MCDONNELL DOUGLAS

SPACE STATION SYSTEMS ANALYSIS STUDY

PART 1 FINAL REPORT

VOLUME 2

Technical Report

1 SEPTEMBER 1976

MDC G6508

CONTRACT NO. NAS 9-14958
DPD NO. 524
DR NO. MA-04

APPROVED BY:

R. J. GUNKEL
STUDY MANAGER, SPACE STATION STUDY

G. V. BUTLER
PROGRAM MANAGER, SPACE STATION

J. W. CRAIG
MANAGER
SPACE STATION SYSTEMS ANALYSIS STUDY

PREPARED FOR: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

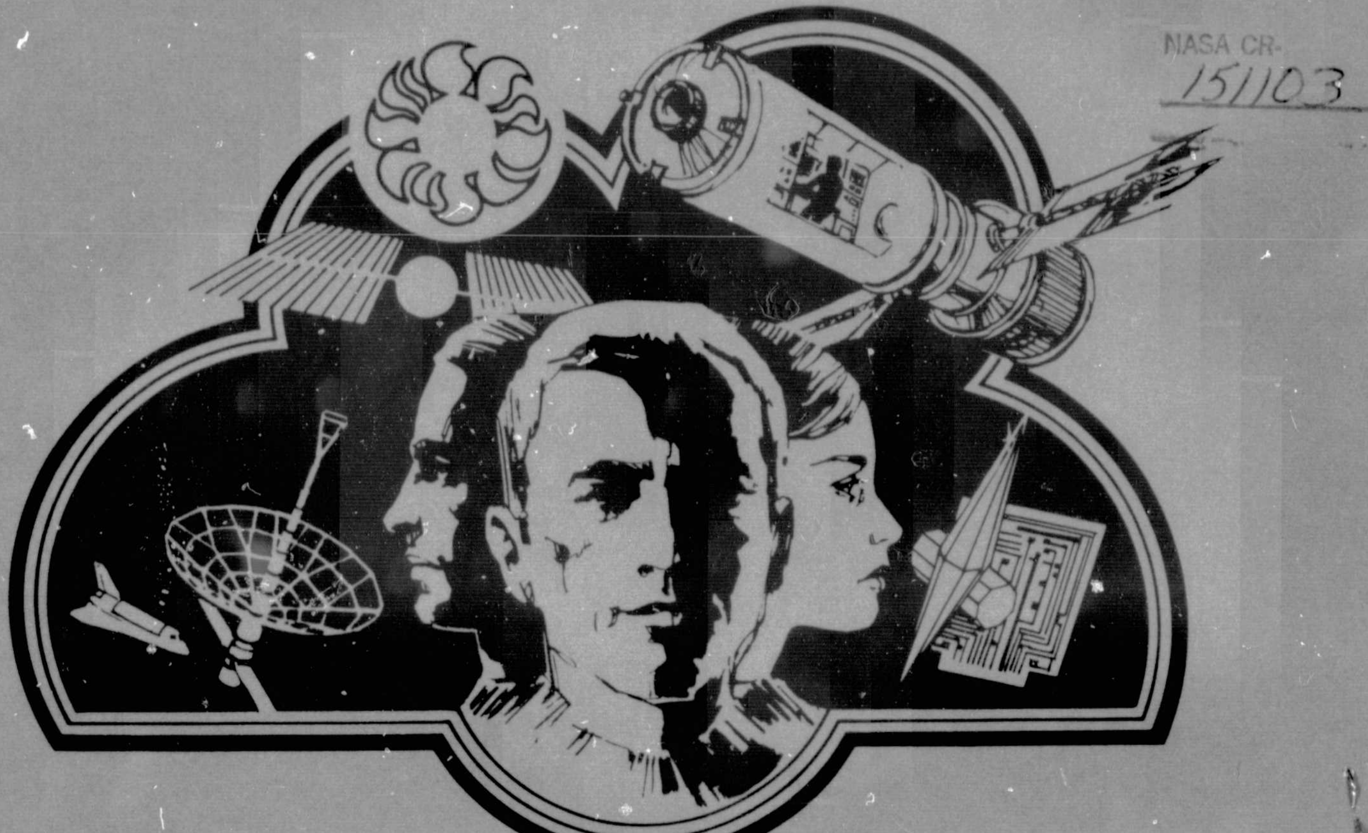
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST

5301 Bolsa Avenue, Huntington Beach, CA 92647

1 SEPTEMBER 1976

MDC G6508

NASA CR-151103



SPACE STATION SYSTEMS ANALYSIS STUDY

PART 1 FINAL REPORT
VOLUME 2
Technical Report

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

CONTRACT NO. NAS 9-14958
DPD NO. 524
DR NO. MA-04

MCDONNELL DOUGLAS CORPORATION

PREFACE

The Space Station Systems Analysis Study is a 15-month effort (April 1976 to June 1977) to identify cost-effective Space Station systems options for a permanent manned space facility capable of orderly growth with regard to both function and orbit location. The study activity is organized into three parts. Part 1 is a five-month effort to define and evaluate program options; Part 2 is a five-month effort to define and evaluate system options within the selected program options; and Part 3 is a five-month effort to further define selected program/system options.

The purpose of this report is to document the results of Part 1 of the study with specific reference to the Space Station objective selection and the rationale for this selection, and to describe potentially feasible program options for the development of future Space Station systems.

This volume is submitted as part of DR-MA-04, which consists of the following items:

- Volume 1 - Executive Summary
- Volume 2 - Technical Report
- Volume 3 - Appendices
  - Book 1 - Objective Data
  - Book 2 - Option Data and Costing

During Part 1 of the study, subcontract support was provided by TRW Systems, Aeronutronic Ford Corporation, and the Raytheon Company.

Questions regarding this study activity should be directed to:

Jerry W. Craig; Code EA4
Manager, Space Station Systems Analysis Study
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058
Telephone (713) 483-4073

or

R. J. Gunkel
Study Manager, Space Station Systems Analysis Study
McDonnell Douglas Astronautics Company - West
Huntington Beach, California
Telephone (714) 896-3958

CONTENTS

Section 1
INTRODUCTION

The purpose of the study documented in this report is to examine potential Space Station system options for a permanent, manned, orbital space facility and to provide data to NASA program planners and decision makers for their use in future program planning. It is not the intent to justify specific space program objectives, per se, but rather to identify the range and extent of potential requirements that might reasonably be imposed on a Space Station system. To accomplish this goal it has been necessary to identify and examine a number of specific potential objectives. While the objectives described in this report do not represent approved NASA programs, they were found to be most useful by the design engineers and program analysts in bounding and investigating viable alternatives for the implementation and orderly growth of a permanent Space Station system.

Key inputs to this analysis were the Outlook for Space (NASA SP-386), the JSC and MSFC 1975 Geosynchronous Space Station Study reports, the JSC Six-Week Study on a Space Solar Power Development Laboratory, and the Aerospace study of the Commonality of Space Vehicle Applications to Future National Needs (NASw-2727).

The objectives derived from the Outlook for Space and the supplemental sources were evaluated as to their importance as determinants in deriving requirements for future Space Station system elements. Criteria used in this ranking were Need (degree of satisfaction of basic needs), Benefits (potential for providing significant economic benefits), Space Station Applicability, Time Frame for implementation, Cost Confidence, Technical Confidence, and the available Data Base.

With this information, JSC and MDAC personnel then identified 10 key Space Station system objectives. These were categorized into five major objectives and five supporting objectives. The major objectives were to support the development of (1) Satellite Power Systems, (2) Nuclear Energy Plants in Space, (3) Space Processing, (4) Earth Services, and (5) Space Cosmological Research and Development. The five supporting objectives were to define space facilities which would be basic building blocks for future systems and were: (1) a Multidiscipline Science Laboratory (general-purpose facility), (2) an Orbital Depot to maintain, fuel, and service orbital transfer vehicles, (3) Cluster Support Systems to provide power and data processing for multiple orbital elements, (4) a Sensor Development Facility, and (5) the facilities necessary to enhance man's Living and Working in Space.

The requirements stemming from each of these objectives were then examined in the context of their suitability in defining Space Station system program options.

The overall approach to establishing an initial set of program options was based on developing a spectrum of Space Station programs which represented a reasonable range of feasible approaches for accomplishing the objectives. The options varied with respect to: (1) orbits, (2) the type of Space Station involved, (3) the transportation concepts used, (4) the number of Space Station complexes involved in different orbits, (5) the schedule (and sequence) for realizing objectives, and (6) the depth to which objectives were met (e.g., one option might involve only doing the basic R&D for a set of objectives while another might develop pilot plants for the same set). Options in some cases emphasized one major objective or excluded some objectives where there was a rationale for doing so. Forty-five program options were created and were compared with respect to each other to determine the ones which warranted further analysis. Nine selected options were then analyzed in greater depth to provide data to NASA which could be used to select a limited number of options to be used as the basis for the analyses to be conducted in Part 2 of the study.

During the performance of Part 1 of the study, the concept of a basic Space Station Construction Base (described in Section 4) evolved as the baseline system from which the program options were developed. This initial orbital facility was visualized as including a power module, crew module, control center, core (berthing) module, fabrication and assembly module, and cargo module. As will be described in the discussion of program options (Section 3), specific mission hardware such as a laboratory module or laboratory support module can be added to the baseline system, as determined by the requirements identified for each program option, to provide growth versions of the basic facility.

In developing the program options, currently proposed NASA mission models and other related mission planning materials were reviewed to determine the preliminary studies which will most likely be accomplished during STS/Spacelab missions programmed for the 1980 to 1983 time period. These missions can be expected to include activities in the areas of space processing, life sciences, physics and astronomy, Earth sciences, and space technology. This background data provided the point of departure for establishing the functional requirements defined in the present study and implemented in the program options considered for the time period beyond 1983.

In the following pages of this report, the procedure followed in the selection of the objectives for the Space Station system is summarized, the creation of the program options is described, and the critical configuration and transportation requirements are identified.

The key terms used in this report and their definitions are as follows:

Objective

Space activity areas or goals which appear to be key determinants in identifying future Space Station systems requirements.

Example: "Provide a permanent space test capability for evaluation of the technical and economic feasibility of a satellite power system."

Functional Requirement

One of a subset of activities or steps necessary to achieve an objective.

Example: "Evaluate RFI effects produced by large scale microwave power transmission systems."

Objective (Program) Element

Physical facilities, equipment, test apparatus, etc., necessary to perform each functional requirement.

Example: 1.7 megawatt RF antenna, 2.2 megawatt solar array.

Program Option

A set of multiple objective elements supporting a selected group of objectives, which permit the development of programmatic schedule and costing data.

Example: "Space Station and mission hardware (elements)
Orbit location(s)
Transportation requirements
Schedule
Cost."

Section 2

SUMMARY OF STUDY EFFORT AND RESULTS TO DATE

Figure 2-1 presents the study schedule as revised to indicate the current plans and status. This report contains the results of the first five months of study effort (Part 1). During this part of the study, Space Station objectives were defined and selected, mission descriptions prepared, and functional requirements derived in support of the establishment of candidate program options. In addition to Space Station System Hardware being defined to Level 3 of the WBS, Transportation System requirements were also identified. During Part 2 of the study, Space Station and mission hardware will be further defined to Level 4 of the WBS and alternative system options evaluated. This will permit the most desirable Space Station designs to be refined during the later tasks of the study and programmatic data on related costs and schedule projections prepared and provided to the NASA program planners for their use and consideration.

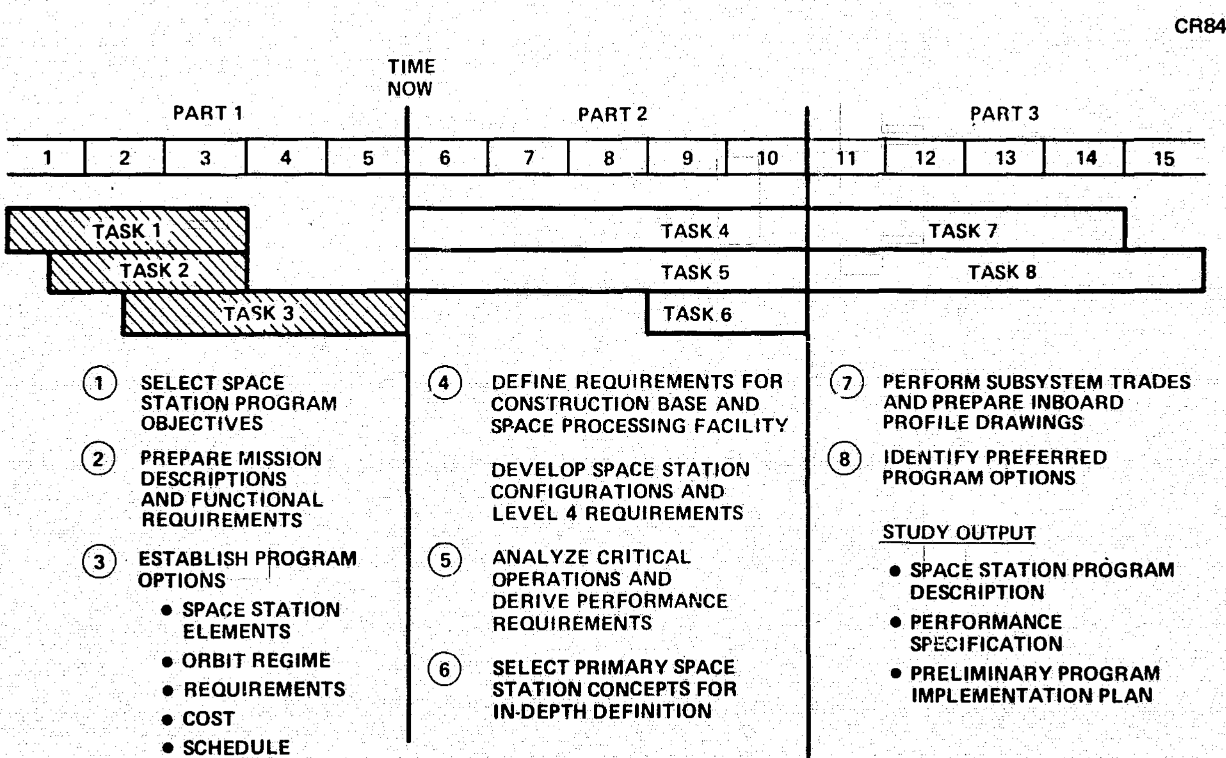


Figure 2-1. Space Station Study

2.1 IDENTIFICATION OF OBJECTIVES FOR SELECTION

During the initial period of Part 1, the primary objective was to review the available background data on space objectives (and to supplement these data where necessary) in order to select jointly with NASA a representative set of missions goals or objectives sufficient to describe the range and extent of the potential requirements which might reasonably be placed on a Space Station system.

Key inputs to this analysis were the Outlook for Space (NASA SP-386), the JSC and MSFC 1975 Geosynchronous Space Station Study reports, the JSC Six-Week Study on a Space Solar Power Development Laboratory, and the Aerospace study of the Commonality of Space Vehicle Applications to Future National Needs (NASw-2727). The data base and derivation criteria are more fully discussed in Section 3 of this report. Basically the identification and derivation process followed the procedural steps of (1) analyzing and grouping the 61 "Outlook for Space" program objectives and 18 Aerospace initiatives within seven Space Station categories and 76 individual functional objectives, (2) evaluation of 76 functional objectives against criteria dependent and independent of Space Station functions, and (3) identification of a resultant of 10 key Space Station System objectives with high benefit potential.

The 10 key objectives were grouped into three major categories and recommendations made as follows:

Construction Related	
Satellite Power System	Has great commercial potential, two pilot plant concepts recommended
Nuclear Energy	Recommend deferring for the present
Earth Services	Has great potential, several antennas recommended.
Space Cosmological R & D	30m Radiotelescope recommended for demonstration.
Space Manufacturing	
Space Processing	Tremendous commercial potential for modest initial investment. Recommended for inclusion in system options.

Supporting Objectives

Cluster Support System	Early applications not recommended
Depot	Marginal for unmanned satellites - needed to support major objectives - may support planetary missions. Recommended R&D only for early Space Station activities.
Multidiscipline Science Lab	Needed to realize ultimate potential
Sensor Development	Space environment offers significant advantages for development and testing. Recommended for inclusion in early Space Station activities.
Living and Working in Space	Needed to exploit man's capability. Recommended as mandatory for all early Space Station options.

Those in the construction related category require a "construction base" capability prior to their development. The supporting objectives, as the name implies, supply either necessary or highly desirable services/support to both the operational objectives and NASA's continuing advanced space research efforts.

Space manufacturing covers the broad range of potential high-value products that might benefit from operations in the space environment.

2.2 APPROACH TO DEVELOPMENT OF PROGRAM OPTIONS

The overall approach to establishing an initial set of program options, the logic of which is shown in Figure 2-2, was based on determining a variety of Space Station programs which represent different approaches to realizing the objectives justified in Task 1. These options varied with respect to: (1) orbits, (2) the type of Space Station involved, (3) the transportation concepts used, (4) the number of Space Station complexes involved in different orbits, (5) the schedule (and sequence) for realizing objectives, and (6) the depth to which objectives are met (e.g., one option might only involve doing the basic R&D

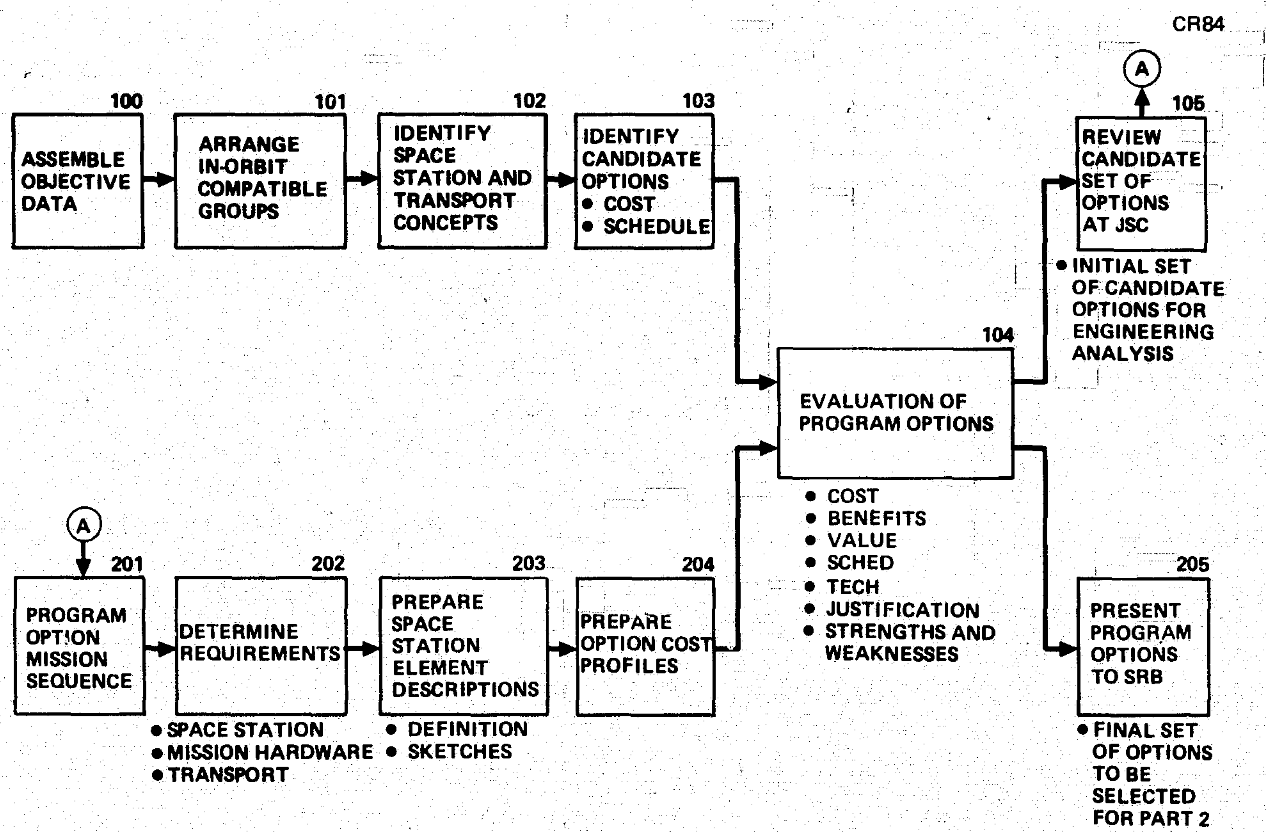


Figure 2-2. Program Option Selection Logic

for a set of objectives while another might develop pilot plants for the same set). Some options emphasized one major objective or excluded some objectives where there was a rationale for doing so. The various options were then compared with respect to each other to determine those which warranted further analysis. These selected options were analyzed in greater depth to supply data to NASA to allow selection of those to be taken into Part 2 of the study.

Forty-five program options were initially defined and evaluated. From this analysis, nine program options, shown in Table 2-1, were selected for further analysis. Also shown are the objective elements that are included within each option. It can be seen that there is a wide range of achievement represented by the candidate options. Detailed discussion of these options is included in Section 4 of this report.

The Part 1 tasks also included programmatic activities in program option planning and related ROM costing. An initial set of cost assumption/costs was developed from previous Space Station studies, NASA technical reports

MCDONNELL DOUGLAS

Table 2-1

PROGRAM OPTION OBJECTIVE ELEMENTS

PROGRAM OPTIONS (Options 1 and 3)

OBJECTIVE ELEMENTS	1	A	B	C	D	E	H	3	A	B	C	D	E
SPS													
Component Development and Testing	84	84	84	84	84	84	84	84	84	84	84	84	84
Orbital Power Source							85						
Antenna Test (Mini Pilot Plant)				86		86	86				86		
SPS Pilot Plant (LEO)	91	91	91		88	91	91	91	91		91	91	91
SPS Pilot Plant (GEO)	93	93	93		89	93	93						
Space Processing													
Development and Test	84	84	84	84	84	84	84	84	84	84	84	84	84
Process Optimization	87	87	87	87	85	87	87	87	87	87	87	87	87
Silicon Ribbon Pilot Plant	90	90	90		87		90	90	90	90		90	90
Blanket Pilot Plant	90	90	90		87		90	90	90	90		90	90
Commercial Processing Pilot Plant			95		93			95	95	95	95	95	95
Earth Services													
4m Radiometer	84	84	84	84	84	84	84	84	84	84	84	84	84
30m Radiometer	90	90	90	90	87	85	85			90			90
100m Radiometer			90		87					90			90
300m Radiometer (LEO)			90		87					90			90
300m Radiometer (GEO)			90		87								
Multibeam Lens (LEO)			90		87								90
Multibeam Lens (GEO)			90		87								
Cross-Phased Array (LEO)			90		87					90			90
Cross-Phased Array (GEO)			90		87								
Multidiscipline Science Lab													
Basic Research - Min Level						84	84						
Basic Research - Maxi Level	84	84	84	84	84			84	84	84	84	84	84
Living and Working in Space													
Limited Research	84	84	84	84	84	84	84	84	84	84	84	84	84
Extensive Research	86	86	86	86	86	86	86	86	86	86	86	86	86
Demonstrate Techniques	91	91	91		88		91	91	91	91		91	91
Construction Support	91	91	91		88		91	91	91	91		91	91
Large Radio Telescope													
Component Development and Test	87	87	87	87	85	87	84						
Mark II Radio Telescope	90	90	90	90	87	90	85						
Test Operations	90	90	90	90	87	90	85						
Depot													
Component Development and Test	84	84	84		84		84	84	84	84	84	84	84
Large OTV Depot													
Small OTV Depot	91	91	91		91								91
Cluster													
MSPP													
Large Cluster Component Development	84	84	84	84	84	84	84	84	84	84	84	84	84
Large Cluster Pilot Plant													
Option Characteristics													
LEO Only								●	●	●	●	●	●
LEO + GEO Unmanned	●	●	●	●	●	●	●						
LEO + GEO Manned													
LEO + PEO													
Shuttle	188	121	256	136	302	88	130	97	71	135	64	98	185
HLLV		13							6				
OTV Cargo	3	3	6	3	6		3						
OTV Manned													

PROGRAM OPTIONS (Options 4, 5 and 9)

OBJECTIVE ELEMENTS	4	A	B	C	D	E	5	A	B	C	D	9	A	B	C	D
SPS																
Component Development and Testing	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Orbital Power Source																
Antenna Test (Mini Pilot Plant)					86				86						86	
SPS Pilot Plant (LEO)	91	91	91			91						91	91	91		91
SPS Pilot Plant (GEO)	93	93	93	93		93	93	93		93	93	93	93	93		93
Space Processing																
Development and Test	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Process Optimization	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
Silicon Ribbon Pilot Plant	90	90	90	90		90	90	90	90	90	90	90	90	90		90
Blanket Pilot Plant	90	90	90	90		90	90	90	90	90	90	90	90	90		90
Commercial Processing Pilot Plant				95							95					
Earth Services																
4m Radiometer				84			84	84	84	84	84					
30m Radiometer				90			90	90	90	90	90					
100m Radiometer				90												
300m Radiometer (LEO)				90							90					
300m Radiometer (GEO)				90							90					
Multibeam Lens (LEO)				90							90					
Multibeam Lens (GEO)				90							90					
Cross-Phased Array (LEO)				90							90					
Cross-Phased Array (GEO)				90							90					
Multidiscipline Science Lab																
Basic Research - Min Level																
Basic Research - Maxi Level	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Living and Working in Space																
Limited Research	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Extensive Research	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86
Demonstrate Techniques	91	91	91	91		91	91	91	91	91	91	91	91	91		91
Construction Support	91	91	91	91		91	91	91	91	91	91	91	91	91		91
Large Radio Telescope																
Component Development and Test							87	87	87	87						
Mark II Radio Telescope							90	90	90	90						
Test Operations							90	90	90	90						
Depot																
Component Development and Test	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Large OTV Depot	91	91	91	91	91	91	91	91	91	91		91	91	91	91	91
Small OTV Depot											91					
Cluster																
MSPP	90	90	90	90	90	90					90	90	90		90	90
Large Cluster Component Development	87	87	87	87	87	87	93	84	84	84	87	87	87	84	87	87
Large Cluster Pilot Plant	90	90	90	90	90	90					90	90	90		90	90
Option Characteristics																
LEO Only																
LEO + GEO Unmanned																
LEO + GEO Manned	S	S	S	S	S	S	P	P	P	P	P	P	P	P	P	P
LEO + PEO																
Shuttle	476	644	129	577	359	356	393	386	248	150	645	357	234	252	289	139
HLLV			76							62						55
OTV Cargo	26	50	26	32	2	26	38	38	38	38	44	7	8	7	7	7
OTV Manned	29		29	29	29	29	28	26	22	28	38	15	15	15	15	15

PROGRAM OPTIONS (Options 14, 16 and 17)

OBJECTIVE ELEMENTS	14	A	B	C	D	E	16	A	B	C	D	E	F	G	17	A
SPS																
Component Development and Testing	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Orbital Power Source																
Antenna Test (Mini Pilot Plant)				86							86					
SPS Pilot Plant (LEO)	91	91	91		91	88	91	91	91	91		91	91	88	91	91
SPS Pilot Plant (GEO)	93	93	93		93	89	93	93	93	93		93	93	89		
Space Processing																
Development and Test	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Process Optimization	87	87	87	87	87	85	87	87	87	87	87	87	87	85	87	87
Silicon Ribbon Pilot Plant	90	90	90		90	87	90	90	90	90		90	90	87	90	90
Blanket Pilot Plant	90	90	90		90	87	90	90	90	90		90	90	87	90	90
Commercial Processing Pilot Plant			95		95	93				95			95	93	95	95
Earth Services																
4m Radiometer	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
30m Radiometer	90	90	90	90	90	85	90	90	90	90	90	90	90	87	90	90
100m Radiometer			90		90	87				90			90	87	90	90
300m Radiometer (LEO)			90		90	87				90			90	87	90	90
300m Radiometer (GEO)			90		90	87				90			90	87		
Multibeam Lens (LEO)					90	87	90	90	90	90	90	90	90	87	90	90
Multibeam Lens (GEO)					90	87	90	90	90	90	90	90	90	87		
Cross-Phased Array (LEO)			90		90	87				90			90	87	90	90
Cross-Phased Array (GEO)			90		90	87				90			90	87		
Multidiscipline Science Lab																
Basic Research - Min Level																
Basic Research - Maxi Level	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Living and Working in Space																
Limited Research	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Extensive Research	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86
Demonstrate Techniques	91	91	91		91	88	91	91	91	91	91	91	91	88	91	91
Construction Support	91	91	91		91	88	91	91	91	91	91	91	91	88	91	91
Large Radio Telescope																
Component Development and Test	87	87	87	87	87	85							87	85		
Mark II Radio Telescope	90	90	90	90	90	88							90	88		
Test Operations	90	90	90	90	90	88							90	88		
Depot																
Component Development and Test	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84
Large OTV Depot	91	91	91	91	91	91	91	91	91	91	91	91	91	88		
Small OTV Depot										91			91	88	91	91
Cluster																
MSPP					90	87	90	90	90	90	90		90	87	84	84
Large Cluster Component Development	84	84	84	84	87	84	87	87	87	87	87		87	85	84	84
Large Cluster Pilot Plant					90	87	90	90	90	90	90		90	87		
Option Characteristics																
LEO Only																
LEO + GEO Unmanned																
LEO + GEO Manned	P	P	P	P	P	P	S	S	S	S	S	S	S	S		
LEO + PEO															S	P
Shuttle	251	177	348	193	488	477	426	686	166	507	364	306	486	531	193	212
HLLV		20							63							
OTV Cargo	3	3	9	3	9	9	3	254	3	9	3	3	9	9		
OTV Manned	16	16	16	16	20	17	29		29	29	29	29	29	29		

and the MDAC data base. Space Station configuration and mission hardware descriptions were devised for each option as the basis for comparative ROM cost development. These concepts are presented in Section 4.

Preparation of Space Station configuration sketches emphasized several basic conceptual approaches to the initial five-to-ten man station. In each case, an approach to achieving both evolutionary growth and option functional support flexibility was developed.

Transportation requirements were derived for each Part 1 program option. Conclusions reached to date include (1) the large logistics required for some program options require the use of a heavy-lift launch vehicle (HLLV), (2) the Shuttle-derived HLLV to be used for future option analysis should be in the 60,000- to 112,000-kg payload range, (3) the relatively few orbit transfer vehicle (OTV) cargo and OTV-planned performance requirements suggested a common vehicle be considered, (4) the Depot should be reconsidered in light of Item 3, and (5) the payload/transportation system interfaces should be kept to a minimum as a goal.

During Part 1 of this study, it was found that many objectives required large space structures for their implementation and development. As a result, a concept of a basic Space Station Construction Base evolved during the study. This concept is believed to represent the significant first step to be taken in the development of the next generation of space operations beyond the early STS/Spacelab missions. The implementation of this construction base concept would also provide a basic Space Station system facility to which new modules and/or capabilities could be added in building-block fashion as demand warranted. Accordingly, it is recommended that during Part 2, this concept be pursued and a special emphasis task be initiated to define the requirements for fabrication/assembly module(s) that can evolve from small orbital operations to a full construction base capable of building the largest antenna system identified in Part 1. Questions of orbital construction versus earth-based construction should be addressed by examining specific point designs. It is suggested that an antenna and solar array for a satellite power system, a 30m radiometer, and a multibeam lens antenna system be considered as candidates for point design analysis.

A second area which would appear to warrant special emphasis during Part 2 is the area of space processing. Process steps for two or three selected production cases with attractive commercial promise need to be defined. This would require the definition of such factors as control parameters, elapsed times, equipment, and resources required in order to identify the system requirements for Space Station elements, mission hardware, and transportation systems.

As a third point, emphasis must also continue to be placed on the control of costs through better design. In particular, an examination of low-cost structure and its application to module design is recommended as an area of continuing emphasis throughout Part 2.

Finally, inasmuch as transportation costs are a significant factor in total program costing, it is recommended that attention also be directed in Part 2 toward analyses of the most cost-effective use of potential transportation vehicles.

2.3 CONCLUSIONS

The past five months work have resulted in the generation of adequate objective/option data to support entry into the Part 2 activities; this data is presented in this report. In addition, the data base developed during this effort is available and documented in a format permitting rapid derivation of additional options if deemed necessary by NASA.

Section 3
SELECTION OF OBJECTIVES

The initial task of the study examined a broad spectrum of potential research and application objectives requiring space platforms. Subsequent to this examination, a selection was made of a definitive number of objectives which appeared to have significant benefits as well as requiring Space Station system elements in their accomplishment. These selected objectives then served as a basis from which Space Station requirements could be defined and program options synthesized. In summary, the selection process involved (1) review of the study data base, (2) preliminary selection of desirable objectives within the data base, and (3) description of the rationale and justification of the selected objectives insofar as Space Station applicable requirements are concerned.

In our analysis, ten Space Station system objectives were identified for which manned Space Station systems appeared to have the potential of contributing significant support. These objectives covered a spectrum of potential applications from commercial operations to pure science. Four of the objectives involved space construction of large antennas, solar arrays and power systems. Five more provided a supporting research and development base for other objectives and the tenth represented an early step in the development of a space manufacturing capability. Each of these objectives was studied independently in some detail to determine the implication for the Space Station and to establish design requirements. As a result of this effort, nine of the ten objectives studied were recommended for inclusion in the development of Space Station program options; an objective involving nuclear energy in space was recommended for deferral pending further study.

The requirements stemming from each objective were then examined in the context of their suitability in defining Space Station options. As an example, the time frame of some individual requirements lay beyond the period of interest for Space Station program options (approximately through 1995). Accordingly, these were not included in the final set of functional requirements to be accommodated by program options. For the surviving functional requirements from each objective, companion hardware concepts were postulated. These data were the basis for the establishment of program options to be described in section 4 of this document.

3.1 DATA BASE

With the concurrence of NASA, it was decided that the information in Outlook for Space (NASA SP-386, January 1976) would be the primary reference for the description of key goals and objectives. This document identified 61 program objectives; Table 3-1 summarizes salient characteristics of the 61 objectives.

Forty-five of the objectives, as defined in SP-386, described a requirement for the support of man in space. The basis for identification of the 45 program objectives requiring man's involvement was the correlation of these objectives to manned systems as contrasted to automated systems as defined in SP-386. These relationships are shown in Table 3-2.

At this juncture it was recognized that selection of a lesser set of objectives upon which to base the Space Station systems analysis study would be desirable if such a set would still encompass a sufficiently broad range of requirements. Also, the objectives with high potential for benefiting man should be chosen. Accordingly, a two-faceted approach was taken. In the first, demographic analyses were made and affected populations were identified to expand the data base with regard to "who" and "how many" are benefited. The second facet was to have a broad spectrum of investigators at NASA JSC and MDAC (including subcontractors) evaluate each objective with respect to a set of criteria which would allow, on a statistical basis, a determination of those objectives considered to be most important for further consideration in the study. These data when considered collectively formed the basis for selection of a reduced set of objectives to be further analyzed.

Table 3-1
PROGRAM OBJECTIVES

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15,16	17
Global Crop Forecasting	022	1360	550	2025	3385	23	4	39	9	10	10	55	1986	1993P	2,8
Water Availability	012	810	550	1149	1959	24	3	15	9	10	10	52	1986	1993P	4,8
Land Use	013	750	0	1820	2570	46	3	24	9	9	9	10	1981	1998P	0
Marine Resources	014	660	550	490	1150	25	3	16	7	9	9	53	1986	1993P	5,8
Timber Inventory	015	675	0	1390	2065	47	3	25	8	9	9	11	1981	1997P	0
Rangeland Assessment	016	660	0	1373	2053	48	3	26	8	9	9	12	1981	1998P	0
L.S. Weather Forecasting	021	762	308	1256	2018	35	2	2	9	9	9	28	1983	1990P	2,8
Weather Modification	022	460	290	1420	1860	36	2	3	8	8	8	29	1983	1990P	4,4
Climate Prediction	023	2325	20	4325	6650	44	4	47	4	4	4	56	1986	1993P	1
Stratopheric Change	024	295	0	415	710	49	2	4	4	6	8	18	1982	1997P	0
Water Quality	025	20	0	40	60	50	2	5	9	10	10	1	1981	2000P	0
Marine Weather Forecasting	026	302	180	550	852	42	1	1	8	8	8	50	1986	1992P	3,6
Local Weather and Severe Storm	031	757	290	1265	2022	37	3	21	9	9	10	30	1983	1990P	2,7
Tropopheric Polluntants	032	493	0	645	1138	51	3	27	8	9	9	21	1982	1996P	0
Hazards from In-Site Meas	033	40	0	80	128	60	2	9	4	8	9	19	1982	2000L	0
Comm/Nav Capability	034	400	0	530	930	52	3	28	4	6	9	22	1982	2000L	0
Earthquake Prediction	035	360	0	290	550	53	3	29	4	6	8	59	1991	1999P	0
Harmful Insects	036	1455	550	2308	3763	26	3	17	9	9	10	54	1986	1993P	2,6
Solar Power Station	041	53000	52400	10000	63000	1	4	32	5	7	8	24	1982	1995PG	12,9
Power Relay via Satellites	042	2200	21500	20000	22200	2	5	49	5	7	8	57	1987	2000PG	127,0
Waste Disposal	043	500	0	5226	5726	54	4	48	4	6	8	47	1984	19900	0
World Geologic Atlas	044	648	0	1409	2057	61	3	31	4	5	6	23	1982	1998P	0
Domestic Communications	051	320	0	1150	1470	55	2	6	8	9	9	37	1984	1999O	0
Intercontinental Comm	052	245	0	1160	1405	56	2	7	8	9	9	51	1986	1996O	0
Personal Communications	053	45	0	90	135	57	2	8	8	9	9	58	1988	1989O	0
Basic Physics and Chemistry	061	446	446	0	446	29	3	19	4	6	9	20	1982	1999L	17,0
Materials Science	062	907	907	0	907	15	3	13	4	6	9	4	1981	2000L	19,0
Inorganic Processing	063	0	1000	1000	1000	13	3	12	4	6	9	3	1981	1999L	18,0
Biological Materials	064	446	446	0	446	30	3	20	4	6	9	7	1981	1999L	18,0
Effects of Gravity on Life	065	235	235	0	235	41	3	22	4	6	9	8	1981	1999L	18,0
Living and Working in Space	066	888	888	0	868	17	3	14	4	6	9	5	1981	1999L	18,0
Physiology and Disease	067	457	457	0	457	26	3	18	4	6	9	6	1981	1999L	18,0
Earth/S Magnetic Field	071	1415	1020	0	1415	11	3	10	4	5	6	2	1981	1991P	7,2
Crustal Dynamics	072	749	0	150	899	56	3	30	4	5	6	31	1983	1999P	0
Ocean Interior and Dynamics	073	649	20	1220	1869	45	3	23	4	5	6	9	1981	2000P	,6
Dynamics of Lower Atmosphere	074	730	290	1190	1920	38	5	39	4	5	6	35	1983	1990P	2,8
Dynamics of Strato/mesosphere	075	2390	340	430	2820	33	4	43	4	5	6	25	1982	2000P	2,6
Ions/Magnetosphere Coupling	076	660	340	1995	2655	34	4	44	4	5	6	14	1981	2000P	9.8
Universe Beginning	081	4126	1020	0	1415	12	3	11	4	6	9	38	1984	1990L	1,5
How Galaxies Form and Evolve	082	5991	790	0	5991	18	4	35	4	6	9	32	1983	2000L	2,2
What are Quasars	083	6985	790	0	6985	19	4	36	4	6	9	33	1983	2000L	1,9
Universe Expansion	084	3971	270	0	3971	39	4	45	4	6	9	45	1984	2000L	1,1
Nature of Gravity	085	2720	75	0	2720	43	5	60	4	6	9	36	1983	19841	,0
Nature of Stellar Explosions	091	6675	0	0	6675	59	5	61	4	6	9	27	1982	2000L	0
Nature of Black Holes	092	5405	720	0	5405	21	4	38	4	6	9	42	1984	2000L	2,1
Formation of Elements	093	6670	270	0	6670	40	4	46	4	6	9	46	1984	2000L	,6
Nature of Cosmic Rays	094	6600	420	0	6600	31	4	41	4	6	9	43	1984	2000L	1,0
Interstellar Matter	202	8451	890	0	8451	16	4	34	4	6	9	40	1984	2000L	1,7
Interstellar Dust	102	6995	790	0	6995	10	4	37	4	6	9	41	1984	2000L	1,8
Solar Activity	103	7405	420	0	7405	32	4	42	4	6	9	44	1984	2000LP	,9
Corona and Plasma	104	5210	990	0	5210	14	4	33	4	6	9	39	1984	2000L	3,0
Ultimate Fate of Sun	105	4910	490	0	4910	27	4	30	4	6	9	13	1981	2000L	1,9
Formation of Solar System	111	59845	6300	0	59845	8	5	55	4	6	9	34	1983	2000LO	1,8
Planets and Satellites	112	61725	6950	0	61725	4	5	51	4	6	9	15	1981	2000LO	2,1
Atmospheric Dynamics	113	41250	6820	0	41250	5	5	52	4	6	9	16	1981	1000LO	3,1
Magnetic Fields	114	58145	6800	0	58145	6	5	53	4	6	9	17	1981	2000LO	2,2
Origin of Life on Earth	121	46719	5930	0	46719	9	5	56	4	6	9	60	1993	2000LO	,9
Extraterrestrial Life	122	37896	5920	0	37096	10	5	57	4	6	9	61	1999	2000LO	,2
Organic Chemistry in Universe	123	56549	6520	0	56549	7	5	54	5	6	9	26	1982	2000LO	2,1
Other Start with Planets	124	2740	620	0	2740	22	5	58	4	6	9	49	1984	2000L	3,6
Exo-Intelligent Life	125	27890	7200	0	27890	3	5	50	4	6	9	48	1984	2000L	4,1

LEGEND:

Column	Contents
1	Outlook for Space Program Objectives Short Title
2	Outlook for Space Theme ID No.
3	R&D Cost (Millions)
4	Manned Systems Cost (Millions)
5	Operational Cost (Millions)
6	Total Cost (Millions)
7	Rank Order of Total Cost
8	Technical Risk (5 High, 1 Low)
9	Rank Order of Technical Risk

Column	Contents
10	Persons Affected by 1990 (Logarithm)
11	Persons Affected by 2000 (Logarithm)
12	Persons Affected by 2050 (Logarithm)
13	Rank Order of Leverage Index
14	Initial Flight Date (Year)
15	Final Flight Date (Year)
16	Orbital Regime (L = Low Earth Orbit, P = Polar Orbit, G = Geostationary Orbit, O = Other)
17	Leverage Index ([C15-C14]*C4/C3)

Table 3-2

RELATIONSHIPS BETWEEN "OUTLOOK FOR SPACE" OBJECTIVES AND MANNED SPACE SYSTEMS

ORIGINAL PAGE IS OF POOR QUALITY

Manned Space Systems (38) / "Outlook for Space" Objectives (45)	Global Crop Production Forecasting (011)	Water Availability Forecasting (012)	Living Marine Resource Assessment (014)	Large-Scale Weather Forecasting (021)	Weather Modification Experiments Support (022)	Climate Prediction (023)	Global Marine Weather Forecasting (026)	Local Weather and Severe Storm Forecasting (031)	Control of Harmful Insects (036)	Sola-Power Stations in Space (041)	Power Relay via Satellites (042)	Basic Physics and Chemistry (061)	Materials Science (062)	Commercial Inorganic Processing (063)	Biological Materials Research and Application (064)	Effects of Gravity on Terrestrial Life (065)	Living and Working in Space (066)	Physiology and Disease Processes (067)	Earth's Magnetic Field (071)	Ocean Interior and Dynamics (073)	Dynamics and Energetics of Lower Atmosphere (074)	Structure, Chemistry, and Dynamics of the Stratosphere Mesosphere (075)	Ionosphere-Magnetosphere Coupling (076)	How did the Universe Begin? (081)	How do Galaxies Form and Evolve? (082)	What are Quasars? (083)	Will the Universe Expand Forever? (084)	What is the Nature of Gravity? (085)	What is the Natureof Black Holes? (092)	Where and How Were Elements Formed? (093)	What is the Nature of Cosmic Rays? (094)	What are the Composition and Dynamics of Interstellar Matter? (101)	Why and How Does Interstellar Dust Condense Into Stars and Planets? (102)	What are the Nature and Cause of Solar Activity? (103)	Corona and Interplanetary Plasma (104)	What is the Ultimate Fate of the Sun? (105)	What Process Occurred During Formation of the Solar System? (111)	How do Planets, Large Satellites, and Their Atmospheres Evolve? (112)	How Can Atmospheric Dynamics be Quantified? (113)	What are the Origin and History of Magnetic Fields? (114)	How Did Life on Earth Originate? (121)	Is There Extraterrestrial Life in the Solar System? (122)	What Organic Chemistry Occurs in the Universe? (123)	Do Other Stars Have Planets? (124)	Can We Detect Extraterrestrial Intelligent Life? (125)
Solar Power Space Test Activity (1008)										•																																			
Solar Power Prototype – Development (1009)										•																																			
Power Relay Space Testing (1012)											•																																		
Power Relay Prototype – Development (1013)											•																																		
"Short Term" Physical Chemical Research – Crew Operated (1028)												•																																	
"Long-Term" Physical Chemical Research – Crew Operated (1029)												•																																	
"Short-Term" Low-g Material Science Research – Crew Operated (1030)													•																																
"Long-Term" Low-g Material Science Research – Crew Operated (1031)													•																																
Commercial Processing – Crew Operated (1032)														•																															
"Short-Term" Biological Materials Research – Crew Operated (1033)															•																														
"Long-Term" Biological Materials Research – Crew Operated (1034)															•																										•				
Preliminary Effects of Gravity on Life – Crew Operated (1035)																•																													
Effects of Gravity on Life – Crew Operated (1036)																•																													
Human Performance in Space – Development (1037)																	•																												
Human Performance in Space – Operational (1038)																	•																												
Preliminary Disease Processes Research – Crew Operated (1039)																		•																											
Disease Processes Research – Crew Operated (1040)																		•																											
Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) – Crew Operated (1045)																			•			•	•												•			•	•	•					
1m UV Telescope (1049)																								•			•		•	•	•	•		•	•	•		•	•						
Infrared Interferometer (1053)																									•	•			•			•	•										•	•	
Large Cryogenic IR Telescope (1054)																									•	•	•		•			•	•			•	•	•						•	
Eotvos Effect Experiment (1064)																												•																	
Large Ambient IR Telescope (1072)																									•	•	•			•		•	•			•	•	•	•				•		
Spacelab Solar Telescope Cluster (1075)																			•			•	•							•	•			•	•					•					
Solar Monitor (1076)						•														•		•	•											•	•	•			•						
4 Person Near Earth Orbit Space Station* (1112)												x	x	x	x	x	x	x																											
12 Person Near Earth Orbit Space Station* (1113)												x	x	x	x	x	x	x																											•
12 Person Geosynch Space Station* (1114)																																													
12 Person Lunar Base* (1115)																																					•	•		•	•				•
Crew Operated Flight To Mars* (1116)																																					•	•	•	•	•	•	•		
Industrial Space Facility* (1117)												x	x	x	x																														
Long Wavelength Microwave System – Development (2007)	•	•	•			•			•																																				
Long Wavelength Microwave System – Operational (2008)	•	•	•			•			•																																				
Stratospheric Constituents Monitoring System – Development (2024)						•																																							
Sea Survey System – Development (2027)						•	•																																						
High Resolution Sea Survey System – Development (2029)						•	•																																						
VISSR Atmospheric Sounder System – Development (2031)				•	•			•						•							•																								
Storm Satellite Survey System – Development (2033)				•	•			•													•																								
Orbit LEO										•	•	•	•	•	•	•	•	•						•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Req'd PEO	•	•	•			•	•		•										•	•		•	•											•											
GEO				•	•			•		•	•										•																•	•	•	•	•	•	•		
Other																																													

• = Objective/system relationship described in SP 386
x = "Induced" relationship

3.1.1 Demographic Analysis

Figure 3-1 is a plot of the data shown in Table 3-1, indicating demographic impacts (Columns 10, 11, and 12); the broken line across the top of the chart represents a projection of the world future population by the eminent demographer, T. Frejka*. Each of the program objectives can be associated with one of the nine curves shown on the figure. This data was useful in determining objectives emphasizing future human needs.

3.1.2 Constituency Analysis

Another data compilation examined the 38 earth-oriented activities (themes 01 through 07 described in SP-386) to determine potential advocates within the governmental, industrial, and academic communities. This information was useful in estimating whether a sizeable constituency (i.e., a large population of interested groups) existed for a particular research or applications area. If so, that area should warrant special consideration in planning

CR84

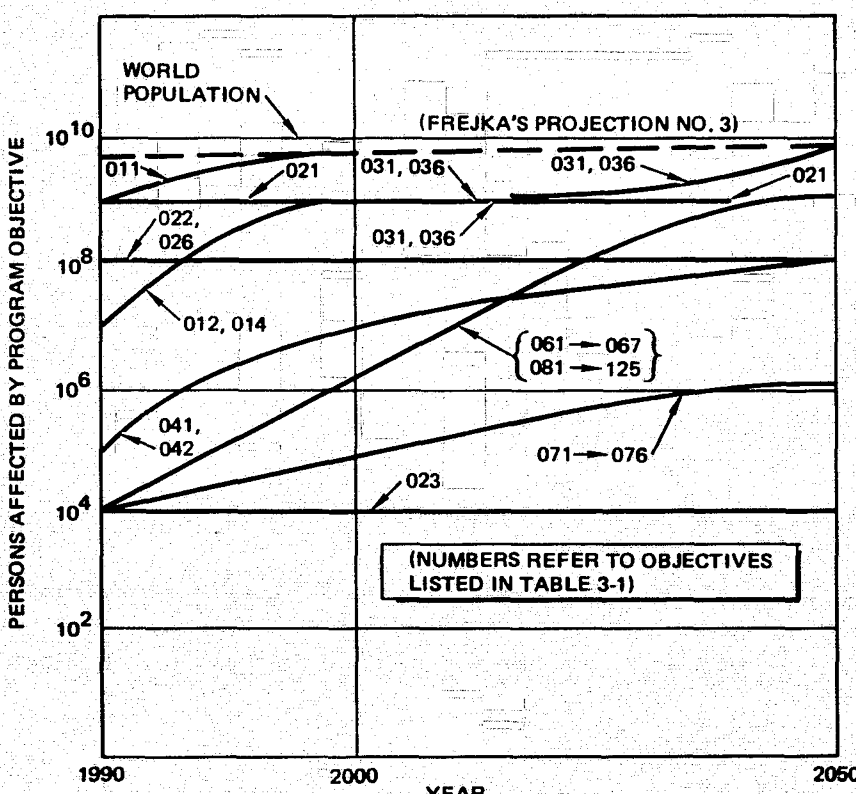


Figure 3-1. Program Objectives – Demographic Impact Projections

*The Future of Population Growth Alternative Paths to Equilibrium, Tomas Frejka, Table A, Page 220, John Wiley and Sons, New York, 1973.

future program activities. It was found that the 38 activities could be matched to the interests and needs of at least 89 influential institutional "entities" within the executive and legislative branches of the U. S. government, major industrial sectors of the economy and academic disciplines. The results of this advocacy analysis are presented in matrix form in Table 3-2.

Nineteen program objectives were found to be of interest to 30% or more of the potential constituency (Table 3-3). Table 3-4 summarizes the number of program objectives associated with each of the institutional entities. Table 3-5 identifies 12 candidate program objectives which claim the largest number of potential constituents while serving each of the seven earth-oriented themes of the Outlook for Space report.

3.1.3 Overall Objective Evaluation and Ranking

With the concurrence of NASA, the objectives from SP-386, supplemented by data available through the Study of the Commonality of Space Vehicle Applications to Future National Needs (Aerospace Contract NASw-2727), were categorized into six theme areas:

A. Large-scale space fabrication and construction R&D.
B. Space transportation system depot.
C. Satellite servicing.
D. Science R&D.
E. Space R&D.
F. Public service facility.

For each objective in each theme area, Space Station dependent and Space Station independent criteria were considered, as follows:

A. Criteria independent of Space Station function:
   1. Needs—Degree of applicability of objectives in satisfying future needs of man.
   2. Benefit—To what degree costs can be justified in terms of potential benefits.
   3. Cost Confidence—Degree of confidence in prediction of how much it will cost to achieve objective.

