABRIC. MODULES	9.06	0.0	9.06	5.37	5.37	0.27	5.64	0.0	0.0	0.0	14.69
1.1.12.4.6	SUPPORT EQUIP	5.56	0.0	5.56	0.58	0.58	0.03	0.61	0.0	0.0	0.0	6.17
1.1.12.4.6.1	SUPPORT LNK INS	5.56	0.0	5.56	0.58	0.58	0.03	0.61	0.0	0.0	0.0	6.17
1.1.12.4.9	GSE	1.51	0.0	1.51	0.11	0.11	0.01	0.11	0.0	0.0	0.0	1.62
1.1.12.5	MICRO TRANS ANTA	27.76	0.0	27.76	11.13	11.13	0.56	11.69	0.0	0.0	0.0	39.44
1.1.12.5.1	PROJ. MGMT.	2.52	0.0	2.52	0.82	0.82	0.04	0.87	0.0	0.0	0.0	3.39
1.1.12.5.2	SE & I	2.08	0.0	2.08	0.85	0.85	0.04	0.89	0.0	0.0	0.0	2.98

Figure 8-6A Cont

1.1.12.5.4	INT FIXTRS/JIGS	0.26	0.0	0.26	0.04	0.04	0.00	0.05	0.0	0.0	0.0	0.30
1.1.12.5.4.1	DEPLOYMENT FIX	0.18	0.0	0.18	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.21
1.1.12.5.4.2	PIVOT SUPPORT	0.07	0.0	0.07	0.02	0.02	0.00	0.02	0.0	0.0	0.0	0.09
1.1.12.5.5	SUPPORT EQUIP	0.17	0.0	0.17	0.02	0.02	0.00	0.03	0.0	0.0	0.0	0.20
1.1.12.5.6	TRANSMIT ANTENNA	20.62	0.0	20.62	9.24	9.24	0.46	9.70	0.0	0.0	0.0	30.32
1.1.12.5.6.1	PRIMARY STRUCT.	0.22	0.0	0.22	0.05	0.05	0.00	0.06	0.0	0.0	0.0	0.27
1.1.12.5.6.2	SAR/ELE MECH INT	1.30	0.0	1.30	0.04	0.04	0.00	0.04	0.0	0.0	0.0	1.34
1.1.12.5.6.3	RF CONVERTERS	3.20	0.0	3.20	0.09	0.09	0.00	0.09	0.0	0.0	0.0	3.29
1.1.12.5.6.4	PHS CONTRL ELECT	7.10	0.0	7.10	1.35	1.35	0.07	1.42	0.0	0.0	0.0	8.52
1.1.12.5.6.5	POWER DIST.	8.20	0.0	8.20	1.41	1.41	0.07	1.48	0.0	0.0	0.0	9.68
1.1.12.5.6.6	WAVEGUIDES	0.60	0.0	0.60	6.30	6.30	0.31	6.61	0.0	0.0	0.0	7.21
1.1.12.5.9	GSE	2.10	0.0	2.10	0.15	0.15	0.01	0.15	0.0	0.0	0.0	2.26
1.1.12.6	ROTY JT/MT INSTA	19.80	0.0	19.80	8.24	8.24	0.41	8.66	0.0	0.0	0.0	28.46
1.1.12.6.1	PROJ. MGMT.	1.80	0.0	1.80	0.61	0.61	0.03	0.64	0.0	0.0	0.0	2.44
1.1.12.6.2	SE & I	1.49	0.0	1.49	0.63	0.63	0.03	0.66	0.0	0.0	0.0	2.15
1.1.12.6.5	ROTY JT/MAST	13.80	0.0	13.80	5.65	5.65	0.28	5.93	0.0	0.0	0.0	19.73
1.1.12.6.5.2	ROTY JT (BALL)	11.60	0.0	11.60	5.10	5.10	0.25	5.35	0.0	0.0	0.0	16.95
1.1.12.6.5.3	MT STR (DAL-SO)	1.36	0.0	1.36	0.34	0.34	0.02	0.36	0.0	0.0	0.0	1.72
1.1.12.6.5.5	POWER DISTR.	0.84	0.0	0.84	0.21	0.21	0.01	0.22	0.0	0.0	0.0	1.06
1.1.12.6.7	ORB TEST EQUIP	1.22	0.0	1.22	1.25	1.25	0.06	1.31	0.0	0.0	0.0	2.53
1.1.12.6.7.1	LOAD BANK	1.22	0.0	1.22	0.90	0.90	0.04	0.94	0.0	0.0	0.0	2.16
1.1.12.6.7.2	LOAD KLYSTRON	0.0	0.0	0.0	0.35	0.35	0.02	0.37	0.0	0.0	0.0	0.37
1.1.12.6.9	GSE	1.50	0.0	1.50	0.11	0.11	0.01	0.11	0.0	0.0	0.0	1.61
1.1.12.7.4.1	HLDG FIXT & RN G	1.63	0.0	1.63	2.44	0.0	0.0	0.0	0.0	0.0	0.0	1.63
1.1.12.7.4.2	CARRIAGE	0.17	0.0	0.17	0.33	0.0	0.0	0.0	0.0	0.0	0.0	0.17
1.1.12.8	SOLR CELL BLKT I	89.91	0.0	89.91	51.34	51.34	2.57	53.91	0.0	0.0	0.0	143.82
1.1.12.8.1	PROJ. MGMT.	8.17	0.0	8.17	3.80	3.80	0.19	3.99	0.0	0.0	0.0	12.17
1.1.12.8.2	SE & I	6.75	0.0	6.75	3.93	3.93	0.20	4.12	0.0	0.0	0.0	10.87
1.1.12.8.4	FRAME ASSY ADDIT	4.69	0.0	4.69	1.17	1.17	0.06	1.23	0.0	0.0	0.0	5.92
1.1.12.8.4.1	SUPP'TS-BLKT MOD	2.58	0.0	2.58	0.65	0.65	0.03	0.68	0.0	0.0	0.0	3.26
1.1.12.8.4.2	SUPP'TS-GUDE TKS	0.75	0.0	0.75	0.19	0.19	0.01	0.20	0.0	0.0	0.0	0.95
1.1.12.8.4.3	BLKT/BU ASSY STA	0.68	0.0	0.68	0.17	0.17	0.01	0.18	0.0	0.0	0.0	0.86
1.1.12.8.4.4	BLKT BU INST STA	0.68	0.0	0.68	0.17	0.17	0.01	0.18	0.0	0.0	0.0	0.86
1.1.12.8.5	SUPPORT EQUIP	22.47	0.0	22.47	1.44	1.44	0.07	1.51	0.0	0.0	0.0	23.98
1.1.12.8.5.1	SHIP & DISPG MOD	1.44	0.0	1.44	0.34	0.34	0.02	0.35	0.0	0.0	0.0	1.79
1.1.12.8.5.2	GUDE TK-BLKT DPY	13.15	0.0	13.15	0.82	0.82	0.04	0.86	0.0	0.0	0.0	14.01
1.1.12.8.5.3	BLNSEF CASSETTE	3.15	0.0	3.15	0.10	0.10	0.01	0.11	0.0	0.0	0.0	3.25
1.1.12.8.5.4	BLKT BU INSTLR	4.73	0.0	4.73	0.19	0.19	0.01	0.20	0.0	0.0	0.0	4.93
1.1.12.8.6	SOLR CELL BLKT	41.01	0.0	41.01	40.52	40.52	2.03	42.55	0.0	0.0	0.0	83.56
1.1.12.8.9	GSE	6.82	0.0	6.82	0.48	0.48	0.02	0.50	0.0	0.0	0.0	7.32
1.1.12.9	REFLECTOR INSTAL	0.89	0.0	0.89	0.26	0.26	0.01	0.28	0.0	0.0	0.0	1.16
1.1.12.9.1	PROJ. MGMT.	0.08	0.0	0.08	0.02	0.02	0.00	0.02	0.0	0.0	0.0	0.10
1.1.12.9.2	SE & I	0.07	0.0	0.07	0.02	0.02	0.00	0.02	0.0	0.0	0.0	0.09
1.1.12.9.5	SUPPORT EQUIP	0.0	0.0	0.0	0.05	0.05	0.00	0.05	0.0	0.0	0.0	0.05
1.1.12.9.5.1	SHIP & DISPG MOD	0.0	0.0	0.0	0.05	0.05	0.00	0.05	0.0	0.0	0.0	0.05
1.1.12.9.6	REFLECTOR BLKT	0.67	0.0	0.67	0.17	0.17	0.01	0.18	0.0	0.0	0.0	0.85
1.1.12.9.9	GSE	0.07	0.0	0.07	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.07
1.1.12.10	H PERF TR S IN V	26.22	0.0	26.22	46.03	46.03	2.30	48.34	0.0	0.0	0.0	74.56
1.1.12.10.1	PROJ. MGMT.	2.38	0.0	2.38	3.41	3.41	0.17	3.58	0.0	0.0	0.0	5.96
1.1.12.10.2	SE & I	1.97	0.0	1.97	3.52	3.52	0.18	3.70	0.0	0.0	0.0	5.66
1.1.12.10.4	INTERFACE FIXTS	4.33	0.0	4.33	1.84	1.84	0.09	1.93	0.0	0.0	0.0	6.26
1.1.12.10.6	PROPULSION UNIT	15.56	0.0	15.56	37.13	37.13	1.86	38.98	0.0	0.0	0.0	54.54
1.1.12.10.9	GSE	1.99	0.0	1.99	0.14	0.14	0.01	0.15	0.0	0.0	0.0	2.13
1.2	STS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	273.00	0.0	273.00	273.00
1.2.4	SHUTTLE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	273.00	0.0	273.00	273.00

Figure 8-6A Cont

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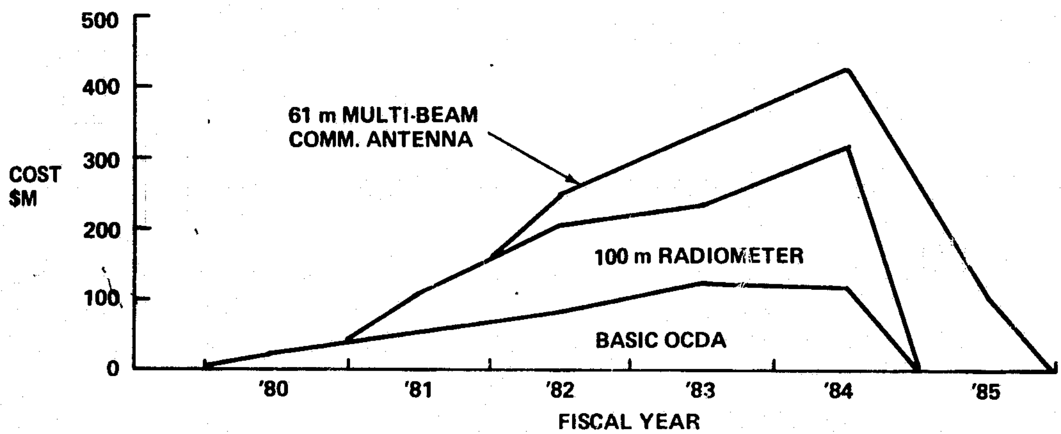
$M						TOTAL
20.9	103.5	244.5	339.1	422.0	99.7	1229.7



MISSION							TOTALS $M
1. BASIC OCDA	20.9	51.5	82.0	123.1	118.6		396.1
2. 100 m RADIOMETER		52.0	120.7	112.2	190.3		475.2
3. 61 m MULTI-BEAM COM. ANT.			41.8	103.8	113.1	99.7	358.4

Figure 8-7 Program 3 Annual Funding Requirements

***** NOTES ON SPACE MODEL INPUTS *****

WHEN INPUTS ARE DOLLAR THRUPUTS COL. 1 IS FOR DDT&E, COL. 2 IS FOR PRODUCTION, COL. 3 IS FOR OPERATIONS
WHEN INPUTS ARE WTS SPECIFIED AS KG,KG COL. 1 IS FOR NON-REPLICATED WT. COL. 2 IS FOR TOTAL DRY WT.
WHEN INPUTS ARE WTS SPECIFIED AS KG COL. 1 IS FOR TOTAL DRY WT.
WHEN INPUTS ARE SPECIFIED AS KG,SM,KG COL. 1 IS FOR NON-REPLICATED EPS WT(LESS ARRAY). COL. 2 IS FOR ARRAY AREA IN SQ. METERS.
COL. 3 IS FOR TOTAL DRY WT. OF EPS(LESS ARRAY)