Table 3-3

CONSTITUENCIES OF EACH PROGRAM OBJECTIVE

	Program Objective	No. of Constituents	% of All Entities
031	Local Weather/Storm Forecasting	46	52
021	Large-Scale Weather Forecasting	45	51
033	Hazard Forecasting from In-Situ Measurements	40	45
022	Weather Modification Experiments Support	38	43
051	Domestic Communications	36	40
035	Earthquake Prediction	35	39
041	Solar-Power Stations in Space	34	38
023	Climate Prediction	33	37
042	Power Relay Via Satellites	33	37
052	Intercontinental Communication	33	37
026	Global Marine Weather Forecast	31	35
061	Basic Physics and Chemistry	34	37
025	Water Quality Monitoring	31	35
034	Comm-Navigation Capability	29	33
036	Control of Harmful Insects	28	31
012	Water Availability Forecast	27	30
043	Hazardous Waste Disposal in Space	27	30
024	Stratospheric Changes and Effects	27	30
053	Personal Communications	27	30
044	World Geologic Atlas	25	28
062	Materials Science	25	28
032	Tropospheric Pollutants Monitoring	23	26
064	Biological Materials Research and Application	22	25
066	Living and Working in Space	21	24
072	Crustal Dynamics	21	24
013	Land Use and Environmental Assessment	20	22
063	Commercial Inorganic Processing	19	21
067	Physiology and Disease Processes	19	21
011	Global Crop Forecasting	18	20
014	Living Marine Res. Assessment	17	19
015	Timber Inventory	17	19
074	Dynamics etc. of Lower Atmosphere	16	18
073	Ocean Interior and Dynamics	16	18
075	Structure etc. of Stratosphere	15	17
076	Ionosphere-Magnetosphere Coupling	14	16
071	Earth's Magnetic Field	14	16
065	Effects of Gravity on Life	14	16
016	Range Land Assessment	14	16

Largest Constituencies for:
- Weather/Environment
- Communications
- Solar Power

Smallest Constituencies for:
- Earth Sciences

Table 3-4

ENTITIES RANKED IN ORDER OF THE NUMBER OF PROGRAM OBJECTIVES OF CONCERN

Executive Branch			
38	National Science Foundation (NSF)	6	Federal Power Commission
38	National Academy of Sciences (NAS)	4	Treasury
28	Commerce	4	Energy Resources Council
23	Interior	4	Office of Telecomm Policy
20	Agriculture	4	Federal Communication Commission (FCC)
20	Transportation	4	Federal Maritime Commission
17	State	3	Justice
16	Health, Education, and Welfare (HEW)	3	Federal Energy Administration (FEA)
15	Council on Environmental Qualification	3	US Postal Service
8	Housing and Urban Development (HUD)	3	Water Resources Council
8	Environmental Protection Agency (EPA)	1	US Information Agency (USIA)
6	Energy Research and Development Agency (ERDA)	0	Labor
Senate Committees/Subcommittees			
38	Aeronautical and Space Sciences	9	Disaster Relief (Public Works)
38	HUD and Industrial Agencies (Appropriations)	7	Science, Technology, and Commence (Commerce)
20	Agriculture and Forestry	7	Foreign Relations
17	Oceans and Atmosphere (Commerce)	6	Environmental and Land Research (Interior)
13	Environmental Pollution (Public Works)	6	Merchant Marine (Commerce)
11	Environment (Commerce)	4	Communications (Commerce)
11	Surface Transportation (Commerce)	4	Minerals, Materials and Fuels (Interior)
10	Energy Research and Water Research (Interior)	3	Water Resources (Public Works)
House Committees/Subcommittees			
38	Space Science and Applications (S&T)	7	International Relations
38	HUD and Industrial Agencies (Appropriations)	7	Oceanography (Merchant Marine)
21	Agriculture	5	Mines and Mining (Interior)
17	Science Research and Technology (S&T)	5	Water and Power Research (Interior)
15	Environment and Atmospheric (S&T)	5	Fisheries (Merchant Marine)
15	Energy and Environment (Interior)	4	Communications (Commerce)
13	Health and Environment (Commerce)	4	Energy and Power (Commerce)
11	Water Resources (Public Works)	3	Transportation and Commerce (Commerce)
10	Coast Guard and Navigation (Merchant Marine)	3	Energy R&D (S&T)
10	Merchant Marine (Merchant Marine)		
Major Industries			
38	Instrument Manufacturing	5	Metals Mining
19	Agriculture	5	Coal Mining
14	Fishing	4	Oil and Gas Extraction
13	Communications	4	Nonmetallic Minerals Mining
13	Gas and Electric Utilities	4	Chemical Manufacturing
10	Water Transportation	3	Petroleum Refining and Distribution
10	Air Transportation	3	Metals Manufacturing
9	Forestry	3	Machinery Manufacturing (Incl Elec)
6	Rail and Motor Transportation	3	Transportation-Equipment Manufacturing
Major Academic Disciplines			
24	Social Sciences	6	Chemistry
12	Physics	6	Metallurgy
11	Meteorology	5	Genetics
11	Oceanography	4	Geology
11	Biology	1	Astronomy (Plus 23 if the Hearth extraterrestrial PO's are included)
10	Medical/Pharmaceutical		
7	Physiology		

Table 3-5

TOP-RATED OUTLOOK FOR SPACE PROGRAM OBJECTIVES BASED ON CONSTITUENCY ANALYSIS

031	Local Weather and Storm Warning Forecasting
021	Large-Scale Weather Forecasting
033	Hazard Forecasting from In-Situ Measurements
022	Weather Modification Experiments Support
051	Domestic Communications
061	Basic Physics and Chemistry
041	Solar-Power Stations in Space
042	Power Relay Via Satellites
052	Intercontinental Communications
012	Water Availability Forecasting
062	Materials Science
072	Crystal Dynamics

4. Technical Confidence—Probability of realizing objective regardless of cost.
5. Data Base—Degree to which objective has been studied, phenomena understood, and engineering solutions identified.

B. Criteria dependent on the Space Station function:
1. Role for the Space Station—Degree to which Space Station is required.
2. Time Frame Applicability—Period between 1985 and the year 2000 in which Space Station will be required.

Space Systems evaluation forms were prepared, and a team of engineers, scientists, and program planning specialists at NASA-JSC and MDAC examined the objectives in each theme category for each of the criteria. Sample formats and the guidelines used by the analysts appear in Volume 3, Book 1, with a listing of individuals who contributed to the analysis. The composite listing of the objectives in rank order according to total score are presented in Table 3-6.

Table 3-6 (Page 1 of 2)

LIST OF OBJECTIVES* ORDERED BY TOTAL RATING SCORE

ID* No.	Title	Score
A01	Solar Power Station	23
A05	Long Wavelength MW System	20
E20	Intercontinental Communications	20
A07	Miscellaneous Communication Functions	19
E01	Global Crop Prediction	19
E07	Large-Scale Weather Forecast	19
A08	Nuclear Plant in Space	18
E02	Water Availability	18
E18	Control of Harmful Insects	18
E22	Commercial Inorganic Processing	18
B01	Solar Power Station	17
B03	Communication and Other GEO Sats	17
C02	Service at PEO	17
C03	Service at LEO	17
E04	Marine Resources	17
E09	Climate Prediction	17
E12	Global Marine Forecasting	17
E23	Biological Materials R&D	17
F01	Global Crop Prediction	17
A02	Satellite Power Relay	16
B02	Satellite Power Relay	16
C01	Service at GEO	16
E03	Land Use	16
E10	Stratospheric Changes	16
E13	Local Weather and Storms	16
E14	Tropospheric Pollutants	16
E16	Communications/Navigation	16
E19	Domestic Communications	16
F07	Large Scale Weather Forecast	16
F20	Intercontinental Communications	16
A04	Industrial Space Facility	15
E25	Physiology and Disease	15
F02	Water Availability	15
F10	Stratospheric Changes	15
D01	Science and Biology R&D	14
D02	Atmospherics, Magnetospherics and Plasmas in Space (AMPS)	14
D05	Sensor Development	14
E06	Rangeland Assessment	14
E11	Water Quality Monitoring	14

*See Volume 3, Book 1 for listing of objectives by theme area and ID No.

Table 3-6 (Page 2 of 2)

LIST OF OBJECTIVES* ORDERED BY TOTAL RATING SCORE

ID* No.	Title	Score
E15	Hazards Forecasting	14
E24	Living and Working in Space	14
F03	Land Use	14
F04	Marine Resources	14
F12	Global Marine Forecasting	14
F16	Communications/Navigation	14
F18	Control of Harmful Insects	14
F19	Domestic Communications	14
A06	Large Scale MW Telescope	13
D03	1-Meter UV Telescope	13
E05	Timber Inventory	13
E21	Personal Communications	13
E32	Iono/Magnetosphere Coupling	13
F09	Climate Prediction	13
F11	Water Quality Monitoring	13
F13	Local Weather and Storms	13
F14	Tropospheric Pollutants	13
A03	Weather Modification	12
A09	Energy Generation in Space (RTG)	12
D04	EOTVOS Experiment	12
E31	Strato/Mesophere Dynamics	12
F15	Hazards Forecasting	12
F21	Personal Communications	12
E08	Weather Modification	11
E17	Earthquake Prediction	11
E26	Ozone Layer Replenishment	11
E29	Ocean Interior Dynamics	11
E30	Lower Atmosphere Dynamics	11
F05	Timber Inventory	11
F06	Rangeland Assessment	11
F08	Weather Modification	11
F17	Earthquake Prediction	11
E27	Earth Magnetic Field	10
E28	Crustal Dynamics	10
F22	World Geologic Atlas	9
B05	Space Debris Sweeper	7
B04	Space Launch and Return Base	6

*See Volume 3, Book 1 for listing of objectives by theme area and ID No.

3.2 PRELIMINARY SELECTION OF OBJECTIVES

Using the available data* and background material, including the specific information described in Section 3.1, the NASA-JSC and MDAC Space Station teams jointly selected representative mission goals and objectives. The selected objectives were deemed sufficient to provide the desired range and extent of Space Station system requirements.

Ten key objectives were selected. These were broken down into five major objectives to support the development of (1) Satellite Power Systems, (2) Nuclear Energy Plants in Space, (3) Space Processing, (4) Earth Services, and (5) Space Cosmological Research and Development; and five supporting objectives: (1) a Multidiscipline Science Laboratory (general-purpose facility), (2) an Orbital Depot to maintain, fuel, and service orbital transfer vehicles, (3) Cluster Support Systems to provide power and data processing for multiple orbital elements, (4) a Sensor Development Facility, and (5) the facilities necessary to enhance man's Living and Working in Space.

The agreed upon objective statements for the selected 10 are as follows:

1. Satellite Power Systems (SPS)—"Provide a permanent space test capability for evaluation of the technical and economic feasibility of SPS."
2. Nuclear Energy—"Provide a permanent space test capability for evaluation of the technical and economic feasibility of a nuclear energy plant in space."
3. Earth Service—"Conduct research and development and construct large antennas and associated hardware required for:

   A. Domestic and international communications services

      Personal communication systems

      Electronic mail communication

   B. Earth and atmospheric survey

      Global crop production forecasting

      Water availability forecasting

      Marine resource assessment

      Climate prediction

      Control of harmful insects."

*Other valuable sources of data pertinent to objective identification and selection which were used included the JSC and MSFC 1975 Geosynchronous Space Station Study reports and the JSC Six-Week Study on a Space Solar Power Development Laboratory.

4. Space Cosmological Research and Development—"To construct a large scale MW (microwave) telescope for conduct of scientific R&D and maintain associated systems for the following science objectives:

   How do galaxies form and evolve?

   What are quasars?

   What is nature of stellar explosions?

   What are composition and dynamics of interstellar matter?

   What organic chemistry occurs in the universe?

   Why and how does interstellar dust condense into stars and planets?

   Can we detect extraterrestrial intelligent life?

5. Space Processing—"Conduct research and development to determine the technical and economic feasibility of commercial inorganic processing and biological materials applications, and support, as appropriate, the initial commercial utilization of these processes."

6. Cluster Support Systems—"Evaluate feasibility, construct, and maintain a centralized facility which provides power and data processing for orbital elements by clustering or long distance electromagnetic transmission."

7. Orbital Depot—"Fabricate a depot to maintain, fuel, and service orbital transfer vehicles necessary to deliver earth applications and scientific satellites to GEO."

8. Multidiscipline Science Laboratory—"Provide a multidiscipline laboratory to conduct space research for:

   Basic physics and chemistry

   Materials science

   Life sciences

   Earth sciences."

9. Sensor Development Facility—Provide a facility for the test and evaluation of optical sensors for:

   Earth sciences

   Cosmological phenomenon."

10. Living and Working in Space — "Demonstrate long term living and working in space as related to other manned space objectives."

Following the joint JSC and MDAC selection of the 10 objectives, the study team prepared summary documentation identifying for each objective the following information:

- Groundrules and Assumptions
- Rationale and Justification
  - Needs and benefits
  - Application to space
  - Space Station implications
- Requirements and Constraints
  - R&D requirements
  - Space Station requirements
  - Critical constraints (including significant design drivers and impacts/conflicts with other objectives)
- General Schedule Constraints
- Mission Sequence Flow
- Trade Studies data Where Applicable

These "objective data packages" are included in Volume 3 of this report. The Space Station system requirements identified in these data packages provide the material for the development of the potential program options to be discussed in Section 4.

3.3 RATIONALE FOR OBJECTIVES

This section presents the results of the analyses performed on the candidate objectives and their Space Station relationship.

The rationale for the basic objectives is discussed. The objectives are generally concerned with:

1. Furthering man's physical well-being by providing energy, goods, and services that require and/or can be produced at lower cost in the space environment (Satellite Power System, Nuclear Energy, Space Processing, Sensor Development, and Earth Services),
2. Furthering man's basic knowledge (Space Cosmological R&D and Multidiscipline Science Laboratory)
3. Providing support and data that will permit more effective accomplishment of the other space objectives (Depot, Cluster Support, and Living and Working in Space).

The functional requirements for satisfying each objective are presented along with associated objective elements (hardware items, R&D programs, etc.) The rationale for Space Station support of each objective is given which involves consideration of minimum overall cost, the duration and scope of effort required to support each objective, and the flexibility provided by the capabilities of Space Station.

3.3.1 Satellite Power System (SPS)

3.3.1.1 Rationale for SPS Objective

The ultimate goal of the SPS objective is to provide a nondepletable, cost-competitive, environmentally acceptable primary energy system capable of supplying a major fraction of the world's electrical energy needs, which are expected to grow by a factor of 2 to 3 by the year 2000. The potential benefits to the US and to the world from achieving this goal can hardly be overstated. At its ultimate potential, a cost-competive SPS could provide a permanent solution to the worldwide energy shortage and transform the US from a politically vulnerable energy importer to the world's dominant energy exporter. At a lower usage level, SPS would slow the depletion of fossil fuels (e.g., oil and coal) and complement the use of other alternate energy sources such as the breeder reactor.

As cited in Reference 3-1, one advantage that a space-based solar power system offers over a comparable terrestrial system is an average solar energy availability 6 to 15 times the average terrestrial value. This increase is attributable to almost continuous sunlight, near-normal solar angle of incidence, and absence of atmospheric attenuation or cloud interference. The SPS also offers the major advantage of being able to transmit power directly to the region of the user power grid; energy export is easily accomplished. By comparison, the cost of energy conversion and transportation for systems such as ocean thermal energy can represent the major cost to the user (Reference 3-2). Implementation of an SPS would take advantage of the very lightweight structures possible in space and the potential to use space manufactured solar cells.

Present estimates indicate that SPS could be cost-competitive with other alternate energy sources during the late 1990's and beyond. In Reference 3-3, JSC presented cost projections for various ground- and space-based solar power systems (summarized in Table 3-7). Power cost from SPS ranges from 32 to 105 mills/kWh versus 39 mills/kWh for conventional power plants and 50 to 160 mills/kWh for various forms of ground solar power.

Although the uncertainty in projecting future costs of new power systems is very large, it appears that SPS is a viable candidate to provide the needed quantities of electrical power in the time period subsequent to the year 2000. It is sufficiently promising that continuing studies and preliminary technology work should be accomplished in the near term to better define the SPS option.

3.3.1.2 Rationale for Space Station to Support SPS
Implementation of SPS will require an enormous construction effort and a hugh expenditure of funds: a basic 5-GW plant is estimated to cost $3.5 to $10B (Reference 3-4) and the cumulative cost of a network of SPS capable of meeting 10 to 20% of US electric power needs beyond the year 2015 could exceed $1 trillion (Reference 3-1). Prior to seriously considering even an initial commercial venture of this magnitude, data must be obtained to validate the technical and economic viability of SPS. The data required are of two general types: cost data, especially with regard to labor productivity in constructing and operating the SPS; technical data concerning microwave power transmission and the producibility of low-cost, high-efficiency solar cells in large quantity.

Table 3-7
1985 ELECTRIC ENERGY COST PROJECTIONS

	Ground Based*					Space-Based
	Conventional	Photovoltaic	Solar Thermal	Wind	Ocean ΔT	Solar Power Satellite
$/kW	980	1,500	2,500	1,000	5,000	1,880-5,020
Mills/kW/h	39	80-100	130-160	50-75	100-140	32-105

*Presented by Dr. Blyden, ERDA, Rice University, March 25, 1976.

Several issues must be resolved before an SPS system development decision can be made:

1. Projected power-collection systems are enormous in size, so the capability to economically fabricate, assemble, and check out large structures on orbit must be established. Consequently, it must be determined exactly how a full-scale SPS should be built and what the related man-machine productivity will be. This is fundamental to establishing future SPS production costs.
2. Various methods and design approaches for energy collection and distribution must be evaluated. These solutions will be impacted by the need for avoidance of high-voltage arcing due to plasma interactions during periods of high solar activity.
3. RFI issues must be resolved including potential interference with radio astronomy, the Shuttle/Space Station, and other communications systems.
4. Environmental concerns with respect to the ionosphere where its interaction with the radiated power beam could affect such things as radio communications, and potential long-term effects of microwave radiation in the vicinity of the rectenna.

In order to resolve the above issues, major space structures are required in orbit. The Space Station can act as the factory to produce these structures on orbit and support their testing. The SPS functional requirements (Figure 3-2) are supported by three objective elements. The first of these (component development) is a laboratory-scale investigation of components, subsystem technology, and man-machine investigations of elementary fabrication and assembly tasks. It features a pallet-mounted, 86m, tapered, linear-array antenna used for orbit-to-orbit testing to evaluate phase control, beam quality, and RFI aspects of microwave power transmission. Because of the setup and tear-down time required, these tests are efficiently performed on a Space Station. Concurrent component development tests will also produce sections of solar collector structure at this time.

Pilot Plant I is intended to act as the basis for deciding in 1987 on future SPS development. It involves: (1) fabrication and assembly of a 2.2-MWe solar array; (2) fabrication/assembly of a 1.7-MW_{RF} microwave antenna;

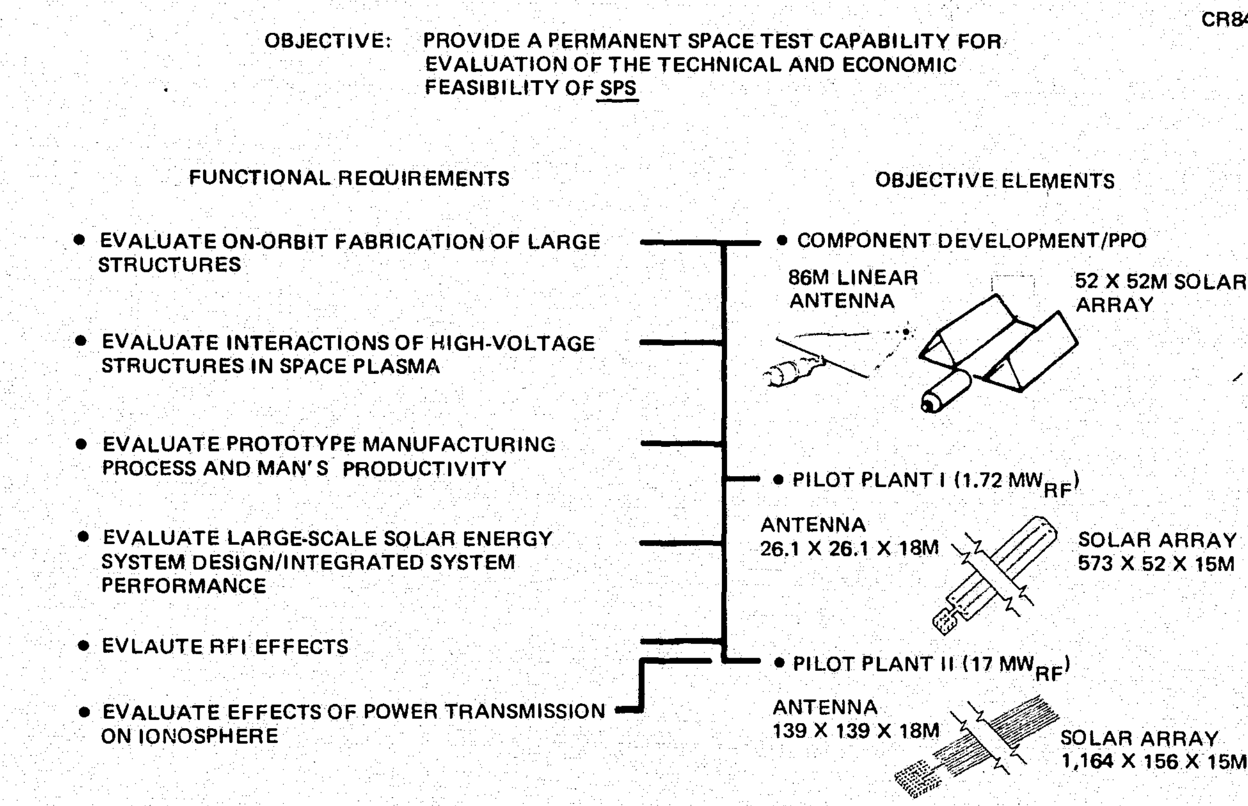


Figure 3-2. Satellite Power System Objective Elements

and (3) orbit-to-orbit and orbit-to-ground testing. Pilot Plant I is intended to provide an early demonstration of concept feasibility and engineering data for the SPS prototype design upon which future design and cost estimates can be firmly based.

Pilot Plant II would be a first step in development of an operational system and involves the fabrication/construction and test of a 17-MW_{RF} pilot plant. Pilot Plant II is a "partial prototype" of the SPS and is constructed using a construction base that demonstrates prototype production methods and processes and develops construction, operation, and repair procedures by experience under realistic conditions.

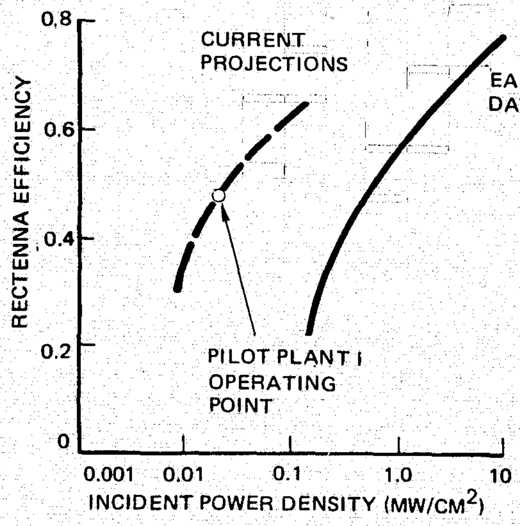
Pilot Plant I provides an integrated system feasibility demonstration with respect to fabrication, construction, operation, and system performance. A critical aspect of the microwave system is the fabrication/assembly and thermal/structural aspect of the maximum power density subarrays; demonstration of these aspects is considered a mandatory SPS development test.

The power requirement to test, at maximum density, 1 subarray of a 9 subarray antenna is shown in Figure 3-3 as a function of the dimension of one side of a square subarray. For this purpose, the full-scale subarray and supporting substructure should be employed. MDAC has selected (with assistance of Raytheon) a subarray 8.7 x 8.7m as representative. The resulting power requirement is 1.7.9 MW_{RF} and 2.238 MWe at the solar array. A test antenna should also contain a number of subarrays to establish (1) structural/thermal edge effects in such a test, and (2), productivity/learning curve data. For these reasons, an antenna design using nine 8.7 x 8.7m panels has been adopted (26.1 x 26.1m). This size is compatible with the prototype SPS.

Recent data has indicated that rectenna efficiencies, at low-incident power levels, are much higher than originally estimated. Hence, judicious use of 1.719 MW_{RF} power can provide a reasonable LEO-to-ground-power transmission demonstration (e.g., approximately 4.85 kWe for a 200 by 200m rectenna at a range of 556 km) with a 9-subarray antenna. Estimated rectenna efficiency is 48% at 0.025 MW/cm^2.

CR84

- PILOT PLANT I MUST SUPPORT SYSTEM DEVELOPMENT DECISION IN 1987
- PILOT PLANT II MUST PROVIDE FIRM COST AND MANUFACTURING DATA FOR FULL-SCALE PLANT



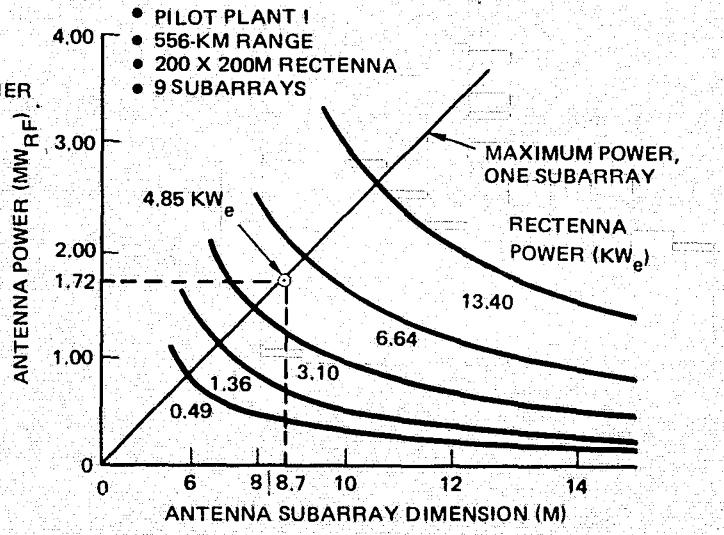


Figure 3-3. Pilot Plant Sizing Rationale

Pilot Plant II features a 64-element subarray (8 x 8 at 17.4 x 17.4m each), 17-MW_{RF} antenna and a 21-MWe power source. Pilot Plant II is considered a "partial prototype" because it employs the same design features and construction methods as the SPS prototype; it is fabricated by a construction base that is assembled with the aid of the Space Station and supported by the Space Station during the construction and operations phases. It can provide a ground-power-transmission demonstration from GEO. A rectenna efficiency of 30% can be obtained at 0.001 MW/cm^2 power density by coupling a number of elements in series per diode. This provides a further improvement in efficiency. Thus, power from synchronous orbit could be demonstrated as well as the critical closed-loop pointing/tracking of the ground rectenna by a large orbital antenna under realistic conditions.

Space Station provides the most cost-effective means for accomplishing the SPS program. A cost comparison has been made between the 17-MW Pilot Plant II, built with Space-Station-supported tooling (representive of that to be used in prototype construction), and a similar power Pilot Plant built with minimum tooling and supported by sortie missions. For this purpose, the pilot plant built during sortie missions was derived from designs described in the recent Raytheon effort, Microwave Power Transmission Systems Studies, accomplished for NASA Lewis Research Center (December 1975). Details of this cost analysis will be found in Volume 3.

The costs are summarized in Table 3-8 in two categories: (1) dedicated construction base equipment, and (2) multipurpose construction equipment.

Table 3-8

COMPARISON OF SPS PILOT PLANT II CONSTRUCTION COSTS
($ Billion)

	Space Station	Shuttle Sortie
Dedicated construction base and logistics	1.012	2.277
Space Station and other multipurpose construction equipment	2.080	0.556
Total	3.092	2.833

Dedicated construction base and logistics include all of the tooling and equipment that are useful only in the fabrication of the pilot plant. The second category includes all multipurpose equipment: Space Station and Spacelab modules, remote manipulator, crane modules, etc. Both categories include the cost of required logistics transportation, but do not include the Pilot Plant DDT&E or recurring costs (other than transportation), since these were assumed to be equal in both cases.

The total cost of the Space-Station-supported construction program appears larger than the sortie-supported program ($3.09 billion for Space Station versus $2.83 billion for sorties). However, two-thirds of the Space Station costs are in multipurpose equipment versus only 20% of the sortie costs. In the context of a total Space Station program, much of this cost would be shared by other users of Space Station, including the other nine objectives in this study. If none of the multipurpose costs are charged to SPS, the Space Station offers a $1.265 billion cost advantage. If half of the multipurpose costs are charged to SPS, Space Station still provides a $0.5 billion advantage.

The Space-Station-built pilot plant used prototype tooling typical of the tooling to be used in eventual construction of a commercial SPS. It is, therefore, concluded that the use of Space Station is not only less expensive, with reasonable allocation of multipurpose costs, but also significantly more valuable in providing simulation of construction procedures. The relative advantages and disadvantages of Space Station are further summarized in Table 3-9.

3.3.2 Nuclear Energy

3.3.2.1 Rationale for Nuclear Power Objective

The expanded use of nuclear fission power plants, especially with the advent of breeder power reactors, is one of the more promising means of compensating for the depletion of oil and gas reserves.

A potential benefit of operating a nuclear reactor in orbit involves potential safety and environmental benefits. However, there are major penalties associated with the orbital operation due to the cost to transport fuels and

Table 3-9

EVALUATION OF SPACE STATION-SUPPORTED SPS PILOT PLANT DEVELOPMENT

Space Station Advantages	Space Station Disadvantages
1. A significant cost saving ($1.265 x 10^9 on the basis of dedicated construction/logistic cost)	1. A large Space Station/ construction base investment is required.
2. A multipurpose Space Station and construction base is available before, during and after pilot plant construction for: • Other objectives/functions • Pilot plant testing including operations and maintenance demonstrations • Early and continuing space laboratory R&D for SPS • Prototype system production	2. Earlier Shuttle sortie R&D capability (perhaps for a partial pilot plant). 3. Perhaps too expensive or late for small, early pilot plants.
3. Lower development risk • Orbital fab of waveguides and structural elements is eliminated • No particle contamination or risk of machining on orbit	
4. Demonstration of a production scheme suitable for prototype/ production SPS's (which must utilize a Space Station scheme, because sorties would be too expensive).	
5. A better crew learning situation.	

construction and operating materials to orbit, the cost and power loss in transmitting power to earth, and the less efficient/higher cost of waste heat rejection via space radiators versus the lower rejection temperature and smaller heat exchangers possible with a ground-based systems.

Data from the Boeing/MSFC study comparing plant costs of space- and ground-based nuclear power plants are summarized in Table 3-10. These data indicate that a space-based nuclear power plant can be expected to cost at least eight times more per kilowatt than an equivalent ground-based nuclear power plant. Total power costs are compared in Table 3-11. These data show the space-generated nuclear power to cost roughly three times that of an equivalent ground-based nuclear power plant; additionally, the estimates on space-based power may easily be low by a factor of 2. Whether constraints on operation of ground-based nuclear plants will justify the much higher cost of a space-based plant is difficult to foresee. Moreover, the available technical and economic data are not adequate to support an accurate assessment of space nuclear systems.

3.3.2.2 Rationale for Space Station Support of Nuclear Power

Several specific technical issues must be resolved by testing in space to establish the technical feasibility of nuclear power in space. Moreover, the economic viability of space nuclear power is a primary function of construction labor productivity, which can only be evaluated by substantial pilot-plant activity. The Space Station program can evaluate these technical and economic issues on a reasonable scale before commitment to a full-scale prototype at geosynchronous orbit is considered.

Efforts during the early phase of Space Station operations (1983 - 1986) would be limited to concept and subassembly technique development. It is expected that at most, one workshop module would be required to support these efforts and that they would be done with the existing crew.

Subsequent to 1986, after a firm conceptual basis has been established, the addition of another crew module and a second workshop module containing a significant unpressurized volume and automated handling equipment, would be required. This equipment should suffice until a decision to deploy a pilot plant is made - probably in the early 1990's. At this time, the appropriate construction jigs for radiator modules and pressure vessel construction would be added. Either further crew expansion or total dedication of the station during pilot plant construction would probably be required.

Table 3-10

PLANT COST COMPARISON (1985)

Plant Type		1985 Cost — $/kW
Space-Based nuclear plant*		8,169
Power satellite	4,713	
Transportation	2,925	
Rectennas	289	
Miscellaneous	242	
Coal-Fired plant**		
High-sulfur coal		650
Low-sulfur coal		910
Ground-Based nuclear plant** (nonbreeder)		1,005

*Data from Boeing/MSFC Study escalated from 1976 to 1985 dollars at 4% per year — 62 unit program (includes 2% DDT&E)

**Data from American Nuclear Society Publication "Q&A Nuclear Power and the Environment."

Table 3-11

POWER COST COMPARISON (1976)

Plant Type	Cost 1976 $	Plant Availability	Cost Normalized to 70% Availability
Space Based — Nuclear Breeder*	23.6 mills/kWh	92%	31.02 mills/kWh
Ground Based — Nuclear Nonbreeder**	12.8 mills/kWh	70%	12.8 mills/kWh
Ground Based — Nuclear Breeder***	9.8 mills/kWh	70%	9.8 mills/kWh

*Costs from Boeing/MSFC Study. Availability calculated from data in briefing charts.

**From American Nuclear Society Publication "Q&A Nuclear Power and the Environment." Average 1975 nuclear power costs escalated to 1976 at 4 percent.

***Assumes fuel costs of 10% of total rather than 30% national average for nonbreeders.

Adequate ground demonstration of the breeder concept selected for space, and resolution of the weight and cost issues raised by space seem certain to delay construction of a pilot plant until the 1990's. However, the bulk of the work devoted to SPS will apply either directly or supportively (e.g., large-scale construction techniques) to nuclear energy as well. Those specific component/technology tests suitable for an earlier time frame can be accommodated by minimal modular addition to an SPS-oriented Space Station option. Since a Space Station program that does not explicitly include nuclear energy still has sufficient flexibility to allow redirection to nuclear energy when and if a decision to include it is made, nuclear energy is not recommended as an early candidate objective.

3.3.3 Earth Services

3.3.3.1 Rationale for Earth Services Objective

The Earth Services objective is concerned with earth observation, communication, and navigation applications for earth-orbiting satellites. The benefits from these applications have been recognized and enjoyed for many years. Even greater economic and social benefits can be expected from improved communication and observation systems. If is difficult to assign a dollar value to improved earth observations, but Reference 3-5 suggests possible savings resulting from the ability to perform more precise management of resources to be on the order of $3 billion per year while Reference 3-6 estimates of the value of future satellite communication systems to be on the order of $1.8 billion per year.

Improved communication and observation systems will generally involve more complex satellites with much larger antennas. Today's satellite communication systems essentially trade complexity on the ground for simplicity in orbit. Future communication systems may reverse this practice in order to permit the use of small, portable, low-cost ground equipment. For example, communication concepts such as electronic mail (Reference 3-6) would require large, multiple-beam satellite antennas capable of accommodating on the order of 1,000 beams. Similarly, the desire for improved resolution and more efficient data processing in earth observations will lead to larger, more complex earth-survey satellites. For example, the requirement for resolutions of 10 to 30m for agriculture and land use surveys (References 3-7 through 3-9) and 1 to 30m for water resource surveys (Reference 3-10) will require microwave antennas in the range of 30 to 100m in diameter. Other applications, such as personal navigation (Reference 3-6) would require very high aspect ratio antennas several km long.

3.3.3.2 Rationale for Space Station Support of Earth Services

The antennas required for many of the future Earth Services applications are too large to be erected by current unfurling techniques, but rather must be assembled in space by construction crews. Furthermore, the tolerance constraints will require in-space alignment and calibration. The development antenna) the estimated size to which this antenna could be increased was in the range of 25 to 28m in diameter limited by structural considerations of unfurling. The distortion limit was estimated to be between 30 to 38m. and implementation of these in-space construction techniques can best be supported by Space Station. Also, because of the complexity and expense of future Earth Services satellites, it will become cost-effective to prolong their life by periodic maintenance and servicing – a function that will be supported by Space Station. In addition, Space Station is required to support radiometer and data processing development tests that exceed Shuttle mission durations.

To help define the Space Station requirement, three typical Earth Services systems were identified: an electronic mail system requiring a large, multiple-beam antenna; a personal navigation system requiring a large, high-aspect ratio, cross-phased array antenna; and an earth observation microwave radiometer requiring a large parabolic antenna. The functional requirements and configurations of antennas required for each application are illustrated in Figure 3-4.

The initial development of antennas and verification of construction and assembly techniques on the Space Station centers about a low-resolution radiometer 30 meters in diameter, a size considered the minimum which requires on-orbit construction. Development continues on increasing sizes of antennas up to a 300m antenna which provides a high-resolution capability for radiometry.

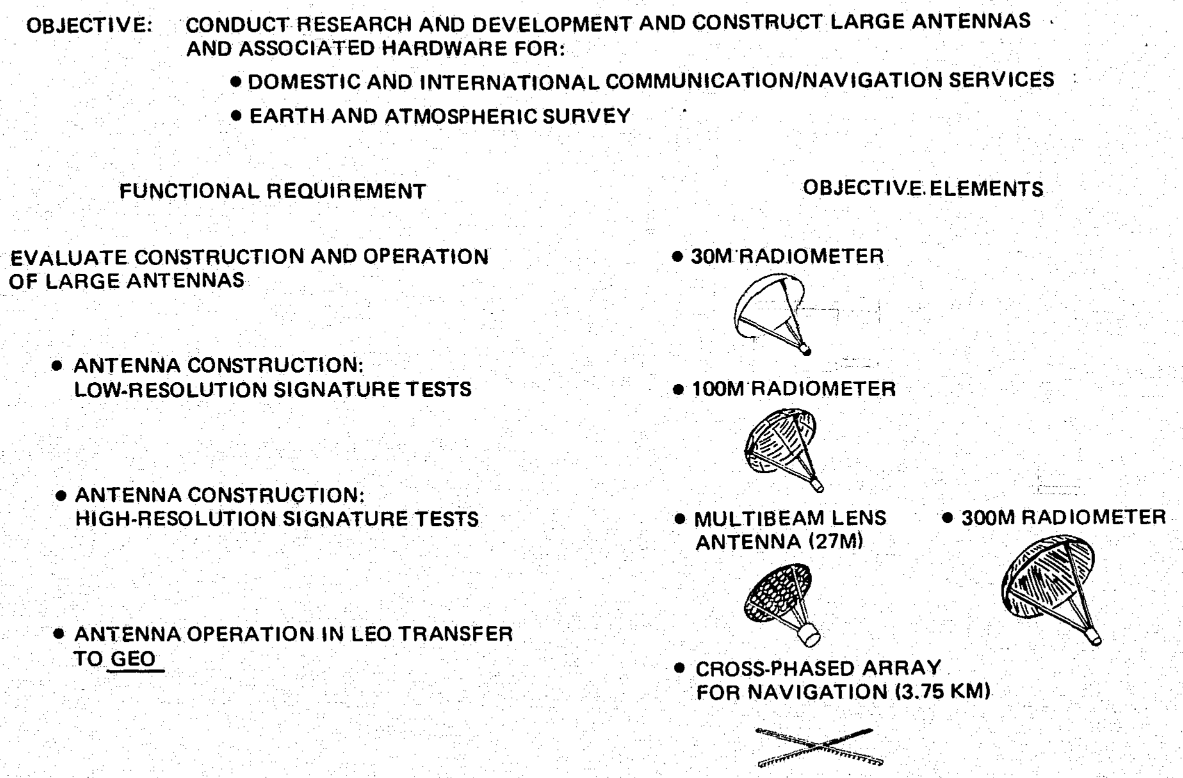


Figure 3-4. Earth Services

The parabolic antennas for radiometry would focus very small signal emissions in the lower frequency spectrum. The parabolic antennas will consist of a built-up truss structure, to give the necessary stiffness, and an appropriate reflector such as a wire mesh. Graphite epoxy is used as the structural material to meet the extremely small structural distortion limits which must be maintained at the frequencies of interest.

Other types of antennas need to be evaluated. Accordingly, an active antenna, the multibeam lens antenna, and an extremely large, 3. 25-km communication antenna, are included.

Antenna configuration analysis and definition studies were performed to establish a firm basis for Space Station requirements. The multiple-beam lens antenna system provides high gain for point-to-point communications. The beams are focused through 1,000 4. 6 cm-diameter cylinders assembled in a 27m-diameter structure. The antenna was sized to service 100,000 post offices, sending 10 pages of data per second, and had the capability of 1,000 simultaneous beams.

The cross-phased array navigation antenna is conceived to provide navigational fixes with a relative accuracy of ±90m. The antenna would produce two extremely narrow beams swept orthogonally, which could indicate location, heading, and speed on small portable ground devices. The cross-phased array consists of an extremely long series of modules. Radio-frequency energy is distributed to each module by use of a low-loss beam waveguide having a succession of shaped reflectors. Energy is extracted through a slot in the reflectors. The phase of the radiation elements would be controlled by hardwire from a central control unit.

An analysis was made to determine the limiting size (diameter) of antennas that are unfurled. The primary problem in deploying large antenna is maintaining structural tolerances or distortion; accordingly, this parameter was investigated. Using available data on two deployable antenna concepts, distortion vs diameter was plotted with the two sets of data being such that a smooth transition from one set of data to the other is possible. Assuming these curves to be representative of what accuracy can be realized in deployable antennas, achievable gain was calculated and an S-band example plotted. As can be seen in Figure 3-5, the effect of distortion is to lower gain significantly at large apertures, indicating (in the example) that, for antennas

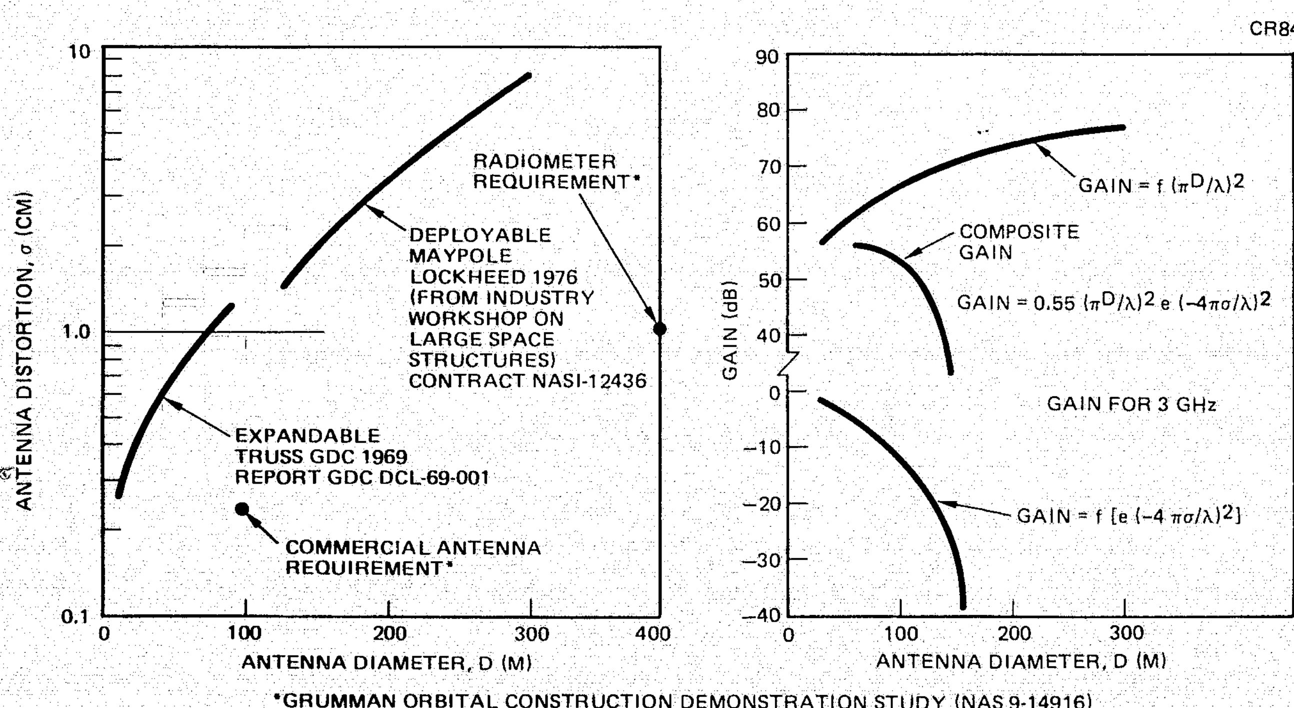


Figure 3-5. Earth Services Impact of Distortion on Gain of Unfurled Antennas

greater than about 60m in diameter, new approaches such as on-orbit construction coupled with use of materials with very low coefficients of expansion are required. To provide a "distortion margin" of 2, antennas 30m in diameter and larger probably should be assembled on orbit rather than unfurled.

As a check of this value, the Lockheed Missiles and Space Company was contacted to determine what the performance might be for an antenna design that has been flown. For the configuration used on ATS-6 (a 9m flexible rib antenna), the estimated size to which this antenna could be increased was in the range of 25 to 28m in diameter limited by structural considerations of unfurling. The distortion limit was estimated to be between 30 and 38m.

3.3.4 Space Cosmological Research and Development

3.3.4.1 Rationale for Space Cosmological R&D Objective

This objective addresses basic questions about the nature of the universe identified in Outlook For Space.

Answers to basic questions regarding the galactic processes, the nature of quasars, the nature of stellar explosions, the composition and dynamics of interstellar matter, the search for other planets and solar systems, and the search for extraterrestrial life requires access to the full electromagnetic spectrum. While certain regions of the spectrum are accessible to earth-based systems, space platforms offer observational advantages in the x-ray, UV, parts of the IR (see sensor development discussion), and in the low-RF portions of the spectrum. In the RF regions in particular, the need for very large antenna structures requires space assembly and construction.

By using an antenna system in space, for example, water absorption bands can be eliminated and the detailed study of planetary surfaces — especially surface compositional studies in the visible and near-IR regions of the spectrums — can be carried out to a greater degree of resolution. Geo-chemical mapping of the planets and their satellites might also be carried out.

Pursuit of each of the aforementioned questions would be furthered by large-scale microwave telescopes. Therefore, this objective is specifically directed toward the construction of large-scale microwave telescopes with special emphasis on the search for extraterrestrial intelligence (SETI). The SETI application was selected to size the requirements because of the very low signal levels ($10^{-28} - 10^{-30}$ W/m^2) and hence very large required collector aperture as established in the Cyclops study (Reference 3-11).

Conceptual design for three radiotelescope systems representing a logical approach to SETI are contained in Reference 3-12. The utlimate system, identified as Mark IV, is considered representative of the intent of the Outlook For Space System 1098. The two predecessor systems, identified as Mark II and Mark III, are R&D building blocks to advance to the state-of-the-art required by the Mark IV system. The Mark II system requires a 30m diameter collector. The Mark III system requires a 300m collector and a 500m RFI shield. The Mark IV system requires a 3,000m collector and a 5,000 RFI shield.

3.3.4.2 Rationale for Space Station Support of Space Cosmological R&D

The Space System objective identified for consideration in this study was to produce a highly useful radiotelescope while developing the technology for space-based astronomy at the longer (RF) wave lengths. This objective has three elements, as shown in Figure 3-6.

The first phase is the Component Development and Test, which involves system analysis and prototype construction of advanced electronic instruments, such as receivers and data processors for use on the ground.

In the intermediate phase, activities are planned which will use space systems as well as earth-based radiotelescopes. The Mark II system identified in the Ames SETI activity was selected as the model for the Space Station system requirements analysis for the intermediate phase activities. During this phase, the R&D emphasis will be directed toward solution of the electronic problems (i.e., low-noise amplifiers, scanning feeds, pattern recognition data processors) which will be directly applicable to very-large-scale and ultraprecision electromagnetic collectors (300 to 3,000m in diameter with surface accuracies of 1 mm overall). Work will concentrate on thermal

OBJECTIVE: TO CONSTRUCT A LARGE-SCALE MICROWAVE TELESCOPE FOR CONDUCTING SCIENTIFIC R&D AND MAINTAINING ASSOCIATED SYSTEMS FOR SEVEN "OUTLOOK FOR SPACE" SCIENCE PROGRAM OBJECTIVES

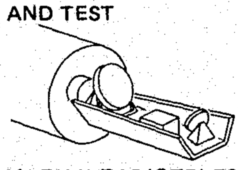
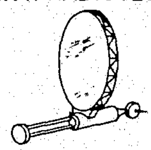
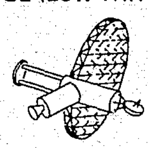
FUNCTIONAL REQUIREMENTS	OBJECTIVE ELEMENTS
• EVALUATE ABERRATION CORRECTING SCANNING FEED SYSTEMS	• COMPONENT DEVELOPMENT AND TEST  PALLETIZED TESTS
• DEMONSTRATE ON-ORBIT CONSTRUCTION AND OPERATION	• MARK II RADIOTELESCOPE 
• DEMONSTRATE TRANSFER TO GEO	• LARGE (LOW-THRUST) OTV  TRANSFER TO GEO

Figure 3-6. Space Cosmological R&D

stabilization, lightweight materials, construction techniques, assembly methods, pointing and control methods, active figure correction schemes, etc. A primary problem to be solved is control of surface accuracy. On-orbit construction should help eliminate distortion problems associated with unfurling antennas. However, complementary techniques such as electronic scanning will be required to determine effective surface accuracy.

The third step is testing the telescope at GEO. An unmanned OTV is required to transport the telescope to GEO for these operations. The ultimate goal of this objective is to develop the technology for even larger radiotelescopes in space and, thus, of equal importance is the requirement to demonstrate that such hardware can be successfully constructed and operated in orbit.

Figure 3-7 shows several projected systems on a wavelength/aperture slot, indicating probable space-based requirements. The radioastronomy window wavelengths (from 10 cm to 10m) are generally lacking as requirements on the chart since these observations are currently being made from ground

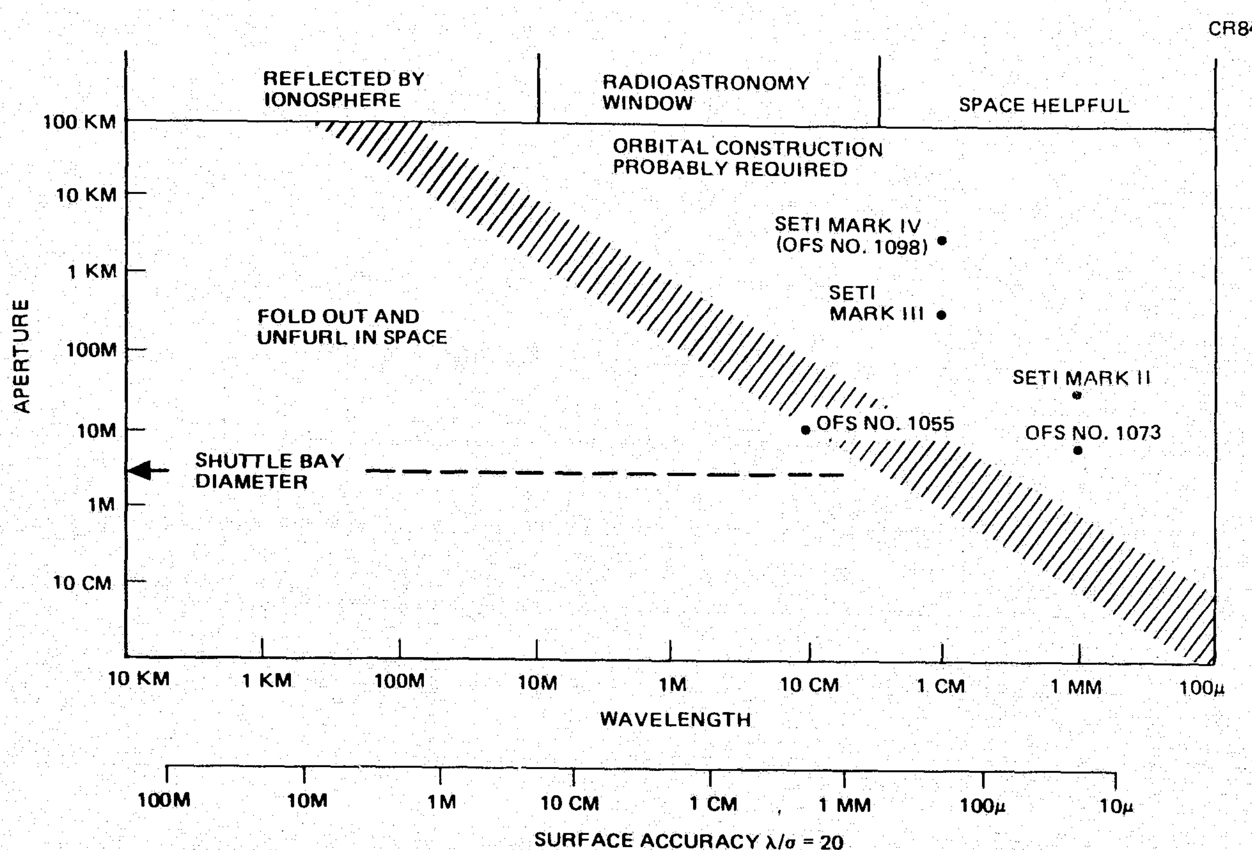


Figure 3-7. Radio-Frequency Antennas in Space

observatories. The Outlook for Space System 1055 is the one exception in this window. However, this system is the space component of a ground-based very-long-wavelength interferometer. In this case, a 10m microwave telescope is carried in a highly eccentric orbit to extend the baseline to several earth radii; the purpose is to obtain milli-arcsec resolution of radio sources.

The SETI Mark II radiotelescope is a slightly smaller version of OFS System 1073. It operates in the 300g Hz region of the spectrum and require s a primary collector surface accuracy of 50 microns. To achieve this degree of precision, advanced techniques for on-orbit construction must be employed, including in-space adjustment of the primary and secondary optical figure.