OCDA-P3 INPUTS---- MODE

WBS	COST ELEMENT	UNIT MEAS	INPUT1	INPUT2	INPUT3	INPUT4	SHIPSET QTY	GRD TST	COMN/COMPLEX DDT&E	COMN/COMPLEX FSUN	STATE OF DEV DDT&E	STATE OF DEV FSUN
1.1.3.1	STRUCTURE	KG	143.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.3.2	DOCKING MODULE	KG	145.10	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.3.3	COMM&DATA HNDLG.	DLR	0.825	2.700	0.0		1	0.0				
1.1.3.4	ELECTRICAL POWER	DL2,KG2	0.04	1.18	396.80	1209.10	1	0.0	1.00	1.00	1.00	1.00
1.1.3.6	ATT. CONTROL	DLR	3.419	5.526	0.0		1	0.0				
1.1.4.1	STRUCTURE	KG	3870.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.2	POWER DISTR.	KG	2233.10	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.3	PROPULSION	KG	20.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.4.4	ATT. CONTROL	DLR	5.000	5.000	0.0		1	0.0				
1.1.4.5	ANTENNAS	DLR	0.0	0.030	0.0		1	0.0				
1.1.5.1	STRUCTURE	KG	1972.30	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.2	POWER DISTR.	KG	4393.70	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.3	MANIPULATOR	KG,DL2	438.10	0.0	0.06	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.4	TRAVELLER	KG	64.90	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.5.5	ROTARY JOINT	DLR	8.250	3.800	0.0		1	0.0				
1.1.6.1	STRUCTURE	KG	268.90	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.2	SOLAR BLANKET	SM	192.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.4	POWER DISTR.	KG,KG	768.30	23.60	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.6.5	TILT MECHANISM	KG	15.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.7.1	MMU	KG	102.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.11.4	INTER FIXTS/JIGS	KG	1000.00	0.0	0.0	0.0	1	0.0	0.50	0.50	1.00	1.00
.1.12.11.5.1	STRUCTURE	KG	4238.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.1.12.11.5.2	SURFACE MESH	KG	200.00	0.0	0.0	0.0	1	0.0	0.50	0.50	1.00	1.00
.1.12.11.5.3	HUB	KG	600.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.1.12.11.5.4	MAST	KG	200.00	0.0	0.0	0.0	1	0.0	0.30	0.30	1.00	1.00
.1.12.11.5.5	MECHANICAL	KG	1000.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.11.5.6.2	ATTITUDE CONT.	DLR	5.000	0.400	0.0		1	0.0				
.12.11.5.6.3	COMM	DLR	3.000	3.000	0.0		1	0.0				
.12.11.5.6.4	ELECT. POWER	DLR	2.500	4.000	0.0		1	0.0				
.12.11.5.6.5	DATA MGMT.	DLR	5.000	2.000	0.0		1	0.0				
.1.12.11.5.7	SENSORS	DLR	10.000	3.000	0.0		1	0.0				
.1.12.11.6.1	RIB FAB MOD	KG	2497.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.11.6.2.1	STRUCT/MECH.	KG	998.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.11.6.2.2	TRUCK	KG	568.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.11.6.2.3.1	CONTROLS	KG	79.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.11.6.2.3.2	ECLS	DLR	1.000	0.500	0.0		1	0.0				
.11.6.2.3.3	BUBBLE HATCH	KG	497.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.1.12.11.6.3	ALIGN&TEST EQUIP	KG	100.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.1.12.11.7.1	FREE FLYERS S/C	DLR	3.700	7.400	0.0		1	0.0				
.1.12.11.7.2	EXP PEC STRUCT	DLR	0.100	0.100	0.0		1	0.0				
.1.12.11.7.3	EXP PEC ELECT	KG	7.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.12.4.1.1	STRUCTURE/THERM	KG,KG	100.00	100.00	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.12.4.1.2	FEED/DIPLEXER	KG	125.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.12.4.1.3	COMM. ELECTRNS	KG	450.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.12.4.1.4	TT & C	KG	30.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.12.4.1.5	ACS	KG	188.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.12.4.1.6	ELECT POWER&INT.	KG	1700.00	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.12.4.2.1	STRUCTURE	KG	15479.40	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
.12.12.4.2.2	ELECT	KG	1721.80	0.0	0.0	0.0	1	0.0	1.00	1.00	1.00	1.00
1.1.12.12.5	INT FIXTS	KG	1020.40	0.0	0.0	0.0	1	0.0	0.50	0.50	1.00	1.00
1.2.4	SHUTTLE	DLR	0.0	0.0	273.000		1	0.0				

OTHER INPUTS

END ITEM QUANTITY = 1
PERCENT LEARNING = 0.750
REFERENCE YEAR = 1977.
INFLATION FACTOR = 0.0

Figure 8-8 Program 3 – SPACE Cost Model-Inputs

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**** NOTES ON SPACE MODEL OUTPUT ****

FIRST UNIT COST IS TOTAL PER SHIPSET
PRODUCTION COST IS TOTAL FOR THE NUMBER OF END ITEMS SPECIFIED

DCDA-P3 GENERAL COST OUTPUT (MILLIONS OF 1977. CONSTANT DOLLARS)