It is apparent that assembly of structures the size of the Mark II and Mark IV telescopes will require long-duration Space Station support. Moreover, Space Station will be required to develop space construction techniques and support various other areas of technology development. For example, the current concepts for the Mark III and Mark IV telescopes involve satellites with precise stationkeeping capability to scan the image plane so as to direct the beam without orienting the main dish. The feed system on the subsatellite is designed to correct for spherical abervation. These techniques reduce the complexity of the main dish, but should be proven in space prior to embarking on the full-scale telescope.

3.3.5 Space Processing

3.3.5.1 Rationale for Space Processing Objective

Space processing may ultimately provide commercially significant sources of unique and valuable products not producible at competitive costs on earth. The long-term reduced gravity experienced on a space platform minimizes or eliminates gravity-induced phenomena (e.g., convection) that hamper or preclude certain processes from taking place on earth. Likewise, containerless processes, such as levitated melting and heat treating, can eliminate contamination introduced by the crucible. A rather extensive data base from Apollo, Skylab, ASTP, sounding rockets, and ground-based research substantiate that processing in space presents both a significant promise and challenge. As specific examples, crystal growth and electrophoretic separation experiments in Apollo and Skylab have demonstrated considerably improved qualities in space-grown semiconductor crystals, and have shown substantial benefits in purifying and separating biological materials.

The major thrust of the Space Processing objective is to advance promising space processing concepts to the commercial production stage. Outlook for Space (NASA SP-386), Reference 3-13, describes the technical and scientific basis for the high expectation of success for future space processing applications. Further detailed in this report are the two principal directions (Program Objectives 063, Commercial Inorganic Processing, and 064, Biological Materials Research and Applications). Further substantiation and technical details are to be found in the committee working papers of the related main study report. Reference 3-14 cites a projected increase in value added for products using semiconductor silicon produced in space in ribbon form. Other pertinent data related to justification of space processing are included in References 3-15 through 3-22.

3.3.5.2 Rationale for Space Station Support of Space Processing

The space processing objective elements are shown in Figure 3-8. The initial element (a Process Development and Testing phase) is an early activity (1984) to demonstrate the economic feasibility of the basic processes involved in biologicals, inorganics, and silicon ribbon manufacture. A portion of a lab module is used to accomplish this activity with the specialized equipment as noted.

The next phase of activity (the Process Optimization for Production), circa 1987, is aimed at refining the biological and inorganic processes for volume (continuous) production. Separate dedicated modules are provided for biologicals and inorganics for this level of activity.

In later phases, the Silicon Ribbon/Blanket Pilot Plant can be used to support the SPS Pilot Plant II whenever the latter is included in an option. Shuttle-delivered, ground-fabricated modules are used to build the pilot plant.

The Commercial Process Pilot Plant is a continuous, high-production rate facility that produces material for commercial markets. A separate dedicated facility may be required for each product line.

Note that commercial inorganic processing refers to single crystals, metal oxides, and matrix and composite materials where essentially the basic elements and inorganic compounds are the raw materials. Biological materials refer to working with living matter. Organic materials, i.e., carbon compounds, have not been prominent in space processing proposals to date although this extremely important class of substances could be the subject of future space activities.

Requirements for space processing differ due to the type of production facility to be used. As shown in Figure 3-9, Biologicals requirements are characterized by maintenance of an ambient environment necessary to support various forms of living materials and live processing. This environment is in contrast to the elevated temperatures and pressure necessary to effect phase changes in materials such as glasses, metals, and ceramics. Temperatures in these processes typically range from $1,000^{\circ}$ to as high as

CR84

OBJECTIVE: CONDUCT R&D TO DETERMINE THE TECHNICAL AND ECONOMIC FEASIBILITY OF:

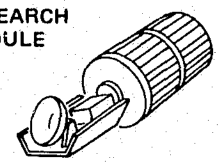
- COMMERCIAL INORGANIC PROCESSING
- BIOLOGICAL MATERIALS PROCESSING AND APPLICATIONS. SUPPORT INITIAL COMMERCIAL USE

FUNCTIONAL REQUIREMETNS

- EVALUATE CELL SEPARATION, CULTURES, AND GENERATION LIMITS
- EXTEND PROCESS FURNACE TECH
- EVALUATE SILICON RIBBON FABRICATION
- TEST CONTINUOUS CELL ENRICHMENT AND SEPARATION
- EVALUATE BIOLOGICALS OPERATIONS
- DEMONSTRATE FURNACE OPERATIONS
- DEMONSTRATE SILICON RIBBON PRODUCTION
- SUPPORT SPS PILOT PLANT FABRICATION
- DEMONSTRATE COMMERCIALLY SIGNIFICANT BIOLOGICALS AND INORGANIC PRODUCTION

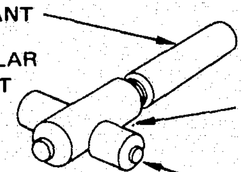
OBJECTIVE ELEMENTS

- PROCESS DEVELOPMENT AND TEST



- ELECTROPHORETIC SEPARATORS
- SILICON FUSING
- LEVITATION FURNACE
- PALLET-MOUNTED SOLAR FURNACE

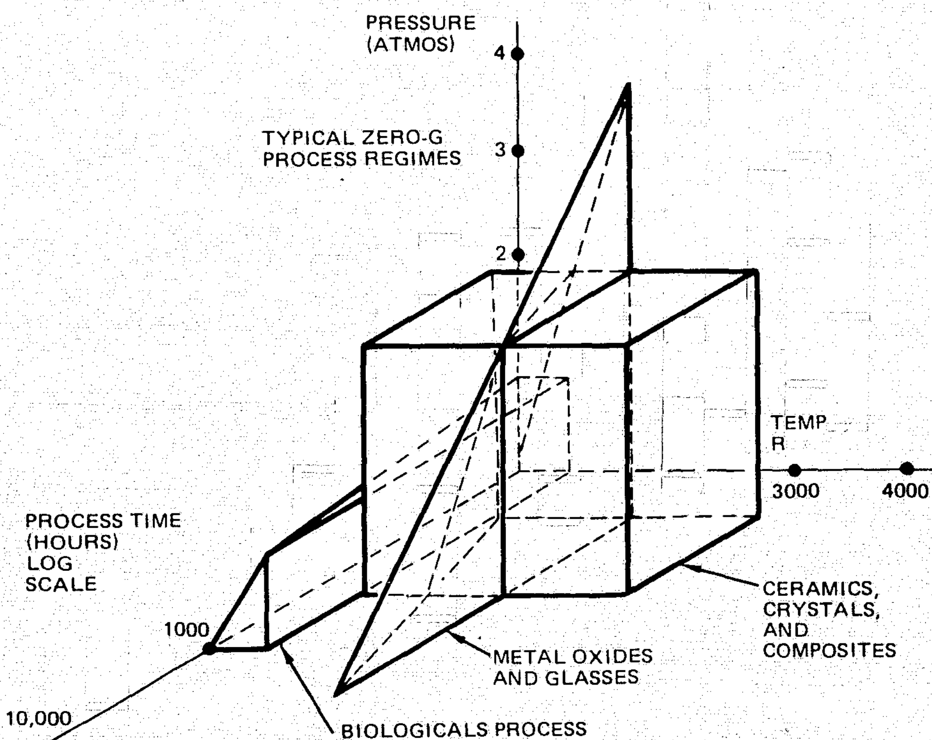
- PROCESS OPTIMIZATION FOR QUANTITY PRODUCTION
- SI RIBBON PLANT
- SI RIBBON/SOLAR CELL BLANKET PILOT PLANT



- COMMERCIAL PROCESS PILOT PLANT

Figure 3-8. Space Processing

CR 84



EQUIPMENT REQUIREMENTS

FURNACE
5-KG CHARGE, 30 KW

LEVITATION FACILITY
25-CM DIAMETER CHARGE

BIOLOGICAL PROCESS

FACILITY
1.0 LITER/DAY THROUGHPUT

CHEMISTRY/FLUIDS

PROCESS

PROCESS CONTROLS
BIOLOGICAL AND
HAZARDOUS MATERIALS
ISOLATION

Figure 3-9. Space Processing Pressure, Temperature, and Process Time Envelopes for Different Classes of Materials

$3,000^{o}C$. The process times involved require long-term missions and the capabilities to support a broad range of activities.

Types of equipment needed for space processing work on the Space Station include a furnace facility, containerless process facility, biological process facility, chemical/fluid process facility and control, and data acquisition services. These facilities should be designed for modular replacement of apparatus within a facility as the research or production emphasis changes and should be capable of supporting experimental or production work for a broad array of activities in crystal growth, purification, separation, mixing, solidification, and chemical/physical and fluids processing.

Space Station is projected to play a major role both in the R&D phase of Space Processing and in the transition from R&D to Pilot Plant operations. The justification for Space Station versus other space systems (e.g., Spacelab, free-flyers) is based upon technical and economic factors which differentiate between scientific pursuits and commercially oriented operations. Spacelab and other single-mission flights will continue to provide useful preliminary data on new space processing concepts, but lack the complexity of equipment and continuity of effort necessary to advance these concepts to the commercial stage.

For example, production of the enzyme urokinase is one of the promising early applications of space processing. Space production of urokinase involves a multistep process in which urokinase-producing kidney cells are separated by electrophoresis. After separation, the cells must be cultured for a period of about 30 days. On Spacelab, the cells would be returned to earth for culturing; with Space Station, culturing would be part of the integrated space processing cycle. While Spacelab would provide useful data on the critical electrophoretic separation step, it would provide only fragmentary data on the overall process efficiency required to assess commercial feasibility.

A key role of Space Station will be to bridge the gap between the point at which the technological feasibility of a given space process has been demonstrated and the point at which it can be considered as a commercial venture. As the development of each candidate space process matures from laboratory-scale basic investigations to pilot-plant-scale demonstration, the duration, crew size, power, and support equipment requirements will expand beyond the capability of Spacelab- and sortie-supported missions. This transition will be relatively less critical to some processes, e.g., biological processing, where scale-up can be achieved by parallel use of multiple small units, and more critical for some material processes, where process scale size may strongly influence the technical and economic characteristics of the product. The flexibility of Space Station to provide relatively high power, long-duration, manned support is essential to supplying the diverse support requirements of the variety of candidate space process developments.

3.3.6 Cluster Support System

3.3.6.1 Rationale for Cluster Support System Objective

Major economies are potentially achievable by a centralized facility which would provide power and other utility services to user satellites. In the basic mode clusters of satellites would be hardwire connected to the Cluster Support System. Other options considered would transfer power by microwave or laser transmission to user satellites or to an OTV.

To evaluate the economic viability of the basic cluster mode, a satellite traffic model for the year 1980 to 2000 period was developed based on the Outlook for Space study. The number and mass of satellites launched each year is summarized in Figure 3-10. The number and mass of satellites on orbit is plotted in Figure 3-11 for various assumed average satellite lifetimes. It can be seen that for typical lifetimes on the order of 7 years, in excess of 100 satellites can be expected in orbit after 1990, with approximately 50 of these in geosynchronous orbit.

Analysis of the subsystem weight and cost distribution of the different satellites indicates that the power systems account for between 18 and 43% of the satellites' weight and 10% of the cost. Total mass of all satellite power systems totals about 130,000 kg for the 20-year time period. The equivalent launch cost is $578 million. Recurring cost for the satellite

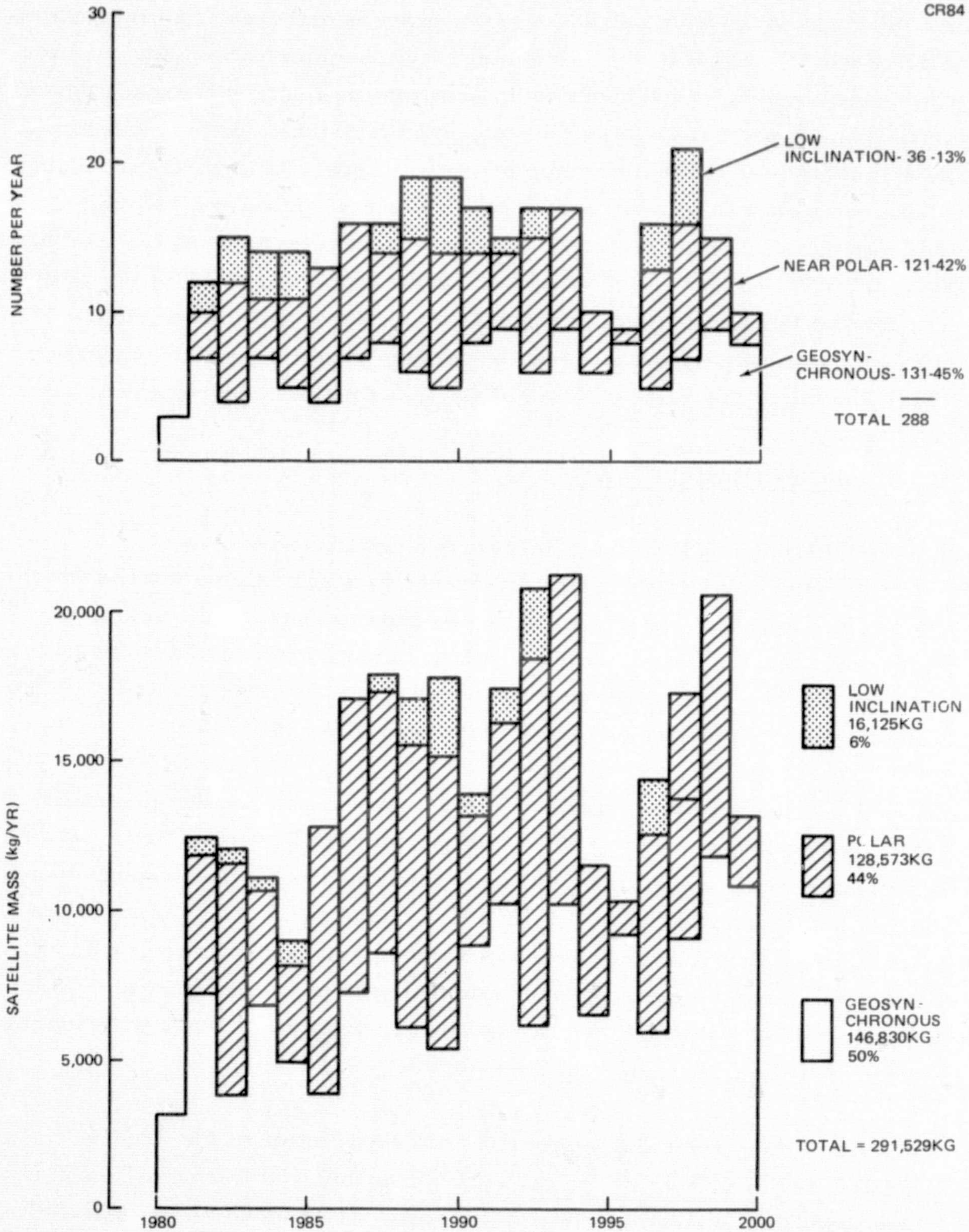
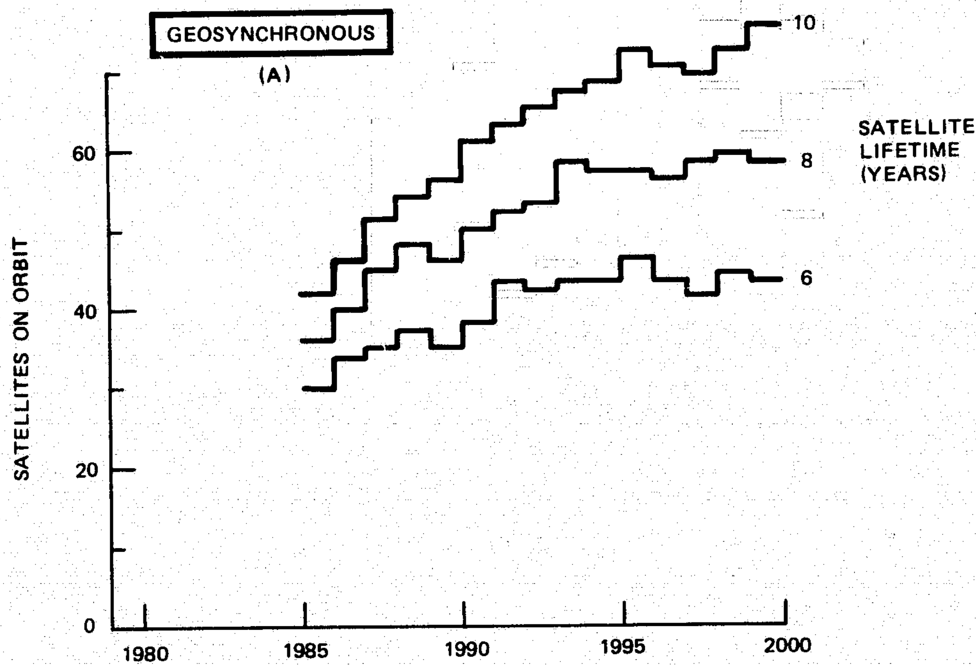


Figure 3-10. OFS Projected Satellite Deliveries



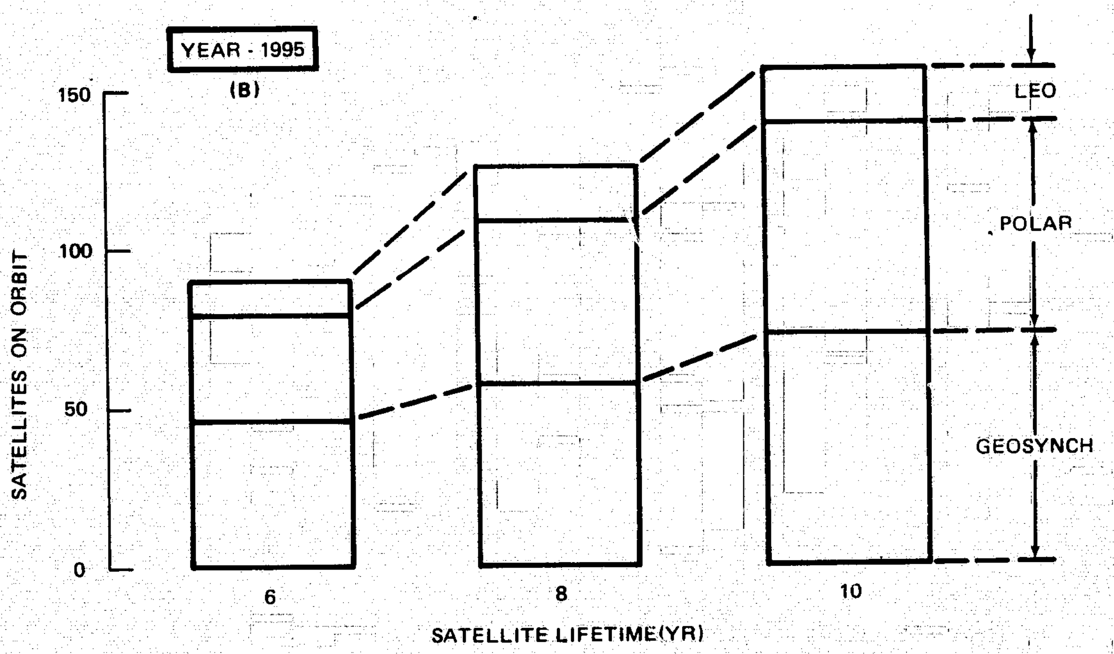


Figure 3-11. Number of Satellites on Orbit

ORIGINAL PAGE IS
OF POOR QUALITY

power system using a power system cost fraction of 10% is estimated to be approximately $600 million through the year 2000. Nonrecurring costs are estimated to be 3 to 5 times recurring costs. The total value of satellite power systems for the period from 1980 to 2000 is therefore on the order of $2.5 billion. For comparison, a 30 kW cluster sized for a representative 10-satellite cluster is estimated to cost $300 million for development plus $200 million per unit for recurring costs.

The feasibility of transmitting power to user satellites by microwave and by lasers was therefore evaluated. It is concluded that microwave transmission is economical only for ranges less than 1 km since for longer ranges the cost of the antennas would exceed the cost of the replaced individual power systems. Similarly, power transmission by laser beam to user satellites was found not to be cost competitive with individual power systems. However, the concept of propelling an OTV by laser transmission was found to be sufficiently promising to justify further study. In one concept, the laser beam would heat a propellant (e.g., cesium) to high temperatures to obtain high specific impulse.

It is concluded that the potential cost savings are sufficient to consider development of the cluster concept only in the attached mode. Longer-term development of laser power transmission for propulsion purposes also deserves further consideration.

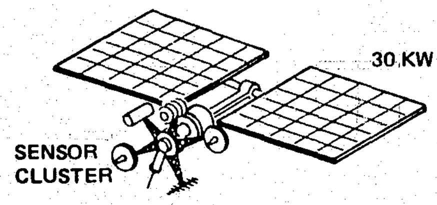
3.3.6.2 Rationale for Space Station Support of Cluster Support System

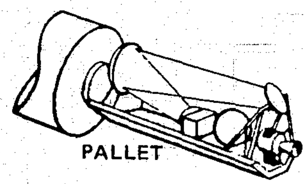
The Space Station would serve several important roles in implementing the cluster concept including: providing the power module for initial cluster demonstrations; supporting development of cluster components, construction, and operating techniques; and supporting R&D tests of laser propulsion technology.

The Cluster Support System objective elements are illustrated in Figure 3-12. The initial program will use the Multipurpose Space Power Platform (MSPP) and/or the Space Station power module to evaluate problems of operating in the cluster attached mode.

OBJECTIVE: EVALUATE FEASIBILITY, CONSTRUCT AND MAINTAIN A CENTRALIZED FACILITY WHICH PROVIDES POWER AND DATA PROCESSING FOR ORBITAL ELEMENTS BY CLUSTERING OR LONG-DISTANCE ELECTROMAGNETIC TRANSMISSION

FUNCTIONAL REQUIREMENTS	OBJECTIVE ELEMENTS
• EVALUATE CLUSTERING CONCEPT	• MULTIPURPOSE SPACE POWER PLATFORM
• DEVELOP POWER TRANSFER CONCEPT	• LARGE CLUSTER COMPONENT DEVELOPMENT
• DEMONSTRATE POWER TRANSFER BY LASER	• LARGE CLUSTER PILOT PLANT





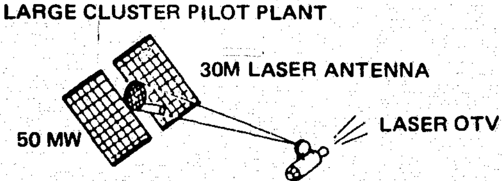


Figure 3-12. Cluster Support System

Another facet of the cluster concept is to supply power to an on-orbit OTV via laser transmission of energy. This system requires operation in a low-g environment and thus palletized tests are necessary. The ultimate demonstration of the laser-powered OTV requires a large power source and a vehicle with a laser-operated propulsion system. Energy is transmitted from the power plant by a 30m-diameter laser antenna system to an OTV. The OTV would have a collector lens which focuses the laser beam through a laser-transparent window so that the propellant (e.g., cesium) is heated to high temperatures, resulting in a high specific impulse.

3.3.7 Depot

3.3.7.1 Rationale for Depot Objective

Projections in the Outlook for Space study indicate a substantial traffic to geosynchronous orbit in the late 1980's, with at least 8 satellites delivered per year for communications, earth services, and scientific purposes. Increased traffic can be expected as costs are reduced. The launch costs to

GEO are a significant part of the total costs. The overall launch cost can be lowered by developing an orbital Depot to service and permit reuse of the OTV. The cost of transporting an OTV from the ground to orbit and back is eliminated. Also, payload deliveries are not tied directly to Shuttle launch schedules, which should be of benefit in smoothing Shuttle launch operations.

Another anticipated cost savings is in the design of the OTV. By having the OTV reside only in orbit, it will not have to withstand the loads it would encounter if it were delivered in a fueled condition via the Shuttle. Assuming a low-thrust engine were used, which would limit axial acceleration loads to about 0.1g and could operate at essentially zero NPSH, the design of the OTV could be extremely light. As a result, propellant requirements would drop, along with the attendant costs of transport of propellants.

The yearly costs of operating the Depot for an assumed traffic of ten 1,800 kg satellites per year was calculated and compared against the cost of supporting the same traffic with: (1) the Shuttle-delivered cryogenic tug from Reference 3-23 operated in both the reusable and expended mode, and (2) the interim upper stage (IUS). The IUS average recurring costs were assumed to be a minimum $1.5 million each, based on current design goals and the Boeing IUS study results. It was also assumed that two IUS/payload combinations could be delivered in one Shuttle launch. The cryogenic tug point design from Reference 3-23 was used for comparison purposes.

As can be seen in Figure 3-13, the Depot has the potential for providing the lowest operating cost. However, the Depot requires an initial investment estimated to be somewhere between $800M and $1B for such things as storage tanks and propellant distribution structure, crew modules, and a depot hanger (based on the MDAC Space Station and MFSC studies and data presented in Reference 3-24). Assuming the depot would replace the IUS, the time to recoup the investment is dependent on the mission rate as shown in Figure 3-14. The time to "break even" and the potential savings in satellite delivery costs are marginal in justifying a depot. Higher traffic rates, commensurate with the implementation of a major objective such as SPS, however, clearly justify the development of the Depot concept. Also, it can be anticipated that the Depot concept will evolve into a facility supporting the

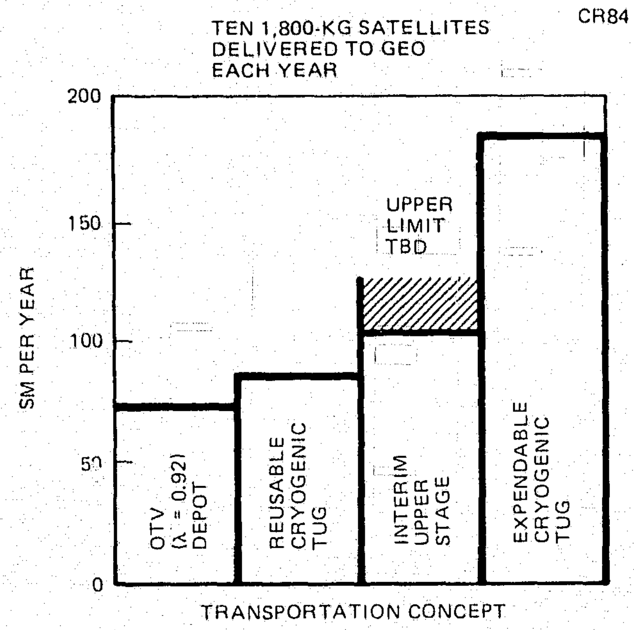


Figure 3-13. Operational Costs

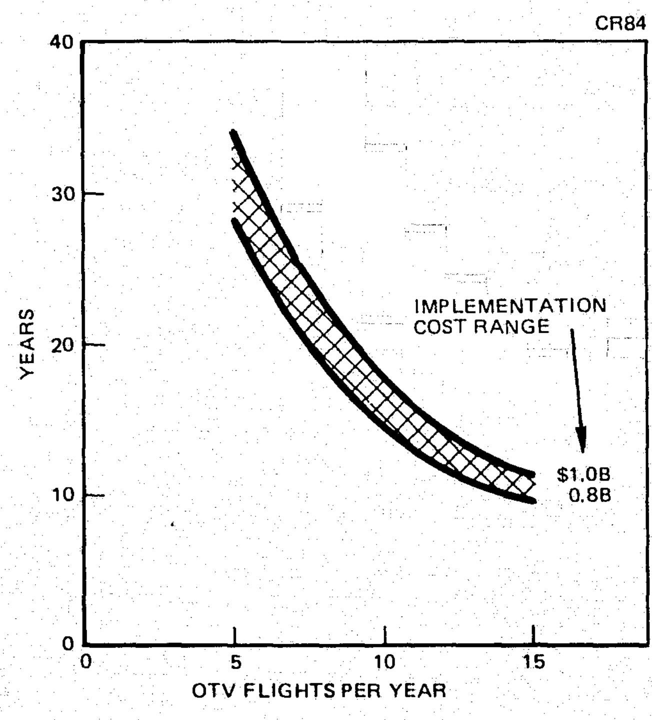


Figure 3-14. Investment Return Time

assembly, launch, and recovery of interplanetary vehicles. Scientific payloads such as the Mars sample-return mission are quite complex and the Depot concept offers considerable potential to support this type of mission.

3.3.7.2 Rationale for Space Station Support of Depot

The Depot functional requirements and elements are shown in Figure 3-15. The economic benefits from the Depot concept lie in the performance advantage and design concepts made practical from having an on-orbit launch site and in operating autonomously over long periods of time. Providing this capability requires significant manned operations and long-term operations on orbit. The Space Station is required to support the long-term manned operation. Alternative OTV/Depot concepts such as unmanned Shuttle-visited platforms or expendable OTV's lack the broad range of capabilities required for the later 1980's as traffic increases in volume and types of payloads. Analysis of the operations associated with the Depot mode (e.g., propellant transfer, satellite receiving and checkout, OTV maintenance and repair) reveal that the majority of them do not lend themselves to automation; automation would significantly increase the cost of the depot and materially reduce the reliability of operations.

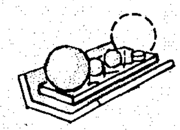
OBJECTIVE: FABRICATE A DEPOT TO MAINTAIN, FUEL, AND SERVICE ORBITAL TRANSFER VEHICLES NECESSARY TO DELIVER EARTH APPLICATIONS AND SCIENTIFIC SATELLITES TO GEO

FUNCTIONAL REQUIREMENTS

- LONG-DURATION PROPELLANT TRANSFER AND STORAGE R&D
- OPERATIONAL DEMONSTRATION OF THE DEPOT FUNCTION
- DEMONSTRATE OPERATION WITH LARGE OTV
- DEMONSTRATE POTENTIAL FOR SUPPORTING PLANETARY MISSIONS

OBJECTIVE ELEMENTS

- COMPONENT DEVELOPMENT AND TEST



- OTV DEPOT

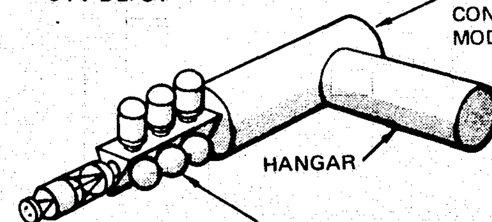


Figure 3-15. Depot

Another requirement for a manned Depot stems from payloads such as the large antennas needed for the Earth Services objective. Because of their size, they cannot be delivered to low earth orbit already mated to an OTV. Rather, they must be constructed or assembled on orbit and subsequently mated to an OTV for transfer.

It is concluded that the most effective way to operate a Depot is to have it manned for long-term operation and to provide controlled storage for extended periods of time consistent with anticipated traffic and ground launch vehicle capabilities. A Space Station in low earth orbit can accomplish this function. The Space Station also provides the capability for conducting tests to develop techniques for propellant transfer and storage and OTV maintenance and repair.

3.3.8 Multidisciplinary Science Laboratory (MDSL)

3.3.8.1 Rationale for MDSL Objective

The motivation behind an MDSL in space is three-fold:

1. Many diverse areas of science and technology use the services of a manned orbiting laboratory (Outlook for Space identified 45).
2. Much of the expensive space system hardware required by such missions is common to all manned research areas.
3. Within fiscal reality, it is unlikely that separate facilities can be justified for most areas in the near future.

The basic concept of the MDSL is that it should provide general laboratory services; experiment-peculiar equipment is included as necessary and is charged to the program in question. Functional requirements and objective elements are shown in Figure 3-16. Equipment items in the MDSL inventory might include:

Hard-Data Processing Facility. Film processors and storage, video data display and control console, microfilmer, light table, spectrophotometer, densitometer, and operations console.

Electronic/Electrical Laboratory. Instrumented test bench, battery charger, high-voltage source, high-energy counter calibration equipment, and glove box.

Experiment and Test Isolation Laboratory. Hazard detection system; electrical and vacuum power center/hydraulic/pneumatic work station; cryogenic, fluid, and high-pressure gas storage; airlock; chemistry and physics glove box; and analysis and storage unit.

Optical Sciences Laboratory. Optical work station, microdensitometer, monochromator spectrometer, modulation transfer function measurement system, optical spectrum analyzer, airlock and optical window.

Mechanical Laboratory. X-ray diffraction unit, experiment and isolation test panel, laminar flow glove box, specimen tester, metallographic tester and microscope, thermostructural test equipment, and x-ray generator.

OBJECTIVE: PROVIDE A MULTIDISCIPLINE LABORATORY TO CONDUCT SPACE RESEARCH FOR:

- BASIC PHYSICS AND CHEMISTRY
- EARTH SCIENCES AND SPACE SCIENCES
- PHYSIOLOGY AND DISEASE PROCESSES
- MATERIALS SCIENCE
- GRAVITY EFFECTS
- APPLIED R&D

FUNCTIONAL REQUIREMENTS

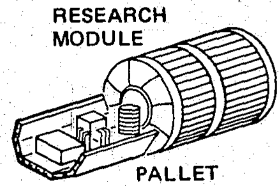
- PERFORM SPACE RESEARCH

BASIC SCIENTIFIC DISCIPLINES

APPLIED RESEARCH IN SUPPORT OF OTHER OBJECTIVES

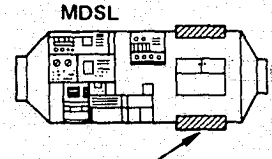
OBJECTIVE ELEMENTS

- BASIC RESEARCH – MINIMUM LEVEL



USE OF SPACELAB HARDWARE ADAPTED TO SPACE STATION

- BASIC RESEARCH – MAXIMUMUM LEVEL



DATA PROCESSING/ EVALUATION

ELECTRICAL, ELECTRONIC, OPTICAL, AND MECHANICAL MAINTENANCE AND REPAIR

ISOLATED EXPERIMENTS

EVA AND IVA SUPPORT

Figure 3-16. Multidiscipline Science Laboratory (MDSL)

Biomedical/Bioscience Laboratory. Biochemical and biophysical analysis unit, bicycle ergometer, lower body negative-pressure device, and body mass measuring device.

Data Evaluation Facility. Multiformat viewer editor and microfilm retrieval system; film reader; copy machine; stereo viewer; image processing and data management control station; working image, permanent video and digital storage; time reference unit; TV camera control and video tape recorder, hard copy printer; and scientific computer.

The most important payload support characteristic of an MDSL is the availability of man as an observer, decision-maker, and operator. Experience on Skylab offers substantial evidence that the presence of man can add significantly to mission success and enhance the productivity of spaceflight activities with respect to improvisation and modification. The correction of simple equipment malfunctions and relocation of power cables to service different apparatus are two examples.

In data management and communications, the crewman's presence will allow the system to be simpler, with plug-in panels instead of automatic switching. He will be able to make discretionary judgments with respect to what, how, and where data are to be handled. A crewman can also initiate or suspend communications or data management functions as required to better use the capacity of the system.

3.3.8.2 Rationale for Space Station Support of MDSL

Almost without exception, all space research tasks that can be performed in low earth orbit could, in theory, be accomplished by a series of Orbiter sortie missions using Spacelab hardware. Even tasks requiring continuous presence of man in orbit could be done with overlapping 7-day sortie missions by transfer of the Spacelab module from one Orbiter to the next (not possible without some modification of current hardware designs). While this approach may be impractical, it is a possibility which might be considered in many space research missions. Thus, a critical issue to be addressed is to determine where a Space Station laboratory is cost-effective as compared with the operation of the sortie lab.

Figure 3-17 compares the effectiveness in accomplishing identical missions with alternative space platforms. In deriving the data, a typical multi-discipline research program used in the Phase-B Space Station study served as the model. The product of man-hours and equipment pounds required in orbit was used as the basic index of productivity. The reference program required a productivity index of 630×10^6 man-hours kilograms (mh kg) for its accomplishment (typical of a 6-man Space Station).

To compare costs between sortie missions and Space Station operation, we assumed that a 6-man Space Station was employed to maximum capacity (estimated to be 320×10^6 mhp per year) and compared its cost to that of sortie missions working to the same level. Sortie missions of 7 days and longer were included. As sortie mission time extends, available manpower increases. However, the payload available decreases (more weight must go into consumables) and the product of sortie manpower and available payload weight peaks at a 30-day mission; thus this duration was also considered. Space Station costs were taken from the Phase-B study with an inflation

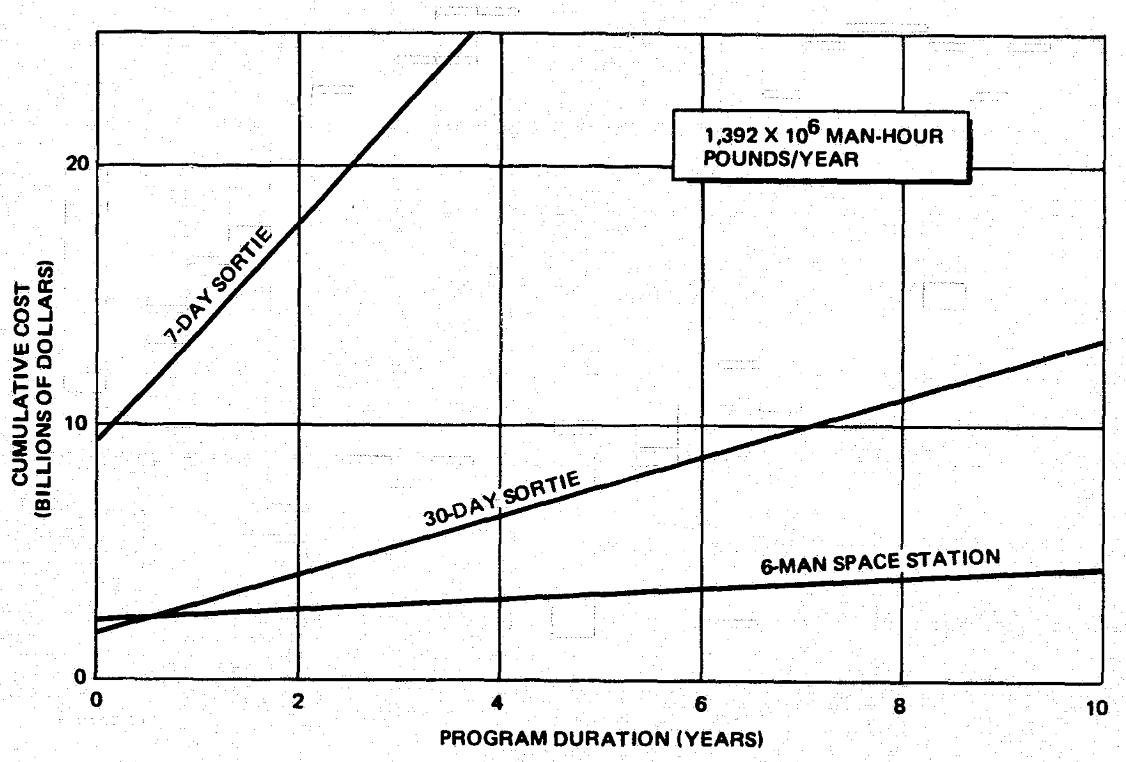


Figure 3-17. MDSL Cumulative Program Costs

factor to produce an estimate in 1976 dollars. A three-Orbiter fleet, capable of 15-day turnarounds, was assumed. Additional Orbiters and Spacelabs were assumed to cost \$300M and \$42M each, respectively. Operationally, it was assumed that Orbiter flights cost \$17.25M each and no additional facilities were required for the maximum use (229 flights per year). Since each program was assumed to accomplish the same orbital research program, no research equipment costs were included.

The most significant conclusion that can be reached from data of this type is that justification of the Space Station does not depend upon a unique mission capability (long duration, large electrical power capacity, etc.). Rather, its fundamental efficiency allows considerable cost advantage even when the missions could be accomplished by a series of Orbiter/Spacelab sorties.

3.3.9 Sensor Development

3.3.9.1 Rationale for Sensor Development Objective

There are a number of sensors in the IR, visible, and UV portions of the spectrum that would profit from orbit-based support. As an example, long-wavelength infrared LWIR sensors are extremely difficult to test and calibrate on earth. Such sensors must be mounted in a cold chamber simulating the space environment to reduce background photon flux. In such a chamber, it is difficult to mount a gimbal and simulate scanning and tracking against a calibrated blackbody source. Such testing and calibration usually require months in ground simulation facilities and are very costly.

It is potentially feasible to test and calibrate these sensors on a Space Station under ideal dynamic conditions that duplicate the final operational and environmental conditions. IR sensors for earth-oriented as well as for astronomical use could be tested in this fashion.

In space, many natural targets (stars, galaxies, etc.) emit radiations over large spectral regions. These radiations can be calibrated and separated spectrally to be monitored and used as radiation standards for calibration instruments involving spectrographic measurements. Using natural standards would greatly simplify calibrations and would decrease considerably the calibration equipment and sources required.

Optical sensors could be developed in orbit for use in orbital-based earth and astronomical observations. Since the final application of these sensors is in space, it is reasonable to expect that some aspects of their development, manufacture, and assembly might best be accomplished in space. These areas include: (1) space manufacture of sensor materials and components, (2) space testing of sensor components, and (3) space assembly and servicing of sensor systems.

Examples of components whose manufacture might benefit from the space environment are mirrors and lenses, filter coatings, deposition phototubes, crystal growth for detectors, and detectors and detector arrays. For example, the zero-g, high-vacuum, low-contamination space environment may permit manufacture of large optical elements of higher quality and lower cost then those manufactured on earth and transported to orbit. Terrestrial fabrication of glass for large telescopes is limited by thermal stresses induced during fabrication and requiring annealing at temperatures which are limited by deformation of the glass under its own weight. In zero gravity, this limitation on annealing temperature would be largely eliminated. Contamination from crucible and furnance atmosphere could also be largely eliminated in space, permitting manufacture of optical elements with more rigidly controlled optical and physical properties. Figure 3-18 summarizes contamination considerations. With this potential for low deformation and controlled properties, it may be possible to cast large optical elements directly to finisned dimensions. Moreover, the freedom from gravity and launch-induced loads should permit the design of thinner, lighter, and more efficient mirror blanks.

3.3.9.2 Rationale for Space Station Support of Sensor Development

Sensor Development in space will require the relatively sophisticated, long-duration manned support which Space Station is designed to supply. The essentially continuous nature of the Sensor Development tasks precludes effective support by means such as Shuttle sorties. Required facilities include a clean laboratory, a clean vacuum laboratory, an optical fabrication shop, and a pallet for final assembly and mounting of sensors and instruments.

CR 84

ORBITER EFFLUENTS

SOURCE	AVERAGE RATE	PRINCIPAL CONSTITUENTS
VERNIER CONTROL SYSTEM	1.06 KG/HR ①	H_2O, N_2, CO, CO_2, H_2, NO
REACTION CONTROL SYSTEM	16.6/STAR SIGHT ②	SAME AS VCS
FLASH EVAPORATOR	10.9 KG/HR ③	H_2O
TRASH H_2O	0.02 KG/HR ④	H_2O
CABIN ATMOS LEAKAGE	0.16 KG/HR ③	N_2, O_2, CO_2
OUTGASSING	0.004 KG/HR ③	POLYMETHYL SILOXANES

① NASA JSC PROGRAM H4R RSC

② MDC G6367 DOD STS PAYLOAD INTERFACE SUPPORT STUDY

③ MARTIN MARIETTA ORBITER CONTAMINATION CONTROL STUDY MCR-76-12

④ RI (INFORMAL DATA)

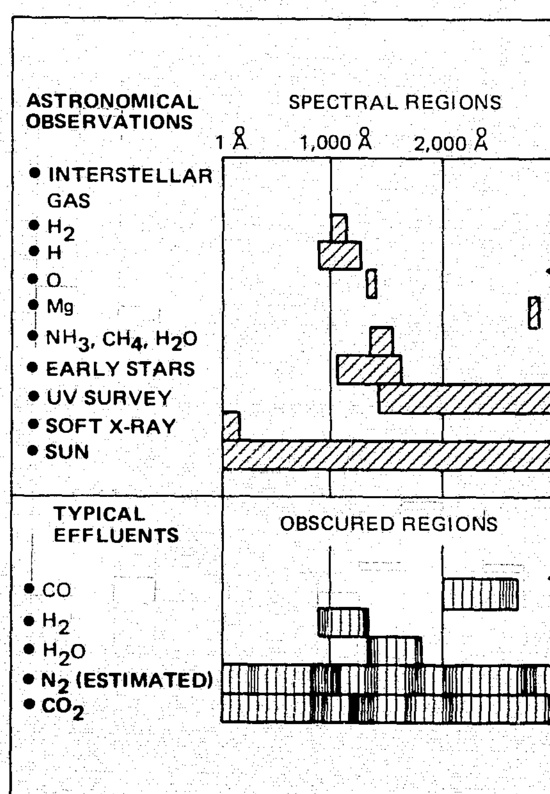


Figure 3-18. Considerations for Sensor Operation

Three phases of Sensor Development activity are anticipated during the 1984 and 1996 period. The hardware elements involved in the first two phases are depicted in Figure 3-19.

The initial optical sciences laboratory will be part of Multidiscipline Science Laboratory (MDSL) that would provide an optical work station, an airlock, optically flat windows, and basic instrumentation including such items as microdensitometers, spectrometers, and optical spectrum analyzers. Palletized sensors and target satellites also will be needed.

The second-generation Optical Sensor Development Facility (OSDF) will include pressurized and vacuum labs and an optical shop. The optical shop will include facilities for grinding, polishing, inspection, cutting, and welding. The manned laboratory will include optical benches, gimballed platforms, and appropriate instrumentation. The vacuum laboratory might include facilities for vacuum deposition, preparation of optical coatings, detector assembly, etc. It has been suggested that melting and forming glass

CR84

OBJECTIVE: PROVIDE A FACILITY FOR THE TEST AND CALIBRATION OF OPTICAL SENSORS FOR:

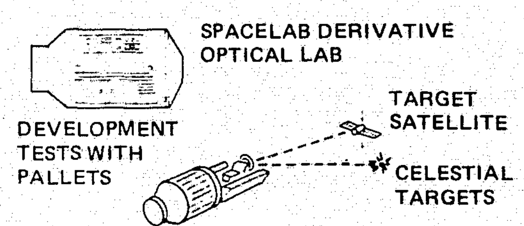
- EARTH SCIENCES
- COSMOLOGICAL PHENOMENA

FUNCTIONAL REQUIREMENTS

- EVALUATE TECHNIQUES FOR CALIBRATION AND TEST OF OPTICAL SENSORS

OBJECTIVE ELEMENTS

- DEVELOPMENT AND TEST



FUNCTIONAL REQUIREMENTS

- EVALUATE TECHNIQUES FOR FABRICATION, ASSEMBLY, TEST, AND CALIBRATION OF OPTICAL SENSOR SYSTEMS

OBJECTIVE ELEMENTS

- FABRICATION AND EVALUATION

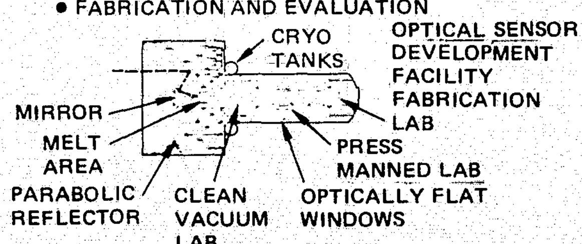


Figure 3-19. Sensor Development

lenses and mirrors with greatly improved optical characteristics is possible in zero-g. If this proves feasible and if electrical energy supply is limited, melting of glass might require the installation of a large solar collector and the construction of a solar furnace.

The processes that might be accomplished in this facility include:

- System or subsystem calibration and alignment of optical systems
- Acceptance testing of delivered components
- Final finishing and assembly of optical and other components
- Application of surface coatings
- Assembly and forming of large, lightweight structures
- General-purpose light machining, forming, and electron beam and laser welding
- Crystal growth for forming perfect crystals and/or semiconductor fabrication.

As experience is gained, a third-generation OSDF (circa 1996) will be needed. This more sophisticated facility will consist of a 4.5 x 15m free-flying module operating in conjunction with the earlier facilities that can remain attached to the Space Station. As in the earlier facilities, numerous remotely controlled small satellites will be required. The free-flying facility will be intermittently manned and be capable of independent unmanned station-keeping for periods of 30 days or more.

A cost analysis of the OSDF, documented in Volume 3, indicated that the cost of optical equipment is about $21M and would be roughly the same cost as for comparable equipment in an earth-based laboratory. Given the fabrication and calibration advantages of the space facility, the cost comparison tends to support justification of the OSDF. However, the cost of developing and maintaining ($100 to $400M) a sensor development platform will have to be compared with the cost of deploying and redeploying the present space sensors, and should be the subject of further study.

Another aspect of considering orbital sensor test, calibration operations activities, is considerations of the advantages of the space environment and what it means to the space platform provided. Optical sensors provide essential data for earth-oriented observations and astronomical research. When coupled with the viewing vantage point of a space platform, vast improvements in observational programs can be realized. The attenuation of the earth's atmosphere limits outward viewing primarily to the visible portion of the spectrum (4000 to 8000Å) and to portions of the radio region of the spectrum (1 cm to 10m). The infrared is transmitted through the atmosphere only in fragmented bands. For advancement in astronomy and to further our understanding of cosmological processes it is essential that observational opportunities be expanded by placing optical instruments, covering the IR to extreme UV portions of the spectrum, above the earth's atmosphere.

Other functions that benefit from the space environment include:

1. Assembly of and servicing sensors for:
   - Remote sensing and earth resource satellites
   - Atmospheric sounding satellites
   - Astronomical telescopes
2. Testing of LWIR sensors where cryogenic backgrounds and remote sources are available.
3. Manufacture of sensor or telescope mirrors, crystal growth, filter coatings, deposition phototubes, detectors, and arrays where high vacuum is needed.

If the above functions are performed in space, the Space Station will have to provide a contamination-free environment. Other studies have evaluated the Space Shuttle in terms of effluents which might degrade performance (Figure 3-18).

Water, if it deposits on IR sensors, clearly degrades performance. Effluent gases decrease signal-to-noise ratios, create false images, decrease incident radiation, scatter light and filter out certain wavelengths. The polymethyl siloxanes will adhere to optical surfaces. In a current study being performed for DOD, the deposition of polymethyl siloxanes on second surface mirrors was computed to be in excess of 50Å in thickness. The Space Station, since it can be operated in modes producing fewer contaminates (e.g., using control moment gyros rather than reaction control systems), should, with care, be able to provide an improvement in effluent environment over that of the Shuttle.

3.3.10 Living and Working in Space

3.3.10.1 Rationale for Living and Working in Space Objective

There has been much speculation about the future role of man in advanced space systems. It has been suggested that unmanned vehicles (e.g., teleoperators) under ground control might be more economical and effective in the space environment. The experience of the past 10 years, however, suggests that the man-machine combination can function more effectively than the machine alone; examples are the outstanding performance of the Apollo 13 crew in safely bringing back their crippled craft, as well as the overall performance of the Skylab crews. The wealth of material brought back from the moon by the Apollo missions, when contrasted with the information provided by the unmanned Luna 16, graphically demonstrates the value of man's direct involvement.

Review of the other space objectives indicates the requirement for significant direct participation of man in space. The projected crew requirements are summarized in Table 3-12. In addition to the user crew, a Space Station crew is required to operate the basic station (Figure 3-20). With potentially large total on-orbit crew requirements in the latter portion of the demonstration period, it will be extremely beneficial to improve their efficiency in performing useful work.

Operating costs of future space applications will be influenced by crew rotation interval requirements and efficiency over extended career durations. Figure 3-21 illustrates the sensitiveness of Space Station costs to career durations. Man's ability to tolerate the space environment for long durations, say for 1 or 2 y ars, is by no means apparent from the data accumulated so far. Crew sizes for the near and distant future are projected in Figure 3-22. Early Space Station missions will require crews of 10 to 50 persons. Ultimately (after the 1995 demonstration period), on-orbit crew size could be on the order of 500 to 1,000 persons (located or deployed in several locations). This construction-base level of operation brings with it an entirely new group of essentially unexplored problem areas. Whereas, in small Space Stations, members of the crew will perform a variety of

Table 3-12

PRELIMINARY ESTIMATE OF USER CREW NEEDED ON-ORBIT (PEAK) FOR VARIOUS MANNED SPACE OBJECTIVES

	1980	1985	1990	1995
Objectives	Cu_1	Cu_2	Cu_3	
1. SPS	1	8	3	
2. Space Processing	4	8	12	
3. Earth Services	3	5	8	
4. Depot	1	2	10	
5. Cluster Support	4	6	20	
6. Nuclear Energy	6-8	6 to 8	6 to 8	
7. Sensor Development	4	Not Applicable	24	
8. Living and Working in Space	2	3	3	
9. Scientific R&D	0	4	5	
10. Multidisc Lab	4	8	8	

|← Demonstration Phase →|

Operational Period

$Cu_{1,2,3}$ = User crew average requirement for time phases indicated

Note: User crew data is not necessarily additive. Time phasing of program options will dictate total crew on orbit at any point in time

Table 3-12

PRELIMINARY ESTIMATE OF USER CREW NEEDED ON-ORBIT (PEAK) FOR VARIOUS MANNED SPACE OBJECTIVES

1980 1985 1990 1995

Objectives	Cu_1	Cu_2	Cu_3
1. SPS	1	8	3
2. Space Processing	4	8	12
3. Earth Services	3	5	8
4. Depot	1	2	10
5. Cluster Support	4	6	20
6. Nuclear Energy	6-8	6 to 8	6 to 8
7. Sensor Development	4	Not Applicable	24
8. Living and Working in Space	2	3	3
9. Scientific R&D	0	4	5
10. Multidisc Lab	4	8	8

|← Demonstration Phase →|

Operational Period

$Cu_{1,2,3}$ = User crew average requirement for time phases indicated

Note: User crew data is not necessarily additive. Time phasing of program options will dictate total crew on orbit at any point in time

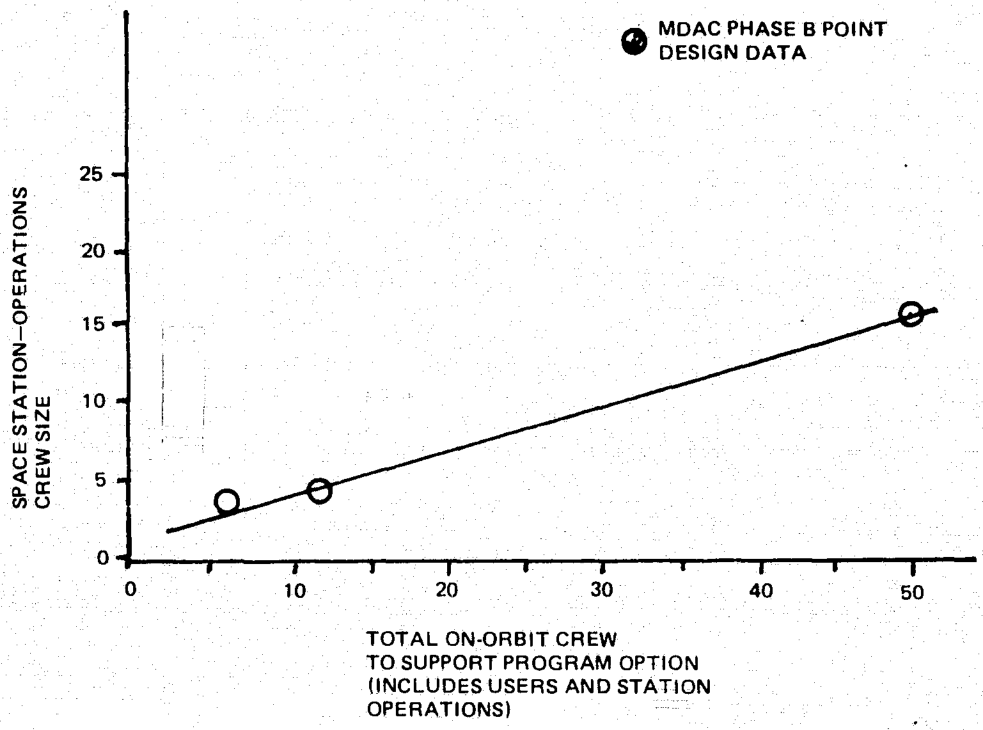


Figure 3-20. Space Station Operating Personnel Required as a Function of Total On-Orbit Crew Needs

tasks using multipurpose equipment and facilities, the construction base will dictate specialty crew members using large dedicated facilities. The implications in terms of psychological interactions and support requirements for such large crews involved in space construction and system operations for extended periods in orbit are largely unexplored.

3.3.10.2 Rationale for Space Station Support of Living and Working in Space
Three primary goals are associated with the Living and Working in Space objective:

A. To better understand physiological problems which degrade performance and or physical health and processes, and to develop methods of controlling or counteracting them.
B. To establish the capability for long-duration space flight of up to 720 days. This would be done in increments on many subjects and would require five to 10 years to complete.
C. To optimize man's on-orbit productivity through determining his capabilities and then providing the environment, tools, work cycles, etc., that allow maximum exploitation of man's capabilities.

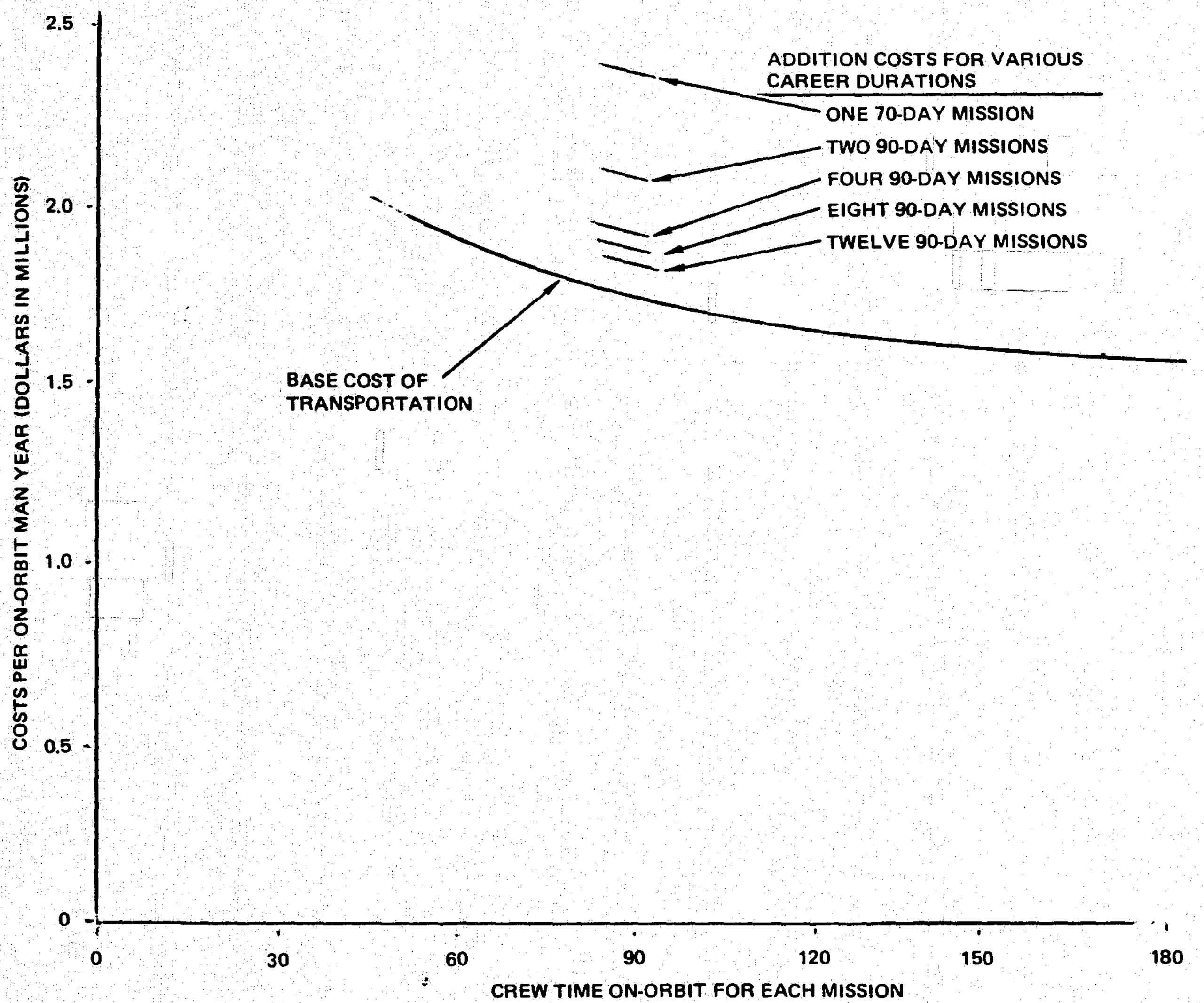
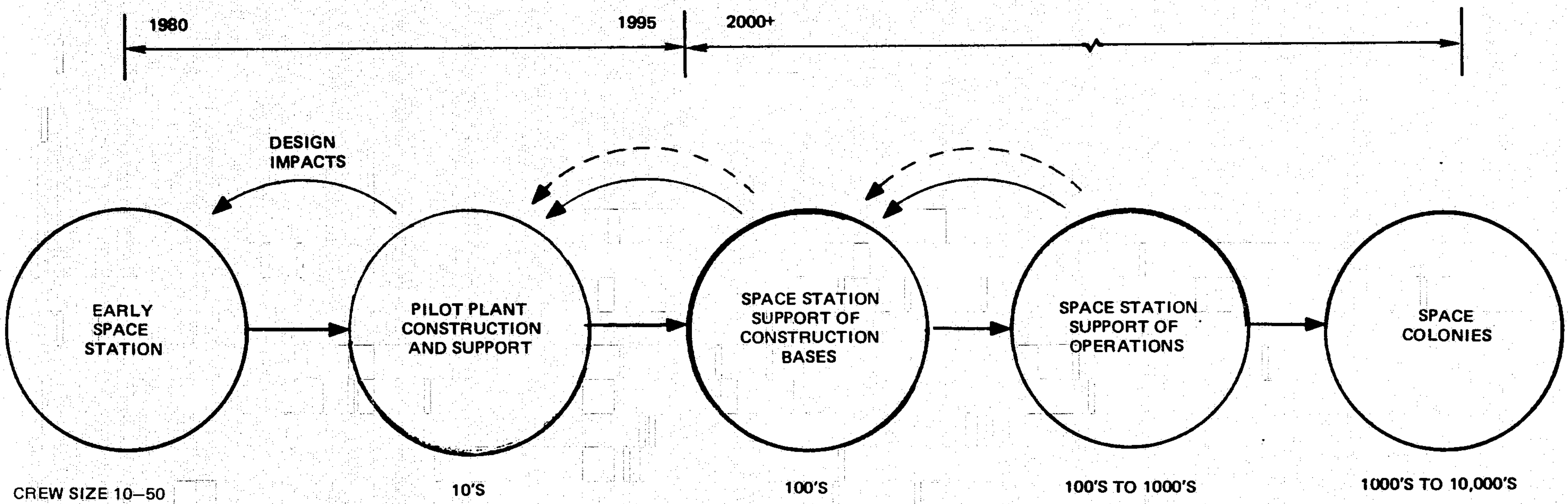


Figure 3-21. Manpower Cost Sensitivities



EARLY STATION DESIGN SHOULD:

- REFLECT TEST CAPABILITIES TO DEMONSTRATE FUTURE SYSTEMS AND OPERATING PROCEDURES

Figure 3-22. Space Station Implications Based on Projected Needs

The functional requirements imposed on the Space Station are geared to address these goals. In addition, a continuing goal of the living and working in space objective is to support all manned activities to assure continued high levels of performance. This goal includes basic health care and health maintenance procedures.

The Living and Working in Space objective provides for sequential, progressively more sophisticated, data collection on the ability of man to tolerate prolonged space flight and on his productive capability in support of other station objectives.

The Space Station's ability to provide a long-duration platform for R&D investigations can produce considerable savings over shorter Spacelab operations. These savings are primarily related to transportation costs due to (1) fewer flights necessary to accomplish a specific amount of research, (2) longer crew times on orbit per duty period, and (3) greater crew career time on orbit. These features of Space Stations must be exploited to obtain maximum benefits to the objectives and should be considered operational requirements in the Station.

The longer on-orbit duration for the Space Station compared with Spacelab (10 years versus 7 to 30 days) results in a need for facilities with permanent equipment.

Transportation costs are a significant factor in achieving this objective. In some objectives involving large construction operations such as SPS and space processing, the transportation costs are related less to the crew cycle than to the material being delivered. But, in the case of the living and working objective, long-duration testing is a major factor; the research lab equipment does not change frequently. Whereas on the Spacelab a dedicated life science module would be required to make over 50 flights of 7- and 30-day durations, a Space Station may be able to accomplish the same research program with only the equivalent of 7 or 8 flights. Much of the equipment could remain on orbit for the duration.

Figure 3-23 illustrates the differences in the above for life sciences research. As can be seen, there is a $290M savings in Space Station compared to Spacelab for the indicated mission assumptions with most of the savings in transportation.

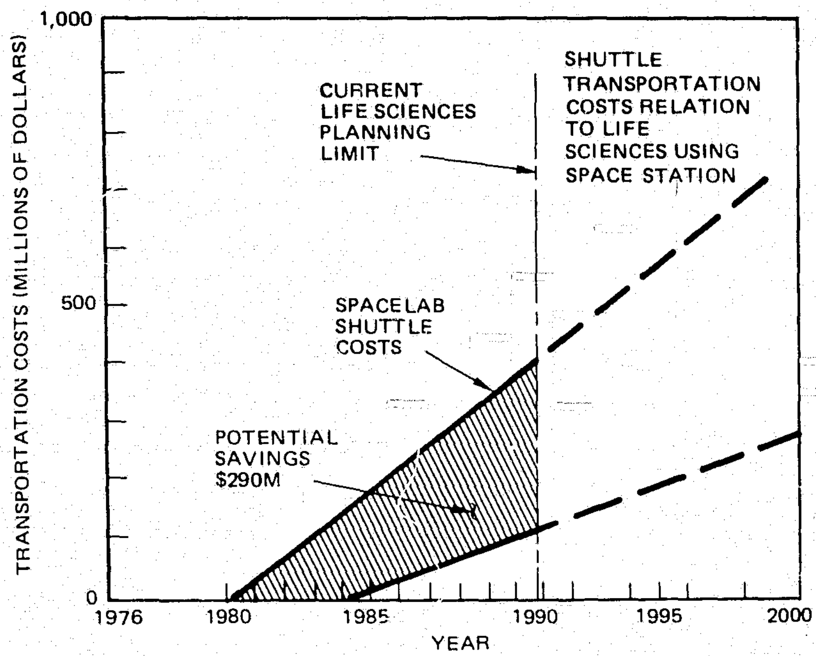
The functional requirements and the associated objective elements for the Living and Working in Space objective are illustrated in Figure 3-24.

Objective element 1 (Limited Research) depicts an early minimodule approach to the conduct of life sciences research. This minimodule would be outfitted as an orbital laboratory with vertebrate-holding facilities, gas and liquid biochemical assay instrumentation, light microscopy instruments, slide preparation equipment, and a small, interactive data storage and manipulation capability. Its purpose would be to verify and extend the research on biological systems previously collected during Spacelab missions.

Objective Element 2 (Extensive Research) shows a Space Station module dedicated to research necessary to qualify man biomedically for prolonged orbital tours of duty, to the development of medically indicated countermeasures (conditioning devices) and to the orbital qualification of IVA/EVA tools and restraints necessary to enhance man's productivity during later fabrication and assembly operations. Included would be biochemical assay equipment, light microscopy, electronics devoted to cardiovascular research, exercise devices, and a volume allocated to tool storage and exercise (including a workbench). To permit EVA tool demonstrations, an airlock will be required which will also serve as a recompression chamber.

Objective Element 3 (Demonstration of Techniques) is an approach to the orbital examination of manned fabrication and assembly techniques and assumes that man has essentially been qualified for prolonged orbital durations. This configuration will be outfitted to permit use of sophisticated tools for IVA/EVA as well as the orbital demonstration of manned maneuvering devices oriented toward augmenting large construction base operations. Volume will be required for tool storage and deployment as well as component part structural fabrication and assembly.

CR84



ASSUMPTIONS

- SHUTTLE – $17.3M PER FLIGHT
- SPACELAB AND SPACE STATION – NO CHARGE
- SPACELAB PROGRAM
  - 2 MINILABS PER YEAR SHARED
  - 2 DEDICATED PER YEAR
- SPACELAB SHARED COST 15% X 17.3 = $2.5M
- SPACE STATION RESEARCH EQUIPMENT EQUIVALENT IN SCOPE TO SPACELAB
- SPACE STATION LAUNCH INTERVAL 90 DAYS MINIMUM TO SUPPORT LIFE SCIENCES

Figure 3-23. Space Station Versus Spacelab Costs for Life Sciences Research

CR84

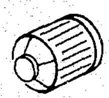
OBJECTIVE: DEMONSTRATE LONG-TERM LIVING AND WORKING IN SPACE RELATED TO OTHER MANNED SPACE OBJECTIVES

FUNCTIONAL REQUIREMENTS

- VERIFY SPACELAB RESULTS, DEVELOP PREDICTIVE TECHNIQUES AND CONTROL OF MOTION SICKNESS, VESTIBULAR PROBLEMS, CARDIOVASCULAR DEGRADATION, ETC
- ESTABLISH LONG-TERM ADAPTABILITY (720 DAYS); DEVELOP COUNTERMEASURES TO MUSCULAR AND SKELETAL PROBLEMS
- DEVELOP CREW CAPABILITIES, METHODS, AIDS, CYCLES, ETC
- OPTIMIZE MAN'S PRODUCTIVITY ON-ORBIT
- SUPPORT CONSTRUCTION OF SYSTEMS FROM OTHER OBJECTIVES

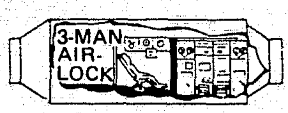
OBJECTIVE ELEMENTS

- LIMITED RESEARCH



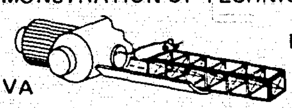
EQUIPMENT ADAPTED FROM SPACELAB

- EXTENSIVE RESEARCH



BIO-OUTFITTED MDSL

- DEMONSTRATION OF TECHNIQUES



EVA ASSEMBLY

IVA

- CONSTRUCTION SUPPORT

Figure 3-24. Living and Working in Space

ORIGINAL PAGE IS OF POOR QUALITY

3.4 OBJECTIVE SUMMARY

As noted in Figure 3-25, the results of the objective substudies verified their selection in all but one case — nuclear power. The studies also revealed that Space Station involvement is necessary to each objective to satisfy the associated functional requirements.

The objectives from which functional requirements were derived and hardware concepts synthesized all exhibit a capability for yielding significant benefits. They also impose a significantly broad spectrum of requirements on the Space Station itself so that as new requirements evolve, the ability of the Space Station to accommodate them is highly probable.

One of the primary requirements identified in the analysis of the selected objectives was the need for the Space Station to support on-orbit construction. The alternative to on-orbit construction would be deployment from the Shuttle. The determination of what structures should be deployed vs constructed on orbit involved considerations of: allowable tolerances (tolerances on unfurled structures become difficult to control as size increases); total weight (structures weighing more than the Shuttle payload delivery capability require some form of on-orbit assembly/construction), manpower and logistics costs (as structures become larger, the total cost of transporting men and machinery in a sortie mode eventually exceeds that associated with providing a permanent capability on orbit); and type of structure involved (rugged, stiff structures are more difficult to unfurl).

Based on analytical considerations, predictions of achievable levels of distortion and tolerance requirements for such things as communication, radiometry, and radio telescope antennas, it appears that any antenna above 30m in diameter and any structural array heavier than can be delivered in a single Shuttle flight probably will have to be constructed on orbit. Objective elements which must be constructed on orbit are illustrated in Figure 3-26.

Another aspect of the various objectives involves a determination of what activities could be performed by means of a Shuttle sortie mission and what activities require the Space Station. As an example, investigations of problems

CONSTRUCTION RELATED	
SATELLITE POWER SYSTEM	HAS GREAT POTENTIAL; TWO PILOT PLANT CONCEPTS RECOMMENDED
NUCLEAR ENERGY	RECOMMEND DEFERRING FOR THE PRESENT
EARTH SERVICES	HAS GREAT POTENTIAL; SEVERAL ANTENNAS SUGGESTED
SPACE COSMOLOGICAL R&D	30M RADIOTELESCOPE RECOMMENDED FOR DEMONSTRATION
SPACE MANUFACTURING	
SPACE PROCESSING	TREMENDOUS COMMERCIAL POTENTIAL FOR MODEST INITIAL INVESTMENT
SUPPORTING OBJECTIVES	
CLUSTER SUPPORT SYSTEM	EARLY APPLICATIONS RECOMMENDED. DEVELOPMENT FOR NEW USES SUGGESTED
DEPOT	MARGINAL FOR AUTO SATELLITES; NEEDED FOR OTHER OBJECITVES; SUPPORTS PLANETARY MISSIONS
MULTIDISCIPLINE SCIENCE LAB	NEEDED TO REALIZE ULTIMATE POTENTIAL OF SPACE ENVIRONMENT
SENSOR DEVELOPMENT	SPACE ENVIRONMENT OFFERS SIGNIFICANT ADVANTAGES; RECOMMENDED FOR INCLUSION
LIVING AND WORKING IN SPACE	NEEDED TO EXPLOIT MAN'S CAPABILITY

Figure 3-25. Objective Summary

caused by motion sickness, which generally run their course in 3 days, can be done by sortie, but evaluation of adaptability to long-duration flight is virtually impossible in this mode.

In the example highlighted in Figure 3-27, bench maintenance and repair techniques can be performed in a Shuttle sortie mode, while demonstration of OTV engine changeout requires Space Station support due to time and volume requirements. Certain payload handling and checkout tests could be done by Shuttle sortie though final demonstration would have to be done on the Space Station itself. The propellant storage and transfer test program would have to be conducted entirely on the Space Station because of the time duration. However, preliminary tests in zero-g gaging could be performed by Shuttle sortie.

Important work can be performed in the sortie mode. However, the fact that a Space Station is required to satisfy each objective and, collectively, could do the work more economically, leads to the conclusion that the majority of the objective efforts should be performed on the Space Station.

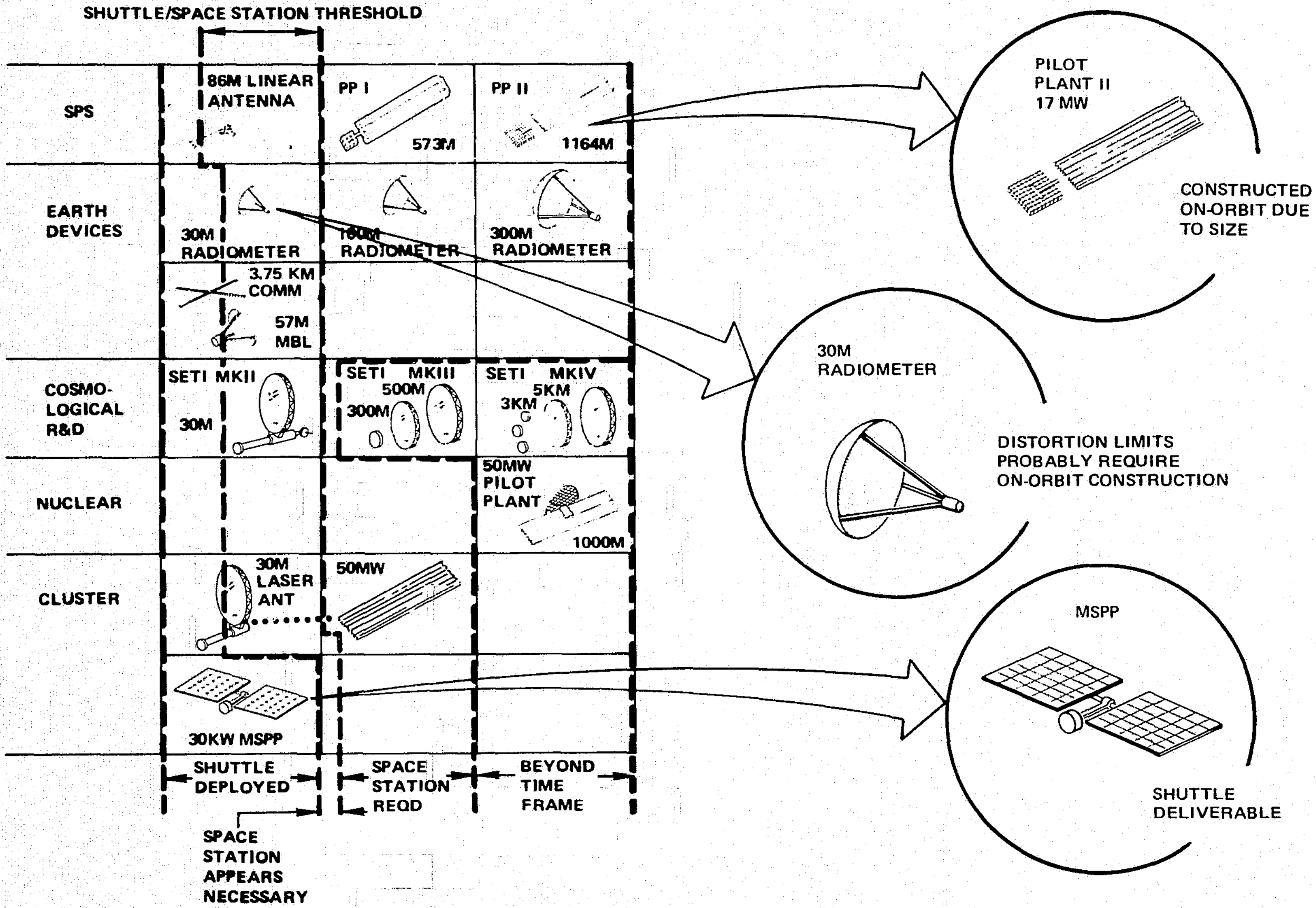


Figure 3-26. On-Orbit Construction –– Shuttle Sortie/Space Station Threshold

OBJECTIVE	OBJECTIVE ELEMENTS				
SPS	R&D	PILOT PLANT I	PILOT PLANT II		
SPACE PROC	R&D	PROCESS OPT	SI RIBBON PILOT PLANT	COMMERCIAL PROCESS PILOT PLANT	
EARTH SERVICES	30M RADIOMETER	100M RADIOMETER	300M RADIOMETER	MBL 27M	CROSS-PHASED COMM
MDSL	BASIC RESEARCH MINIMUM	BASIC RESEARCH MAXIMUM			
L&WS	LIMITED RESERACH	EXTENSIVE RESEARCH	TECHNIQUE DEMO	CONSTRUCTION SUPPORT	
COSMOLOGICAL R&D	R&D	SETI MARK II	GEO TESTS		
DEPOT	R&D	SMALL OTV DEPOT	LARGE OTV DEPOT		
CLUSTER	MSPP	COMP DEVEL	LARGE CLUSTER		
SENSORS	R&D	FABRICATION			

- POTENTIAL FOR SHUTTLE SUPPORT
- SPACE STATION SUPPORT REQUIRED

DEPOT R&D	POTENTIAL FOR SHUTTLE SUPPORT	REQUIRE SPACE STATION SUPPORT
M&R TECHNIQUES		
BENCH FUNCTIONS	✓	
ENGINE CHANGEOUT		✓
PAYLOAD HANDLING AND CHECKOUT		
PAYLOAD MATING	✓	✓
DYNAMIC TESTING		✓
PROPELLANT TRANSFER AND STORAGE		
GAGING	✓	✓
STORAGE		✓
TRANSFER		✓

Figure 3-27. Objective Element Support Summary

3.5 REFERENCES FOR SECTION 3

3-1. Williams, R.J. - Geosynchronous Satellite Solar Power - Published as Chapter 8 of Solar Energy for Earth - An AIAA Assessment, April 1975

3-2. Dugger, G.L. - Ocean Thermal Energy Conversion - Published as Chapter 10 of Solar Energy for Earth - AN AIAA Assessment, April 1975

3-3. Covington, C. - JSC - Summary of JSC SPS Studies - Presented at MDAC, May 27, 1976

3-4. Glaser, P.E. - Solar Power via Satellite - Astronautics and Aeronautics, PP 60-63, August 1973

3-5. Outlook for Space - Appendix 13

3-6. Study of the Commonality of Space Vehicle Applications to Future National Needs - Aerospace Corp. Report No. ATR-75(7365)-2, March 1975

3-7. Outlook for Space - Appendix I

3-8. Outlook for Space - Appendix II

3-9. Outlook for Space - Appendix III

3-10. Outlook for Space - Appendix IV

3-11. Project Cyclops - 1971 Summer Faculty Fellowship Program in Engineering Systems, NASA CR114445, revised edition July 1973

3-12. OAST Space Theme Workshop, Volume II; Theme Summary III - Search for Extraterrestrial Intelligence, working papers, Langley Research Center, April 26 - 30, 1976.

3-13. Outlook for Space - NASA SP-386, January 1976

3-14. Feasibility Study of Commercial Space Manufacturing - McDonnell Douglas Astronautics Company - East, December 1975

3-15. Manned Orbital Systems Concepts Study, Books 2 and 5. McDonnell Douglas Astronautics Company - West, September/October 1975

3-16. Practical Applications of Space Systems - 1974 Summer Study, Space Applications Board Assembly of Engineering, MRC, Washington, DC 1975

3-17. Ayres, R. - Technological Forecasting and Long-Range Planning. McGraw Hill, New York 1960

3-18. Proceedings of the Third Space Processing Symposium, Skylab Results - Marshall Space Flight Center, Alabama, April 30, 1974

3-19. The Application Program - NASA Headquarters, Office of Applications, Washington, DC - May 1974

3-20. Beneficial Uses of Space - Phases I and II Technical Reports, General Electric Company, Valley Forge Space Center, November 1973

3-21. Stine, H. - Third Industrial Revolution: The Exploitation of the Space Environment - Spaceflight.

3-22. Space Processing Perspectives and Goals - (2 Articles) - Astronautics and Aeronautics - May 1975, Volume 13, No. 5

3-23. Space Tug Systems Study (Cryogenic) - MDAC Report MDC G5051, Jan. 1972

3-24. In Space Propellant Logistics and Safety - (NAR) SD-72-SA-0053-3 - June 1972

3-25. Maynard, O.E., et al, Raytheon - Microwave Power Transmission System Studies - NAS3-17835, NASA CR-134886, December 1975

3-26. Greenblat, E.J. and Heiss, K.P., ECON - Space-Based Solar Power Conversion and Delivery Systems Study, Interim Summary Report - NAS 8-31308, ECON Report 76-145-1B, March 31, 1976

3-27. Gardiner, R.A., et al, JSC Six-Week Study, Space Solar Power Development Laboratory - JSC-09991, October 1975

3-28. Arndt, G.D. and Leopold, L., JSC - Minimum Sizing Requirements for a Space Station to Support SPS Testing - June 14, 1976

3-29. Space Processing Payload Equipment Study - TRW Contract NAS8-31494

3-30. Space Processing Payload Equipment Study - GE Contract NAS8-31495

3-31. Expandable Truss Antenna Growth Characteristics - Convair Report GDC DCL-69-001 - March 1969

3-32. Industry Workshop on Large Space Structures - NASA Report No. CR-144997, May 1976

3-33. The Shuttle Imaging Microwave System Environment - Invited Paper prepared for Sessions on Spacecraft Microwave Sensors of the IEEE National Telecommunication Conference - New Orleans - December 1975

Section 4
SPACE STATION PROGRAM OPTIONS

The transition from the Shuttle-Spacelab missions to early Space Station is addressed and the Space Station program options developed and analyzed in Part 1 are discussed in terms of their synthesis, requirements definition, element description, and transportation requirements.

Prior to development of program options a brief study was undertaken to define the prior Shuttle Spacelab mission accomplishments and their potential impact on early Space Station activities, and to define criteria for a reasonable transition to Space Station activities.

STS and Spacelab missions prior to the Space Station period can reasonably be expected to provide, in some measure, a research base in support of the Space Station objectives. An important piece of planning information would be an assessment of the level of achievement (relative to the objectives) that the first years of STS and Spacelab could be expected to reach. This assessment should include: (1) a mission model of STS and Spacelab flights for the 1980-1983 time period, (2) an assumption of the payloads to be flown on Spacelab during this period, (3) an estimate of the level of achievement relative to Space Station objectives expected from these precursor flights.

A mission model for STS and Spacelab flights for the calendar years 1980 through 1983 is shown in Table 4-1. The sources of the data include an MSFC planning document for the initial three years, "Early STS Mission Plans" dated June 22, 1976, and the so-called Yardley "572" plan, a NASA Headquarters schedule dated September 20, 1974.

Table 4-2 identifies specific and relevant payloads and experiments assumed to be assigned to Spacelab Missions 3 through 19 that could be expected to contribute to the seven pertinent Space Station objectives (Depot and Cluster, as specific operational support, are not addressed by Spacelab missions). The payloads are described in the two sources of mission planning information cited previously. Further descriptions of these payloads can also be found in the other sources of NASA payload planning information, such as the Space Shuttle Payload Description (SSPD) activity documentation.

Table 4-1
SYNOPSIS OF STS/SPACELAB MISSIONS

	1980	1981	1982	1983	CUM
Number of STS flights	5	16	23	48	92
Number of Spacelab missions	2	8	9	17	36
30-Day missions	-	-	-	(2)	(2)
Space processing payloads	TBD	2	4	4	10
Life science payloads	TBD	4	2	3	9
Physics/astronomy payloads	TBD	1	2	4	7
Applications payloads	TBD	2	4	4	10
Technology (OAST) payloads	TBD	3	5	7	15

→| Assigned |← Assumed →|

Table 4-3 summarizes, by calendar year and by Space Station objectives areas, the payloads and experiments shown in the source of planning data to be flown on Spacelab. By examining the experimental goals for each payload, the following tentative conclusions can be made relative to the degree of supporting R&D achievements expected from the Spacelab program:

Solar Power Station. Very limited penetration. Rudimentary beginnings of assembly techniques and stabilization of large structures.

Space Processing. Expect products and processes to be identified with econom economically attractive commercial interest.

Earth Services. Moderate penetration and beginnings of large-scale instrument development to work with a 30m radiometer.

Sensor Development. Significant penetration in working with several classes of advanced instruments (i.e., multifrequency synthetic aperture radar, tunable lasers, cryogenic-cooled IR telescopes).

Cosmological R&D. Limited achievements toward long-range goals. Applicable work with 30m antenna.

Multidiscipline Science Lab. Moderate achievements in many areas of scientific and applications interest.

Living and Working in Space. Excellent beginnings. Two 30-day missions; ready for long-term missions (90-750 days).

Table 4-2

SPACELAB PAYLOADS

Solar Power System
- Space environment effects on composites (SL No. 6)
- Large space structural elements (SL No. 6)
- Solar array materials (SL No. 6)
- Large deployable antenna (SL No. 11)

Space Processing
- Stationary column electrophoresis (SL No. 3)
- Continuous flow electrophoresis (SL No. 3)
- Furnace bank (SL No. 3)
- Auxiliary payload power supply (SL No. 3)
- Free-flow electrophoresis (SL No. 5)
- Isothermal heating facility (SL No. 5)

Earth Services
- Mark II interferometer (SL No. 5)
- Bandwidth compression modulation (SL No. 5)
- Adaptive multibeam antenna (SL No. 5)
- One-way navigation (SL No. 5)
- End-to-end information system (SL No. 6)
- Imaging radar applications (SL No. 7)
- Metric Camera (SL No. 7)
- Microwave radiometer/scatterometer/altimeter (SL No. 7
- Large deployable antenna (SL No. 11)

Space Cosmological R&D
- RFI survey (SL No. 7)
- Large deployable antenna (SL No. 11)

Sensor Development
- Mark II interferometer (SL No. 5)
- Imaging radar applications (SL No. 7)
- Lidar/laser sounder (SL No. 7)
- IR radiometer (SL No. 7)
- Shuttle imaging microwave system (SL No. 14)
- Earth viewing applications lab (SL No. 16)

Living and Working in Space
- Life sciences minilab (SL No. 5)
- Life Sciences Mod I (SL No. 4)
- Life Sciences Mod II (SL No. 12)
- Integral vestibular test stand (SL No. 14)

Multidiscipline Science Laboratory
- Atmospheric cloud physics (SL No. 3)
- Drop dynamics (SL No. 3)
- Advanced heat pipes (SL No. 6)
- Column density monitor (SL No. 6)
- Pointing technology lab (SL No. 6)
- Superfluid helium properties (SL No. 6)
- Aerospace sensing module (SL No. 6)
- TWT open-envelope experiment (SL No. 7)
- 11 solar and astrophysics instruments (SL No. 9)
- Amps and subsatellite (SL No. 13)
- 6 astronomy and astrophysics instruments (SL No. 19)

Table 4-3

SPACELAB PAYLOAD ACHIEVEMENTS (TYPICAL)

CY	Solar Power System	Space Processing	Earth Services	Sensor Development	Cosmological R&D	Multidiscipline Science Lab	Living and Working in Space
1980	Payloads to be selected from proposals submitted in response to AFO (SL 1 and 2) →	→	→	→	→	→	→
1981	Space environment effects on composites (OAST No. 17) solar array materials evaluation (OAST) No. 43)	Electrophoresis crystal growth, and solidification experiments (E-2, E-3, F-5)	Zero-g cloud physics (EO-01-S) multibeam antenna (CN-16-S) Mark II interferometer	Imaging radar (EO-20-S) high-speed interferometer (EO-19)	RIF survey (CN-04-S) obtain precise data on terrestrial noise sources	Solar observations with Apollo telescope mount and other instruments	Life sciences minilab (ML-2A) life sciences Mod I (LS-09S)
1982	Large space structures technology experiments (OAST No. 15) attitude control of flexible structures (OAST No. 23)	Free-flow electrophoresis (SP-01) and isothermal heating facility (SPE 80/85) repeat	Large deployable antenna (CN-07-S) RFI survey (CN-04-S), bandwidth compression studies (CN-21-S)	Tunable lasers (ST-37S), support of cryogenic-cooled astronomy telescope	Large deployable antenna (CN-07-S) basic experience with 30-M dia dish	Stellar observations with IR cryogenic telescope, astrophysics, cosmic rays and amps (1)	Minilab and life sciences Mod II, integral vestibular test stand (LSE-03)
1983	Figure control of large deformable structures (OAST No. 22)	Advanced experiments TBD	Advanced cloud physics (EO-01-S) multifrequency dual-polarized microwave radiometry (OP-03-S)	Multifrequency synthetic-aperture radar (OAST No. 33)	Figure control of large deformable structures (OAST No. 22)	Cosmic ray survey, UV survey, wide field galactic survey, deep sky survey, solar physics and amps	30-day life science missions with Mod II (LS-09S)

AFO = Announcement for flight opportunity (April 1976)

(1) Atmospherics, magnetospherics and plasmas in space

It can be anticipated, since the initial investment will already have been made in the STS/Spacelab system that these facilities will continue to be operational after 1983. Accordingly, economic considerations alone would dictate the continued use of the Shuttle/Spacelab whenever feasible. This system can thus be expected to continue to support short-duration (7 to 30 days) manned operations for many years.

If the traffic model developed for new programs were kept to a minimal level (less than 12 shuttle flights per year), and limited to missions generally requiring less than 7 to 30 days, the SST/Spacelab could accomplish them within NASA's discretionary budget. However, if future traffic models include operations requiring 30 days or longer for completion, require the construction of large space structures or have heavy power demands, a Space Station system supported by a continued Shuttle/Spacelab program would provide lower total program costs through the greater operational efficiency inherent in operations of extended duration. With regard to the point of greater operational efficiency of Space Station, observations made in Skylab III indicate that an 85% learning curve for performance improvement over extended periods is a reasonable expectation; this would result in considerable savings in orbital man-hours required to accomplish repetitive and continuing tasks.

Based upon these considerations, it is our recommendation that objectives, involving the construction of large structures, requiring more than 30 days and/or more than 20 kW of power in their accomplishment, be used as the criteria for requiring a Space Station system for efficient accomplishment. Table 4-4 summarizes these conclusions.

Figure 4-1 summarizes the relative degree of objective penetration of these early Spacelab activities; they range from significant impact on space station planning for Living and Working in Space, Space Processing, and Sensor development to limited impact on SPS and Cosmological R&D.

Interest areas examined to date, which appear to require a Space Station (more than 30 days of multiple manned-crew space activities, or require large amounts of power, or require the construction of large structures for their accomplishment) fall into the areas of space manufacturing and space construction. Typical examples are shown in Table 4-5. In addition, other

Table 4-4

SHUTTLE/SPACELAB, SPACE STATION THRESHOLD

Shuttle/Spacelab Only	Shuttle/Spacelab + Space Station
• Already in development • Allows greater NASA discretion in funding new programs and payload development • Supports 7- to 30-day manned operations	• Can support missions requiring - Extended duration - Construction or large space structures - Heavy power demand • More efficient in manned space operations • Composite program costs less for given level of accomplishment

Conclusion

Space Station threshold: Activities requiring more than 30 days for accomplishment, more than 20 kW, or construction of a large space structure, or a combination of these factors.

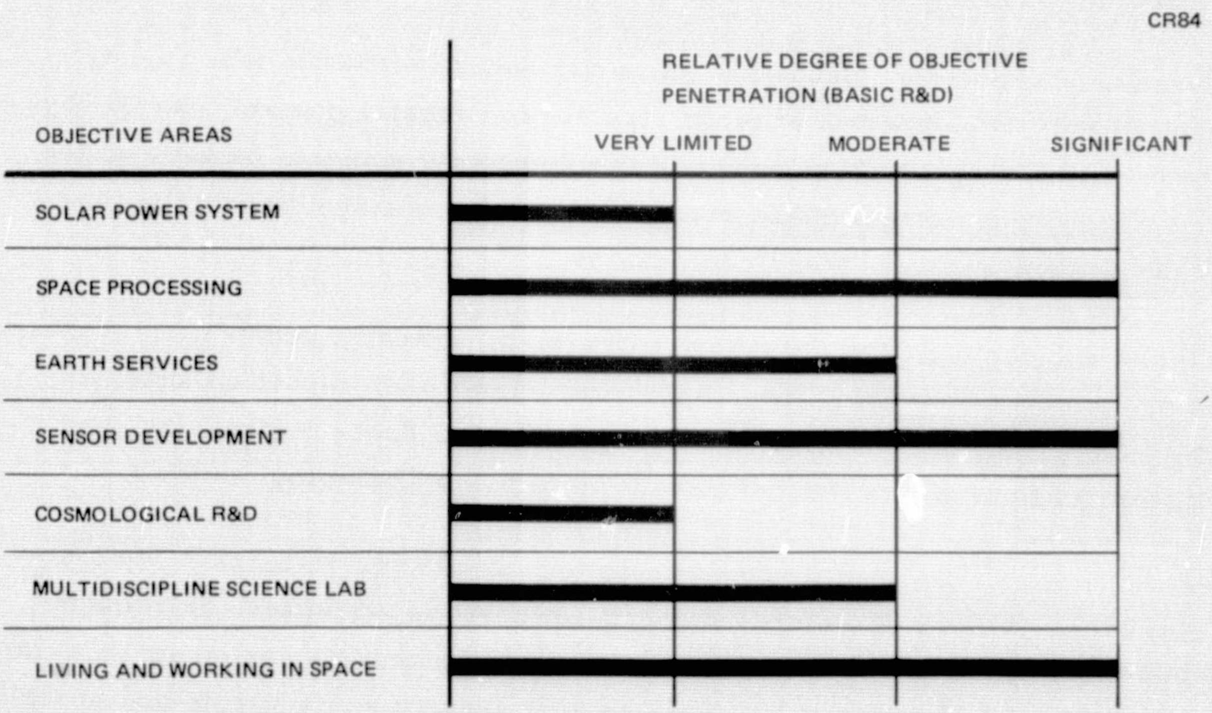


Figure 4-1. Spacelab Support of Space Station Objectives

Table 4-5

INTEREST AREAS REQUIRING SPACE STATION

Category	Controlling Factor(s)
Space Manufacturing	
• Space processing	Power and duration
Space Construction	Large space structures
• Satellite power system	Power and duration
• Earth services	Duration
• Space cosmological	R&D duration
Support Operations	Duration
• Cluster support system	Power and duration
• Depot	Duration
• Multidiscipline science laboratory	Duration
• Sensor development	Duration
• Living and working in space	Duration

support operations can be identified which would profit by the availability of a continuously operating manned facility in space.

4.1 PROGRAM OPTION DEFINITION

Potential Space Station programs were defined in order to illustrate parametric effects on programmatics and design, and thus allow comparisons, sensitivity studies, and selections to be made. These potential programs were termed Program Options. A Program Option consists of the six major elements illustrated in Figure 4-2: the objectives accommodated, major hardware elements needed, the orbit regime, transportation requirements, program schedule, and costs. The objectives accommodated are the portions or elements of each major objective (defined in Section 3) that are satisfied or accommodated in the particular program option being analyzed.

The Program Options were developed in two phases in Part I, as shown in Figure 4-3. Initially seven basic program options were formulated. These were characterized primarily by variations in orbit regimes, residency mode (permanent or sortie), and objectives accommodated.

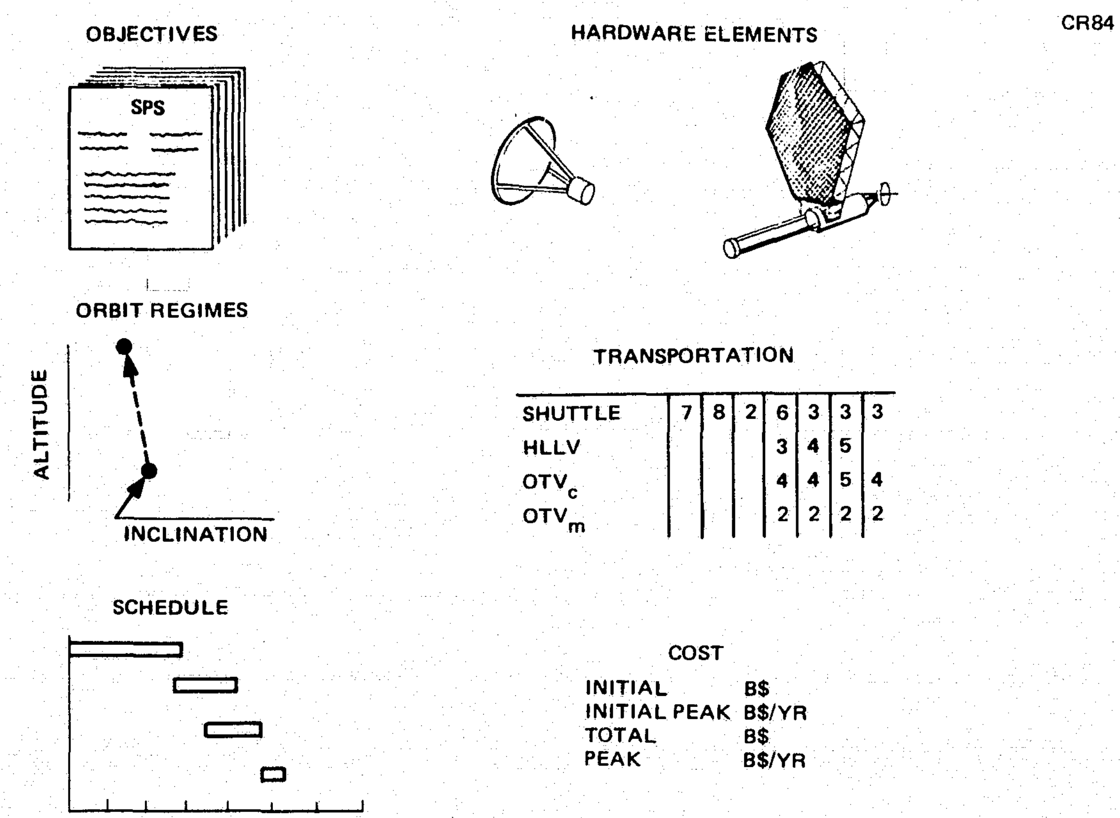


Figure 4-2. Program Option Elements

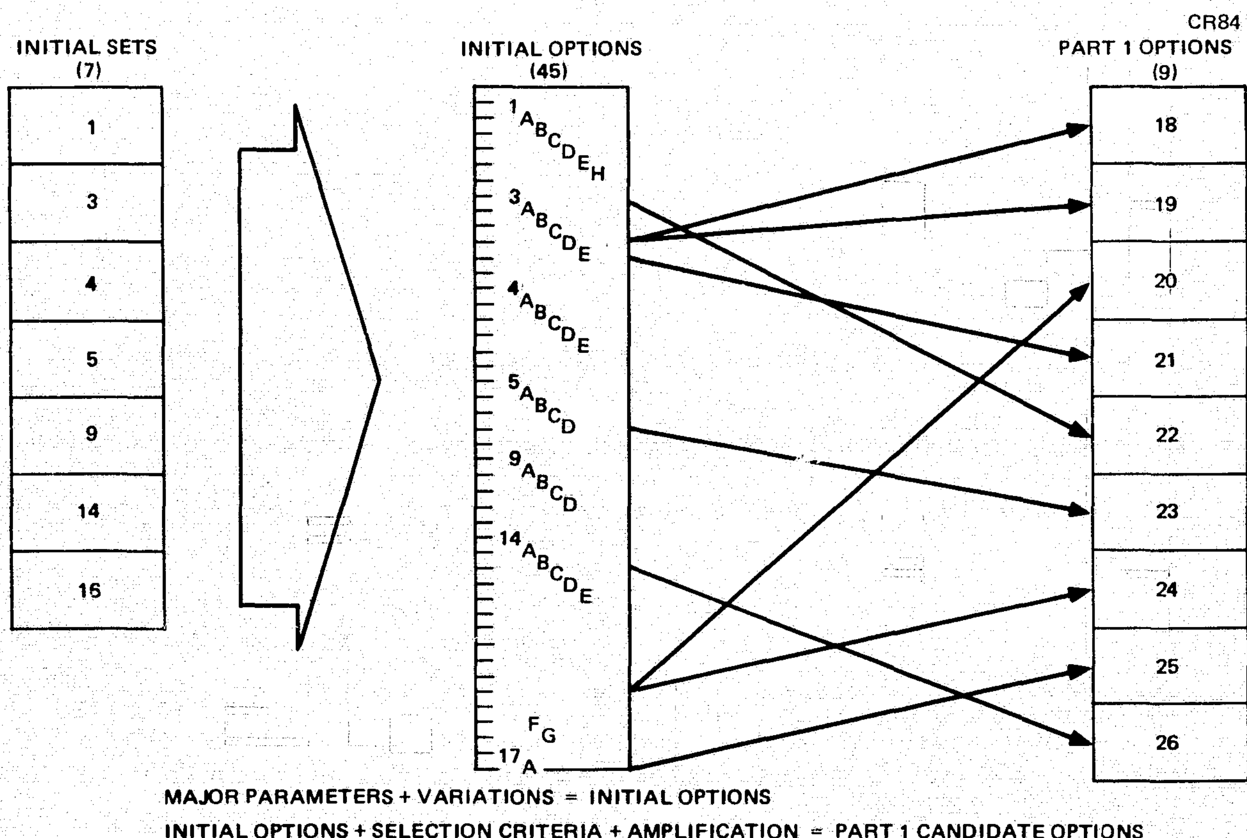


Figure 4-3. Program Option Genealogy

Each of the basic seven options was then varied by allowing changes in the level of objective accomplishment, transportation mode, crew residence type, schedule, and equipment status (commonality and alternate designs). The resulting program options totaled 45, as shown in Table 4-6. Each of these 45 was then analyzed to define the six elements (Figure 4-2) for each option. The emphasis at this time was to develop options that covered all reasonable combinations of objective elements, represented a broad range of program costs, covered the various orbit regimes of interest and included some reasonable growth contingencies such as the HLLV. The resulting data was evaluated and selection criteria were established and applied to reduce the 45 to the nine indicated, which were renumbered to distinguish them from the original set. Data for these nine candidate options are presented in detail as the output of Part I to allow the evaluation and further selection of options by the NASA.

4.2 SPACE STATION REQUIREMENTS

Each objective was divided into objective elements, each element being an autonomous activity that supported the objective, and functional requirements for each. The objective elements and their respective Space Station requirements are summarized in Table 4-7. The parameters that have the biggest influence on the space station design are orbit, crew size, duration of activity, power required, volume, and special equipment required.

The total Space Station requirements were then derived by integrating the contributions from each element of the potential program options. These were drawn from those objective elements that were a part of each program option as summarized in Table 4-7. Those objective elements included in each program option contributed their respective Space Station requirements. These were integrated in terms of men, duration, schedule, electrical power, and hardware elements. The relationship between the objectives and the objective element is shown in Table 4-8 for each program option. The entry data indicates the initiation of the orbital activity for that particular element. Thus, Tables 4-7 and 4-8 give a traceable account of the origin of Space Station requirements for each of the original 45 program options.