WBS	COST ELEMENT	DDT&E: ENG DES AND DEV	DDT&E: GRD TEST HDWR	DDT&E: TOTAL	PRODUCTION: FIRST UNIT	PRODUCTION: VEHICLE PROD	PRODUCTION: INITIAL SPARES	PRODUCTION: TOTAL	OPERATIONS: OPER ACT.	OPERATIONS: OPER SPARES	OPERATIONS: TOTAL	TOTAL
1.0	ORB CONS DM PROJ	668.06	0.0	668.06	275.79	275.79	12.57	288.36	273.00	0.0	273.00	1229.42
1.1	ORB CONS DM ART.	168.98	0.0	168.98	161.58	161.58	6.86	168.44	0.0	0.0	0.0	337.42
1.1.1	PROJ. MGMT	15.36	0.0	15.36	11.97	11.97	0.0	11.97	0.0	0.0	0.0	27.33
1.1.2	SE & I	12.68	0.0	12.68	12.35	12.35	0.0	12.35	0.0	0.0	0.0	25.04
1.1.3	CORE SYSTEM	13.11	0.0	13.11	18.85	18.85	0.94	19.80	0.0	0.0	0.0	32.90
1.1.3.1	STRUCTURE	3.04	0.0	3.04	0.76	0.76	0.04	0.80	0.0	0.0	0.0	3.84
1.1.3.2	DOCKING MODULE	0.0	0.0	0.0	1.47	1.47	0.07	1.54	0.0	0.0	0.0	1.54
1.1.3.3	COMM&DATA HNDLG.	0.82	0.0	0.82	2.70	2.70	0.13	2.83	0.0	0.0	0.0	3.66
1.1.3.4	ELECTRICAL POWER	5.82	0.0	5.82	8.40	8.40	0.42	8.82	0.0	0.0	0.0	14.64
1.1.3.6	ATT. CONTROL	3.42	0.0	3.42	5.53	5.53	0.28	5.80	0.0	0.0	0.0	9.22
1.1.4	PLATFORM	50.62	0.0	50.62	20.74	20.74	1.04	21.78	0.0	0.0	0.0	72.40
1.1.4.1	STRUCTURE	37.92	0.0	37.92	9.48	9.48	0.47	9.95	0.0	0.0	0.0	47.88
1.1.4.2	POWER DISTR.	3.55	0.0	3.55	2.21	2.21	0.11	2.32	0.0	0.0	0.0	5.88
1.1.4.3	PROPULSION	4.14	0.0	4.14	1.08	1.08	0.05	1.14	0.0	0.0	0.0	5.28
1.1.4.4	ATT. CONTROL	5.00	0.0	5.00	5.00	5.00	0.25	5.25	0.0	0.0	0.0	10.25
1.1.4.5	ANTENNAS	0.0	0.0	0.0	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.03
1.1.4.6	LOG. DOCK PORT	0.0	0.0	0.0	2.94	2.94	0.15	3.08	0.0	0.0	0.0	3.08
1.1.5	ROTATING BOOM	41.36	0.0	41.36	17.42	17.42	0.87	18.29	0.0	0.0	0.0	59.65
1.1.5.1	STRUCTURE	22.64	0.0	22.64	5.66	5.66	0.28	5.94	0.0	0.0	0.0	28.58
1.1.5.2	POWER DISTR.	5.97	0.0	5.97	3.72	3.72	0.19	3.90	0.0	0.0	0.0	9.87
1.1.5.3	MANIPULATOR	0.0	0.0	0.0	3.46	3.46	0.17	3.64	0.0	0.0	0.0	3.64
1.1.5.4	TRAVELLER	4.51	0.0	4.51	0.78	0.78	0.04	0.82	0.0	0.0	0.0	5.33
1.1.5.5	ROTARY JOINT	8.25	0.0	8.25	3.80	3.80	0.19	3.99	0.0	0.0	0.0	12.24
1.1.6	SOLAR ARRAY	23.04	0.0	23.04	79.34	79.34	3.97	83.31	0.0	0.0	0.0	106.35
1.1.6.1	STRUCTURE	0.69	0.0	0.69	1.52	1.52	0.08	1.60	0.0	0.0	0.0	2.29
1.1.6.2	SOLAR BLANKET	18.73	0.0	18.73	74.45	74.45	3.72	78.17	0.0	0.0	0.0	96.90
1.1.6.3	MAST-CANN-NEGS	0.0	0.0	0.0	2.21	2.21	0.11	2.32	0.0	0.0	0.0	2.32
1.1.6.4	POWER DISTR.	3.54	0.0	3.54	1.13	1.13	0.06	1.19	0.0	0.0	0.0	4.72
1.1.6.5	TILT MECHANISM	0.08	0.0	0.08	0.03	0.03	0.00	0.03	0.0	0.0	0.0	0.11
1.1.9	GSE	12.81	0.0	12.81	0.90	0.90	0.04	0.94	0.0	0.0	0.0	13.75
1.1.12	EXPT. REQ. EQ'MT	499.08	0.0	499.08	114.21	114.21	5.71	119.92	0.0	0.0	0.0	619.00
1.1.12.11	RADIOMETER FAB	276.71	0.0	276.71	40.39	40.39	2.02	42.41	0.0	0.0	0.0	319.13
1.1.12.11.1	PROJ. MGMT.	25.16	0.0	25.16	2.99	2.99	0.15	3.14	0.0	0.0	0.0	28.30
1.1.12.11.2	SE&I	20.77	0.0	20.77	3.09	3.09	0.15	3.24	0.0	0.0	0.0	24.01
1.1.12.11.4	INTER FIXTS/JIGS	6.73	0.0	6.73	1.68	1.68	0.08	1.77	0.0	0.0	0.0	8.50
1.1.12.11.5	RADIOMETER	101.90	0.0	101.90	18.53	18.53	0.93	19.45	0.0	0.0	0.0	121.35

Figure 8-8A Program 3 — SPACE Cost Model-Outputs

.1.12.11.5.1STRUCTURE	40.65	0.0	40.65	1.40	1.40	0.07	1.47	0.0	0.0	0.0	42.12
.1.12.11.5.2SURFACE MESH	1.96	0.0	1.96	0.49	0.49	0.02	0.52	0.0	0.0	0.0	2.48
.1.12.11.5.3HUB	4.91	0.0	4.91	1.55	1.55	0.08	1.62	0.0	0.0	0.0	6.54
.1.12.11.5.4MAST	1.18	0.0	1.18	0.29	0.29	0.01	0.31	0.0	0.0	0.0	1.49
.1.12.11.5.5MECHANICAL	27.69	0.0	27.69	2.39	2.39	0.12	2.51	0.0	0.0	0.0	30.20
.1.12.11.5.6SUB SYSTEMS	15.50	0.0	15.50	9.40	9.40	0.47	9.87	0.0	0.0	0.0	25.37
.12.11.5.6.2ATTITUDE CONT.	5.00	0.0	5.00	0.40	0.40	0.02	0.42	0.0	0.0	0.0	5.42
.12.11.5.6.3COMM	3.00	0.0	3.00	3.00	3.00	0.15	3.15	0.0	0.0	0.0	6.15
.12.11.5.6.4ELECT. POWER	2.50	0.0	2.50	4.00	4.00	0.20	4.20	0.0	0.0	0.0	6.70
.12.11.5.6.5DATA MGMT.	5.00	0.0	5.00	2.00	2.00	0.10	2.10	0.0	0.0	0.0	7.10
.1.12.11.5.7SENSORS	10.00	0.0	10.00	3.00	3.00	0.15	3.15	0.0	0.0	0.0	13.15
1.1.12.11.6 SUPPORT EQUIP	101.18	0.0	101.18	12.64	12.64	0.63	13.27	0.0	0.0	0.0	114.45
.1.12.11.6.1RIB FAB MOD	13.07	0.0	13.07	5.21	5.21	0.26	5.47	0.0	0.0	0.0	18.54
.1.12.11.6.2CHERRY PICKER	75.77	0.0	75.77	6.43	6.43	0.32	6.75	0.0	0.0	0.0	82.52
.12.11.6.2.1STRUCT/MECH.	27.66	0.0	27.66	2.39	2.39	0.12	2.51	0.0	0.0	0.0	30.17
.12.11.6.2.2TRUCK	19.84	0.0	19.84	1.48	1.48	0.07	1.55	0.0	0.0	0.0	21.39
.12.11.6.2.3BUBBLE SYS	28.27	0.0	28.27	2.56	2.56	0.13	2.69	0.0	0.0	0.0	30.97
.11.6.2.3.1CONTROLS	8.94	0.0	8.94	0.75	0.75	0.04	0.78	0.0	0.0	0.0	9.72
.11.6.2.3.2ECLS	1.00	0.0	1.00	0.50	0.50	0.02	0.52	0.0	0.0	0.0	1.52
.11.6.2.3.3BUBBLE HATCH	18.34	0.0	18.34	1.32	1.32	0.07	1.38	0.0	0.0	0.0	19.72
.1.12.11.6.3ALIGN&TEST EQUIP	12.34	0.0	12.34	0.99	0.99	0.05	1.04	0.0	0.0	0.0	13.38
1.1.12.11.7 ORB TEST EQUIP	3.90	0.0	3.90	7.54	7.54	0.38	7.92	0.0	0.0	0.0	11.82
.1.12.11.7.1FREE FLYERS S/C	3.70	0.0	3.70	7.40	7.40	0.37	7.77	0.0	0.0	0.0	11.47
.1.12.11.7.2EXP PEC STRUCT	0.10	0.0	0.10	0.10	0.10	0.00	0.10	0.0	0.0	0.0	0.20
.1.12.11.7.3EXP PEC ELECT	0.10	0.0	0.10	0.04	0.04	0.00	0.04	0.0	0.0	0.0	0.15
1.1.12.11.8 GSE	20.98	0.0	20.98	1.47	1.47	0.07	1.54	0.0	0.0	0.0	22.52
1.1.12.12 MULTIBM COMM SAT	222.36	0.0	222.36	73.82	73.82	3.69	77.51	0.0	0.0	0.0	299.88
1.1.12.12.1 PROJ.MGMT	20.21	0.0	20.21	5.47	5.47	0.27	5.74	0.0	0.0	0.0	25.96
1.1.12.12.2 SE & I	16.69	0.0	16.69	5.64	5.64	0.28	5.93	0.0	0.0	0.0	22.62
1.1.12.12.4 MULTI BM COMM S	161.76	0.0	161.76	59.82	59.82	2.99	62.81	0.0	0.0	0.0	224.58
.1.12.12.4.1SUBYS MOD	38.96	0.0	38.96	15.88	15.88	0.79	16.67	0.0	0.0	0.0	55.63
.12.12.4.1.1STRUCTURE/THERM	4.86	0.0	4.86	0.75	0.75	0.04	0.79	0.0	0.0	0.0	5.65
.12.12.4.1.2FEED/DIPLEXER	10.33	0.0	10.33	5.41	5.41	0.27	5.68	0.0	0.0	0.0	16.01
.12.12.4.1.3COMM. ELECTRNS	1.44	0.0	1.44	1.65	1.65	0.08	1.74	0.0	0.0	0.0	3.17
.12.12.4.1.4TT & C	3.99	0.0	3.99	1.35	1.35	0.07	1.41	0.0	0.0	0.0	5.40
.12.12.4.1.5ACS	15.45	0.0	15.45	4.93	4.93	0.25	5.17	0.0	0.0	0.0	20.62
.12.12.4.1.6ELECT POWER&INT.	2.88	0.0	2.88	1.80	1.80	0.09	1.89	0.0	0.0	0.0	4.77
.1.12.12.4.2APERTURE	122.81	0.0	122.81	43.94	43.94	2.20	46.14	0.0	0.0	0.0	168.95
.12.12.4.2.1STRUCTURE	109.58	0.0	109.58	27.40	27.40	1.37	28.77	0.0	0.0	0.0	138.35
.12.12.4.2.2ELECT	13.23	0.0	13.23	16.54	16.54	0.83	17.37	0.0	0.0	0.0	30.60
1.1.12.12.5 INT FIXTS	6.83	0.0	6.83	1.71	1.71	0.09	1.79	0.0	0.0	0.0	8.63
1.1.12.12.8 GSE	16.86	0.0	16.86	1.18	1.18	0.06	1.24	0.0	0.0	0.0	18.10
1.2 STS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	273.00	0.0	273.00	273.00
1.2.4 SHUTTLE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	273.00	0.0	273.00	273.00

Figure 8-8A Cont

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Section 9

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to map out an orbit demonstration program that addresses the construction issues apparent in the design of future large structures. Five future concepts were identified that embodied the requirements and issues for almost all future endeavors. Demonstration and test objectives were formulated and used as the basis for the design of a general purpose construction base that is operated from the Shuttle. This facility, the Orbit Construction Demonstration Article (OCDA), has the potential to help solve many of the technology problems involved with the construction of ultra-large structures in space.