Table 4-6

SPACE STATION OPTIONS SUMMARY

Categories	Options		Suboptions		
Space stations in both LEO and GEO	No. 14	Fabrication and assembly in LEO. GEO tests supported by GEO Space Station.	No. 14	A.	Use of Shuttle-derived HLLV
				B.	Increased complement of objective items
				C.	Ground production of solar cells-use of mini SPS pilot plant
				D.	All objective items
				E.	All objectives, accelerated schedule
			No. 9		Reduced set of objectives
				A.	Reduced objectives, use of mini cluster support base
				B.	Reduced objectives, use of SPS for cluster development
				C.	Reduced objectives, use of SPS mini pilot plant
				D.	Reduced objectives, use of HLLV
	No. 5	Fabrication and assembly also performed at GEO.	No. 5	A.	Use of GEO Space Station construction base in LEO, then transfer to GEO
				B.	All construction at GEO. No LEO construction base.
				C.	Use of HLLV
				D.	All objectives
Space Station in LEO, GEO operations performed in sortie mode	No. 16	Fabrication and assembly done in LEO, GEO tests supported by transient crews.	No. 16	A.	Use of mini-home as transport module to GEO
				B.	Use of HLLV
				C.	Increased complement of objective items
				D.	Use of SPS mini-pilot plant
				E.	Use of SPS pilot plant in cluster development
				F.	All objective items
				G.	All objective items accelerated schedule
	No. 4	Fabrication and subassembly done in LEO. Final assembly and test done at GEO in sortie mode. Reduced set of objective items.	No. 4	A.	Use of mini-home as transport vehicle
				B.	Use of HLLV
				C.	All objectives
				D.	Use of mini-SPS pilot plant
				E.	Use of pilot plant to develop cluster
Space Station and manned operations confined to LEO	No. 1	Fabrication and assembly in LEO hardware transferred to GEO. Tests by remote control.	No. 1	A.	Use of HLLV
				B.	All objectives compatible with category
				C.	Use of mini-SPS pilot plant
				D.	All objectives compatible with category-accelerated schedule
				E.	All objectives compatible with category-reduced accomplishment
				F.	Orbital power source and antenna test
	No. 3	No hardware delivered to GEO. All tests performed in LEO. Reduced set of objective items.	No. 3	A.	Use of HLLV
				B.	Increased complement of objectives
				C.	Use of SPS mini-pilot plant
				D.	Orbit to orbit tests of SPS using orbiting ground station
				E.	All objective items compatible with category
	No. 17	Polar orbit space station.	No. 17	A.	Station also in low-inclination orbit

Table 4-7

SPACE STATION REQUI

Objective Element	Time Period (Nominal)	Orbit	Crew No.	Crew Duration (mo.)	Crew Skills	Power (KWe) Avg/Peak	Data Rate KBPS	Volume (M^3)	Environm Max G	Orientation/ Accuracy	Press. Atm	Temp
Satellite Power System												
Component Develop. and Test.	1983-1995	LEO	2	24	EE, CE, ET	5	10	96	10^{-3}	Solar/±5°	NC	NC
Pilot Plant I	1985-1987	LEO	5	16	EE, CE, Con, ET	10	10	96	10^{-3}	Solar/±10°	NC	NC
Pilot Plant II												
Construction	1992-1993	LEO	10	15	CE, Con, ET	20	10		10^{-3}	Away from Sun	NC	NC
Test	1993-1994	LEO	4	36	EE, ME, ET	3	10		10^{-3}	Solar/±10°	NC	NC
	1994-1995	GEO	2	24	Prop, ET, EE	3						
Space Processing												
Process Develop. and Test	1984-1985	LEO					15	40			0-4	
• Biologicals			1	12	BC, MB	4			10^{-3} to 10^{-4}	NC		±1°
• Inorganics			1	12	P, C	15			10^{-3} to 10^{-4}	NC		
• Silicon Ribbon/blanket			3	4	P, C	4			10^{-4}	NC		
Process Optimization	1987-1988	LEO					15	100				
• Biologicals			1	12	BC, MB, CE	5			10^{-3} to 10^{-4}	NC	✓	
• Inorganics			1	12	P, C, CE	25			10^{-3} to 10^{-4}		✓	
Silicon Ribbon/Blanket Pilot Plant	1990	LEO	4	6	CE, EE, PE	20	15	100-300	10^{-4}	NC	✓	
Commercial Process Pilot Plant	1993 →	LEO	4	Contin.	CE, E	30	15	500	10^{-3} to 10^{-4}	NC	✓	±1°
Earth Services												
30 M Radiometer	1985-1986	PEO/LEO	2	9	EE, CE, Con	5	169 MBPS	17	10^{-2}	Earth/ 0.05°	NC	NC
100 M Radiometer	1988-1990	PEO/LEO	4	18	EE, CE, Con	8	1.7 GBPS	17	10^{-2}	Earth/ 0.05°	NC	
300 M Radiometer	1989-1990	LEO	6	24	EE, CE, Con	12	1.7 GBPS	85	10^{-2}	Earth/ 0.05°	NC	
	1990	GEO	1	2	EE, CE, Con	1	TBD	85	10^{-2}	Earth/ 0.05°	NC	
Multibeam Lens	1990	LEO	2	8	EE, CE, Con	5		85	10^{-2}	Earth/ 0.05°	NC	
	1990	GEO	1	2	EE, CE, Con	1		85	10^{-2}	Earth/ 0.05°	NC	
Cross-phased Array	1991-1992	LEO	6	18	EE, CE, Con	3		85	10^{-2}	Earth/ 0.05°	NC	
	1992	GEO	1	2	EE, CE, Con	1		85	10^{-2}	Earth/ 0.05°	NC	
Multidiscipline Science Lab												
• Basic Research - Min Level	1984 →	LEO/PEO	2	Cont.	Many	7		66	10^{-3} to 10^{-5}	All/0.1°	1	Comfort Zone
• Basic Research - Max Level	1984 →	LEO/PEO	8	Cont.	Many	31	5,000	166	10^{-3} to 10^{-5}	All/0.1°	1	
Space Cosmo. R&D												
• Component Develop. and Test	1987	LEO	1	6	P, EE	1	10-20		10^{-3}	Stellar/0.002°	NC	NC
• 30M Mk II Radiotelescope	1990	LEO	4	6	ME, EE	2	10-20		10^{-3}	Stellar/0.002°	NC	NC
• Test Operations	1990	GEO	1	2	EE	1	10-20		10^{-3}	Stellar/0.002°	NC	NC
Depot												
• Component Develop. and Test	1984-1985	LEO	1	12	Prop, ME,	2	2		10^{-1}	Any		
• Large OTV Depot	1991 ----	LEO	1	Intermit.	ME, Prop, OT	2	2		10^{-1}	Any/0.1°/sec		
• Small OTV Depot	1991 →	LEO	7	Cont.	ME, Prop, OT	2	2		10^{-1}	Any		
Cluster												
• Multipurpose Space Power Platform	1984	LEO	0	-	-	-	2		3.3	Solar/±5°		
• Large Cluster Component Develop.	1984-1985	LEO	2	6	Prop., EE,	5	2		2×10^{-3}	Any	NC	NC
• Large Cluster Pilot Plant	1991	GEO	20	6	Con, CE, ME	30	1,000		0.1	Away from Sun/±5°	NC	NC
Sensor Development												
• Development and Test	1984 →	LEO	2-4	Cont.	OT, SS, ME	10	500 MBPS	100	10^{-3}	Earth and Stellar 0.005 sec		<±1°
• Fab and Evaluation	1988 →	LEO	4	Cont.	OT, SS, ME, EE	10		240	10^{-5}	Earth and Stellar 0.005 sec		<±1°
Living and Working in Space												
• Limited Research	1984 →	LEO	1	Cont.	BM	2	NC	20% MDSL	<0.01g	NC	1	Comfort Zone
• Extensive Research	1986 →	LEO	2	Cont.	BM, IE	4	NC	200		NC	1	
• Demonstrate Techniques	1990 →	LEO	4	Cont.	BM, IE, ST	10	NC	200		NC	1	
• Construction Support	1991 →	LEO	5	Cont.	Con, All	10	NC	200		NC	1	

1. Skill Code: P=Physicist, C=Chemist, BC=Biochemist, MB=Molecular Biology, BM=Biomedical, ChE=Chem Eng, CE=Structural Eng., EE=Elect. Eng., ME=Mech Eng., IE=Industrial Eng., PE=Process Eng., SS=Sensor Specialist, OT=Optical Tech, Con=Construction Tech, ST=Station Support Tech, Prop=Propulsion Specialist, M=Materials Spec., Operations Tech

2. ✓ = Critical Requirement which is TBD
3. NC = Not Critical within reasonable limits

Table 4-7

STATION REQUIREMENTS

Orientation/ Accuracy	Environment Requirements: Press. Atm	Temp	Airflow	Cleanliness	Vib and Acoustics	Lighting (ft-candle)	Special Equipment Required
lar/±5°	NC	NC	NC	100K	√	NC	Beam mapping satellite, share MDSL module, erect 86M linear array antenna and 52 x 52M Solar Array
lar/±10°	NC	NC	NC	√	NC	NC	Crane module, Fab and Assy module, erect 2.24 MW array and 1.7 MW antenna
way from Sun	NC	NC	NC	√	NC	NC	Construction base, silicon ribbon production unit and blanket assy module, pilot plant facility
lar/±10°	NC	NC	NC	√	NC	NC	Operations control module
							Propulsion system
	0.4			Bio-Containment			Share MDSL module
NC		±1°	√	√	√	√	Electrophoretic and mechanical separators
NC			√	√	√	NC	Various furnaces, vacuum wake shield
NC			√	√	√	NC	Solar furnace and silicon fuzing equip.
NC	√		√	√	√	√	Bio. facility and process equip.
	√		√	√	√	NC	Inorganic facility and process equip.
NC	√		√	√	√	NC	Silicon ribbon production unit and blanket assy. module
NC	√	±1°	√	√	√	NC	Commercial process module
arth/ 0.05°	NC	NC	NC	√	√	50-100	Assy. facility, (radiometer components on pallet)
arth/ 0.05°	NC			√	√		Assy. facility, manned mobility device, (radiometer components on pallet)
arth/ 0.05°	NC			√	√		Assy. facility, MMD
arth/ 0.05°	NC			√	√		OTV, depot
arth/ 0.05°	NC			√	√		Assy. facility, beacon satellites (MBL components on pallet)
arth/ 0.05°	NC			√	√		OTV, depot
arth/ 0.05°	NC			√	√		Assy. facility, MMD (array components on pallet)
arth/ 0.05°	NC			√	√		OTV, depot
l/0.1°	1	Comfort Zone	20	Class 100,000	√/40db	50-100	(1) Multidiscipline lab and (1) pallet equip.
l/0.1°	1		20	Class 100,000	√/40db	50-100	(2) Multidiscipline labs, (4) research modules
ellar/0.002°	NC	NC	NC	NC	NC	NC	Share MDSL module, (1) pallet test components
ellar/0.002°	NC	NC	NC	NC	NC	NC	Antenna assy. facility, ( ) pallets telescope components
ellar/0.002°	NC	NC	NC	NC	NC	NC	OTV
ny			NC	NC	0.1g/NC	NC	Share MDSL module, ( ) pallets components
ny/0.1°/sec				Class 100,000 in hangar	10^{-1}g/80-90db	NC	Propellant storage and transfer module, depot control module, loading equip.
ny					10^{-1}g/80-90db	NC	Propellant storage and transfer module, depot control module, loading equip, hangar
lar/±5°			NC	NC	5 g_{rms}/145db	NC	Space station power module
ny	NC	NC	NC	NC	$2x10^{-3}$g/60db	NC	Share MDSL module, laser power transfer test components on pallet
way from n/±5°	NC	NC	NC	NC	√/NC	NC	Silicon ribbon and blanket assy production facility, SPS array tooling, depot, laser powered test vehicle
arth and ellar 005 sec		<±1°	20	10K to 100K	√	50-100	Share MDSL module, target satellites, (1) pallet
arth and ellar 005 sec		<±1°	20	10K to 100K	√	50-100	Optical sensor development module,
C	1	Comfort Zone	20CFM	Class 100,000	<0.01g/<60db	80-100	Share MDSL module, minilabs from spacelab
C	1		20CFM	Class 100,000	<0.01g/<60db	80-100	Life science module
C	1		20CFM	Class 100,000	<0.01g/<60db	80-100	Manned systems demo. module, 3-man airlock, attach struct. for assembly demo.
C	1		20CFM	Class 100,000	<0.01g/<60db	80-100	Life science module, special demo modules

FOLDOUT FRAME 2

Table 4-8

PROGRAM OPTION OBJECTIVE ELEMENTS

PROGRAM OPTIONS

OBJECTIVE ELEMENTS	I	A	B	C	D	E	H	3	A	B	C	D	E
SPS													
Component Development and Testing	84	84	84	84	84	84	84	84	84	84	84	84	84
Orbital Power Source							85						
Antenna Test (Mini Pilot Plant)				86		86	86				86		
SPS Pilot Plant (LEO)	91	91	91		88	91	91	91	91		91	91	91
SPS Pilot Plant (GEO)	93	93	93		89	93	93						
Space Processing													
Development and Test	84	84	84	84	84	84	84	84	84	84	84	84	84
Process Optimization	87	87	87	87	85	87	87	87	87	87	87	87	87
Silicon Ribbon Pilot Plant	90	90	90		87		90	90	90	90		90	90
Blanket Pilot Plant	90	90	90		87		90	90	90	90		90	90
Commercial Processing Pilot Plant			95		93			95	95	95	95	95	95
Earth Services													
4m Radiometer	84	84	84	84	84	84	84	84	84	84	84	84	84
30m Radiometer	90	90	90	90	87	85	85			90			90
100m Radiometer			90		87					90			90
300m Radiometer (LEO)			90		87					90			90
300m Radiometer (GEO)			90		87								
Multibeam Lens (LEO)			90		87								90
Multibeam Lens (GEO)			90		87								
Cross-Phased Array (LEO)			90		87					90			90
Cross-Phased Array (GEO)			90		87								
Multidiscipline Science Lab													
Basic Research – Min Level						84	84						
Basic Research – Maxi Level	84	84	84	84	84			84	84	84	84	84	84
Living and Working in Space													
Limited Research	84	84	84	84	84	84	84	84	84	84	84	84	84
Extensive Research	86	86	86	86	86	86	86	86	86	86	86	86	86
Demonstrate Techniques	91	91	91		88		91	91	91	91		91	91
Construction Support	91	91	91		88		91	91	91	91		91	91
Large Radio Telescope													
Component Development and Test	87	87	87	87	85	87	84						
Mark II Radio Telescope	90	90	90	90	87	90	85						
Test Operations	90	90	90	90	87	90	85						
Depot													
Component Development and Test	84	84	84		84		84	84	84	84	84	84	84
Large OTV Depot													
Small OTV Depot	91	91	91		91								91
Cluster													
MSPP													
Large Cluster Component Development	84	84	84	84	84	84	84	84	84	84	84	84	84
Large Cluster Pilot Plant													
Option Characteristics													
LEO Only								•	•	•	•	•	•
LEO + GEO Unmanned	•	•	•	•	•	•	•						
LEO + GEO Manned													
LEO + PEO													
Shuttle	188	121	256	136	302	88	130	97	71	135	64	98	185
HLLV		13							6				
OTV – Cargo	3	3	6	3	6		3						
OTV – Manned													

OBJECTIVE ELEMENTS	4	A	B	C	D	E	5	A	B	C	D
SPS											
Component Development and Testing	84	84	84	84	84	84	84	84	84	84	84
Orbital Power Source											
Antenna Test (Mini Pilot Plant)					86				86		
SPS Pilot Plant (LEO)	91	91	91			91					
SPS Pilot Plant (GEO)	93	93	93	93		93	93	93		93	93
Space Processing											
Development and Test	84	84	84	84	84	84	84	84	84	84	84
Process Optimization	87	87	87	87	87	87	87	87	87	87	87
Silicon Ribbon Pilot Plant	90	90	90	90		90	90	90	90	90	90
Blanket Pilot Plant	90	90	90	90		90	90	90	90	90	90
Commercial Processing Pilot Plant				95							95
Earth Services											
4m Radiometer				84			84	84	84	84	84
30m Radiometer				90			90	90	90	90	90
100m Radiometer				90							
300m Radiometer (LEO)				90							90
300m Radiometer (GEO)				90							90
Multibeam Lens (LEO)				90							90
Multibeam Lens (GEO)				90							90
Cross-Phased Array (LEO)				90							90
Cross-Phased Array (GEO)				90							90
Multidiscipline Science Lab											
Basic Research – Min Level											
Basic Research – Maxi Level	84	84	84	84	84	84	84	84	84	84	84
Living and Working in Space											
Limited Research	84	84	84	84	84	84	84	84	84	84	84
Extensive Research	86	86	86	86	86	86	86	86	86	86	86
Demonstrate Techniques	91	91	91	91		91	91	91	91	91	91
Construction Support	91	91	91	91		91	91	91	91	91	91
Large Radio Telescope											
Component Development and Test							87	87	87	87	
Mark II Radio Telescope							90	90	90	90	
Test Operations							90	90	90	90	
Depot											
Component Development and Test	84	84	84	84	84	84	84	84	84	84	84
Large OTV Depot	91	91	91	91	91	91	91	91	91	91	
Small OTV Depot											91
Cluster											
MSPP	90	90	90	90	90	90					90
Large Cluster Component Development	87	87	87	87	87	87	84	84	84	84	87
Large Cluster Pilot Plant	90	90	90	90	90	90					90
Option Characteristics											
LEO Only											
LEO + GEO Unmanned											
LEO + GEO Manned	S	S	S	S	S	S	P	P	P	P	P
LEO + PEO											
Shuttle	476	644	129	577	359	356	393	386	248	150	645
HLLV			76							62	
OTV – Cargo	26	50	26	32	2	26	38	38	38	38	44
OTV – Manned	29		29	29	29	29	28	26	22	28	38

OBJECTIVE ELEMENTS	9	A	B	C	D	14	A	B	C	D	E
SPS											
Component Development and Testing	84	84	84	84	84	84	84	84	84	84	84
Orbital Power Source											
Antenna Test (Mini Pilot Plant)				86					86		
SPS Pilot Plant (LEO)	91	91	91		91	91	91	91		91	88
SPS Pilot Plant (GEO)	93	93	93		93	93	93	93		93	89
Space Processing											
Development and Test	84	84	84	84	84	84	84	84	84	84	84
Process Optimization	87	87	87	87	87	87	87	87	87	87	85
Silicon Ribbon Pilot Plant	90	90	90		90	90	90	90		90	87
Blanket Pilot Plant	90	90	90		90	90	90	90		90	87
Commercial Processing Pilot Plant								95		95	93
Earth Services											
4m Radiometer						84	84	84	84	84	84
30m Radiometer						90	90	90	90	90	85
100m Radiometer								90		90	87
300m Radiometer (LEO)								90		90	87
300m Radiometer (GEO)								90		90	87
Multibeam Lens (LEO)										90	87
Multibeam Lens (GEO)										90	87
Cross-Phased Array (LEO)								90		90	87
Cross-Phased Array (GEO)								90		90	87
Multidiscipline Science Lab											
Basic Research – Min Level											
Basic Research – Maxi Level	84	84	84	84	84	84	84	84	84	84	84
Living and Working in Space											
Limited Research	84	84	84	84	84	84	84	84	84	84	84
Extensive Research	86	86	86	86	86	86	86	86	86	86	86
Demonstrate Techniques	91	91	91		91	91	91	91		91	88
Construction Support	91	91	91		91	91	91	91		91	88
Large Radio Telescope											
Component Development and Test						87	87	87	87	87	85
Mark II Radio Telescope						90	90	90	90	90	88
Test Operations						90	90	90	90	90	88
Depot											
Component Development and Test	84	84	84	84	84	84	84	84	84	84	84
Large OTV Depot	91	91	91	91	91	91	91	91	91	91	91
Small OTV Depot											
Cluster											
MSPP	90	90		90	90					90	87
Large Cluster Component Development	87	87	84	87	87	84	84	84	84	87	84
Large Cluster Pilot Plant	90	90		90	90					90	87
Option Characteristics											
LEO Only											
LEO + GEO Unmanned											
LEO + GEO Manned	P	P	P	P	P	P	P	P	P	P	P
LEO + PEO											
Shuttle	357	234	252	289	139	251	177	348	193	488	477
HLLV					55		20				
OTV – Cargo	7	8	7	7	7	3	3	9	3	9	9
OTV – Manned	15	15	15	15	15	16	16	16	16	20	17

OBJECTIVE ELEMENTS	16	A	B	C	D	E	F	G	17	A
SPS										
Component Development and Testing	84	84	84	84	84	84	84	84	84	84
Orbital Power Source										
Antenna Test (Mini Pilot Plant)					86					
SPS Pilot Plant (LEO)	91	91	91	91		91	91	88	91	91
SPS Pilot Plant (GEO)	93	93	93	93		93	93	89		
Space Processing										
Development and Test	84	84	84	84	84	84	84	84	84	84
Process Optimization	87	87	87	87	87	87	87	85	87	87
Silicon Ribbon Pilot Plant	90	90	90	90		90	90	87	90	90
Blanket Pilot Plant	90	90	90	90		90	90	87	90	90
Commercial Processing Pilot Plant				95			95	93	95	95
Earth Services										
4m Radiometer	84	84	84	84	84	84	84	84	84	84
30m Radiometer	90	90	90	90	90	90	90	87	90	90
100m Radiometer				90			90	87	90	90
300m Radiometer (LEO)				90			90	87	90	90
300m Radiometer (GEO)				90			90	87		
Multibeam Lens (LEO)	90	90	90	90	90	90	90	87	90	90
Multibeam Lens (GEO)	90	90	90	90	90	90	90	87		
Cross-Phased Array (LEO)				90			90	87	90	90
Cross-Phased Array (GEO)				90			90	87		
Multidiscipline Science Lab										
Basic Research – Min Level										
Basic Research – Maxi Level	84	84	84	84	84	84	84	84	84	84
Living and Working in Space										
Limited Research	84	84	84	84	84	84	84	84	84	84
Extensive Research	86	86	86	86	86	86	86	86	86	86
Demonstrate Techniques	91	91	91	91	91	91	91	88	91	91
Construction Support	91	91	91	91	91	91	91	88	91	91
Large Radio Telescope										
Component Development and Test							87	85		
Mark II Radio Telescope							90	88		
Test Operations							90	88		
Depot										
Component Development and Test	84	84	84	84	84	84	84	84	84	84
Large OTV Depot	91	91	91	91	91	91	91	88		
Small OTV Depot				91			91	88	91	91
Cluster										
MSPP	90	90	90	90	90		90	87	84	84
Large Cluster Component Development	87	87	87	87	87		87	85	84	84
Large Cluster Pilot Plant	90	90	90	90	90		90	87		
Option Characteristics										
LEO Only										
LEO + GEO Unmanned										
LEO + GEO Manned	S	S	S	S	S	S	S	S		
LEO + PEO									S	P
Shuttle	426	686	166	507	364	306	486	531	193	212
HLLV			63							
OTV – Cargo	3	254	3	9	3	3	9	9		
OTV – Manned	29		29	29	29	29	29	29		

4.3 SELECTION/DESCRIPTION OF CANDIDATE PROGRAM OPTIONS

The 45 program options defined by Table 4-8 were developed in detail. The elements of the figure were integrated for each option and the hardware elements, manning requirements, transportation, power levels, and space station configuration concept was determined. The cost was then developed for each option.

The selection process was designed to select a set of 8 to 10 options that could be refined further and then recommended to NASA/JSC as candidate options for Part 2 of this Space Station study.

The selection of options was made from an original population of 45 by evaluating the options relative to each other with respect to a specific set of selection considerations. These considerations were:

1. Achievement Level. How much does each option accomplish? An additional consideration within this category was early achievement because early efforts in large structures, SPS, and space processing were considered to be especially significant.
2. Potential Revenue Return. To what extent does each option offer the potential to produce revenue?
3. Technical Risk. How much technical risk is inherent in each option?
4. Growth Potential (flexibility of approach). How easy would it be to redirect each option in the event a change in direction was necessary after the effort was started?
5. Transportation. What transportation implications are inherent within each option? New or expensive developments were especially critical.
6. Unique Features. Are there unique features that make an option especially attractive?
7. Cost. What is the cost of each option including annual funding level, and cumulative or total program cost? An important additional consideration was the cost of the initial program because, in a short-term sense, this is an important parameter.

C.2

Having the relative evaluations of the options, it was possible to select seven options which covered a broad range of cost and achievement, with each of the seven being judged the best option in its particular range. This is schematically shown by the seven bars in Figure 4-4.

As expected, an increased level of accomplishment required increased capability and corresponding cost increases. Figure 4-5 relates the cost of each of the seven program options with its corresponding level of accomplishment Those data points near the dark line represents the most cost-effective program options. The solid data points represent the seven options selected as a base for future analyses. Five of them lie along the cost-effective boundary of the data. The two lower selected points are a polar option and a geosynchronous option serviced with a sortie operational mode; they were carried further to assess their potential in more detail, since they were judged to offer potentially unique advantages.

CR84

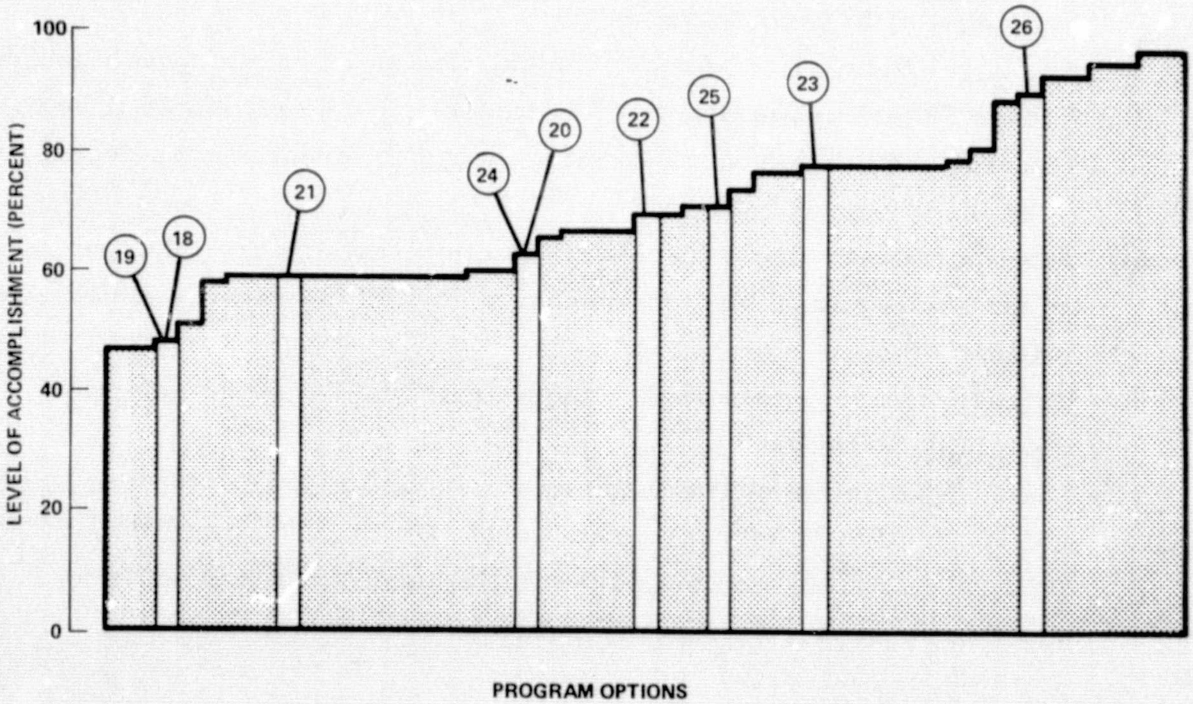


Figure 4-4. Selection of Candidate Options

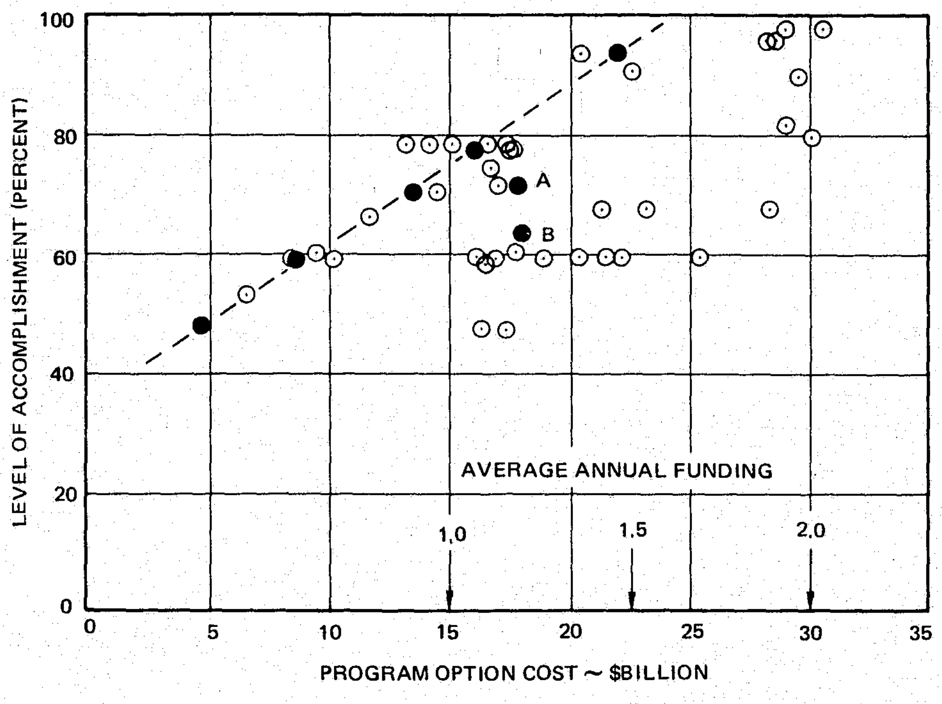


Figure 4-5. Option Cost Effectiveness

Each of these options was then reviewed with NASA/JSC and subsequently modified to include some additional features; also two additional options were defined (18 and 20). These nine options, indicated by the circled numbers in Figure 4-4, were then refined and constitute the set of options that are can candidates to be carried into Part 2 of this study.

These candidate options are described in terms of achievement, Space Station elements, schedule, transportation requirements, and cost. An overall description of the objective elements that are included in each candidate option is given in Figure 4-6.

The cost is divided into three elements, basic station, mission hardware, and transportation, and each of these is further segregated into two time periods, the initial program and the total program. The basic station includes the Space Station functions that are common to all options such as power, crew, control, cargo, core (berthing), fabrication and assembly, and crane. The mission hardware includes the modules and equipment that are required to

OBJECTIVE ELEMENT	OPTION NUMBER 18	19	20	21	22	23	24	25 LEO	25 PEO	26
SATELLITE POWER SYSTEM										
COMP DEVELOPMENT & TESTING	●	●	●	●	●	●	●	●	–	●
SPS PILOT PLANT I	●	●	●	●	●	●	●	–	–	●
SPS PILOT PLANT II (LEO)	–	–	–	●	●	–	–	●	–	●
SPS PILOT PLANT II (GEO)	–	–	–	–	–	●	–	–	–	●
SPACE PROCESSING										
PROCESS DEVELOPMENT & TEST	●	●	●	●	●	●	●	●	●	●
PROCESS OPTIMIZATION	●	●	●	●	●	●	●	●	–	●
SILICON RIBBON PILOT PLANT	–	–	–	●	●	●	–	●	–	●
BLANKET PILOT PLANT	–	–	–	●	●	●	–	●	–	●
COMMERCIAL PROCESSING PILOT PLANT	–	●	●	●	–	–	–	●	–	●
EARTH SERVICES										
30 METER RADIOMETER	●	●	●	●	●	●	●	–	●	●
100 METER RADIOMETER	–	–	●	●	●	●	–	–	●	●
300 METER RADIOMETER (LEO)	–	–	–	–	–	–	–	●	–	●
300 METER RADIOMETER (GEO)	–	–	–	–	–	–	–	–	–	●
MULTI-BEAM LENS (LEO)	–	–	●	–	●	–	●	●	–	●
MULTI-BEAM LENS (GEO)	–	–	●	–	●	–	●	–	–	●
CROSS PHASED ARRAY (LEO)	–	–	–	–	–	–	–	●	–	●
CROSS PHASED ARRAY (GEO)	–	–	–	–	–	–	–	–	–	●
MULTIDISCIPLINE SCIENCE LABORATORY										
BASIC RESEARCH – MIN-LEVEL	●	●	●	●	●	–	–	–	–	–
BASIC RESEARCH – MAX.-LEVEL	–	–	–	–	–	●	●	●	–	●
LIVING & WORKING IN SPACE										
LIMITED RESEARCH	●	●	●	●	●	●	●	●	●	●
EXTENSIVE RESEARCH	–	●	●	●	●	●	●	●	–	●
DEMONSTRATE TECHNIQUES	–	–	–	●	●	●	–	●	–	●
CONSTRUCTION SUPPORT	–	–	–	●	●	●	–	●	–	●
SPACE COSMOLOGICAL RESEARCH & DEV.										
COMPONENT DEVELOPMENT AND TEST	–	–	–	●	–	●	–	–	–	●
MARK II RADIO TELESCOPE	–	–	–	–	–	●	–	–	–	●
TEST OPERATIONS (GEO)	–	–	–	–	–	●	–	–		●
DEPOT										
COMPONENT DEVELOPMENT AND TEST	●	●	●	●	●	●	●	●	–	●
LARGE OTV DEPOT	–	–	–	–	–	●	●	–	–	●
SMALL OTV DEPOT	–	–	●	–	–	–	–	●	–	●
CLUSTER										
MSPP	●	●	●	●	●	●	●	●	–	●
LARGE CLUSTER COMPONENT DEVELOPMENT	–	●	●	●	●	●	●	●	–	●
LARGE CLUSTER PILOT PLANT (GEO)	–	–	–	–	–	–	●	–	–	●
SENSOR DEVELOPMENT										
DEVELOPMENT AND TEST	●	●	–	●	●	●	●	●	●	●
FABRICATION AND EVALUATION	–	●	–	●	●	●	●	●	●	●

Figure 4-6. Candidate Option Program Content

make the products for each objective element that is included in a particular option, such as a biologicals module for Space Processing process optimization, or the material and specific tooling required to construct a 100m radiometer. The transportation includes the total cost of carrying the material to orbit that is required for each option, and any transportation element development cost that may be required for a specific option, such as an orbital transfer vehicle. The initial program period includes those activities that occur prior to any Space Station growth, which is generally about 1986.

4.3.1 Program Option 18

Program Option 18 is summarized by Figures 4-7 through 4-10. The main thrust of this option is early achievements in large space structures, SPS test and construction, and space processing. Later activities have been very limited to reduce the total program cost. The option features a low earth orbit (LEO) construction base and, since all activities are limited to LEO, only Shuttle flights are required.

The initial Space Station is sized for a crew of 10 men, with 5 being launched initially and 5 more about a year later to support increased activity for SPS Pilot Plant I. Since later activities do not require any additional crew increase, this station configuration was intentionally kept as simple as possible by combining the crew and operations functions into a single module and eliminating the core (berthing) module. Although this resulted in the smallest number of modules (8) of any of the option configurations, it does make later station growth more difficult.

The initial program major activities accomplished in this option are: (1) SPS Component Development and Test in 1984, featuring the construction on orbit of an 86m, linear, tapered array antenna to conduct tests for phase control, beam mapping, RFI effects, and microwave tube contamination, and the construction on orbit of a 52m solar collector and array to demonstrate construction techniques and provide additional power for SPS testing; (2) the construction on orbit of SPS Pilot Plant I in 1985 for an integrated SPS system feasibility demonstration of fabrication, operation, and system performance to verify the techniques that will later be used for an SPS prototype; (3) Space Processing Process Development and Test in 1984 to evaluate basic processes for biologicals, inorganics, and silicon-ribbon to determine those processes that are suitable for volume production application; (4) Earth Services 30m radiometer construction on orbit in 1985 to evaluate construction techniques and productivity, and conduct system performance tests and develop data processing techniques. The Multidiscipline Science Lab (MDSL) is activated in 1984 with a crew of two devoted to space-based research in the basic sciences. The remaining objectives are supported

CR84

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84), PILOT PLANT I (85)	
SPACE PROCESSING	PROCESS DEVELOPMENT (84)	PROCESS OPTIMIZATION (87)
EARTH SERVICES	30M RADIOMETER (85)	
MDSL	MINIMUM LEVEL (85)	
LIVING AND WORKING	LIMITED RESEARCH (84)	
DEPOT	COMPONENT DEVELOPMENT (84)	
CLUSTER	MSPP (84), ORBITAL POWER (85)	
SENSOR	DEVELOPMENT TESTING (84)	

CONSTRUCTION BASE HARDWARE	INITIAL STATION	GROWTH STATION ADDITION
POWER MODULE	1	0
CREW/OPERATIONS (MEN)	1 (5/10)	0 (0)
CORE MODULE	1	0
FABRICATION AND ASSEMBLY MODULE	1	0
CARGO MODULE	1	0
CRANE	1	0
MISSION HARDWARE		
MULTIDISCIPLINE SCIENCE LAB	1	0
RESEARCH SUPPORT MODULE	2	0

OPTION FEATURES

LEO SPACE STATION AND CONSTRUCTION BASE

Figure 4-7. Selected Option Descriptions, Option 18

CR84

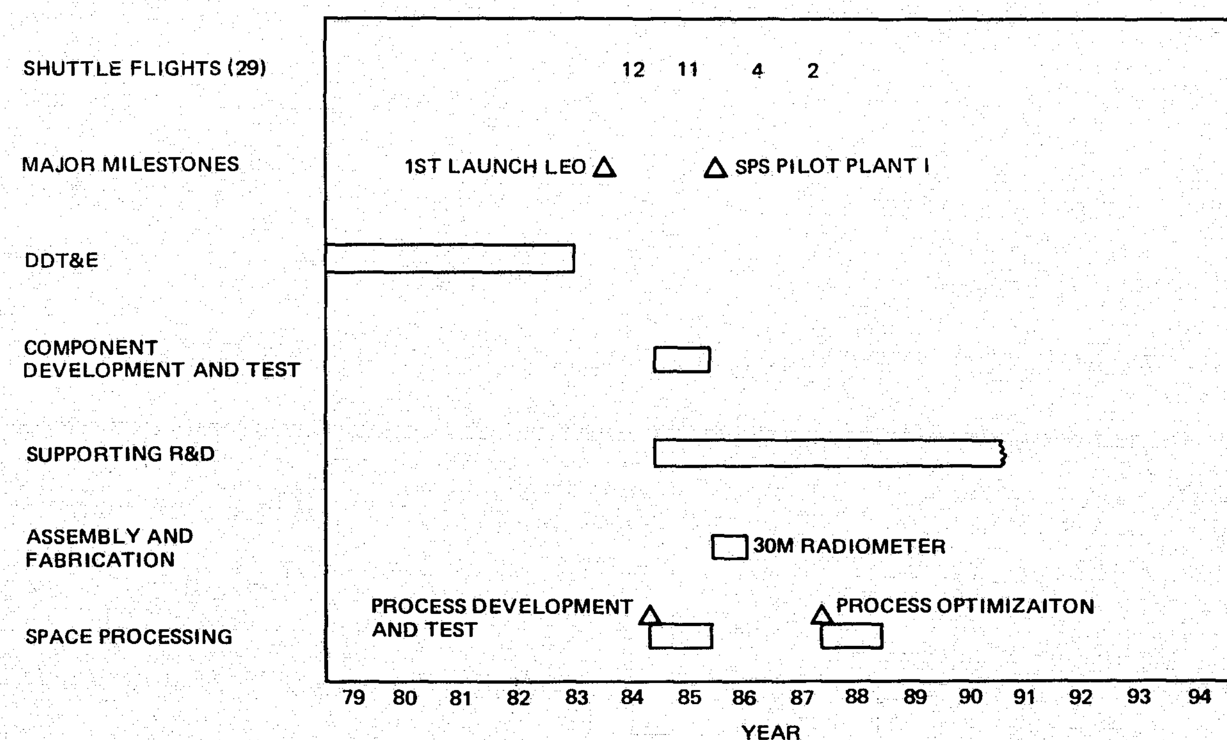


Figure 4-8. Candidate Option 18, Schedule and Transportation

ORIGINAL PAGE IS OF POOR QUALITY

CR84

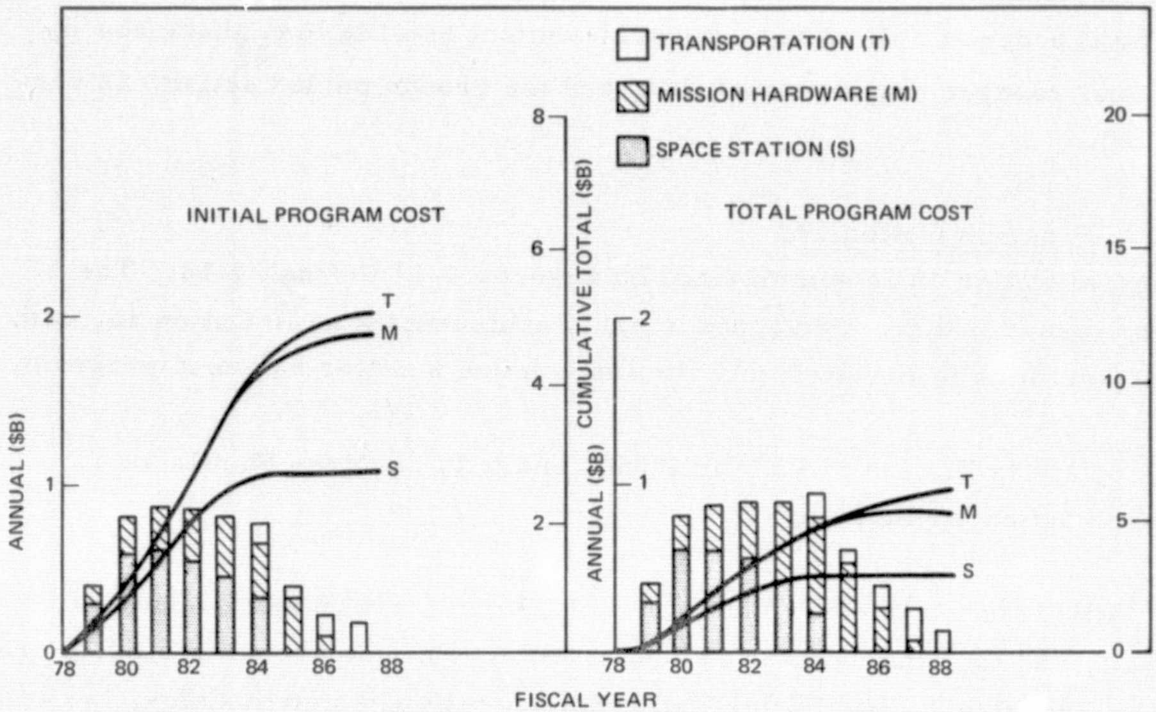


Figure 4-9. Candidate Option 18, Cost

CR84

STRENGTHS	WEAKNESSES
ACHIEVEMENTS SPS PILOT PLANT I 30M RADIOMETER	LOW ACHIEVEMENTS EARTH SERVICES SPACE PROCESSING NO POTENTIAL REVENUE ELEMENTS
EARLY ACCOMPLISHMENT LARGE SPACE STRUCTURES SPS CONSTRUCTION AND TEST SPACE PROCESSING PROCESS DEVELOPMENT	REDUCED MDSL CAPABILITY NO SPACE COSMOLOGY REDUCED LIVING/WORKING CAPABILITY REDUCED SENSOR DEVELOPMENT CAPABILITY
TRANSPORTATION ELEMENTS SHUTTLE	NO POLAR ORBIT ADVANTAGES
LOWEST COST	

	COST ($B) INITIAL PROGRAM	TOTAL PROGRAM
BASIC STATION	2.6	2.6
MISSION HARDWARE	2.0	2.7
TRANSPORTATION	0.4	0.5
TOTAL	5.0	5.8

Figure 4-10. Candidate Options Descriptions,Option 18

at a minimum level with the exception of Space Cosmology, which is not addressed in this option.

The growth period for this option is limited to Space Processing Process Optimization in 1987. This activity includes dedicated modules for biologicals and inorganics to develop the respective processes for quantity production.

This option has the lowest costs of all the options both for the initial program and total program. However, the achievement level is low, there are no potential revenue elements included, and the growth period activity is very limited.

4.3.2 Program Option 19

Program Option 19 is summarized by Figures 4-11 through 4-14. The major thrust of this option again is early achievement as in Option 18, with some additions to the later activities to achieve a better balanced program.

This option is limited to LEO activities and only requires Shuttle as a transportation element.

The initial station is sized for a crew of 10 men, with 6 being launched initially and the other 4 later to support SPS. For the growth period, a crew of 18 is required. The initial station configuration has 10 modules, the additions from Option 18 being required to facilitate the later growth required. Separate crew and operations modules are provided, and a core (berthing) module is included to facilitate the docking of additional modules required for growth. This station has good additional growth capability if required.

The initial program activities for this option are the same as in Option 18 except that Component Development for the Cluster Objective has been added in 1984 to start development of laser-power transfer techniques and components.

During the growth period, the Space Processing Commercial Pilot Plant module has been added in 1990 to allow quantity production of products for sale on a commercial basis; Living and Working in Space activity has been increased to include a dedicated module for the Extensive Research level in 1986; and the sensor objective has been augmented by adding a dedicated module for the Fabrication and Evaluation level in 1988 to develop and fabricate optical sensors in space.

Although this option still has a relatively low initial program cost, the total program cost has been increased modestly. The achievement level is better balanced but Earth Services is still somewhat weak.

CR84

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84), PILOT PLANT I (85)	
SPACE PROCESSING	PROC DEVELOPMENT (84)	PROCESS OPTIMIZATION (87), COMM PILOT PLANT (90)
EARTH SERVICES	30M RADIOMETER (85)	
MDSL	MINIMUM LEVEL (85)	
LIVING AND WORKING	LIMITED RESEARCH (84)	EXTENSIVE RESEARCH (86)
DEPOT	COMPONENT DEVELOPMENT (84)	
CLUSTER	MSPP (84), COMPONENT DEVELOPMENT (84)	
SENSOR	DEVELOPMENT TESTING (84)	FABRICATION AND EVALUATION (88)

CONSTRUCTION BASE HARDWARE	INITIAL STATION	GROWTH STATION ADDITION
POWER MODULE	1	0
CREW MODULE (MEN)	1 (6/10)	1 (8)
CONTROL CENTER	1	0
CORE MODULE	1	0
FABRICATION AND ASSEMBLY	1	0
CARGO MODULE	1	0
CRANE	1	0
MISSION HARDWARE		
LAB MODULE	1	1
LAB SUPPORT MODULE	2	2
OTHERS AS REQUIRED		

OPTION FEATURES

LEO SPACE STATION AND CONSTRUCTION BASE

Figure 4-11. Candidate Option Descriptions,Option 19

CR84

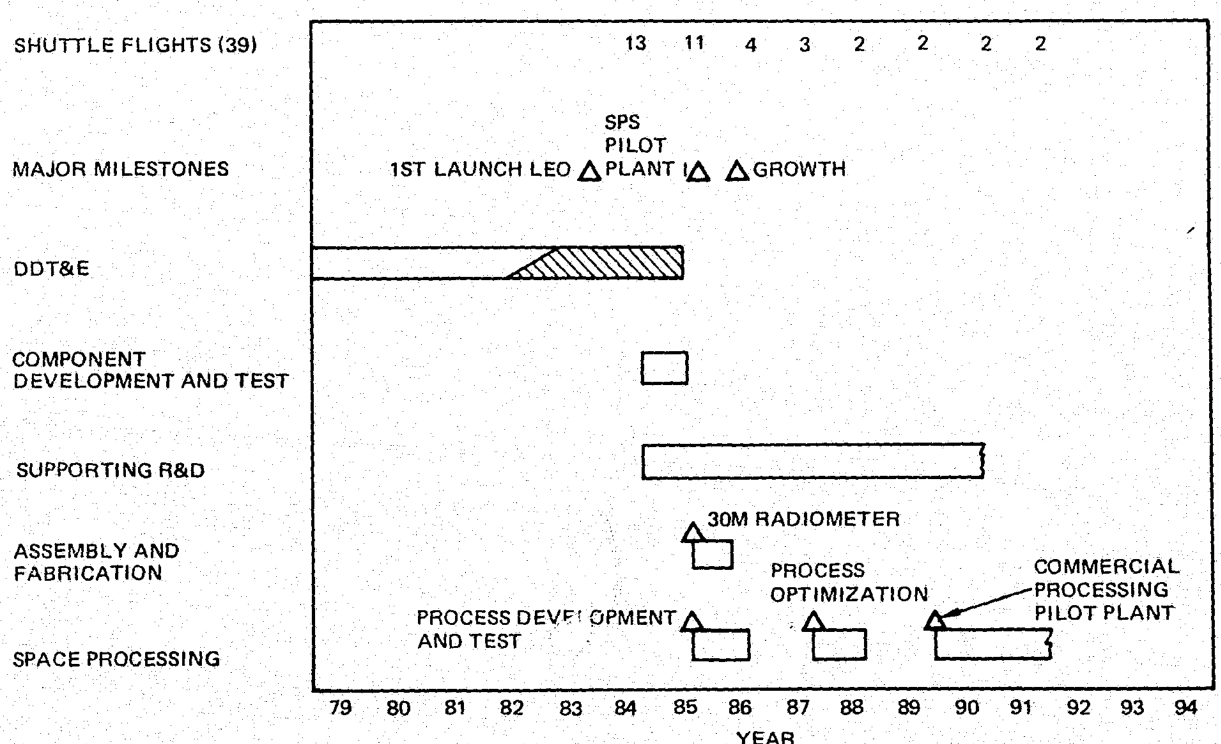


Figure 4-12. Candidate Option 19, Schedule and Transportation

CR84

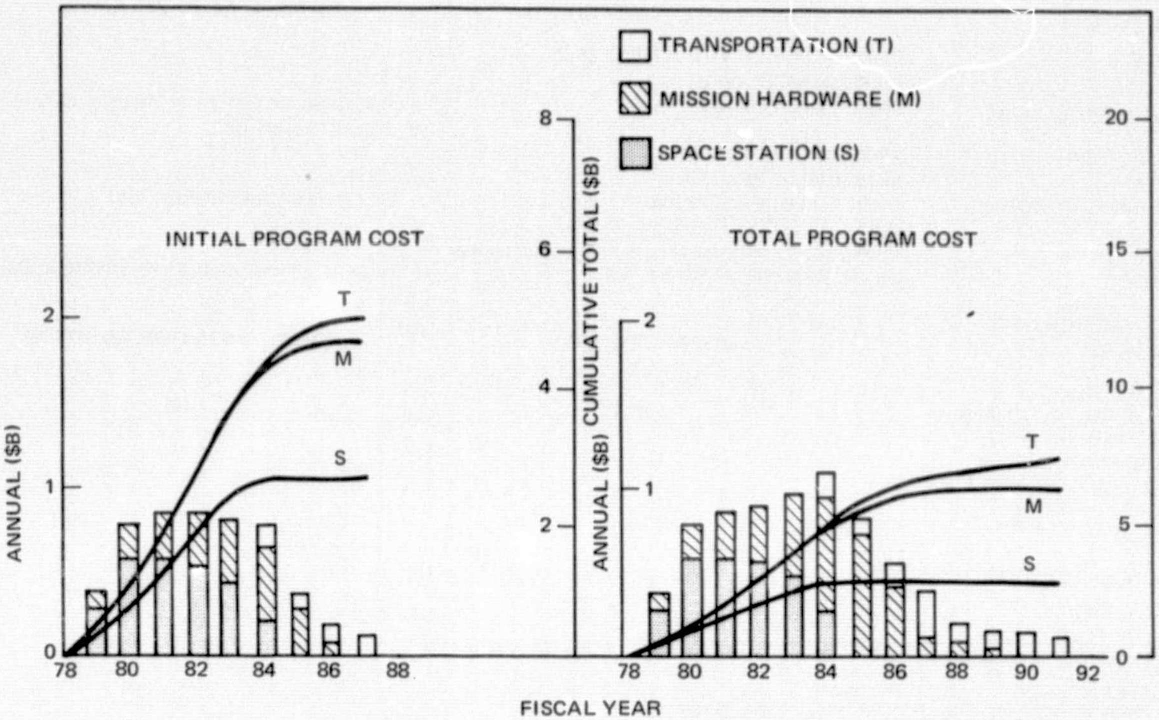


Figure 4-13. Candidate Option 19, Cost

CR84

STRENGTHS

ACHIEVEMENTS
- SPS PILOT PLANT I
- 30M RADIOMETER
- COMMERCIAL SPACE PROCESSING PILOT PLANT

EARLY ACCOMPLISHMENT
- LARGE SPACE STRUCTURES
- SPS CONSTRUCTION AND TEST
- SPACE PROCESSING PROCESS DEVELOPMENT

POTENTIAL REVENUE RETURN
- COMMERCIAL SPACE PROCESSING PILOT PLANT

TRANSPORTATION ELEMENTS
- SHUTTLE

WEAKNESSES

LOW ACHIEVEMENTS
- EARTH SERVICES

REDUCED MDSL CAPABILITY

NO SPACE COSMOLOGY

NO POLAR ORBIT ADVANTAGES

	COST ($B) INITIAL PROGRAM	TOTAL PROGRAM
BASIC STATION	2.7	2.7
MISSION HARDWARE	2.0	3.4
TRANSPORTATION	0.4	1.1
TOTAL	5.1	7.2

Figure 4-14. Candidate Options Descriptions, Option 19

4.3.3 Program Option 20

Program Option 20 is summarized by Figures 4-15 through 4-18. This option adds activities into the growth period, especially the construction and test of large Earth Services antennas, including the first deployment to geosynchronous orbit (GEO), which requires an Unmanned-Orbital-Transfer Vehicle (UM-OTV). An additional objective (sensor) is eliminated. Thus, this option supports all but two of the total complement of objectives.

The initial program in this option is virtually the same as for Option 19; therefore, the initial Space Station and crew complement are the same. The growth-period station has one less module (dedicated sensor module) but the crew size is about the same because of the additional growth activities.

The growth period additions for this option are the 100m radiometer (1988) and the multibeam lens communications antenna (1990) for the Earth Services objective. The former provides large structure construction productivity, earth observation performance verification, and signature data. The latter provides system performance verification for a large, multiple-access communications antenna, and demonstrates transportation of large elements to GEO using an unmanned orbital transfer vehicle. The Small OTV Depot is added in 1989 which provides the facilities to routinely launch small, unmanned satellites to higher orbits and interplanetary spacecraft by using the Space Station as a staging base.

The initial program cost for this option is the same as for Option 19; however, the additional growth items further increase the total program cost and peak annual funding.

4.3.4 Program Option 21

Program Option 21 is summarized by Figures 4-19 through 4-22. This option places heavy emphasis on growth period SPS activities while maintaining a reasonable balance among the other objectives. All nine objectives are supported by this option to some degree.

The initial station and crew size are identical to those for Option 19. The growth station has the same number of modules as in Option 19, but an

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84), PILOT PLANT I (85)	
SPACE PROCESSING	PROC DEVELOPMENT (84)	PROCESS OPTIMIZATION (87), COMM PILOT PLANT (90)
EARTH SERVICES	30M RADIOMETER (85)	100M RADIOMETER (88), MULTILENS (90)
MDSL	MINIMUM LEVEL (85)	
LIVING AND WORKING	LIMITED RESEARCH (84)	EXTENSIVE RESEARCH (86),
DEPOT	COMPONENT DEVELOPMENT (84)	SMALL OTV DEPOT (89)
CLUSTER	MSPP (84), COMPONENT DEVELOPMENT (84)	
SENSOR		

CONSTRUCTION BASE HARDWARE	INITIAL STATION	GROWTH STATION ADDITION
POWER MODULE	1	0
CREW MODULE (5)	1 (6/10)	1 (9)
CONTROL CENTER	1	0
CORE MODULE	1	0
FABRICATION AND ASSEMBLY	1	0
CARGO MODULE	1	0
CRANE	1	0

MISSION HARDWARE		
LAB MODULE	1	1
LAB SUPPORT MODULE	2	1
OTHERS AS REQUIRED		

OPTION FEATURES

LEO SPACE STATION AND CONSTRUCTION BASE, GEO TEST OF MULTIBEAM ANTENNA (UNMANNED)

Figure 4-15. Candidate Option Descriptions,Option 20

CR84

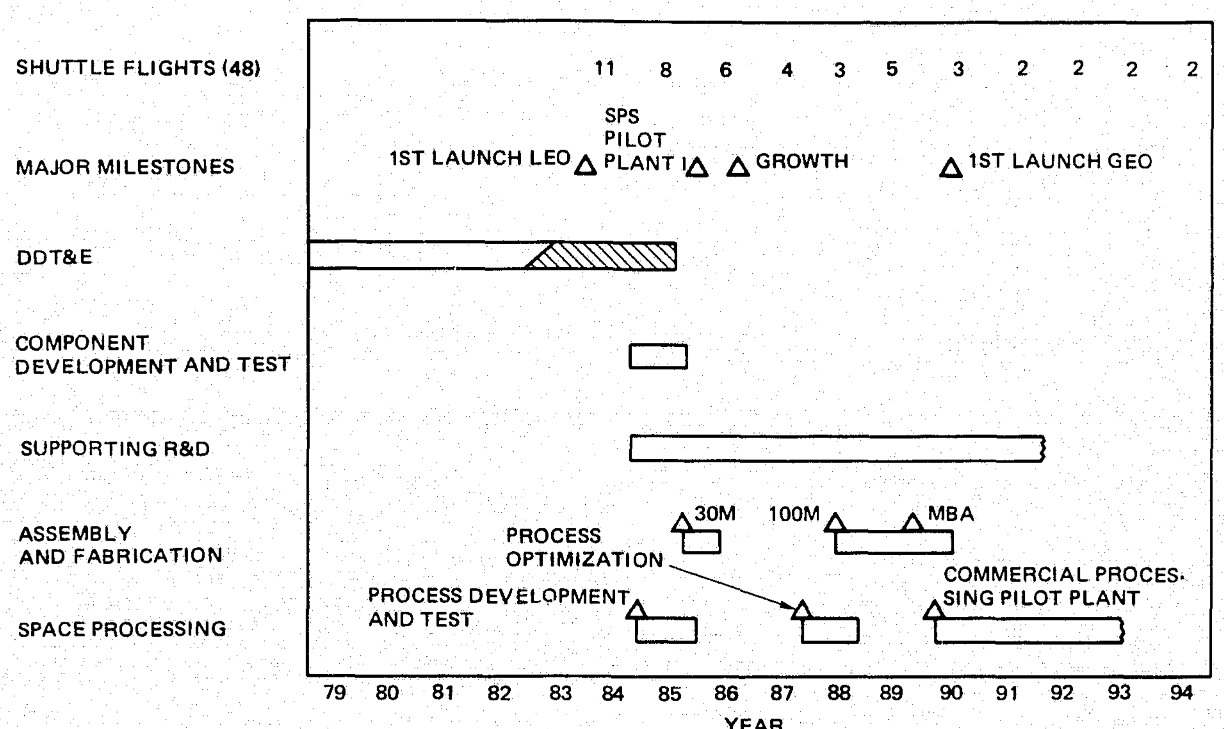


Figure 4-16. Candidate Option 20, Schedule and Transportation

ORIGINAL PAGE IS OF POOR QUALITY

CR84

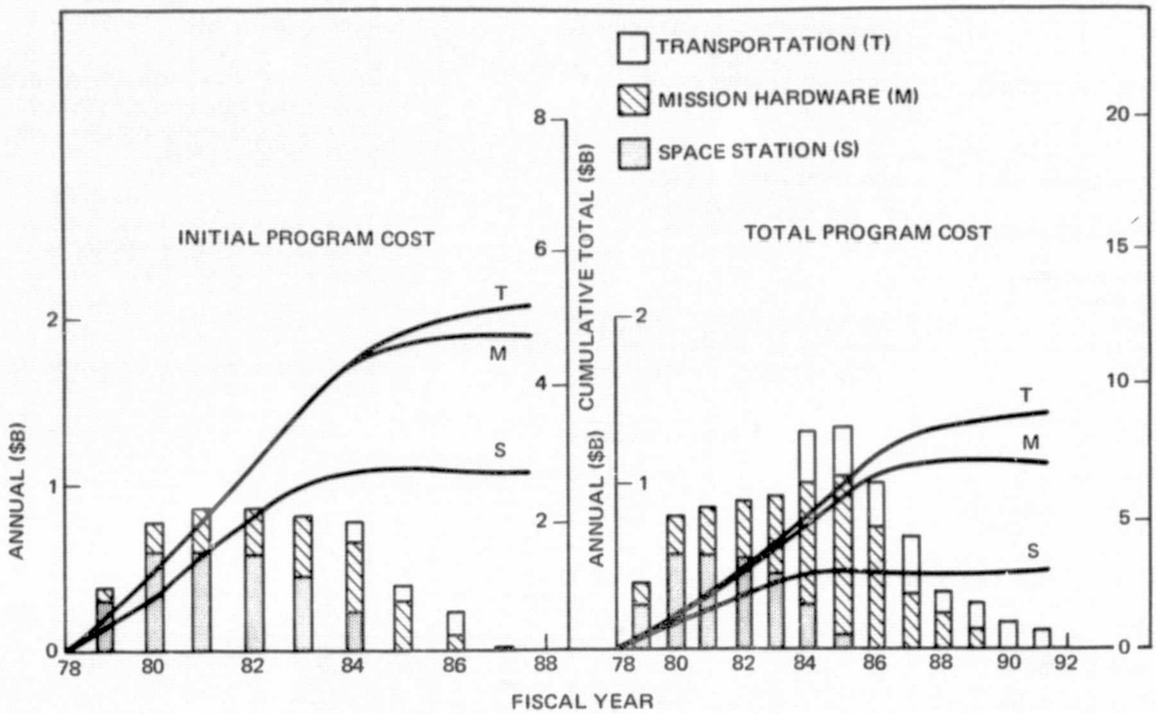


Figure 4-17. Candidate Option 20, Cost

CR84

STRENGTHS	WEAKNESSES
ACHIEVEMENTS	
SPS PILOT PLANT I	REDUCED MDSL CAPABILITY
COMMERCIAL SPACE PROCESSING PILOT PLANT	NO SENSOR DEVELOPMENT
30 AND 100M RADIOMETERS	NO SPACE COSMOLOGY
MULTIBEAM COMMUNICATIONS ANTENNA	NO POLAR ORBIT ADVANTAGES

EARLY ACCOMPLISHMENT
- LARGE SPACE STRUCTURES
- SPS CONSTRUCTION AND TEST
- SPACE PROCESSING PROCESS DEVELOPMENT

POTENTIAL REVENUE RETURN
- COMMERCIAL SPACE PROCESSING PILOT PLANT
- MULTIBEAM LENS COMMUNICATION
- SMALL OTV DEPOT

TRANSPORTATION ELEMENTS
- SHUTTLE
- OTV-UM

	COST ($B) INITIAL PROGRAM	TOTAL PROGRAM
BASIC STATION	2.7	2.7
MISSION HARDWARE	2.0	4.4
TRANSPORTATION	0.4	1.7
TOTAL	5.1	8.8

Figure 4-18. Candidate Options Description,Option 20

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84), PILOT PLANT I (85)	PILOT PLANT II (91)
SPACE PROCESSING	PROC DEVELOPMENT (84)	PROCESS OPTIMIZATION (87), RIBBON PILOT PLANT (90), BLANKET PILOT PLANT (90), COMM PILOT PLANT (93) 100M RADIOMETER (88)
EARTH SERVICES	30M RADIOMETER (85)	
MDSL	MINIMUM LEVEL (85)	
LIVING AND WORKING	LIMITED RESEARCH (84)	EXTENSIVE RESEARCH (86), DEMO (90), CONSTRUCTION SUPPORT (91)
COSMOLOGICAL RESEARCH		COMP DEVELOPMENT (87)
DEPOT	COMPONENT DEVELOPMENT (84)	
CLUSTER	MSPP (84), COMPONENT DEVELOPMENT (84)	
SENSOR	DEVELOPMENT TESTING (84)	FABRICATION AND EVALUATION (88)

CONSTRUCTION BASE HARDWARE	INITIAL STATION	GROWTH STATION ADDITION
POWER MODULE	1	0
CREW MODULE (MEN)	1 (6/10)	1 (9)
CONTROL CENTER	1	0
CORE MODULE	1	0
FABRICATION AND ASSEMBLY	1	0
CARGO MODULE	1	0
CRANE	1	0
MISSION HARDWARE		
LAB MODULE	1	1
RESEARCH SUPPORT LAB	2	2
OTHERS AS REQUIRED		

OPTION FEATURES
LEO SPACE STATION AND CONSTRUCTION BASE

Figure 4-19. Candidate Option Description,Option 21

CR84

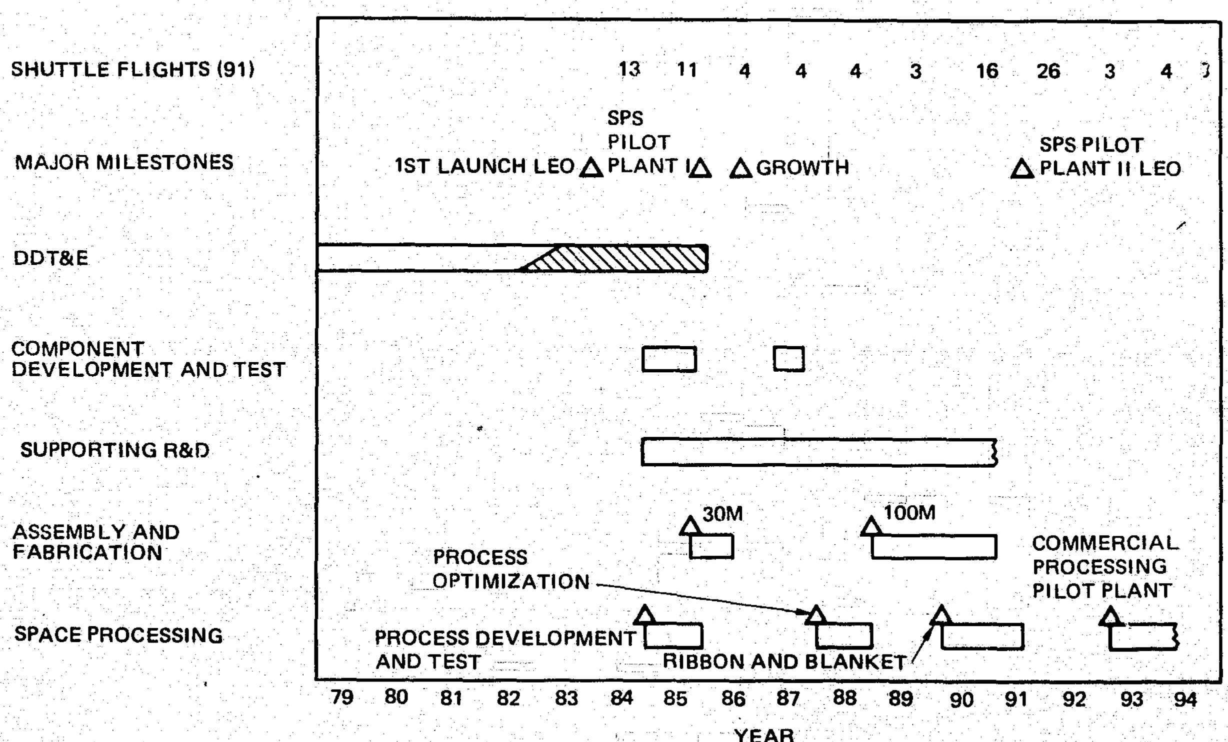


Figure 4-20. Candidate Option 21, Schedule and Transportation

CR84

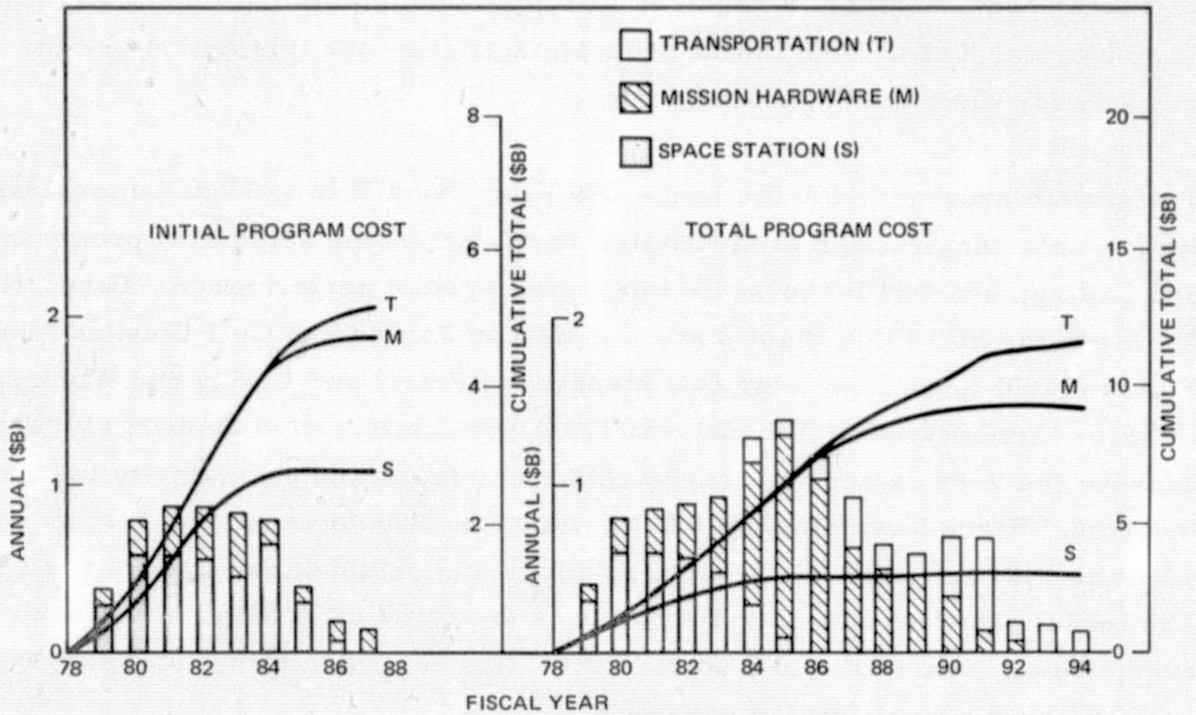


Figure 4-21. Candidate Option 21, Cost

CR84

STRENGTHS	WEAKNESSES
ACHIEVEMENTS	REDUCED MDSL CAPABILITY
SPS PILOT PLANTS I AND II	
COMMERCIAL SPACE PROCESSING PILOT PLANT	NO POLAR ORBIT ADVANTAGES
30 AND 100M RADIOMETERS	
ALL OBJECTIVES INCLUDED	
EARLY ACCOMPLISHMENT	
LARGE SPACE STRUCTURES	
SPS CONSTRUCTION AND TEST	
SPACE PROCESSING PROCESS DEVELOPMENT	
POTENTIAL REVENUE RETURN	
SILICON RIBBON PILOT PLANT	
COMMERCIAL SPACE PROCESSING PILOT PLANT	
TRANSPORTATION ELEMENTS	
SHUTTLE	

ORIGINAL PAGE IS OF POOR QUALITY

	COST ($B) INITIAL PROGRAM	TOTAL PROGRAM
BASIC STATION	2.7	2.7
MISSION HARDWARE	2.0	6.5
TRANSPORTATION	0.4	2.1
TOTAL	5.1	11.3

Figure 4-22. Candidate Options Descriptions,Option 21

additional crew member is required to support the additional objective (Space Cosmological R&D). The initial program activities for this option are the same as for Options 18 and 19.

The growth program adds the large SPS Pilot Plant II in 1991 to demonstrate large-scale construction productivity, verify prototype automated processes and tooling, and test large-scale integrated system performance. Supporting elements for SPS Pilot Plant 2 are the Silicon Ribbon and Cell Blanket Pilot Plants (1990) to furnish solar cell blanket material, and Living and Working in Space Demonstration Techniques (1990) and Construction Support (1991) to address the very extensive man-machine interfaces and productivity issues involved. Space Cosmological R&D Component Development and Test is added in 1987 to conduct low-noise receiver and antenna feed system tests. The initial program cost for this option is the same as for Option 20; however, the addition of the SPS Pilot Plant II has raised both the total program cost and peak annual funding substantially.

4.3.5 Program Option 22

Program Option 22 is summarized by Figures 4-23 through 4-26. This option is very similar to Option 21, the differences being more content in the Earth Services antenna construction and less in Space Processing, and no Space Cosmology objective activities.

These activities require a LEO Space Station and construction base with some elements being delivered to geosynchronous orbit for testing. Thus the Shuttle and UM-OTV are required for transportation.

The initial program, initial Space Station, and initial crew are identical to Option 21. The growth station configuration is the same as Option 21 but one additional crew member is required to support the larger communications antenna construction.

For the growth program, the 100m radiometer (1988) and the multibeam lens communications antenna (1990) have been added, and the Space Processing Commercial Processing Pilot Plant and Space Cosmological R&D Component Development have been deleted when compared to Option 21.

CR84

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84), PILOT PLANT I (85)	PILOT PLANT II (91)
SPACE PROCESSING	PROC DEVELOPMENT (84)	PROCESS OPTIMIZATION (87), RIBBON PILOT PLANT (90), BLANKET PILOT PLANT (90), COMM PILOT PLANT (93)
EARTH SERVICES	30M RADIOMETER (85)	100M RADIOMETER (88) MULTILENS (90) (GEO)
MDSL	MINIMUM LEVEL (85)	
LIVING AND WORKING	LIMITED RESEARCH (84)	EXTENSIVE RESEARCH (86), DEMO (90), CONSTRUCTION SUPPORT (91)
COSMOLOGICAL RESEARCH		COMP DEVELOPMENT (87)
DEPOT	COMPONENT DEVELOPMENT (84)	
CLUSTER	MSPP (84), COMPONENT DEVELOPMENT (84)	
SENSOR	DEVELOPMENT TESTING (84)	FABRICATION AND EVALUATION (88)

CONSTRUCTION BASE HARDWARE	INITIAL STATION	GROWTH STATION ADDITION
POWER MODULE	1	0
CREW MODULE (MEN)	1 (6/10)	1 (10)
CONTROL CENTER	1	0
CORE MODULE	1	0
FABRICATION AND ASSEMBLY	1	0
CARGO MODULE	1	0
CRANE		
MISSION HARDWARE		
LAB MODULE	1	1
LAB SUPPORT MODULE	2	2
OTHERS AS REQUIRED		

OPTION FEATURES

LEO SPACE STATION AND CONSTRUCTION BASE, GEO TEST OF MULTIBEAM ANTENNA (UNMANNED)

Figure 4-23. Candidate Option Descriptions,Option 22

CR84

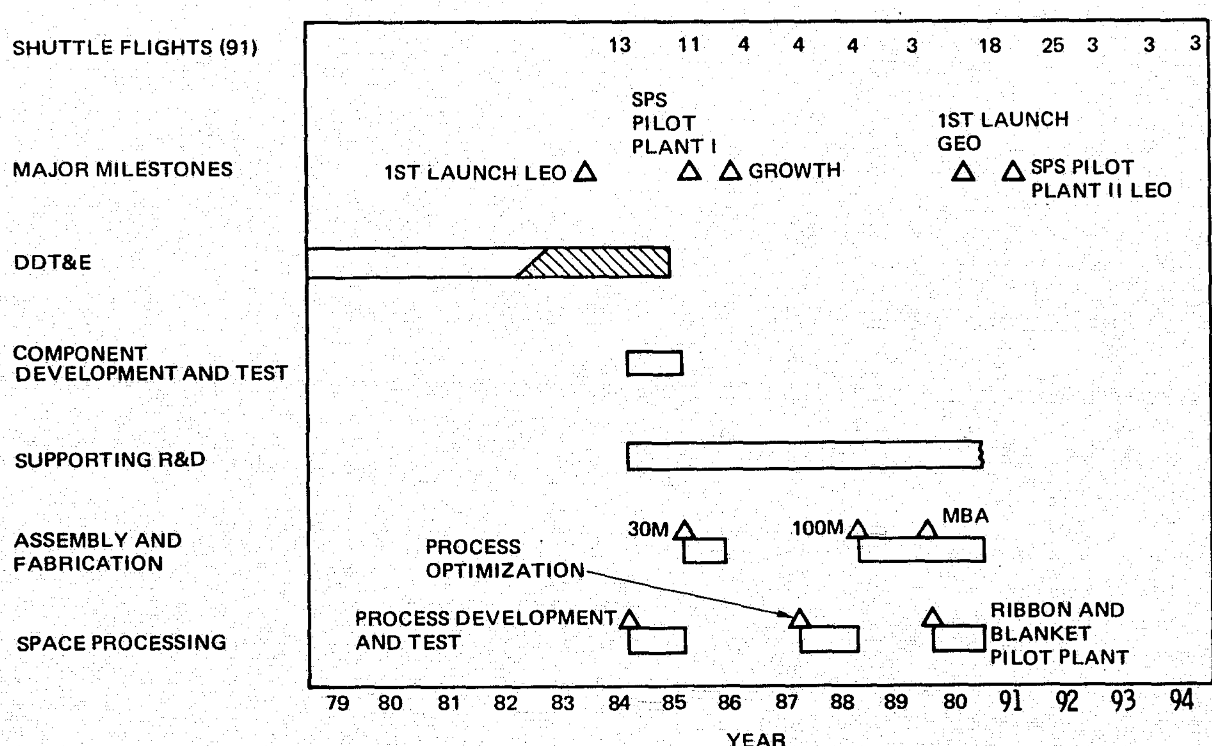


Figure 4-24. Candidate Option 22, Schedule and Transportation

CR84

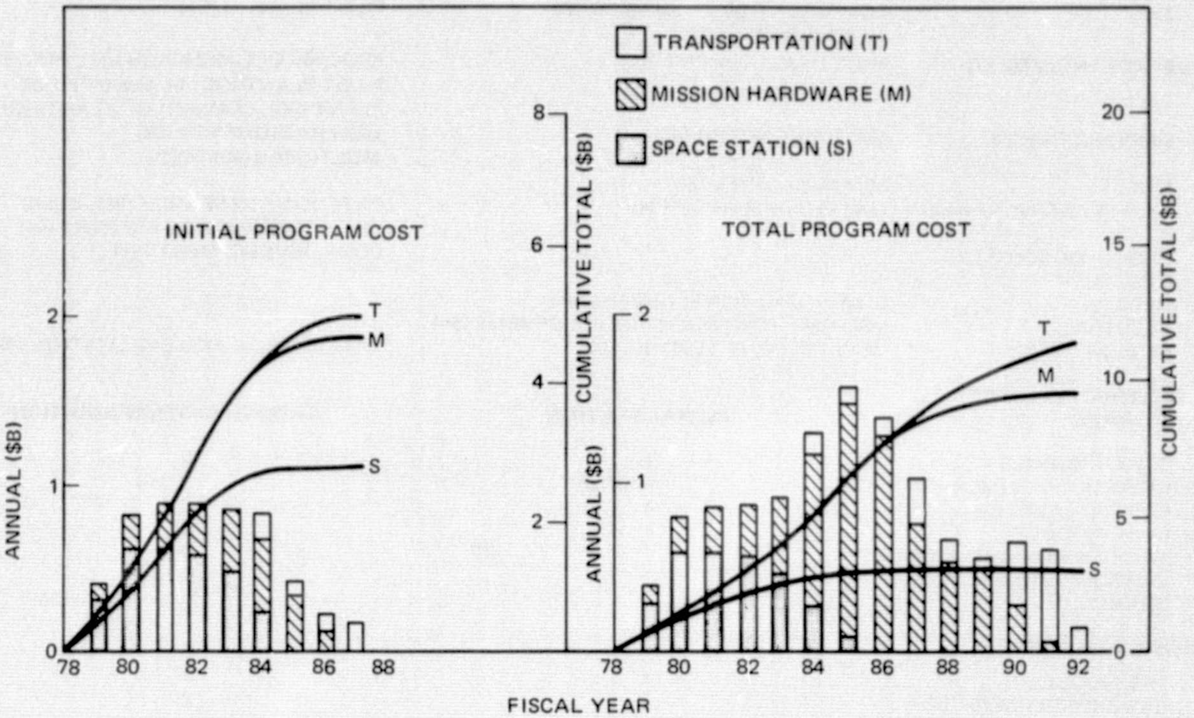


Figure 4-25. Candidate Option 22, Cost

CR84

STRENGTHS

ACHIEVEMENTS
- SPS PILOT PLANTS I AND II
- 30 AND 100M RADIOMETERS
- MULTIBEAM COMMUNICATIONS ANTENNA

EARLY ACCOMPLISHMENT
- LARGE SPACE STRUCTURES
- SPS CONSTRUCTION AND TEST
- SPACE PROCESSING PROCESS DEVELOPMENT

POTENTIAL REVENUE RETURN
- SILICON RIBBON PILOT PLANT
- MULTIBEAM COMMUNICATIONS ANTENNA

TRANSPORTATION ELEMENTS
- SHUTTLE
- OTV-UM

WEAKNESSES

REDUCED MDSL CAPABILITY

NO SPACE COSMOLOGY

NO POLAR ORBIT ADVANTAGES

	COST ($B) INITIAL PROGRAM	TOTAL PROGRAM
BASIC STATION	2.7	2.7
MISSION HARDWARE	2.0	6.9
TRANSPORTATION	0.4	1.9
TOTAL	5.1	11.5

Figure 4-26. Candidate Options Description,Option 22

The cost for Option 22 approximates Option 21, both for the total and initial programs.

4.3.6 Program Option 23

Program Option 23 is summarized by Figures 4-27 through 4-30. This option represents a considerable increase in both program content and program complexity as compared to those so far described. All objectives are addressed, a radio telescope is constructed in the Space Cosmology area for the first time, the MDSL activity is expanded in scope, and the large SPS Pilot Plant is constructed and tested in geosynchronous orbit. This requires a Space Station/construction base at GEO and a manned OTV for support.

The initial program for this option adds additional scope to the MDSL objective by expanding the size of the MDSL facility and adding additional crew for its support. This increases the number of initial Space Station modules to 13 and the initial crew size to 12. The growth-period LEO activities require additional crew growth; and a small Space Station/construction base is deployed at geosynchronous altitude to construct the SPS Pilot Plant and support testing.

The growth-period activities also include the construction and test at GEO of a radiotelescope for the Space Cosmological R&D objective in 1990. A depot facility for a large OTV is included in this option due to the relatively large number of OTV flights required to support the Space Station at GEO and its construction/test activity. An HLLV appears to be cost-effective for this option due to the high volume of logistics flights required.

The cost for this option is substantially higher than any discussed so far because of the additional content and complexity.

It should be noted that there is not general agreement that the deployment to GEO of a large SPS Pilot Plant is a requirement for the SPS objective. However, there are substantial arguments in favor of testing large SPS devices of some sort at GEO and, in this option, we have demonstrated the

CR84

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84), PILOT PLANT I	PILOT PLANT II (91) (GEO)
SPACE PROCESSING	PROC DEVELOPMENT (84)	PROCESS OPTIMIZATION (87), RIBBON PILOT PLANT (90), BLANKET PILOT PLANT (90), COMM PILOT PLANT (93)
		100M RADIOMETER (88)
EARTH SERVICES	30M RADIOMETER (85)	
MDSL	MAXIMUM LEVEL (84)	
LIVING AND WORKING	LIMITED RESEARCH (84)	EXTENSIVE RESEARCH (86), DEMO (90), CONSTRUCTION SUPPORT (91)
COSMOLOGICAL RESEARCH		COMP DEVELOPMENT (87), RADIOTEL (90), TEST OPERATIONS (90), LARGE
DEPOT	COMPONENT DEVELOPMENT (84)	OTV DEPOT (90)
CLUSTER	MSPP (84), COMPONENT DEVELOPMENT (84)	
SENSOR	DEVELOPMENT TESTING (84)	FABRICATION AND EVALUATION (88)

CONSTRUCTION BASE HARDWARE	INITIAL STATION	GROWTH STATION ADDITION LEO	GEO
POWER MODULE	1	0	1
CREW MODULE (MEN)	1 (12)	1 (10)	1 (12)
CONTROL CENTER	1	0	1
CORE MODULE	1	0	0
FABRICATION AND ASSEMBLY	1	0	0
CARGO MODULE	1	0	1
CRANE	1	0	1
MISSION HARDWARE			
LAB MODULE	2	0	0
LAB SUPPORT MODULE	4	0	0
OTHERS AS REQUIRED			

OPTION FEATURES

LEO SPACE STATION AND CONSTRUCTION BASE TO ACCOMPLISH ALL ACTIVITES EXCEPT SPS PILOT PLANT II. RADIOTELESCOPE TRANSPORTED TO GEO. CONSTRUCTION BASE THEN TRANSPORTED TO GEO TO ASSEMBLE SPS PILOT PLANT II AND SUPPORT TESTING.

Figure 4-27. Candidate Option Descriptions,Option 23

CR84

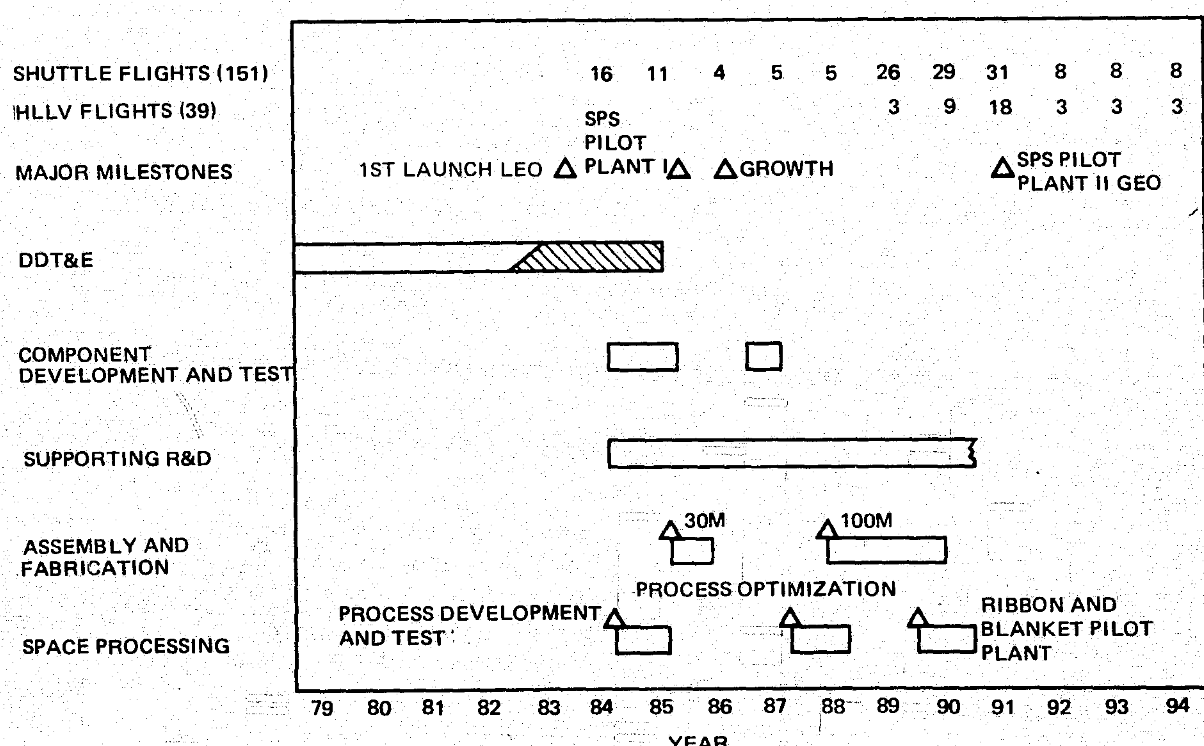


Figure 4-28. Candidate Option 23, Schedule and Transportation

ORIGINAL PAGE IS OF POOR QUALITY

CR84

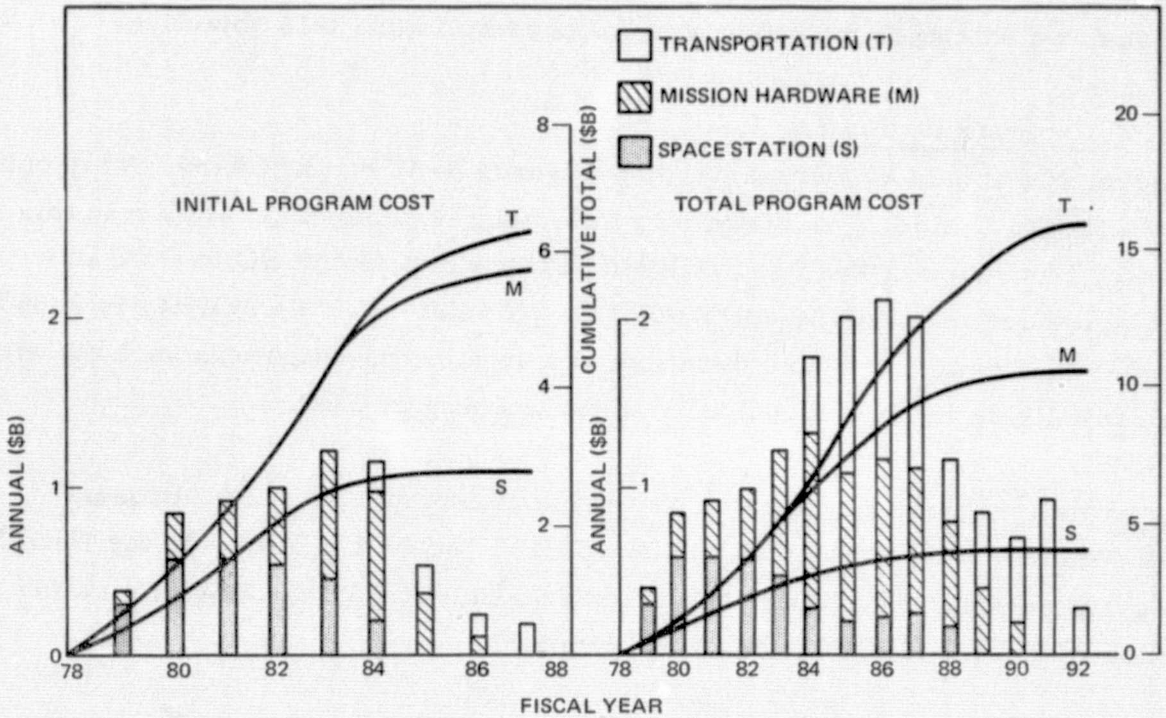


Figure 4-29. Candidate Option 23, Cost

CR84

STRENGTHS

ACHIEVEMENTS
- SPS PILOT PLANTS I AND II (GEO)
- 30 AND 100M RADIOMETERS
- RADIOTELESCOPE
- ALL OBJECTIVES INCLUDED

EARLY ACCOMPLISHMENT
- LARGE SPACE STRUCTURES
- SPS CONSTRUCTION AND TEST
- SPACE PROCESSING PROCESS DEVELOPMENT

POTENTIAL REVENUE RETURN
- SILICON RIBBON PILOT PLANT

TRANSPORTATION ELEMENTS
- SHUTTLE
- OTV-UM
- OTV-M
- HLLV

WEAKNESSES

RISK ELEMENT
- GEO SPACE STATION

NO POLAR ORBIT ADVANTAGES

	COST ($B) INITIAL PROGRAM	TOTAL PROGRAM
BASIC STATION	2.7	3.5
MISSION HARDWARE	3.1	6.7
TRANSPORTATION	0.6	5.6
TOTAL	6.4	15.8

Figure 4-30. Candidate Options Description,Option 23

programmatic effects of constructing large devices at GEO. In later options, we will examine other ways of accomplishing this objective.

4.3.7 Program Option 24

Program Option 24 is summarized by Figures 4-31 through 4-34. This option is similar to Option 23 in that a large element is deployed at GEO — in this case by transporting the Large Cluster Pilot Plant from LEO to GEO in a self-propelled mode using solar electric propulsion. This activity is supported at GEO by a series of short-duration, manned, sortie flights from LEO with the crew living in the manned OTV while working at GEO.

The initial program is the same as Option 23 except that the multibeam lens communications antenna is added in 1986 so that it falls into the initial program period. The initial and growth station at LEO is the same as for Option 23 but the GEO station is not required.

The growth period activities include the Large Cluster Pilot Plant in 1990 to demonstrate the generation of laser energy at GEO and transmit this to a laser-powered OTV for interorbit transport. The SPS Pilot Plant and supporting activities, and the radiotelescope, have been deleted to reduce cost.

The cost of this option approximates that of Option 23.

4.3.8 Program Option 25

Program Option 25 is summarized by Figures 4-35 through 4-38. This option features Space Stations in both LEO and polar earth orbit (PEO) as a means of satisfying those objectives which can benefit from the polar orbit location.

The total complement of activities was selected to cover all objectives except Space Cosmology; within objectives, most elements were addressed except the portion requiring deployment to GEO. This was done to restrict the total program cost.

CR84

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84), PILOT PLANT I (85)	
SPACE PROCESSING	PROC DEVELOPMENT (84)	PROCESS OPTIMIZATION (87)
EARTH SERVICES	30M RADIOMETER (85) MULTILENS (86) (GEO)	
MDSL	MAXIMUM LEVEL (84)	
LIVING AND WORKING	LIMITED RESEARCH (84) EXTENSIVE RESEARCH (86)	
COSMOLOGICAL RESEARCH		
DEPOT	COMPONENT DEVELOPMENT (84)	
CLUSTER	MSPP (84), COMPONENT DEVELOPMENT (84)	LARGE CLUSTER PILOT PLANT (90)
SENSOR		

CONSTRUCTION BASE HARDWARE	INITIAL STATION	GROWTH STATION ADDITION
POWER MODULE	1	0
CREW MODULE (MEN)	1 (12)	1 (9)
CONTROL CENTER	1	0
CORE MODULE	1	0
FABRICATION AND ASSEMBLY	1	0
CARGO MODULE	1	0
CRANE	1	0
MISSION HARDWARE		
LAB MODULE	2	0
LAB SUPPORT MODULE	4	0
OTHERS AS REQUIRED		

OPTION FEATURES

LEO SPACE STATION AND CONSTRUCTION BASE FOR ALL ACTIVITIES EXCEPT LARGE CLUSTER SUPPORT AT GEO. SORTIE TO GEO USED TO SUPPORT LARGE CLUSTER (CREW LIVE ON OTV-M). LARGE CLUSTER TRANSPORTED TO GEO BY SEPS.

Figure 4-31. Candidate Option Descriptions,Option 24

CR84

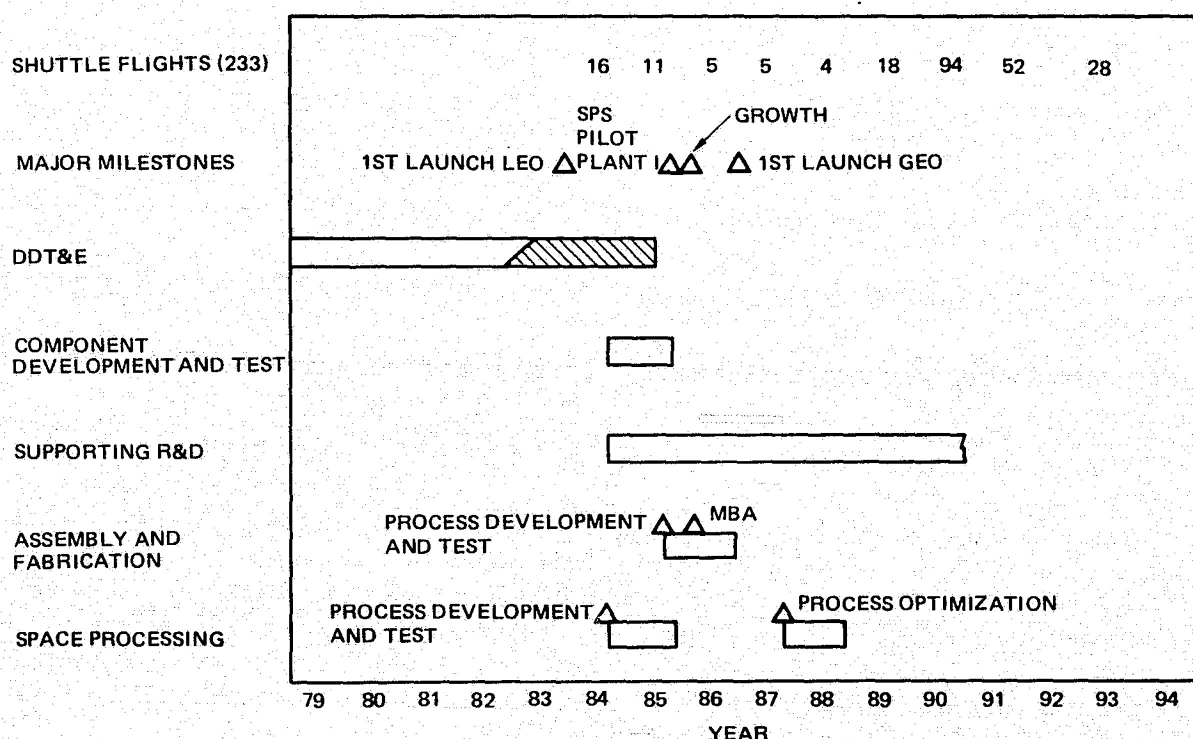


Figure 4-32. Candidate Option 24, Schedule and Transportation

CR84

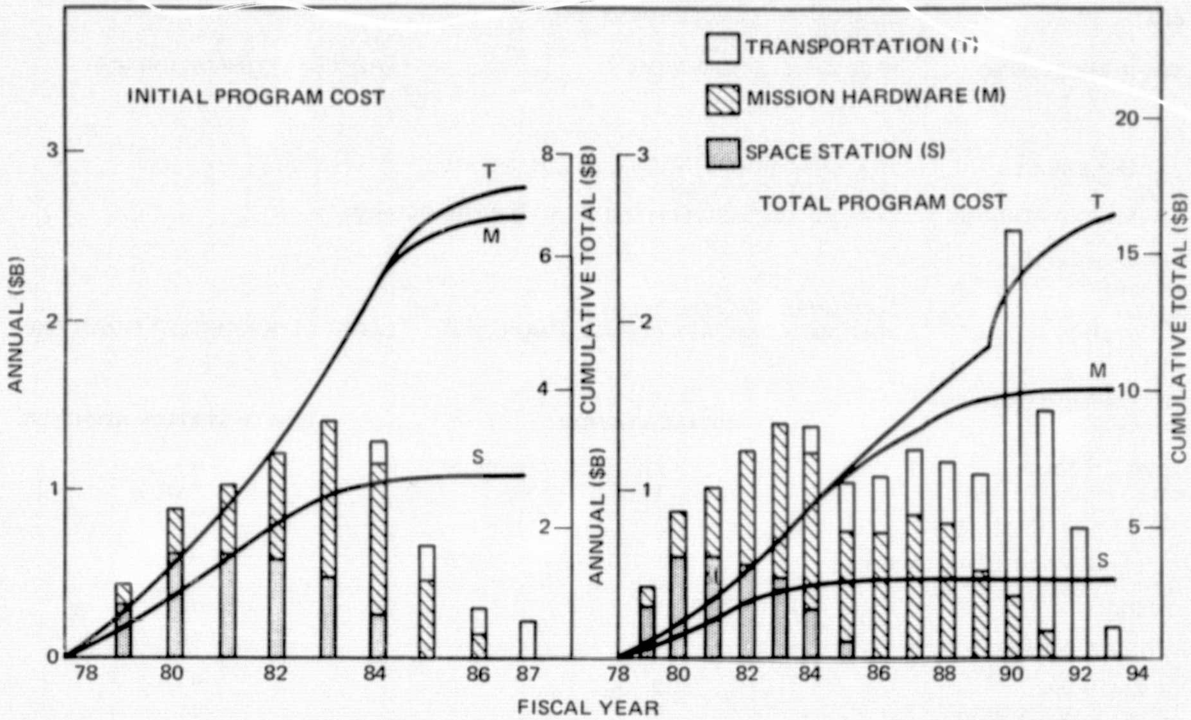


Figure 4-33. Candidate Option 24, Cost

CR84

STRENGTHS

ACHIEVEMENTS
- SPS PILOT PLANT I
- 30M RADIOMETER
- MULTIBEAM COMMUNICATIONS ANTENNA

EARLY ACCOMPLISHMENT
- LARGE SPACE STRUCTURES
- SPS CONSTRUCTION AND TEST
- SPACE PROCESSING PROCESS DEVELOPMENT

POTENTIAL REVENUE RETURN
- MULTIBEAM COMMUNICATIONS ANTENNA

TRANSPORTATION ELEMENTS
- SHUTTLE
- OTV-M
- SEPS

WEAKNESSES

NO SPACE COSMOLOGY

RISK ELEMENT
- TRANSPORT TO GEO OF LARGE STRUCTURE MAN AT GEO (SORTIE)

NO POLAR ORBIT ADVANTAGES

	COST ($B) INITIAL PROGRAM	COST ($B) TOTAL PROGRAM
BASIC STATION	2.7	2.7
MISSION HARDWARE	3.8	7.3
TRANSPORTATION	0.6	6.4
TOTAL	7.1	16.4

Figure 4-34. Candidate Options Description,Option 24

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84)	PILOT PLANT II (91)
SPACE PROCESSING	PROC DEVELOPMENT (84) *	PROCESS OPTIMIZATION (87), RIBBON PILOT PLANT (90), BLANKET PILOT PLANT (90), COMM PROCESS (93)
EARTH SERVICES	30M RADIOMETER (85)	100M RADIOMETER (88),* 300M RADIOMETER, MULTILENS (89) NAV ARRAY (90)
MDSL	MAXIMUM LEVEL (84) MAXIMUM LEVEL (84)*	
LIVING AND WORKING	LIMITED RESEARCH (84)*	EXTENSIVE RESEARCH (86), DEMO (90), CONSTRUCTION SUPPORT (91)
COSMOLOGICAL RESEARCH		
DEPOT	COMPONENT DEVELOPMENT (84)	SMALL OTV DEPOT (91)
CLUSTER	MSPP (84), COMPONENT DEVELOPMENT (84)	
SENSOR	DEVELOPMENT TESTING (84)*	FABRICATION AND EVALUATION (88)*

CONSTRUCTION BASE HARDWARE	INITIAL STATION LEO	INITIAL STATION PEO	GROWTH STATION ADDITION LEO	GROWTH STATION ADDITION PEO
POWER MODULE	1	1	0	0
CREW MODULE (MEN)	1 (12)	1 (6)	1 (10)	0 (0)
CONTROL CENTER	1	1	0	0
CORE MODULE	1	1		
FABRICATION AND ASSEMBLY	1	1	0	0
CARGO MODULE	1	1	0	0
CRANE	1	1	0	0
MISSION HARDWARE				
LAB MODULE	2	1	0	0
LAB SUPPORT MODULE	4	2	0	0
OTHERS AS REQUIRED				

*INDICATES POLAR ORBIT

OPTION FEATURES

LEO SPACE STATION AND CONSTRUCTION BASE AND PEO SPACE STATION AND CONSTRUCTION BASE FOR SELECTED ITEMS

Figure 4-35. Candidate Option Descriptions,Option 25

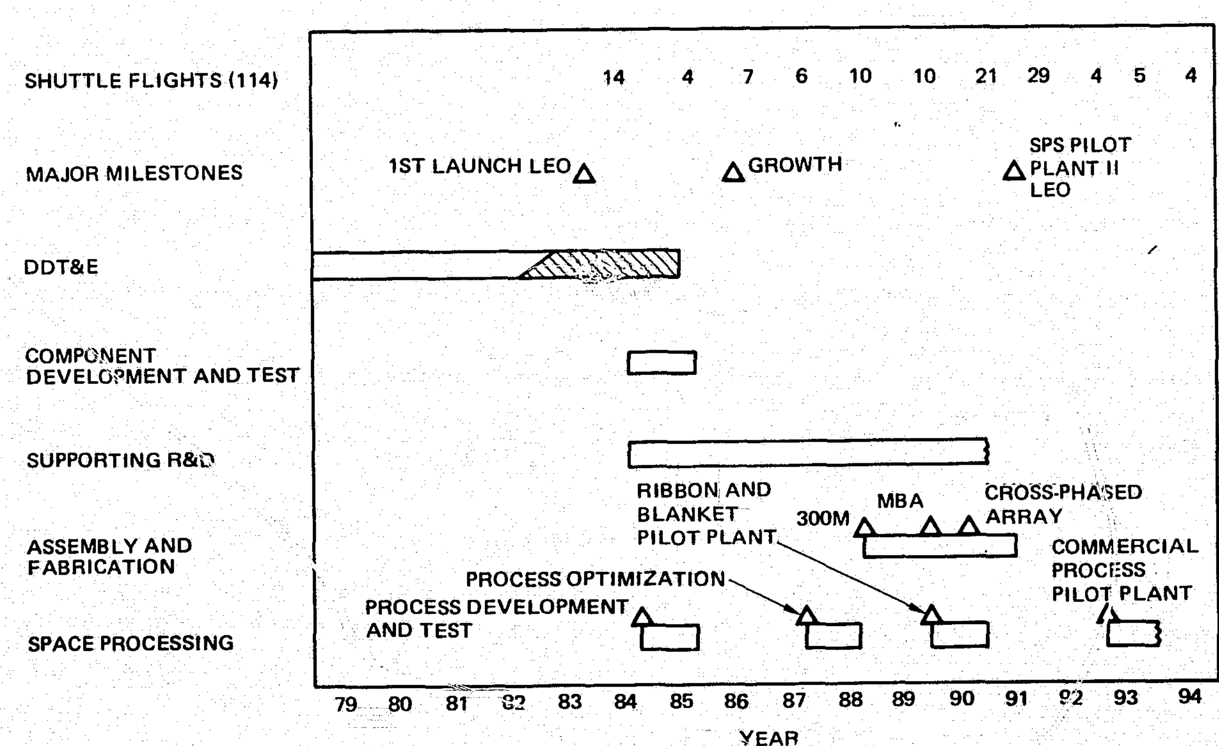


Figure 4-36. Program Options Candidate Option 25A-LEO Schedule and Transportation

CR84

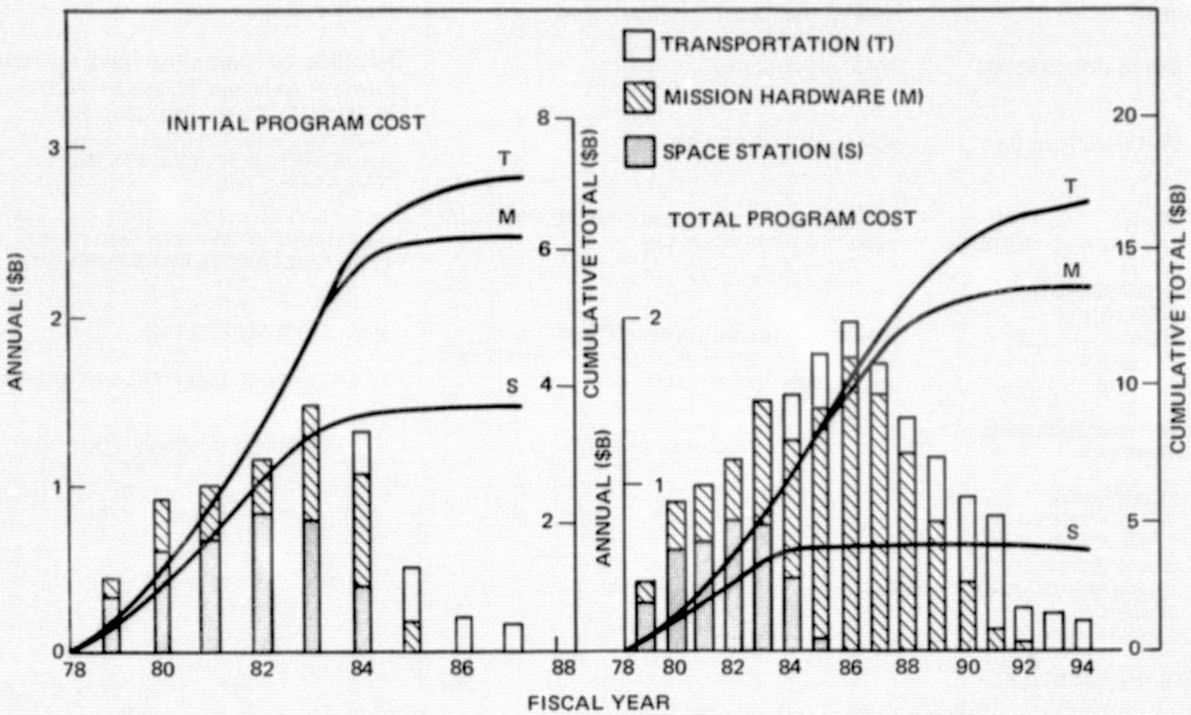


Figure 4-37. Candidate Option 25A-LEO, Cost

CR84

STRENGTHS	WEAKNESSES
ACHIEVEMENTS	
SPS PILOT PLANT II	NO SPS PILOT PLANT I
COMMERCIAL PROCESSING PILOT PLANT	
30, 100, AND 300M RADIOMETERS	EARTH SERVICES LEO ONLY (NO GEO)
MULTIBEAM COMMUNICATIONS ANTENNA	
NAVIGATION ANTENNA ARRAY	NO SPACE COSMOLOGY
EARLY ACCOMPLISHMENT	
LARGE SPACE STRUCTURES	
SPS CONSTRUCTION AND TEST	
SPACE PROCESSING PROCESS DEVELOPMENT	
POTENTIAL REVENUE RETURN	
SILICON RIBBON PILOT PLANT	
COMMERCIAL PROCESSING PILOT PLANT	
MULTIBEAM COMMUNICATIONS ANTENNA	
SMALL OTV DEPOT	
TRANSPORTATION ELEMENTS	
SHUTTLE	

ORIGINAL PAGE IS OF POOR QUALITY

	COST ($B) INITIAL PROGRAM	COST ($B) TOTAL PROGRAM
BASIC STATION	3.5	3.6
MISSION HARDWARE	2.6	9.8
TRANSPORTATION	0.9	3.3
TOTAL	7.0	16.7

Figure 4-38. Candidate Options Descriptions, Option 25

The objective elements deployed in PEO are those with requirements that appear to benefit significantly. In Space Processing, the use of a sun-synchronous orbit permits continuous sunlight for solar furnace applications. In Earth Services and Sensor Development, the instruments could have high-altitude coverage and better viewing angles for ground observations. In Life Sciences, the polar environment offers a different radiation exposure for man in orbit, presenting both an opportunity to gather data and an additional risk.