This study estimates that the assembly of the OCDA itself in three Shuttle flights would meet 29 of the 76 objectives identified. The remainder of the objectives can be met through a series of experiments that utilize the OCDA features of abundant power, rotating boom with manipulators and a work platform to demonstrate and test the complex space fabrication construction techniques needed for economic realization of beneficial programs such as space-based solar power generation.

The basic OCDA program has been estimated to cost $390 million. The cost of follow-on activities are in the range of $1.23 to $1.85 billion.

Several program options exist and should be studied. A series of Shuttle sortie missions are being formulated that will address large structures technology. The possibility exists for utilizing the elements of demonstration articles left in-orbit by these sortie missions as parts of the OCDA's structure. A typical example is the boom for the rotating manipulator crane on the OCDA. The boom could be a product of a previous sortie mission that is testing the operation of an automated beam fabrication module.

The interrelationship of the OCDA function as an extension of the Shuttle and in association with a permanent manned facility should be explored. The Shuttle with extended orbit life time afforded by the OCDA can provide the crew support needed for construction activities.

This study has shown the utility and benefit of a small general purpose construction and structures technology facility in orbit. It is recommended that the OCDA be considered as a viable program option in NASA's planning for advancing large space structures technology by:

- Initiating precursor definition studies (Phases A & B) in time for a 1979 new program start decision
- Plan for a 1984 IOC to benefit from OCDA technology advancements needed to make key decisions in the 1987 time frame on ultra large initiatives like the Solar Power Satellite.

9.1 RECOMMENDED SUPPORTING RESEARCH AND DEVELOPMENT

9.1.1 Operations

During analysis of the radiometer assembly, it was apparent that for the time consuming repetitious operations of assembling the dish, it would be an advantage to extend the space flight time beyond seven days, thereby reducing the number of Shuttle flights required. Orbiter flights beyond seven days not only need additional consumables but also require increased habitation room for the crew. Therefore, the impact on the orbiter was evaluated for a crew of seven to carry out extended operations.

Grumman Space Station Studies required the same orbiter related data as needed during this study to readily determine orbiter payload support capabilities. This payload data was plotted for all consumables as illustrated in Figure 9-1 and summarized in Table 9-1. The data was used to determine the impact on the orbiter as a consequence of OCDA flight plans.

The major impact shown in Table 9-1 is EPS consumables, however, for OCDA applications, power is budgeted to be supplied by the OCDA solar array, and therefore has negligible effect. While the orbiter is docked to the OCDA, the OCDA provides attitude control, so no special orbiter RCS provisions are needed. All other items do not have a significant impact on the orbiter from a weight consideration. Even volume needs are not significant as the largest impact, food stowage (Figure 9-1) requires less than 3 cu m for seven men in orbit for 40 days.

During the first orbiter flight for radiometer construction the turntable and fabrication modules are mounted on the platform, the antenna hub is installed and fabrication operations are commenced. Radiometer construction materials do not require much volume in the orbiter payload bay (less than 12 cu m) and construction could be completed

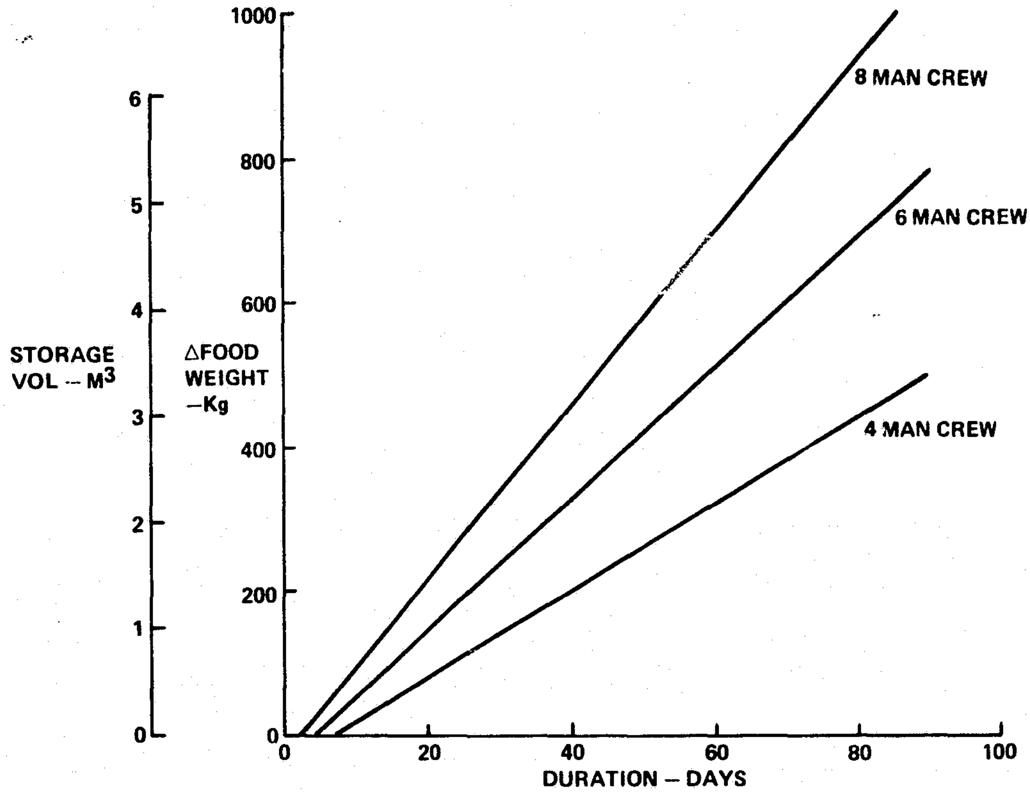

Figure 9-1 Extended Duration Orbiter—Food Requirements Above Baseline

Table 9-1 Extended Orbiter Flight Duration Weight Penalty

		LAUNCH WT. PENALTY (KG)			
		30 DAYS		90 DAYS	
		4 MEN	7 MEN	4 MEN	7 MEN
VEHICLE CONSUMABLES	EPS (20 KW AVE CONT)	11,500	11,500	36,400	36,400
	RCS	1,570	1,570	5,660	5,660
CREW CONSUMABLES	N_2	612	612	2,000	2,000
	LO_2 – Δ REQ'D	240	335	815	1,080
	– AVAIL FROM EPS	406	406	1,245	1,245
	LiOH	147	310	531	982
	FOOD	145	290	510	925
CREW ACCOMMODATIONS	VOLUME (m^3)	24	42	32	56
	SEATS & RESTRAINTS	–	74	–	74
	CREW EQUIPMENT	–	44	–	44
	CREW	–	272	–	272
	HYGIENE	25	56	90	170
	RESCUE	–	79	–	79

in approximately 40 days. Therefore, if the second flight could be extended then the radiometer could be constructed in two flights instead of the eight projected! The most significant orbiter impact would be the additional habitation room required for the crew during extended operations. Figure 9-2 shows that for 40-day operations each crew requires 7 cu m of space. A short spacelab, when combined with the orbiter volume, totals 62 cu m to meet the crew volume requirements of 49 cu m. With a short spacelab, and docking module installed in the cargo bay, one-half of the space remains for additional payload (see Figure 9-3). Actual loading will include center of gravity constraints. It is concluded that future studies should consider extended orbiter operations to reduce the number of flights required, hence operations costs.

9.1.2 Electrical and RF Power

A phased program of technology development should be started as soon as possible. This program will provide the hardware required not only for OCDA, but also, ultimately, for proof-of-design for Solar Power Systems. The program can be broken down into the following design issues:

- High Voltage Solar Array
- Nickel-Hydrogen Batteries
- 200-Volt Distribution and Control
- Rotary Joint
- DC-to-RF Converters.

These items are quite separate from any piece-part developments required for OCDA build-up. Such developments, in fact, would follow from these issues.

Table 9-2 shows in general form, technological studies required for a high voltage solar array development (20 to 40 kV operating point).

For nickel-hydrogen batteries, continuation of currently planned studies and hardware developments is suggested. Additionally, thermal control, especially integral heat pipes, and pressure control and shielding should be studied more vigorously to improve volumetric efficiency. Finally, cycle verification of the assumed high depths of discharge should be undertaken to establish life, failure rate and degradation parameters more firmly.

Table 9-3 outlines areas required to establish feasibility of 200-V distribution and control sections.