The cost of this option is about the same as Options 23 and 24; however, it encompasses significantly more accomplishment. This is because a larger portion of the cost in Options 23 and 24 went to support the transportation required for the GEO operations, whereas in Option 25 this could be applied to additional mission hardware.

4.3.9 Program Option 26

Program Option 26 is summarized by Figures 4-39 through 4-42. This option includes the maximum possible content in all objectives (except polar); therefore, it illustrates a maximum total program that can be accomplished without the use of a polar station.

In this case, the SPS Pilot Plant II and the Large Cluster Pilot Plant are both deployed to GEO by using a self-propelled solar electric system. A small Space Station is established in GEO to house the crew that supports the testing of these items. A manned OTV is used to transport the crew to GEO and an UM-OTV is used to transport the hardware and supplies. A Shuttle-derived HLLV appears to be cost-effective in this option because of the high volume of logistics flights required.

The cost for this option is, of course, the highest; the peak funding is also very high for the total program. The initial program is somewhat lower than for Options 24 and 25 because both of these were special situations that do not apply to Option 26. Option 25 had two Space Stations in the initial program (LEO and PEO); Option 24 had the multibeam lens communications antenna moved into the initial period.

CR84

ACHIEVEMENT	EARLY ACHIEVEMENTS	GROWTH ACHIEVEMENTS
SPS	COMPONENT DEVELOPMENT (84), PILOT PLANT I (85)	PILOT PLANT II (91) (GEO) (93)
SPACE PROCESSING	PROC DEVELOPMENT (84)	PROCESS OPTIMIZATION (87), RIBBON PILOT PLANT (90), BLANKET PILOT PLANT (90), COMM PILOT PLANT (93)
EARTH SERVICES	30M RADIOMETER (85)	100M RADIOMETER (88), 300M RADIOMETER (89), MULTILENS (90), NAV ARRAY (91)
MDSL	MAXIMUM LEVEL (84)	
LIVING AND WORKING	LIMITED RESEARCH (84)	EXTENSIVE RESEARCH (86), DEMO (90), CONSTRUCTION SUPPORT (91)
COSMOLOGICAL RESEARCH		COMP DEVELOPMENT (87), RADIO (90), TEST OPERATIONS (90) (GEO)
DEPOT	COMPONENT DEVELOPMENT (84)	LARGE OTV DEPOT (91), SMALL OTV DEPOT (91)
CLUSTER	MSPP (84), COMPONENT DEVELOPMENT (84)	LARGE CLUSTER PILOT PLANT (91)
SENSOR	DEVELOPMENT TESTING (84)	FABRICATION AND EVALUATION (88)

CONSTRUCTION BASE HARDWARE	INITIAL STATION	GROWTH STATION ADDITION LEO	GROWTH STATION ADDITION GEO
POWER MODULE	1	0	1
CREW MODULE (MEN)	1 (12)	1 (12)	1 (7)
CONTROL CENTER	1	0	1
CORE MODULE	1	0	0
FABRICATION AND ASSEMBLY	1	0	0
CARGO MODULE	1	0	1
CRANE	1	0	1
MISSION HARDWARE			
LAB MODULE	2	0	0
LAB SUPPORT MODULE	4	0	0
OTHERS AS REQUIRED			

OPTION FEATURES

LEO SPACE STATION AND CONSTRUCTION BASE FOR CONSTRUCTION. ANTENNAS AND RADIOTELESCOPE TRANSPORTED TO GEO BY OTV. LARGE CLUSTER AND SPS II TRANSPORTED BY SEPS. GEO SPACE STATION TO SUPPORT TESTING OF ALL GEO ITEMS

Figure 4-39. Candidate Option Descriptions, Option 26

CR84

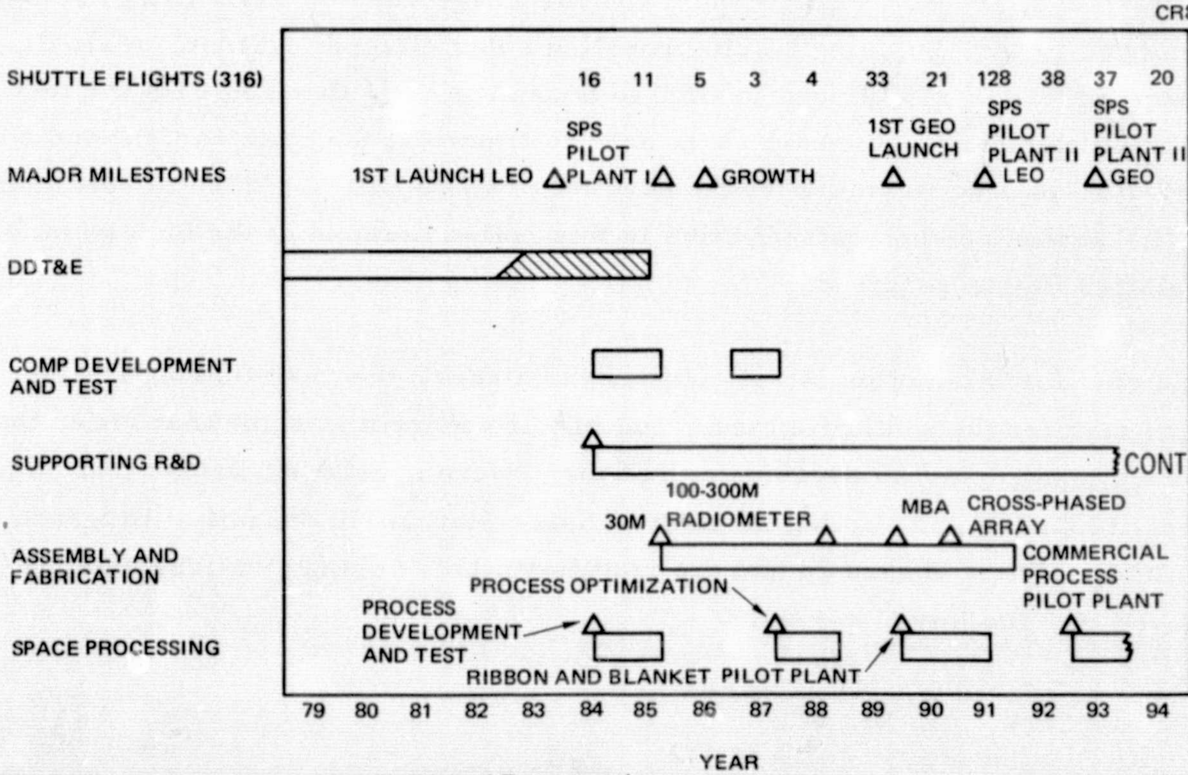


Figure 4-40. Candidate Option 26, Schedule and Transportation

CR84

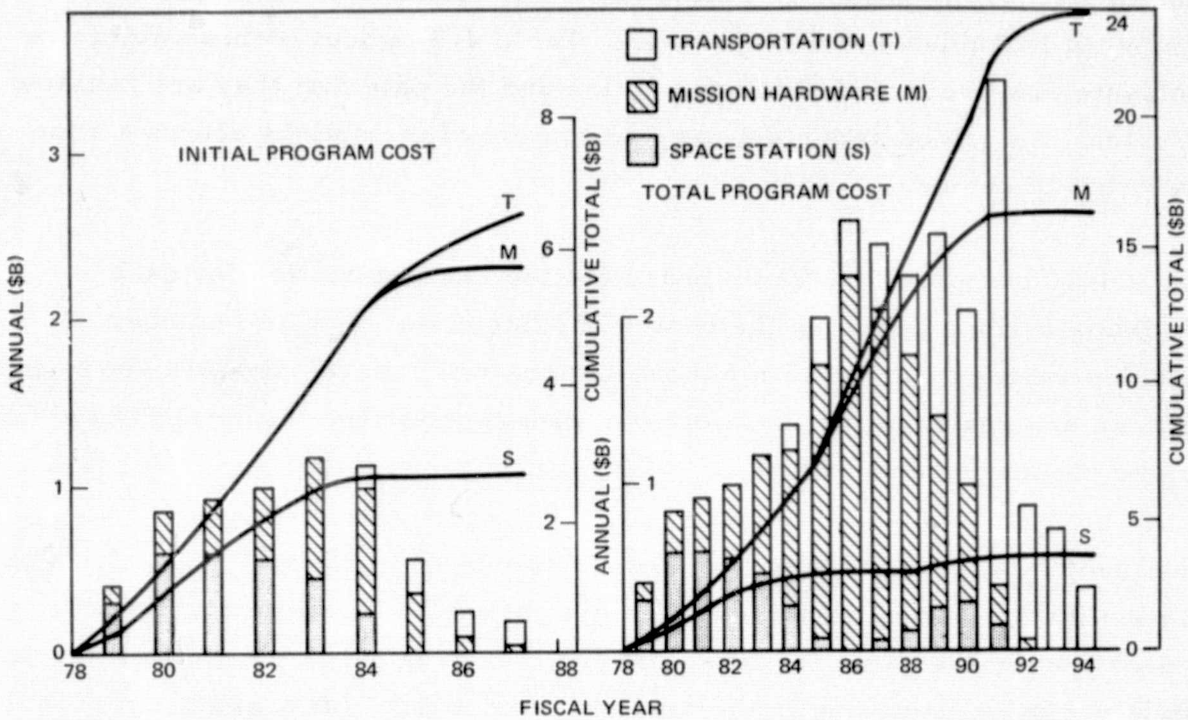


Figure 4-41. Candidate Option 26, Cost

CR84

STRENGTHS

ACHIEVEMENTS
- SPS PILOT PLANTS
- COMMERCIAL PROCESSING PILOT PLANT
- 30, 100, AND 300M RADIOMETERS
- MULTIBEAM COMMUNICATIONS ANTENNA
- RADIOTELESCOPE

EARLY ACCOMPLISHMENT
- LARGE SPACE STRUCTURES
- SPS CONSTRUCTION AND TEST
- SPACE PROCESSING PROCESS DEVELOPMENT

POTENTIAL REVENUE RETURN
- SILICON RIBBON PILOT PLANT
- COMMERCIAL PROCESSING PILOT PLANT
- MULTIBEAM COMMUNICATIONS ANTENNA
- SMALL OTV DEPOT

TRANSPORTATION ELEMENTS

SHUTTLE	SEPS
OTV-UM	HLLV
OTV-M	

WEAKNESSES

RISK ELEMENT
- TRANSPORT TO GEO OF LARGE STRUCTURE
- GEO SPACE STATION

NO POLAR ORBIT ADVANTAGES

	COST ($B) INITIAL PROGRAM	TOTAL PROGRAM
BASIC STATION	2.7	3.5
MISSION HARDWARE	3.1	12.8
TRANSPORTATION	0.6	8.8
TOTAL	6.4	25.1

Figure 4-42. Candidate Options Description, Option 26

The nine program options resulting from Part 1 are summarized and compared in Tables 4-9 through 4-11. Table 4-9 indicates those objective elements that are included in each option and the date that they are initiated on orbit. As can be seen, the varying content of the options allows a wide spectrum of choice.

Table 4-10 compares the basic Space Station characteristics for each candidate option, including the cost of the basic station. The number of modules varies from 5 to 7 for those options which have only a single station, 13 to 14 are required for those options with two stations (either LEO and GEO, or low inclination and polar).

The crew capability varies from 10 for Options 18 to 36 for Option 25 (24 in low inclination and 12 in polar). The cost of the basic space station is approximately the same for those options that have only a single station, the slight variation being due to the cost of the additional crew module required for the growth period in all options except 18. For those options that require two stations, the cost is increased by about $900M.

Table 4-11 compares the total program characteristics for each of the candidate options (basic station, mission hardware and transportation). Again it can be seen that, with the exception of the austere Option 18, the number of modules stays about the same, 10 for the initial program and 14 for the growth program for all the options that have a single space station. The options that require two stations require from 19 to 24 modules and can accommodate from 31 to 36 crewmen, compared with 20 crewmen for the others. Although there is some variation in achievement those options that require two space stations or manned GEO operations tend to be the highest priced, reflecting the increased cost of the hardware and logistics support necessary in those cases.

Table 4-9

COMPARISON OF CANDIDATE OPTIONS (OBJECTIVE ELEMENT USAGE)

	Option Number									
	18	19	20	21	22	23	24	25 LEO	25 PEO	26
Satellite Power System										
Component Development and Test	1984	1984	1984	1984	1984	1984	1984	1984	–	1984
SPS Pilot Plant I	1985	1985	1985	1985	1985	1985	1985	–	–	1985
SPS Pilot Plant II (LEO)	–	–	–	1991	1991	–	–	1991	–	1991
SPS Pilot Plant II (GEO)	–	–	–	–	–	1991	–	–	–	1993
Space Processing										
Process Development and Test	1984	1984	1984	1984	1984	1984	1984	1984	1984	1984
Process Optimization	1987	1987	1987	1987	1987	1987	1987	1987	–	1987
Silicon Ribbon Pilot Plant	–	–	–	1990	1990	1990	–	1990	–	1990
Blanket Pilot Plant	–	–	–	1990	1990	1990	–	1990	–	1990
Commercial Processing Pilot Plant	–	1990	1990	1993	–	–	–	1993	–	1993
Earth Services										
30-Meter Radiometer	1985	1985	1985	1985	1985	1985	1985	–	1985	1985
100-Meter Radiometer	–	–	1988	1988	1988	1988	–	–	1988	1988
300-Meter Radiometer (LEO)	–	–	–	–	–	–	–	1989	–	1989
300-Meter Radiometer (GEO)	–	–	–	–	–	–	–	–	–	1989
Multibeam Lens (LEO)	–	–	1990	–	1990	–	1986	1990	–	1990
Multibeam Lens (GEO)	–	–	1990	–	1990	–	1986	–	–	1990
Cross-Phased Array (LEO)	–	–	–	–	–	–	–	1990	–	1991
Cross-Phased Array (GEO)	–	–	–	–	–	–	–	–	–	1991
Multidiscipline Science Laboratory										
Basic Research, Minimum	1984	1984	1984	1984	1984	–	–	–	–	1984
Basic Research, Maximum	–	–	–	–	–	1984	1984	1984	–	1984
Living and Working in Space										
Limited Research	1984	1984	1984	1984	1984	1984	1984	1984	1984	1984
Extensive Research	–	1986	1986	1986	1986	1986	1986	1986	–	1986
Demonstrate Techniques	–	–	–	1990	1990	1990	–	1990	–	1990
Construction Support	–	–	–	1991	1991	1991	–	1991	–	1991
Space Cosmological Research and Development										
Component Development and Test	–	–	–	1987	–	1987	–	–	–	1987
Mark II Radiotelescope	–	–	–	–	–	1990	–	–	–	1990
Test Operations (GEO)	–	–	–	–	–	1990	–	–	–	1990
Depot										
Component Development and Test	1984	1984	1984	1984	1984	1984	1984	1984	–	1984
Large OTV Depot	–	–	–	–	–	1990	1990	–	–	1991
Small OTV Depot	–	–	1989	–	–	–	–	1991	–	1991
Cluster										
Multiple-Purpose Space Power Platform	1984	1984	1984	1984	1984	1984	1984	1984	–	1984
Large Cluster Component Development	–	1984	1984	1984	1984	1984	1984	1984	–	1984
Large Cluster Pilot Plant	–	–	–	–	–	–	1990	–	–	1991
Sensor Development										
Development and Test	1984	1984	–	1984	1984	1984	1984	1984	1984	1984
Fabrication and Evaluation	–	1988	–	1988	1988	1988	1988	1988	1988	1988

Table 4-10

COMPARISON OF CANDIDATE OPTIONS (INITIAL CONSTRUCTION BASE COSTS)

	Option Number								
	18	19	20	21	22	23	24	25	26
Number of Modules									
Initial Program	5	7	7	7	7	7/0	7	7/6	7/0
Growth Program	5	8	8	8	8	8/5	8	8/6	8/5
Crew Capability(1)									
Initial Program	10	10	10	10	10	12	12	24	12
Growth Program	10	20	20	20	20	34	24	36	31
Orbit Regime/Location	LEO Only	LEO Only	LEO UM-GEO	LEO Only	LEO UM-GEO	LEO GEO	LEO GEO Sortie	LEO PEO	LEO GEO
Transportation Elements	Shuttle	Shuttle	Shuttle UM-OTV	Shuttle	Shuttle UM-OTV	Shuttle UM-OTV M-OTV HLLV	Shuttle M-OTV SEPS	Shuttle (2)	Shuttle UM-OTV M-OTV HLLV SEPS
Initial Program Cum Cost ($B)	2.56	2.62	2.62	2.62	2.62	2.62	2.62	3.54	2.62
Initial Program Peak Funding ($B) (Year)	0.6 (81)	0.6 (81)	0.6 (81)	0.6 (81)	0.6 (81)	0.6 (81)	0.6 (81)	0.8 (82)	0.6 (81)
Total Program Cum Cost ($B)	2.56	2.74	2.74	2.74	2.74	3.52	2.74	3.66	3.52
Total Program Peak Funding ($B) (Year)	0.6 (81)	0.6 (81)	0.6 (81)	0.6 (81)	0.6 (81)	0.6 (81)	0.6 (81)	0.8 (82)	0.6 (81)

(1) Crew capability is what station is capable of accommodating; it is sometimes more than the actual crew used.
(2) Shuttle polar capability required.

4.4 SPACE STATION CONFIGURATION DEVELOPMENT

The Part 1 Space Station concept definition tasks emphasized support of programmatic activities in program option planning and related costing. The range of program options derived for review and selection in Part 1 resulted in broad spectrum of operational and functional supporting Space Station requirements. To expose the breadth of requirements that affect the configuration design drivers, the upper and lower limits and the major objective functions are summarized. The key configuration drivers at the objective level are the construction base, orbital depot, cluster base, space manufacturing, earth services, multidiscipline science laboratory, and test facility.

The wide spread in crew size (5 to 35 men) and in power level (up to 50kW) lead to concepts of modular flexibility coupled with high efficiency per module to minimize the total number of modules in the growth configurations.

Table 4-11

COMPARISON OF CANDIDATE OPTIONS (TOTAL PROGRAM COSTS)

	Option Number								
	18	18	20	21	22	23	24	25	26
Number of Modules									
Initial Program	8	10	10	10	10	13	13	23	13
Growth Program	8	14	13	14	14	19	14	24	19
Crew Capability(1)									
Initial Program	10	10	10	10	10	12	12	24	24
Growth Program	10	20	20	20	20	34	24	36	31
Orbit Regime/Location	LEO Only	LEO Only	LEO UM-GEO	LEO Only	LEO UM-GEO	LEO GEO	LEO GEO Sortie	LEO PEO	LEO GEO
Transportation Elements	Shuttle	Shuttle	Shuttle UM-OTV	Shuttle	Shuttle UM-OTV	Shuttle UM-OTV M-OTV HLLV	Shuttle M-OTV SEPS	Shuttle (2)	Shuttle UM-OTV M-OTV HLLV SEPS
Initial Program Cum Cost ($B)	5.0	5.1	5.1	5.1	5.1	6.4	7.1	7.0	6.4
Initial Program Peak Funding ($B)	0.9	0.9	0.9	0.9	0.9	1.2	1.4	1.5	1.2
(Year)	(81)	(82)	(82)	(82)	(82)	(83)	(83)	(81)	(83)
Total Program Cum Cost ($B)	5.8	7.2	8.8	11.3	11.5	15.8	16.4	16.7	25.1
Total Program Peak Funding ($B)	0.95	1.1	1.3	1.4	1.6	2.1	2.6	2.0	3.5
(Year)	(84)	(84)	(85)	(85)	(85)	(86)	(90)	(86)	(91)

(1) Station capability; crew used in a given phase may be smaller.
(2) Shuttle polar capability required.

Functional requirements of the objectives represent a wide spectrum of activities and products; however, some of them can be accommodated in similar conventional modules and therefore do not place special demands on the Space Station configuration. Predominant drivers are the construction base and orbital depot, which will require new and unique configurations.

Configuration Development which supported the programmatic activity is discussed in the following paragraphs, including groundrules, functional elements, concepts, and assembly procedures.

4.4.1 Space Station Design Drivers

Previous Space Station studies have established an invaluable data bank of Space Station concepts, subsystem designs, tradeoff data, etc. This substantial foundation, in conjunction with actual flight experience from Skylab and Apollo, will permit rapid and effective design and analysis and will be used as the baseline configuration in all vehicles and subsystems.

The primary technical area that must be carefully assessed, however, to assure conformance with the current design drivers, is the Space Station configuration. As shown in Table 4-12, the larger crew sizes and diversity of functional support requirements greatly exceed the requirements of previous studies. Although the initial station may not have greatly different requirements, consideration of more demanding growth flexibility will impose more demanding design drivers.

A major item of crew safety is the personal rescue system. This advanced life support inflatable capsule can be stored efficiently on board the Space Station and, when used in conjunction with crew members wearing pressure suits, should provide an effective rescue system. A thorough evaluation will be made of the crew rescue procedures and related Space Station design concepts in Part 2.

The most significant and dramatic advantage available to this study is the current design/analysis status of the Space Shuttle, which will permit a more realistic Space Station configuration. As noted, the increase in launch payload over the recent Phase B modular Space Station studies permits increased capability in each module, extended logistics periods, and more effective launch support of Space Station objective hardware.

A second element of import is the improved definition of the Orbiter's rendezvous and docking control capability. With a module 15m long, of approximately 15,000 kg, docked to the Orbiter docking module, the Orbiter control authority envelope is exceeded. This may be remedied by control computer modifications. An additional consideration is the effect on the Space Station stability and control subsystem complexity of docking the Orbiter at a radial docking port with its attendant significant effect on the moments of inertia (MOI). Therefore, an alternate approach, a mobile crane on board the Space Station, was included.

The on-board mobile crane is a new element that has been introduced into the Space Station orbital buildup operations. Variations in the concept include single-arm fixed location, single-arm mobile, and two-arm mobile cranes. These include mobility concepts such as, monorail and self-propelling (i.e., walking) crane. Several of these concepts are diagrammed in the following pages.

Table 4-12

DRIVERS COMPARISON WITH PREVIOUS STUDIES

Characteristic	Parevious	Current	Typical Effects
Orbital regime	Primarily LEO	LEO-PEO-GEO	• Crew rescue • Hardware weight • Radiation protection
Crew size	3 to 12	5 to 50	• Additional crew modules • Crew per module, up to 10-12
Crew safety			
Personal rescue systems	N/A	Available	• Hard suits alternate (stowage volume/donning time) • Safety procedures
Shuttle Operations			
Launch 370 km	9,070 kg	29,484 kg	Increased capability modules
Planned landing	9,070 kg	14,515 kg	
Emergency landing	29,485 kg	29,485 kg	
Orbiter docking	No limitations	X-axis only	Limits docking locations
Orbiter manipulator	Module berthing	Module transfer No berthing	Orbiter manipulator modifications Station-mounted mobile crane
Objectives support	Primarily R&D	Scientific R&D	Reduces Orbiter docking flexibility
		Technology R&D	
		Space prog.	
		Large space structures	Clearance envelopes - Large space structures/Solar arrays
		Large antenna/pilot plant testing	

A two-arm traveling crane configuration has several unique operational characteristics:

- It has the mobility to move to all extremities of the Space Station through the use of externally located attach points on the Space Station module's external surface.
- It can handle the exchange of cargo modules virtually without assistance.
- It can provide an airlock for EVA or crew transfer to the Orbiter at all Space Station berthing and docking ports. This has the important advantage of supporting crew rescue from a module by berthing the crane airlock to the module berthing port and removing the crew from an isolated module.
- Assuming the utilization of a new or considerably modified docking mechanism on the Space Station, the interface to the Orbiter can be supplied by this crane module.

4.4.2 Part 1, Option Definition Support

The Space Station descriptions task flow was developed to correspond to the programmatic tasks in ROM costing and preliminary scheduling at the WBS Level 4 (module level). (See Figure 4-43.) The primary subsystems were identified as necessary to support the ROM costing task. The three major programmatic tasks are indicated by the dashed-line boxes. The initial period was devoted to defining options and identifying the functional support requirements that characterize Space Station configuration and operational performance. The main activity in configuration descriptions occurred during Space Station Definition/Costing.

Three distinct tasks were performed to accomplish Part 1 objectives; the fourth task, that of preparing for Part 2, was also completed.

Task 1 established and organized the key assumptions to assure continuity and conformity between the description for each option. These assumptions also initiated the conceptual approach to be used in the Part 2 detail conceptual layouts, e.g., higher density crew modules — 10 to 12 crewmen per module.

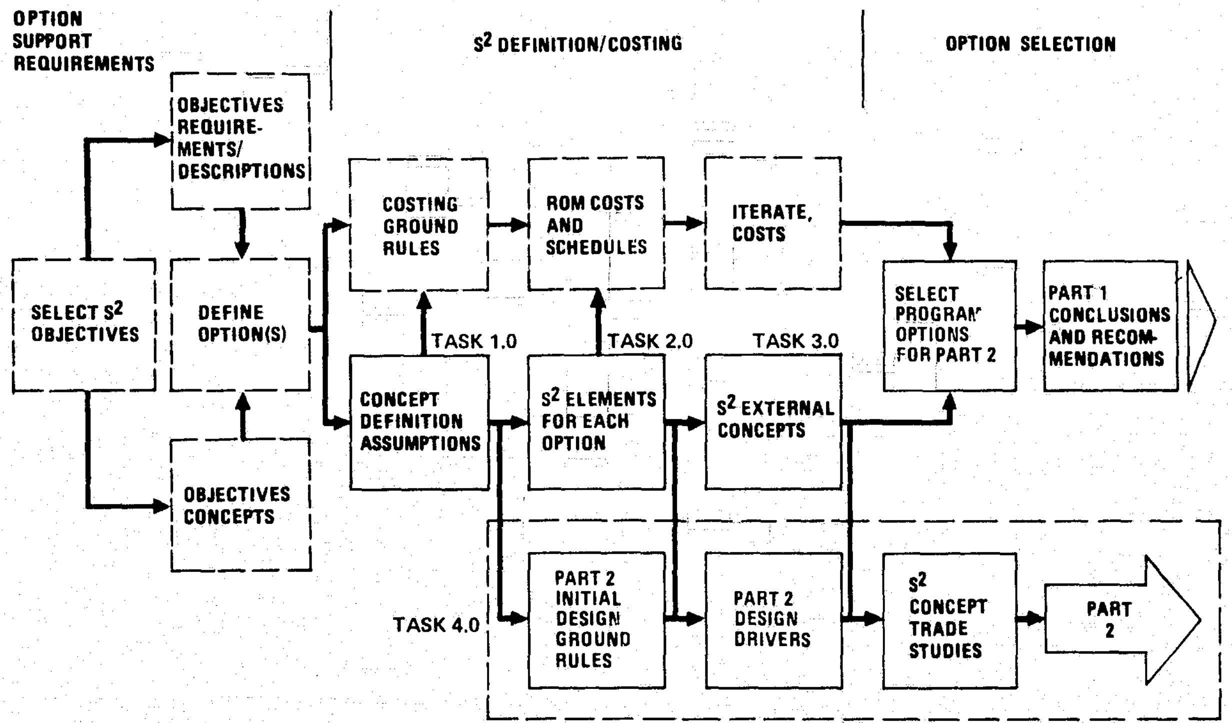


Figure 4-43. Space Station Concepts Part 1 Option Definition Support

Task 2 task integrated the noted assumptions and program option descriptions to establish the outline description of all Space Stations for each program option — a total of approximately 50 options.

Task 3 evaluated and defined several basic Space Station configurations that were sufficiently adaptable to meet the support requirements of any program options. Candidate Space Station configuration conceptual drawings were developed for Options 20, 22, and 24.

Task 4 discussions were held which identified and defined an initial group of preliminary detail design groundrules for Part 2. Key subsystem trades and design groundrules will be described in the Part 2 study plan, reflecting the latest SRB direction.

4.4.3 Costing Support Tasks

Detail task definitions and their interrelationship are shown in Figure 4-44 and the specific tasks described in following paragraphs.

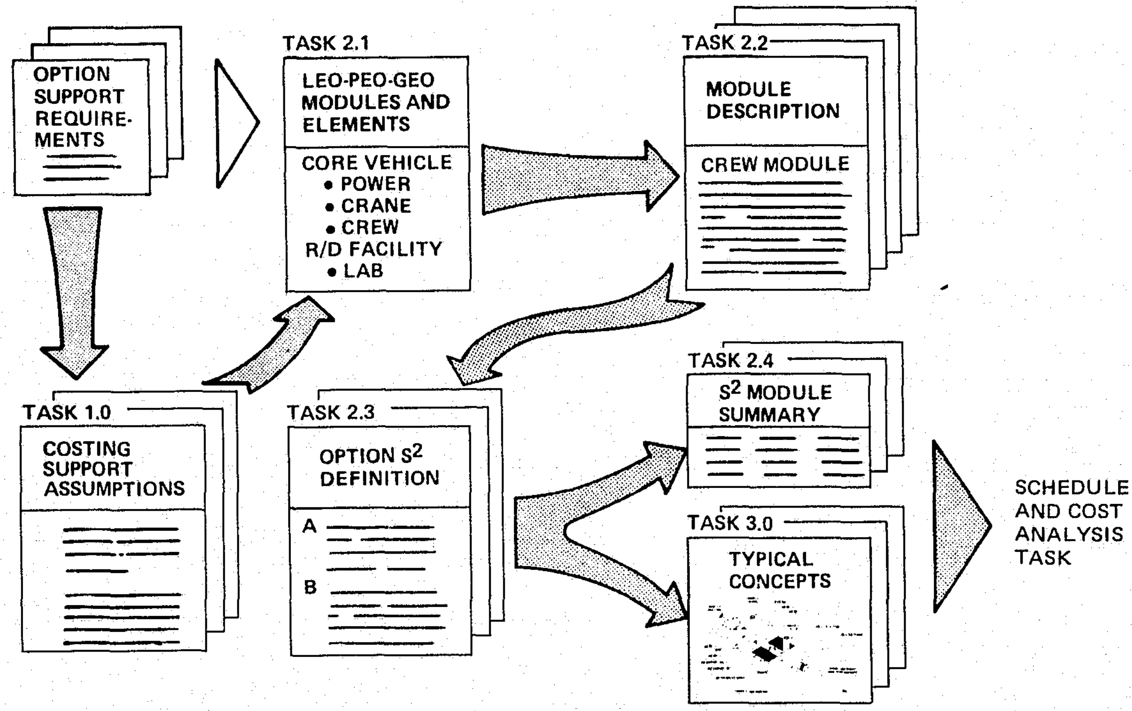


Figure 4-44. Space Station Concepts, Costing Support Tasks (Task 2.0)

Part 1 concentrated on the definition of program options and the identification of beneficial space industrialization and R/D projects. In support of Part 1 objectives, the Space Station concept activity focused on the preliminary definition of Space Station and mission hardware. The task flow shown provided an organized buildup of definitions to support the costing task. Tasks 2.1 and 2.2 developed general definition information for all options by identifying modules and mission hardware (WBS Level 4). Tasks 2.3 and 2.4 utilized this information to develop the preliminary Space Station configuration descriptions for each of the primary options. Suboptions were then reviewed and "delta" adjustments made to the prime descriptions, thus establishing suboption descriptions. Details of each task are included in the individual task descriptions on the next several pages.

4.4.4 Task 1.0, Concept Definition Costing Support Assumptions

The requirement to develop a full range of Space Station descriptions to flesh out the 45 to 50 program options demanded that a set of assumptions be established to assure consistency between the various options. At this point of the study, and considering the large number of Space Station configurations, the method used was to prepare the assumptions necessary to support the ROM costing to the WBS 4th level (i.e., module) and the WBS 5th level (i.e., major subsystem).

The assumptions were derived from previous study results, which were modified where appropriate to be consistent with increased demands of the current program options, e.g., larger crews, up to 31 men in growth stations, a large space structure construction base, etc. The initial assumptions are shown in Table 4-13. All modules and operations were assumed to be Shuttle-compatible, including the large-volume structure required for the OTV maintenance hangar of the orbital depot. A wet configuration of the Shuttle external tank was used as the standard for costing.

The basic module length of 15m is consistent with installation in an Orbiter cargo bay, which has an Orbiter docking module installed.

The relatively high number of crewmen per crew module (10 ± 2) was selected to minimize the number of modules required for the larger stations while simultaneously providing comfortable crew quarters. Using the set of assumptions, Space Station configuration outline descriptions were devised for each option. The primary subsystems were identified as necessary to support ROM costing.

4.4.5 Task 2.1, Functional/Operational Modules and Elements

The first step in describing the Space Station configuration was a preliminary review of all program options to identify a full range of candidate modules and elements. These were divided into the primary functional areas representative of the individual objectives selected to make up program options. In Task 2.1, typical physical and operational characteristics were defined for each module and elements. Thus, in Task 2.3 (Space Station configuration definition), element and module preliminary descriptions were compared to option support requirements and final selections made.

Separation of the core vehicle into LEO and GEO categories resulted from the small GEO station (i.e., 4 to 6 crewmen) and the objective of reducing the number of modules, particularly those going to GEO.

Table 4-13

TASK 1.0, CONCEPT DEFINITION COSTING SUPPORT ASSUMPTIONS[6]

All Modules

- Assume basic 15m module (Shuttle-compatible)
- Selected exceptions where requirements known

Crew Modules

- Sized to 10 ± 2 crewmen
- Available LEO station modules will be used in GEO
- ECLS for 10 + 2 crewmen located in module

  Support of all other modules in each module

- Waste management located in module

Control Center Module

- Contains other support functions

  Data management, communications, crew care. wardroom/galley, etc.

Core (Berthing) Module

- Eight radial docking ports
- International docking mechanism

Power Module

- Highest power level for any growth station version
- Single power module is used wherever possible

Galley/Wardroom

- Crews greater than 6 to 12, in control center module
- Crews of 6 (without station growth requirement), located in crew module

Crane

- One large crane per space station

ECLS

- Decentralized
- Crew quarters ECLS 10 + 2 crewmen

Cargo Module

- Consumables and spares for 12 + 6 crewmen, 90-180 days
- One module for each station plus one backup
- During an objectives-operational period, modules are not interchangeable

Large-Volume Modules

- Shuttle external tank (wet configuration)

Orbital Depot

- Propellants tanks assumed to hold approximately 22,000 kg (≈50k lb)

Typical modules and elements are shown in Table 4-14.

4.4.6 Task 2.2, Typical Module Descriptions Outlines

A Space Station module(s) description outline was prepared as shown in Table 4-15 to identify and assign the key subsystem and operational items to an appropriate module location in support of the ROM costing task. This depth of definition permitted generation of ROM costing information to WBS Level 4 (i.e., module) and key WBS Level 5 items (i.e., subsystems). This descriptive information was prepared to the same level for all modules required to support the program options. Assignment of key subsystems was varied, as appropriate, to minimize program cost without reducing operational efficiency. Identical module descriptions were used for all appropriate or equivalent option support requirements.

The information presented is typical of the preliminary descriptions prepared for all Space Station modules and elements listed in Task 2.1. These are not intended to represent a final set of module characteristics, but rather to provide sufficient definition for the Part 1 costing activity. This assured that the Space Station concept evaluation and subsystem identification were accomplished to WBS Level 5 for guidance of the programmatic analysis.

4.4.7 Task 2.3, Space Station Definition Descriptive Outline

Preliminary Space Station configurations were prepared in the typical descriptive outline form as shown in Table 4-15. The information presented is typical of all LEO and GEO configurations. Item A definitions used the Tasks 2.1 and 2.2 data to assemble the necessary numbers and types of modules to meet the functional support requirements of the prime options. This outline approach provided the costing and scheduling activity with sufficient hardware description to assemble the cost elements.

Initial (1983) Space Station configuration definition is based on the costing groundrules shown; key characteristics and subsystems in each module are as shown on previous charts.

As Part 1 did not include the design definition of Space Station configurations as an objective, the Space Station outline description, number of modules, and types of modules were generally defined from previous study information.

Table 4-14

TASK 2.1, MODULES AND ELEMENTS IDENTIFICATION (TYPICAL)

Core Vehicle, LEO • Power • Crane • Core (berthing) • Control center • Crew • Cargo-station support • Fabrication and assembly Core Vehicle, GEO • Crew/galley • Control center/subsystems • Power/radiation shelter • Cargo - station support • Crane R/D Facility • Laboratory • Lab support • Cargo (pressurized) • Cargo pallet Space Processing • Crystal ribbon • Solar blanket • Commercial pilot plant • Biological • Inorganic • Cargo (pressurized)	Construction Base • SPS Pilot Plant I • SPS Pilot Plant II • 27m Multibeam antenna • 30m Radiometer • 30m Radiotelescope • 100m Radiometer • 4-km navigation array • Cargo (pallet) SPS support • Cargo (pallet) antenna support Test Facility • Test operations center • Satellite berthing • Beacon satellites Orbital Depot • Propellant tanks • Operations center • Propellant distribution • Refueling dock • Hangar Cluster Base • 50 to 100 kw multiuse space power platform • Control center

Table 4-15 (Page 1 of 2)

TASK 2.2, TYPICAL MODULE DESCRIPTION OUTLINE

Basic Station and Construction Base
Power Module
• 4.6m x 18.3m primary structure
• Shuttle docking not required on deployment
• 1,025m^2
• 50 kW - 24-hour average
• High-pressure gas storage tanks
• Power conversion
• Initial G/N, propulsion RCS, checkout, and ECS
• 1 berthing port and 2 end docking ports
Control Center Module (Subsystems)
• 4.6m x 15.2m
• Control center
• Crew care
• Data analysis/management
• G/N hardware
• ECLSS, support other than crew modules
• Communications center
• Galley/wardroom for total crew
Crew Module
• 4.6m x 15.2m
• 12 staterooms (commander's stateroom)
• Personal hygiene
• 10-man ECLSS
Core (Berthing) Module
• 4.6m x 18.3m primary structure
• 8 side berthing and 2 end docking ports
• Main utility distribution
• Power distribution
• EVA airlock

Table 4-15 (Page 2 of 2)

TASK 2.2, TYPICAL MODULE DESCRIPTION OUTLINE

Fabrication/Assembly Module

- 4.6m x 18.3 primary structure
- Pressurized volume
  - EVA airlock
  - Construction control office
  - Test equipment
  - Workshop
  - Selected spares storage
- Unpressurized volume
  - Work stations
  - Fabrication and assembly equipment, jigs and fixtures
  - 2 radial berthing ports

Mobile Crane

- 23m (75 ft) crane
- One power/control head
- Two articulated crane arms

Cargo Module - Station Support

- 4.6m (15 ft) x 15.2m (50 ft)
- Racks
- Fluid/gases storage tanks
- Consumables
- Compacted trash return

This was updated as required to reflect current Space Shuttle performance data, for example, in the identification of the mobile crane. This was added as a potential method for berthing all radially mounted modules. It is not desirable to use the Orbiter with its current stability and control subsystem for radial berthing of modules as the combined CG moves outside of the orbiter's control authority envelope. Other modules and mission hardware elements were defined in a similar outline.

Additional design definition with related detail in the cost analysis will occur in Parts 2 and 3.

As an adjunct to the initial configuration description, a Space Station buildup sequence was prepared to verify the needs and relationships of functional support requirements and assigned modules. This task also supported the transportation requirements analysis. Conceptual sketches of the external configuration were made for selected options (reference Option 20) to assure the feasibility of both the buildup sequence and the module selection. By referring to the results of Task 2, Module Definitions, it was assured that all operational elements had been incorporated and costing elements identified.

The buildup sequence is shown graphically in the Space Station conceptual sketches of Task 3. In a normal buildup sequence (reference Table 4-16), the power module is launched first and placed in orbit in an unmanned mode. The solar arrays are deployed for initial power and the support subsystems activated. In Part 2 it will be determined if the mobile crane can be launched with the power module. The second module launched would be the control center, which provides safety functions, caution and warning, communications, data management, and Space Station command post, thus preparing the station for manned operations. Then, with the launching of the core (berthing) module, crew module, cargo module, and fabrication and assembly module, the core vehicle is complete. Initiation of crew transfer could occur at any point after the junction with the crew module when all crew support subsystems and accommodations are available. Buildup sequence will be analyzed relative to crew operations and safety procedures.

4.4.8 Task 2.4, Typical Summary of Space Station Modules

In order to identify the required modules and maintain an accounting during the Space Station transition through the chronological growth phases, tabulated results were developed for each of the nine primary program options.

This preliminary accounting for all modules that would be available both in orbit and on the ground assured that only the necessary number of modules and missions support hardware would be costed.

In each option, these data were evaluated for the delta change in the sub-options. The complete program options and their subs were summarized as shown typically in Table 4-17.

Table 4-16

TASK 2.3, SPACE STATION DEFINITION (OPTION 20)

1983 Initial LEO Space Station		10 Men
1986 Growth LEO Space Station	+	9 Men
(On Board)		19 Men

A. General Description

- Initial configuration
  - One power module, 1,025m^2 - 50 kW array
  - One mobile crane
  - One control center module (subsystems)
  - One core (berthing) module
  - One crew module - 12 men, and ECLSS (commander's quarters)
  - One fabrication and assembly module
  - One cargo module - station support
  - One laboratory module
  - Two laboratory support modules

B. Configuration Buildup

Buildup Sequence	Module/Mission Hardware Description
1	Power module
2	Crane
3	Control center
4	Core (berthing) module
5	Crew module
6	Cargo module
7	Fabrication and assembly module
8	1st laboratory support module
9	2nd laboratory support module
10	1st laboratory module

Table 4-17

PROGRAM OPTION SUMMARY

Opt. Yr. Orbit	Core Vehicle Modules: Core	Power	Crew	Galley Ward-room	Cargo	Subsys. (ECLSS)	Control Center	Rad. Safety	Airlock	ECS	Berthing (2-8)	Crane	Space Processing Modules/Elements: Biol.	Glass Mats	Metal-lics	Crystal Ribbon	Solar Blanket	Struct. Beam	Cargo Rad	Mani-fold	Cargo Fin
14 1983 LEO	1(10)	1(10)	2	1	2/1	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--
1989 Growth	1	1	2 + 1	1	2/1	--	1	--	--	--	--	1	--	--	--	2	1	--	2/1	1	2/1
1992 Growth	1	1	2+1	1	2/1	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--
1992 GEO	1(4)	1(25)	1	--	2/1	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--

Opt. Yr. Orbit	R/D Facility Modules: Cargo	Pallet	MDL Core	R/D	Orbital Depot Modules/Elements: Hanger 27 ft	Crane	Prop. Tanks	Prop. Dist.	Refuel Dock	Contr Center
14 1983 LEO	4/1	--	2	4	--	--	--	--	--	--
1989 Growth	4/1	--	2	4	--	--	--	--	--	--
1992 Growth	2/1	--	1	2	1	1	7/7	1	1	--
1992 GEO	--	--	--	--	--	--	--	--	--	--

Opt. Yr. Orbit	Construction Base Modules/Elements: Fab.	Assy.	Whse.	Crane	LG Airlock	OPS Center	Dock/Berth Sta.	Cargo Pallets	Cargo (Press)	SPS P. P. Tool.	30M Ant. Tool.	Ant. Pallet	SPS Pallet	Transportation Elements: Manned Mobility Device	Manned Tug	OTV 65K (Berth)	OTV 8K (Berth)	MMD Fac. (Berth)
14 1983 LEO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1989 Growth	1	--	--	2	--	1	3	8/2	--	6	1	2	18	2	--	--	--	1(2)
1992 Growth	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1992 GEO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1/1	1/1	--	--

Opt. Yr. Orbit	Test Facility Modules: Cargo	Beacon Sats	Sat Berth	OPS Ctr.
14 1983 LEO	--	--	--	--
1989 Growth	--	--	--	--
1992 Growth	--	--	--	--
1992 GEO	2/1	--	--	1

Module/Equipment is available from other source

ORIGINAL PAGE IS OF POOR QUALITY

4.4.9 Task 3, Basic Space Station/Constructions Base Concepts

Using the results of the preceding tasks, concept sketches were developed for several primary options. In conjunction with these conceptual external configuration drawings, the general characteristics were prepared using the program options requirements and previous JSC study data. The general shown respectively in Table 4-18 and Figure 4-45. This data is for the early portion of the proposed program; as the program options matured and increased support requirements developed, these were used to define the growth path from the initial construction base.

To complete the space station construction base definitions, the general characteristics and configuration sketches were made as shown in Table 4-19 and Figure 4-46. Reference is made to Section 4.4.11.6 for a more detailed description of the fabrication and assembly module. A review of this material will clarify the conceptual approach used to develop the growth construction base.

4.4.10 Space Station Construction Base Buildup

In previous studies, buildup of a Space Station had been proposed by erecting a large module on the Orbiter docking module and driving the module into the Space Station docking port. Recent simulation of Orbiter operations, including the manipulator operations, indicates that when a module 15m long and weighing approximately 15,000 kg, is docked to the Orbiter docking module, the Orbiter control authority envelope is exceeded. This may be remedied by control computer modifications. However, an additional consideration is the effect on the Space Station stability and control subsystem complexity of docking the Orbiter at a radial docking port with its attendant significant effect on the MOI. Therefore, alternate operational techniques were considered and will be evaluated in greater depths during Part 2 of the study. The objective is to evaluate current Orbiter performance relative to its docking capability and compare that to alternate methods that would be applicable for interfacing with the current Orbiter. In addition, the stability and control authority of the Space Station will be analyzed for docking the Orbiter on the X-axis only or the X-, Y-, and Z-axes.

Table 4-18
OPTION 20 LEO, INITIAL 1983

General Characteristics	
Launch vehicle	Shuttle
Buildup	Station mobile crane
Number of launches	9-10
Orbit	LEO
Crew size	10
Power level	50 kW
Station orientation	Function of orbit
Pointing	Universal
Total mass	130 kg
Total pressurized volume	1560 m^3
Core vehicle	985 m^3
Option facilities	575 m^3
Berthing ports	10 radial + 1 end
Cargo module	1
Crew support	2
Option support	8
Docking ports	
Orbiter (X-axis)	1 + backup
Functional Characteristics	Mission hardware
Multiscience lab	Lab/pallets
Construction base	Fabrication and assembly
Earth services	Fabrication and assembly

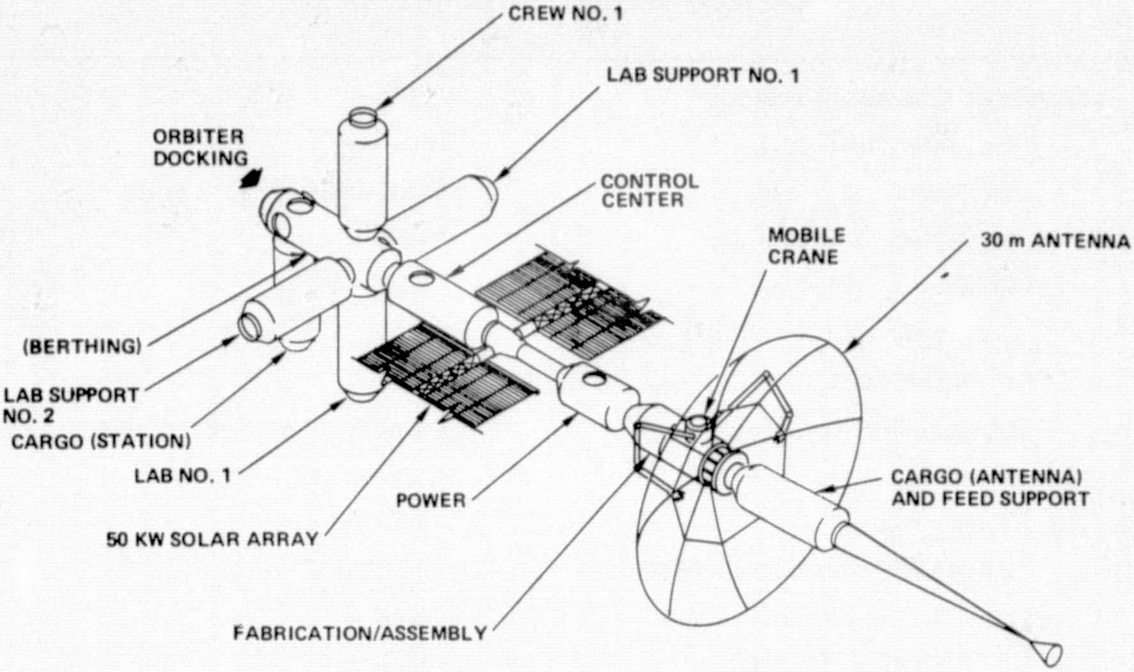


Figure 4-45. Option 20 Initial Construction Base and Mission Hardware 1983-6/10 Man (Typical)

The orbital operational techniques shown in Figure 4-47 use hard docking of the Orbiter by means of the Orbiter docking module, the Orbiter Remote Manipulator System, or a Space Station crane. Option 1 depicts the concept using the Orbiter to hard dock all modules by means of the docking module. Option 2 uses the Orbiter remote manipulator system exclusively. Option 3 uses the Orbiter docking module and introduces a Space Station on-board crane to effect module transfer from Orbiter to berthing port.

Option 4 is an alternate module berthing approach that assures complete flexibility as well as providing an added resource of support for large construction. The application of free-flying concepts to Space Station buildup also provides the added advantage of having an available on-board local manned rescue vehicle. This concept could employ free-flying all modules, free-flying cargo modules which would also serve as a local Tug, or a small dedicated Tug. Depending upon the concept selected, manned versus unmanned operation must be evaluated.