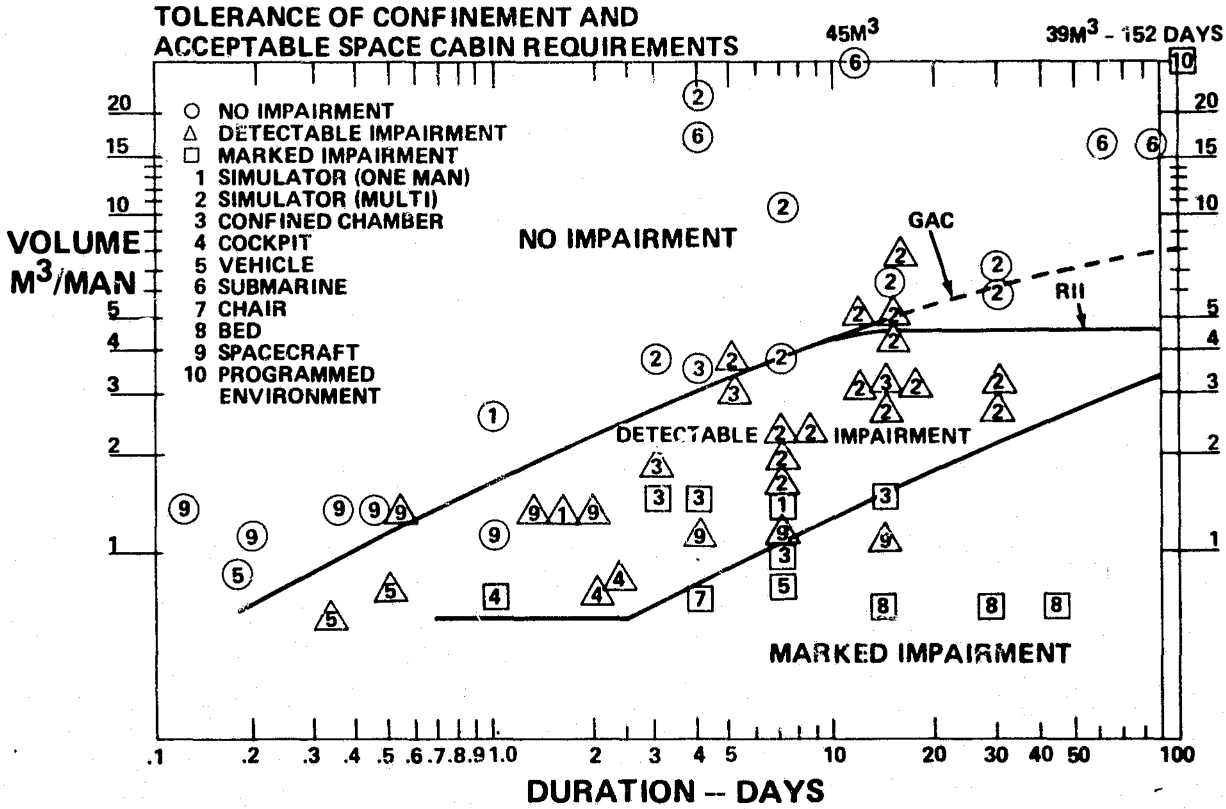

Figure 9-2 Free Volume – Duration Tolerance Factors in Confinement

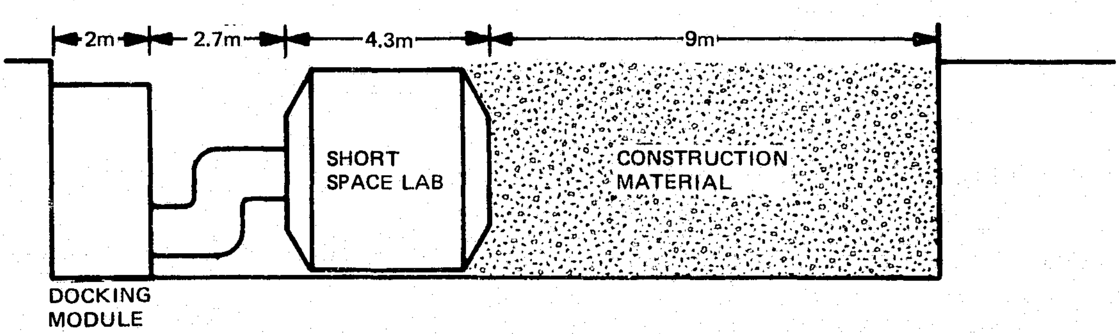

Figure 9-3 Cargo Volume Available for Extended Missions

Table 9-2 Solar Array Technology

HIGH VOLTAGE ANOMALIES - ARCING • SOLAR STORM SUSCEPTIBILITY • DESIGN PARAMETERS • RELIABILITY (FMEA) IMPACTS SURFACE CHARGE EFFECTS ON-ARRAY DISTRIBUTION AND CONTROL • INSULATION - CORONA • CURRENT DENSITY • FAULT ISOLATION AND COMMANDABILITY • SWITCHING/POWER CONTROL/MAINTAINABILITY OUT-OF-ECLIPSE TRANSIENTS - VOLTAGE LIMITING ION CURRENT PHENOMENA • HOT SPOT CONTROL ELECTROSTATIC DIPOLE TORQUES FLATNESS/CONCENTRATION REQUIREMENTS CELLS

Table 9-3 Distribution and Control Technology

CONDUCTOR MATERIALS/PROCESSING • CURRENT DENSITY OPTIMIZATION • JOINT FABRICATION - IR DROP DEGRADATION • INSULATION - MATERIALS, APPLICATION TECHNIQUES • PROTECTION COORDINATION PARAMETRICS
POWER CONTROLLERS/FAULT ISOLATION DEVICES • ARC QUENCHING • DISSIPATION • COMMANDABILITY • PROTECTION ACCURACY • I2t RATINGS • TEMPERATURE SENSITIVITY • LIFE/DEGRADATION

Single-axis two gimbal types should be compared to a true 2-degree-of-freedom design in terms of:

- Current density vs friction and dynamics
- Insulation/corona/arc-over vs travel angle
- Materials sensitivities.

Some orderly study plans should be formulated to work these areas.

Finally, DC to RF conversion should be tackled in at least two major areas. Depressed collector klystrons in the 50-75 kW range should be developed. For amplitrons, parallel vs cascade tradeoff studies should be done including optimization studies of combined cascaded and paralleled configurations for various sizes. Lastly, tradeoffs should be performed - assuming successful development of the depressed collector klystrons - between klystron and amplitron converters.

9.1.3 Platform Logistics and Assembly Subsystem

Future analysis should investigate the best method for controlling translation of the traveler and boom manipulator. The approach to transfering control signals to the boom manipulator requires analysis. The baseline vehicle for study shows a hardwire connection to the manipulator that is rolled out or in when the manipulator is translated. The design of the traveler power pickup from boom mounted rails presents a challenge, as is the method of joining boom rails during assembly. The orbiter and boom manipulator control fidelity should be examined and compared with specific tasks required of the manipulators. Manipulators controls and displays in the orbiter will have to be evaluated considering task requirements. Also, manipulator camera location and illumination at the work site must be evaluated. The location and method of controlling the boom slewing required investigation as well as orbiter payload bay equipment needs. This equipment must provide support for OCDA beams, etc., during launch and also provide ease of retrieval during construction.

9.1.4 Communications and Data Handling Subsystem

9.1.4.1 Impact of Remote Manipulator Earth Control. Studies and simulations are needed to establish the feasibility of this concept. Multiplexed operator signals require processing to control the manipulator. A number of video displays are needed by the operator(s) for feedback to successfully control one or more manipulators. These requirements have a large impact on the C&DH design.

9.1.4.2 High and Low Gain Antenna Locations. It has been assumed that a single high gain antenna is mounted on the core end of the platform and that omni antennas are also mounted on the same end at the platform corners. Platform structure, boom, and solar array interfere with the antenna operation, therefore, this question regarding location needs further analysis.

9.1.5 Attitude Control Subsystem

Future study areas include a more thorough evaluation of actuator technology requirements. In addition, a more detailed analysis should be made to determine the performance impact of moving the boom relative to the platform. In particular, the momentum exchange during a repositioning maneuver and the effect of the changed configuration on the disturbance torques must be considered. Boom reposition rate constraints should be developed. Similar analyses should be conducted for conditions during the construction scenario.

Platform maneuver requirements based on experiment missions, momentum unloading or boom offset inertia balancing should be developed.

The ability of the orbiter to augment control of the OCDA when docked must be evaluated.

Appendix A

ACRONYMS

AFM	Automatic Fabrication Module
ACS	Attitude Control System
BOL	Beginning of Life
C&DH	Communication and Data Handling
CER	Cost Estimating Relationship
CMG	Control Moment Gyro
CP	Cherry Picker
EPS	Electrical Power System
EOL	End of Life
EVA	Extra Vehicular Activity
GEO	Geosynchronous Earth Orbit
GFE	Government Furnished Equipment
GND	Ground
HLLV	Heavy Lift Launch Vehicle
JSC	Johnson Space Center
LEO	Low Earth Orbit
MMS	Multimission Spacecraft
MPTS	Microwave Power Transmission System
MMU	Manned Maneuvering Unit
OCDA	Orbital Construction Demonstration Article
OCDS	Orbital Construction Demonstration Study

ODAPT	Orientation Drive and Power Transfer System
OKS	Orbit Keeping System
PL&AS	Platform Logistics and Assembly Subsystem
RF	Radio Frequency
RFI	Radio Frequency Interference
RIU	Remote Interface Unit
RMS	Remote Manipulator System
S/A	Solar Array
S/C	Space Craft
SEPS	Solar Electric Propulsion System
SPACE	Space Probabilistic Algorithm for Cost Estimating
SPS	Solar Power Satellite
STS	Space Transportation System
STACC	Standard Telemetry and Command Control
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite Systems
WBS	Work Breakdown Structure

Appendix B

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