Table 4-19

OPTION 20 LEO, GROWTH 1987

General Characteristics	
Launch vehicle	Shuttle
Buildup	Station mobile crane
Number of launches	12-13
Orbit	LEO
Crew size	19
Power level	50 kW
Station orientation	Function of orbit
Pointing	Universal
Total mass	185 kg
Total pressurized volume	2140 m^3
Core vehicle	985 m^3
Option facilities	1150 m^3
Berthing ports	10 Radial + 1 end
Crew module	1
Crew support	2
Option support	8
Docking ports	
Orbiter (X-axis)	1 + Backup
Functional Characteristics	Mission hardware
Multiscience lab	Lab/pallets
Construction base	Fabrication and assembly
Earth services	Fabrication and assembly
Antenna tests	Fabrication and assembly

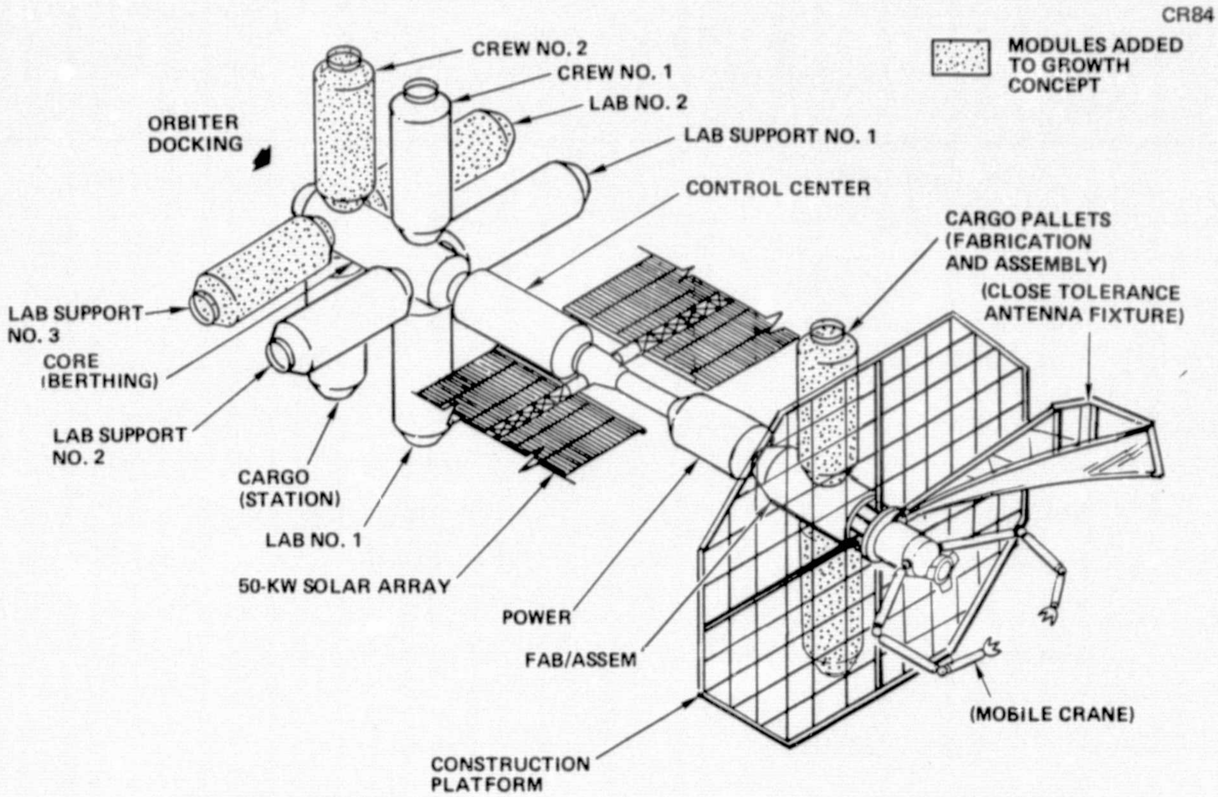


Figure 4-46. Growth Construction Base

The on-board mobile crane is a high-potential element that has been introduced into the Space Station orbital buildup operations. Variations in the concept include single-arm fixed location, single-arm mobile, and two-arm mobile. These include mobility concepts such as monorail and self-propelling (i.e., walking) crane.

A two-arm traveling crane configuration shown in Figure 4-48 Option 3, has several unique operational characteristics:

- It has the mobility to move to all extremities of the Space Station through the use of externally located attach points on the Space Station module's external surface.
- It can handle the exchange of cargo modules virtually without assistance (Figure 4-48).
- It can provide an airlock for EVA or crew transfer to the Orbiter at all Space Station berthing and docking ports. This has the important advantage of supporting crew rescue from a module by berthing the crane airlock tothe module berthing port and removing the crew from an isolated module (Figure 4-49).

CR84

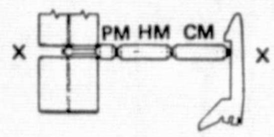
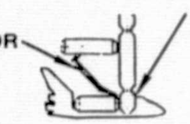
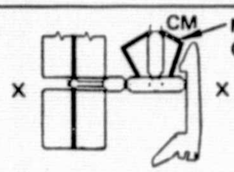
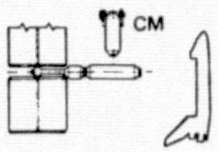
OPTION	TECHNIQUE	COMMENTS
1		• ORBITER DOCKS ALL MODULES MOUNTED ON ORBITER DOCKING ADAPTER • CARGO MODULE EXCHANGE REQUIRES TWO LAUNCHES • EXCEEDS ORBITER CONTROL AUTHORITY
2		• ORBITER HAND-DOCKS TO SPACE STATION • ORBITER MANIPULATOR, TRANSFERS PAYLOAD TO PORT • CREW TRANSFER
3		• STATION ON BOARD MOBILE CRANE WITH ≈23M ARM • CRANE REMOVES MODULE FROM ORBITER PAYLOAD INSTALLATION DEPLOYMENT ASSEMBLY OR REMOTE MANEUVERING SYSTEM • CRANE MOVES MODULE AND BERTHS IT
4		• FREE-FLYING CM (OR OTV) • COULD BERTH OTHER MODULES • EXCELLENT GROWTH STATION OPERATIONS

Figure 4-47. Module Berthing Concepts for Construction Base Buildup

CR84

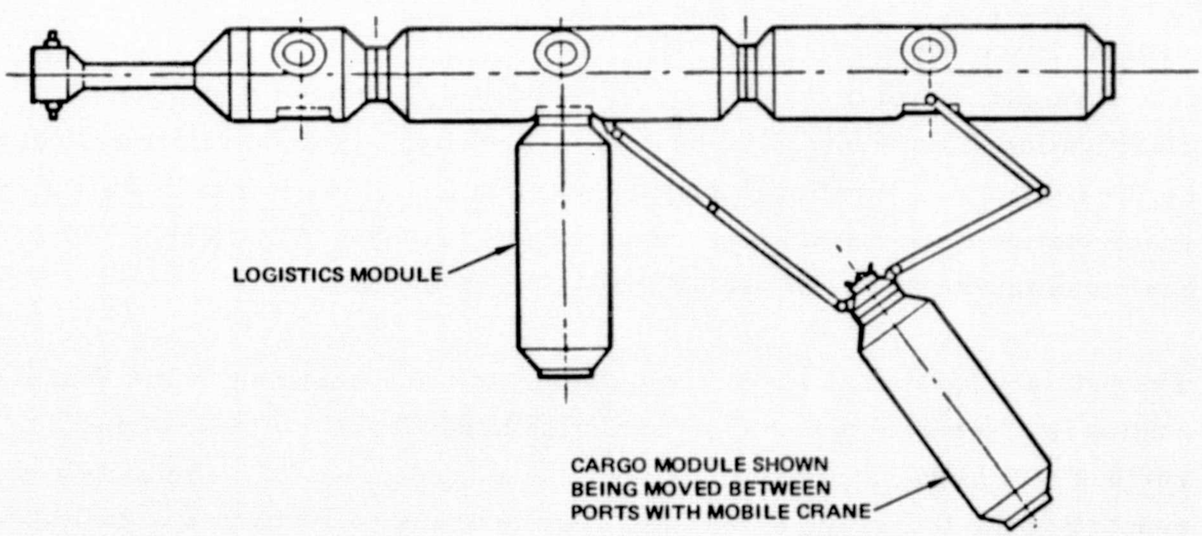


Figure 4-48. Module Transfer

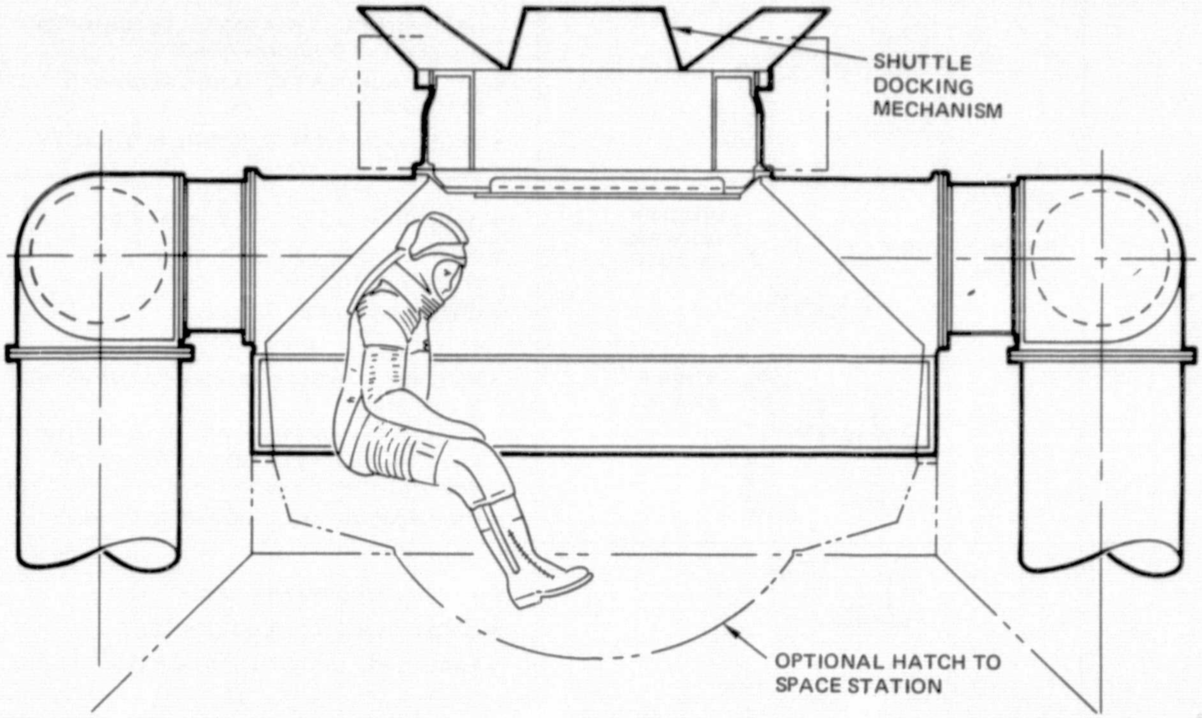


Figure 4-49. On-Board Two-Arm Crane Module

- Assuming the use of a new or considerably modified docking mechanism on the Space Station, the interface to the Orbiter can be supplied by this crane module (Figure 4-49).

4.4.11 Space Station Description

The concepts shown in this report were defined for Part 1 support and clarification of the support to the costing activity. Thus, they are typical and as the finite detail functional support requirements are defined in Part 2, the space station construction base concepts will be changed to comply. The basic configuration(s) will use previous JSC study work.

The primary functional support requirements to be provided by the Space Station is a versatile general construction base capable of addressing the various structural configurations with different degrees of complexity and supporting the full range of options. Primary analysis of various candidate configurations identified basic modules common to all program option requirements. With the launching of these basic modules, a construction base core vehicle is established. The normal buildup sequence is shown in

Figure 4-50. Of these basic modules, the power module and the fabrication and assembly module will represent the greatest conceptual design challenge in Part 2.

A brief description of each module in the core vehicle has been included as a precursor to the more detail definitions of Part 2.

4.4.11.1 Power Module

The power module is 4.6m diameter x 18.3m long and incorporates an externally stowed solar array. When fully deployed, the solar array provides approximately 1.025m^2 panel area (50 kW). A fixed tunnel provides pressurized access to the solar array deployment mechanism for maintenance. The pressurized compartment has two radial berthing ports and houses the necessary electronic subsystems to enable the module to operate in an unmanned mode. Space and structural provisions are provided to accept the CMG's and supply tanks. Four thruster modules containing high and low thrust capability are located on the end domes. End docking ports are included to permit station buildup.

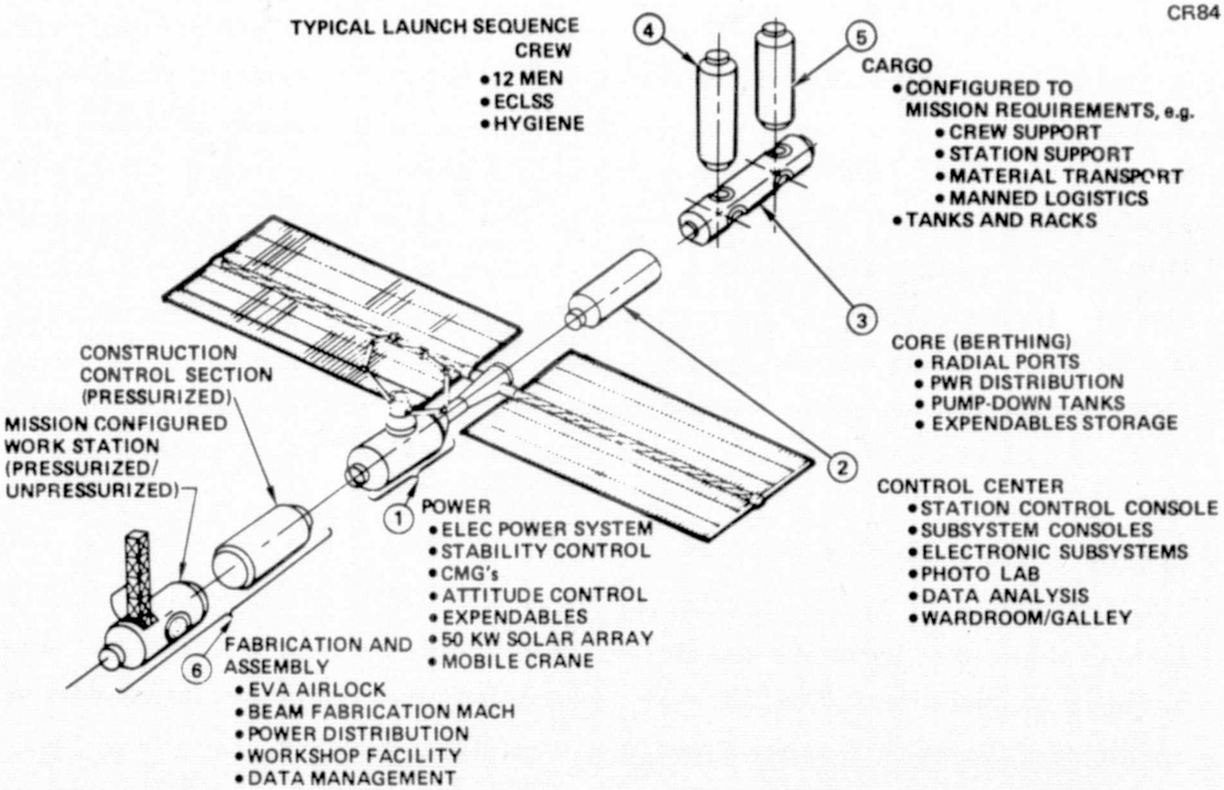


Figure 4-50. Construction Base Core Vehicle

4.4.11.2 Control Center Module

The control center module is 4.6m in diameter x 15.2m long and incorporates the Space Station operations control console. The general interior arrangement will probably use a 1-g longitudinal configuration, providing space for subsystem consoles, data analysis, photo processing, wardroom, galley, and dining area. This module is the control nerve center of the Space Station and contains all the necessary displays and controls to support the station in its normal operating mode. The initial configuration provides for the crew galley/ wardroom accommodations.

4.4.11.3 Core (Berthing) Module

The core module is 4.6m in diameter x 18.3m long and incorporates the radial berthing provisions necessary to accomplish initial Station buildup. The pressurized module incorporated eight radial berthing ports and two end docking ports. The end docking ports are provided to permit Station buildup and to provide a Station-to-Orbiter docking interface. Atmosphere storage tanks are also allocated to the core module.

4.4.11.4 Crew Module

The crew module is 4.6m in diameter x 15.2m long and incorporates provisions for up to 12 crewmen. The interior arrangement will maintain the orientation (e.g., 1g) developed throughout the Station to minimize crew adjustments between modules. Each crew quarter will contain approximately 200 ft^3 of space. Two identical hygiene compartments will be incorporated, each with shower and waste management provisions. A 12-man environmental control and life support system is located in the crew module. This permits complete flexibility in adding or removing crew modules from a space station or the ECLS subsystem would not be perturbed. With a small number of crewmen (e.g., 4 to 6 at GEO) the galley would be incorporated into this module.

4.4.11.5 Cargo Module

The cargo module will be configured to meet specific mission objectives and also as a general logistics carrier. The module is 4.6m in diameter and 8.5m to 18.3m long. The interior of the pressurized compartment will be arranged to provide a special cargo area and a palletized cargo area to accept such items as CMG's and experiment equipment. The palletized area will be configured to support carry-on containers. An unpressurized section will be provided to house fluid tanks and high-pressure gas tanks. The provisions in the cargo module are essentially extensions of existing systems on board the Station.

4.4.11.6 Fabrication and Assembly Module

The fabrication and assembly module is 4.6m in diameter x 18.3m long and incorporates a pressurized control section and an unpressurized work station. The configuration has potential to address various structural configurations with different degrees of complexity while being compatible with the Shuttle as the launch system.

By using the removable work station concept, shown in Figure 4-51, the flexibility to advance in complexity and/or in degree of automation is assured without major changes or adjustments to the basic Space Station. The close proximity of the structural elements cargo pallet to the work station provides a convenient and efficient materials handling method.

Alternate configurations which provide full pressurization capabilities, together with identification and definition of accessories and support equipment, will be undertaken in Part 2.

The preliminary conceptual analysis indicates that a variety of structural configurations can be assembled by this basic fabrication and assembly module. In changing the EVA work station from support of one structure to another, the basic pressurized module would remain berthed to the Space Station while the work station would be exchanged or modified.

Should a large construction work platform be required, it could be assembled as shown in Item 1 (Figure 4-52). The 10 x 10m dimension is typical and does not represent an upper limit. Assembly of platforms of several hundred meters in size should be possible. As noted in Item 3, if antenna tolerance requirements exceed those obtainable by the basic EVA assembly method, a fixture can be assembled which has an adjustable template surface for obtaining the necessary tolerance.

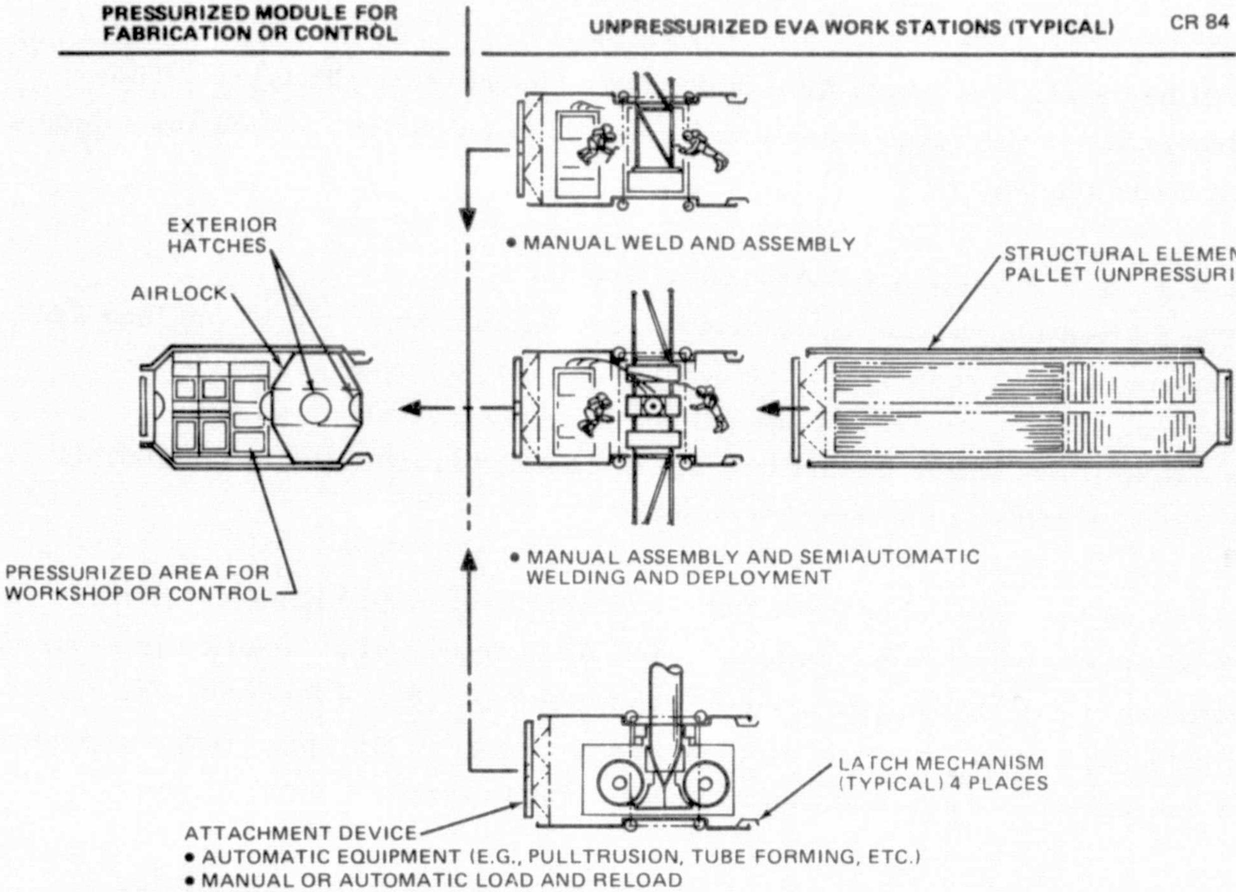


Figure 4-51. Candidate Fabrication and Assembly Module

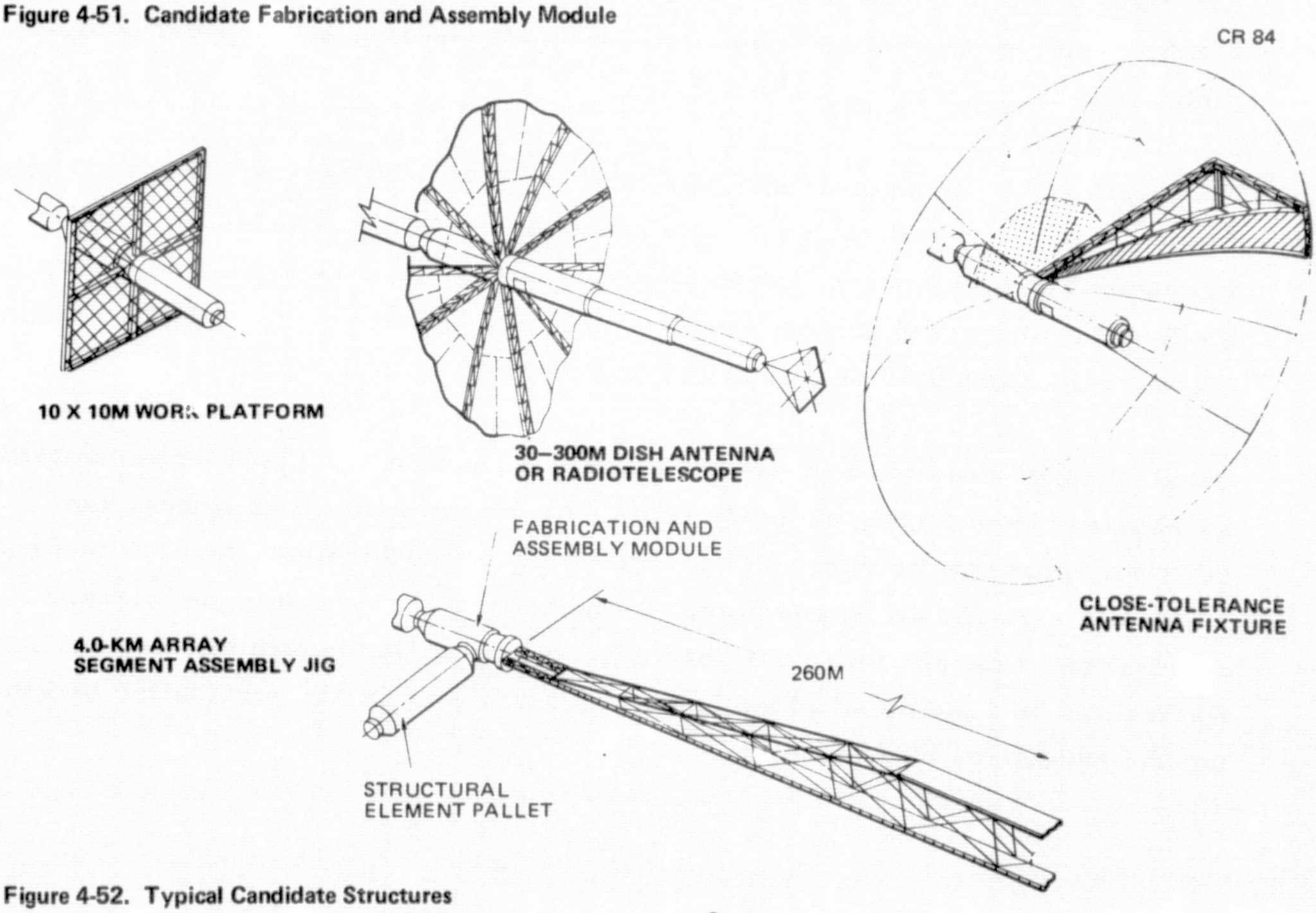


Figure 4-52. Typical Candidate Structures

The range of structures that are illustrated would represent a construction program lasting over several phases of space station growth.

4.4.11.7 Mission Hardware

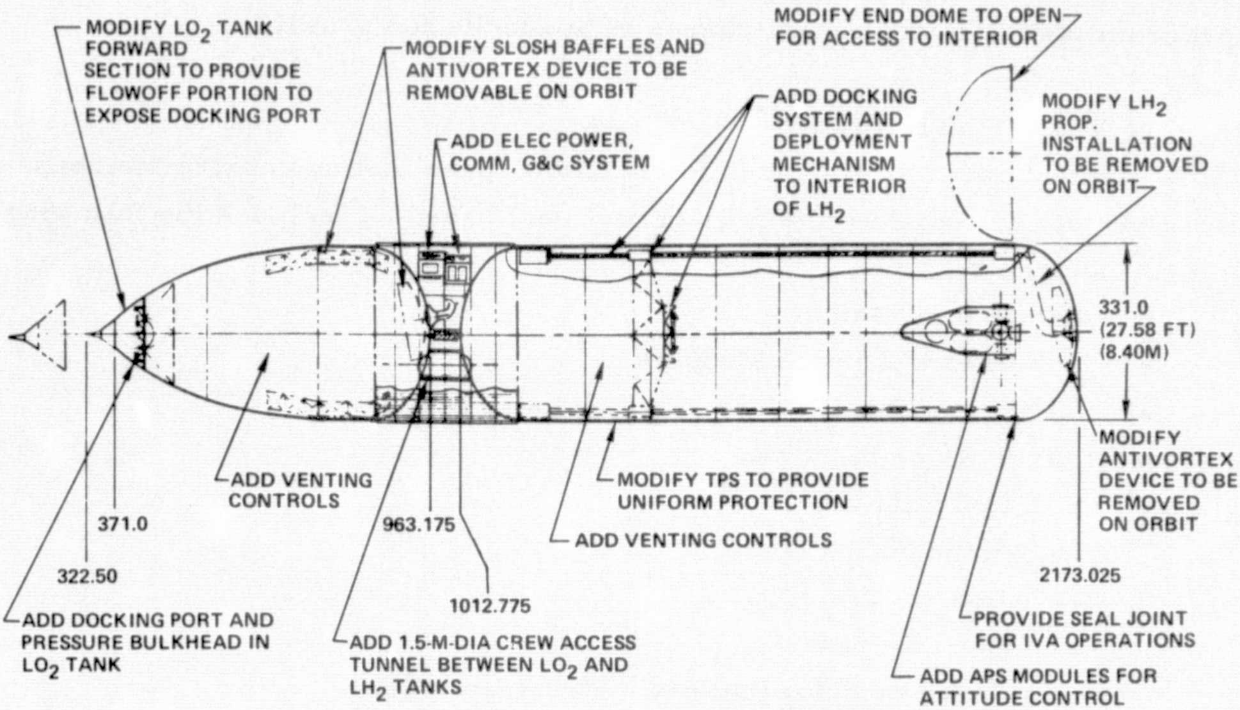
This class of hardware is added to the basic Space Station construction base core vehicle to complete the fully operational base. It includes the following typical elements:

- Laboratory Modules
- Laboratory Support Modules
- Cargo Modules/Pallets - Lab Support
- Large Space Structure
  - SPS pilot plants
  - Antennas
  - Jigs and fixtures
  - Special cranes
  - Cargo modules/pallets - structural parts
  - Etc.
- Orbital Testing
  - Test control modules
  - Beacon satellites (antenna field strength measurement)
  - Satellite servicing clock
  - Etc.

4.4.12 Large-Diameter Space Facility

Various program options have included a requirement for large-volume structures to support detail structural assembly, OTV maintenance, and propellant storage. In order to provide a baseline for the costing task, the Shuttle external tank was selected as a minimum-cost candidate having the necessary operational characteristics. The initial concept evaluated used the Space Shuttle external tank to obtain a large-volume space facility. Both the wet configuration, shown in Figure 4-53 and the dry configuration, shown in Figure 4-54, were considered as candidates. Other concepts included pressurized segments, pressurized shell/modular inserts, external cargo pallets, and large tank.

CR84

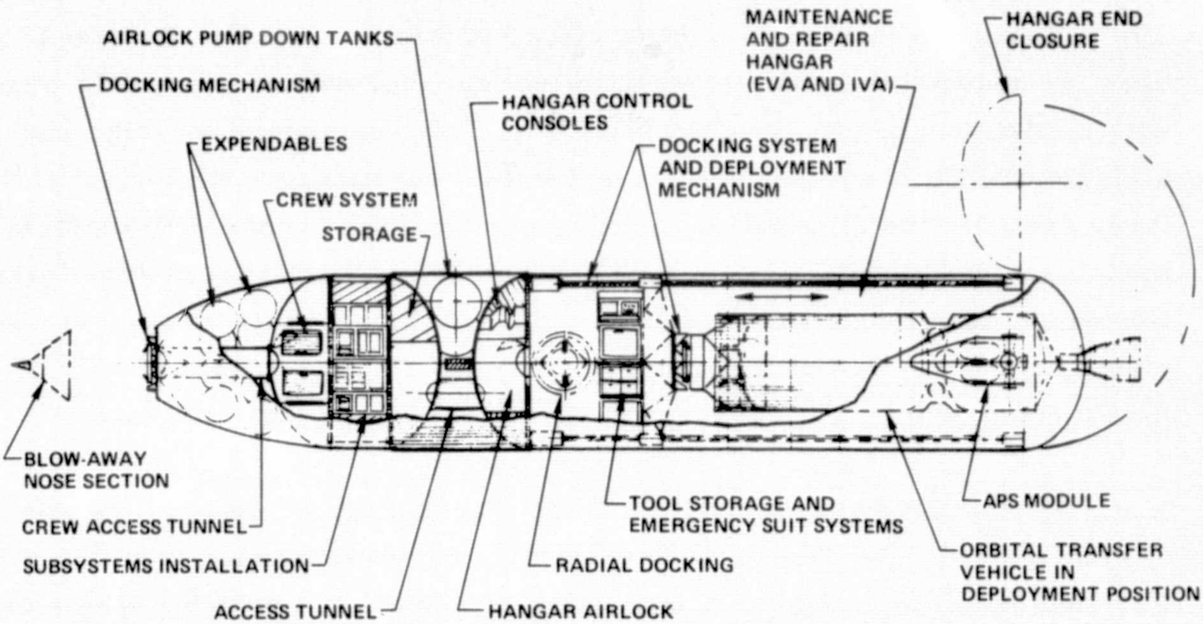


CHARACTERISTICS

- USED AS PROPELLANT TANK BY ORBITER TO LEO
- RELEASED IN LEO – SHUTTLE MONITORS
- REQUIRES PRELAUNCH MODIFICATION OF TANK INCLUDING:
  - SECONDARY STRUCTURE AND/OR SUPPORTS
  - STABILIZATION SYSTEM (RESISTOJET, ION, OR HYPERGOL)
  - COMMUNICATIONS – INITIAL OPERATIONS
  - LARGE-DIAMETER DOCKING AND TRANSFER PORT
  - INTERIOR INTERTANK ACCESS TUNNEL
  - REMOTE RESIDUAL FUEL VENTING CONTROLS
  - TANK OPENING SEALS
  - IMPROVED MICROMETEOROID SHIELDING
  - IMPROVED INSULATION/SURFACE FINISH
- OUTFITTED IN LEO BY EVA/IVA OPERATIONS DURING SUBSEQUENT RESUPPLY MISSIONS
- HABITABLE ENVIRONMENT PROVIDED THROUGH DOCKING CREW QUARTERS/ECLSS MODULE(S)
- INTERNAL MODIFICATIONS AS LARGE SPACE STATION HABITABILITY, STORAGE, OR HANGAR FACILITY THEN MADE UNDER SHIRTSLEEVE CONDITIONS

Figure 4-53. Space Shuttle External Tank, Wet Configuration

CR84



CHARACTERISTICS

- TRANSPORTED TO LEO AS ORBITER PAYLOAD
- ACTIVATED AND INHABITED BY SUBSEQUENT MISSIONS
- PRELAUNCH CONFIGURATION CHANGES REQUIRED:
  - DELETION OF MOST PLUMBING
  - STABILIZATION SYSTEM (CMG OR ACTIVE)
  - COMMUNICATIONS
  - INTERNATIONAL DOCKING PORT(S)
  - MICROMETEOROID SHIELDING
  - ALL HABITABILITY STRUCTURES AND PROVISIONS
  - INTERIOR INTERTANK ACCESS TUNNEL
  - IMPROVED INSULATION/SURFACE FINISH
  - POWER SUBSYSTEM
- ADVANTAGES
  - IMMEDIATE LARGE VOLUME
  - CAN SUBSTITUTE FOR SEVERAL MODULAR SHUTTLE PAYLOADS

Figure 4-54. Space Shuttle External Tank, Dry Configuration

An additional application would be the assembly of a large crew module for construction crews of 100 to 150.

The two large crew modules, Figure 4-55 (Options 1 and 2), are based upon the assembly of completely outfitted and checked out submodule elements with a minimum of interface connections. This would have a design goal of a single umbilical connection. An advantage of this approach for supporting large crews is the elimination of from 5 to 10 of the 4.6m (15 ft) diameter modules. Of the two designs, the pressurized shell with pallet-type installation would be lighter and probably less costly. Conversely, the pressurized elements provide flexibility in element removal, safety of individually pressurized volumes, and exchange of different functional elements.

In the fabrication and assembly or space manufacturing concept, the advantage of external storage of cargo pallets (Option 3) would depend upon the product. For sequential fabrication and assembly procedures, in which a single cargo module can hold more material than required for one item and a variety of

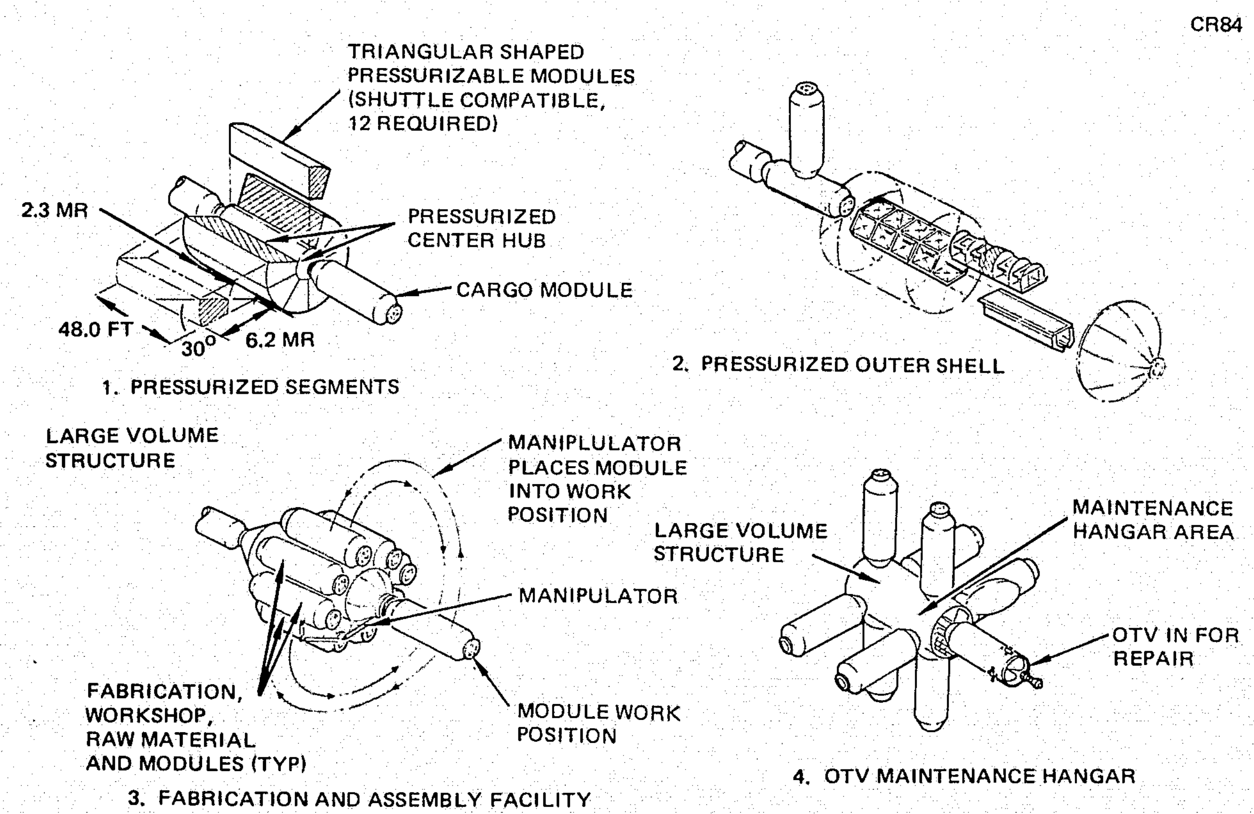


Figure 4-55. Candidate Large-Volume Module Applications

material is required, this chambering concept would be efficient. Unequal MOI's would be minimized and the drag profile should be lower than radial docking.

The OTV maintenance hanger concept is a fundamental application with secondary structure providing the support and servicing. Complex supporting shop facilities would be added through docking of small modules.

The structural design approach, launch approach, and orbital maneuvering of the large volume structures will be analyzed in Part 2. An additional area requiring evaluation is the structural attachment and control requirements for integrating the large volume structure into the modular Space Station. If any of these conceptual applications show merit in supporting early option requirements, the orbital assembly of a Shuttle-compatible configurations would be employed.

4.5 TRANSPORTATION REQUIREMENTS

The transportation analysis conducted in Part 1 included a preliminary definition of the characteristics of the transportation elements, the flights needed for each of the program options analyzed, and early considerations of the influences of potential vehicle interfaces.

4.5.1 Vehicle Analysis

The missions require an overall complement of transportation systems as indicated by Figure 4-56. Mission requirements include earth-to-LEO, PEO, and transfer to GEO. The basic LEO and GEO requirements include all the orbital elements needed in orbit, from payloads to propellant. The Shuttle and HLLV are the carriers for this phase.

GEO transfer requirements include satellites, objective elements, and modules needed on orbit. Launch systems considered include large and small OTV's, manned tugs, electro/chemical systems, and expendable stages.

Vehicle systems used for the Part 1 transportation analysis of the program options are as defined in Table 4-20. Except for the Shuttle, the capabilities will be defined and analyzed as the study progresses.

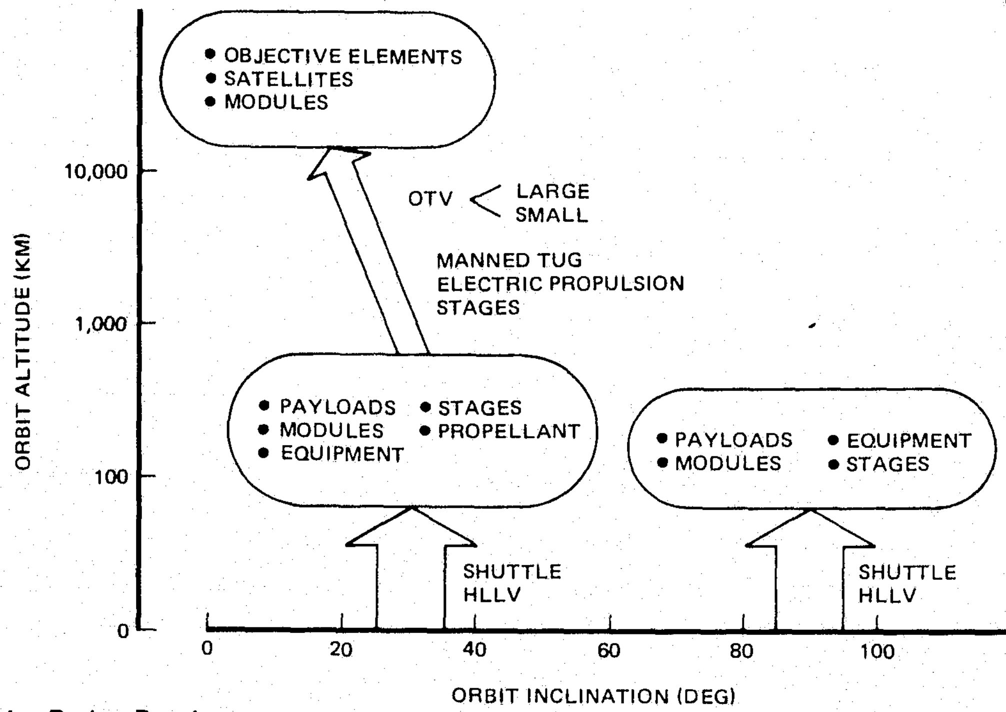


Figure 4-56. Mission Regime Requirements

Table 4-20

TRANSPORTATION SYSTEM ELEMENTS

• Shuttle	07700 Vol. 14 (Rev. D Change 15)
• HLLV	Shuttle-derived 127,000 kg payload $16M/launch
• OTV	29,500 kg GEO payload delivery
• Manned tug	5,500 kg GEO round trip
• SPS/Cluster transfer	Electric: 1,200 4.5N thrusters (10^{-3} g) Chemical: RL-10 Equivalent (10^{-2} g)

The Shuttle consists of the latest configuration; the initial HLLV used was a Shuttle-derived concept defined by JSC. It has a basic 136,000-kg lift capability that includes a payload canister (127,000-kg payload capability). The launch cost was given at $16M each, including the $2M expendable canister. Subsequent review of other HLLV concepts indicates that a lower payload capability system should be selected for future analyses.

The OTV was defined at a 29,500-kg payload to GEO capability. Subsequent parametric analyses will allow the adjusting of this size. The manned tug was sized to transfer crew between LEO and GEO. Its size and relationship to OTV will be determined.

Orbit transfer concepts for large payloads such as SPS include electric, chemical, and combinations. The system chosen for this early analysis was the latter. An electric propulsion system would be used to provide the low-g transfer. The power, supplied by the host solar array (SPS or Cluster) is used to accelerate the system by expelling propellant (typically Argon) at high velocity. Typically 1,200 4.5N thrusters would provide a 10^{-3} g acceleration. A chemical system would also be used to transfer the system quickly through the Van Allen belt to reduce radiation damage to the host solar cells. An RL-10 engine module or equivalent could be used.

A review of the Future Space Transportation Systems Analysis Study indicated that candidate Shuttle-derived concepts for HLLV are as shown in Figure 4-57.

The Shuttle-derived concepts use the Shuttle External Tank (ET), the SRM's, and the Orbiter main engines and Orbiter maneuvering system (OMS). The Orbiter is replaced with a payload canister that is expended in orbit. The payload canister size range of 8 or 9.2m in length and 9.6 or 11.2m in diameter for each concept shown causes the corresponding payload capability range. The main engines and OMS are retrieved for reuse by enclosing them in a return capsule designed for ground landing. The first upgraded concept shown uses a pair o. Shuttle SRM's while the second uses four SRM's with the ET modified to accommodate them. The definitions of these concepts and their effect on the Space Station study elements will be provided in Part 2.

The (OTV) was analyzed parametrically as shown in Figure 4-58. The delivery payload and round trip payload capability for LEO-to-GEO transfer as a function of stage mass and propellant load is shown with corresponding λ' indicated. The OTV delivery capability required to accommodate the program option elements ranges from 5,500 to 90,000 kg. The larger payload elements are antennas and they are not great in number as are the smaller payloads. The bulk of the transfer payloads are

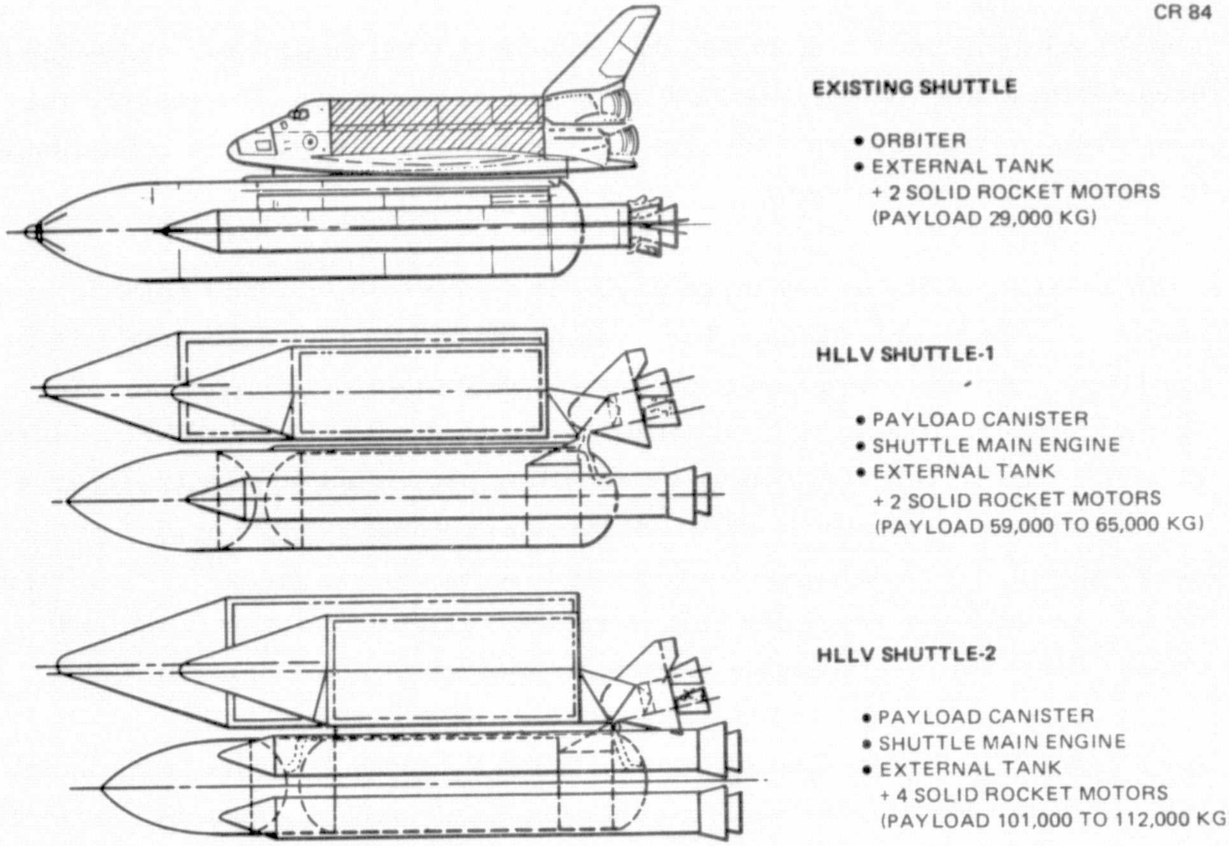


Figure 4-57. Heavy-Lift Logistics Vehicle

CR84

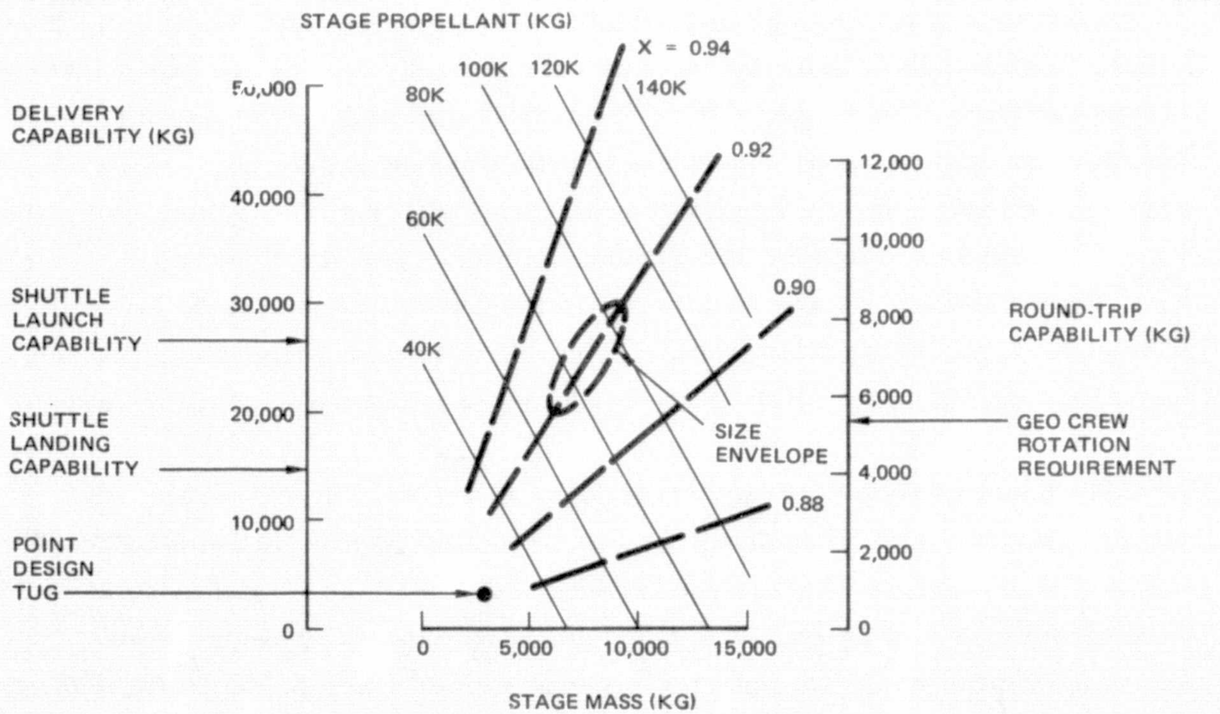


Figure 4-58. OTV Performance Envelope, Geosynchronous

ORIGINAL PAGE IS OF POOR QUALITY

(1) modules or objective element units that are launched LEO-to-GEO transfer in the 5,000 to 9,000-kg round-trip range. Other considerations, such as Shuttle maximum capability to LEO and maximum design landing capability (29,500 kg and 14,500 kg, respectively), also influence the selection. The OTV cargo and manned version requirement similarity must also be considered. Analysis of potential OTV concepts showed that a λ' of 0.92 may be achievable for an orbit-based OTV. Thus the design size of the OTV should be in the range indicated. For the analyses to date, a nominal OTV having 29,500-kg delivery capability was used. Future analyses will determine the recommended OTV size.

In Table 4-21, the design characteristics of a potential lightweight OTV were determined and are compared to those of an earth-based cryogenic tug design determined by MDAC in the tug point design studies performed in 1974. The OTV is lighter in weight by virtue of its newer design concepts, materials, and obviates the need for continuous earth launch and return. The vehicle design features load-carrying 7475 Al propellant tanks, epoxy-fiberglass tubular tank supports, graphite-epoxy isogrid structural shelf, multilayer insulation MLI) on the propellant tanks, a new high-performance zero NPSH LO_2/LH_2 main engine based on extension of Pratt and Whitney RL-10 technology, and a storable bipropellant attitude control system.

The avionics section includes redundant central computers, stellar/inertial attitude reference, TV docking, redundant fuel cells, and electromechanical switching in the power distribution and control system.

4.5.2 Program Option Transportation Analysis

The 45 program options were analyzed to determine respective transportation requirements as shown in Figure 4-59. Each program option definition was reviewed and coupled with detailed objective data from the objective data packages; then a schedule of hardware elements was derived. Vehicle sizing, performance analyses, and systems analysis were used in conjunction with the schedule data to derive a program option element matrix (for use by costing analysts), the transportation requirements for Shuttle, HLLV, OTV, Cargo, and Manned, Electric Propulsion, etc. These analyses resulted in guidelines to be used for the next option analysis iteration.

Table 4-21

LIGHTWEIGHT OTV

($\lambda' = 0.92$)

	Point Design Tug (kg)	Lightweight OTV (kg)
Propellant tanks	351	169
Support structure	504	191
Insulation, meteoroid	96	57
Docking	132	104
Engine	240	59
APS	206	144
Propulsion support	211	130
Avionics	489	275
Shuttle delivery contingent	451	-
	2,680	1,129

CR84

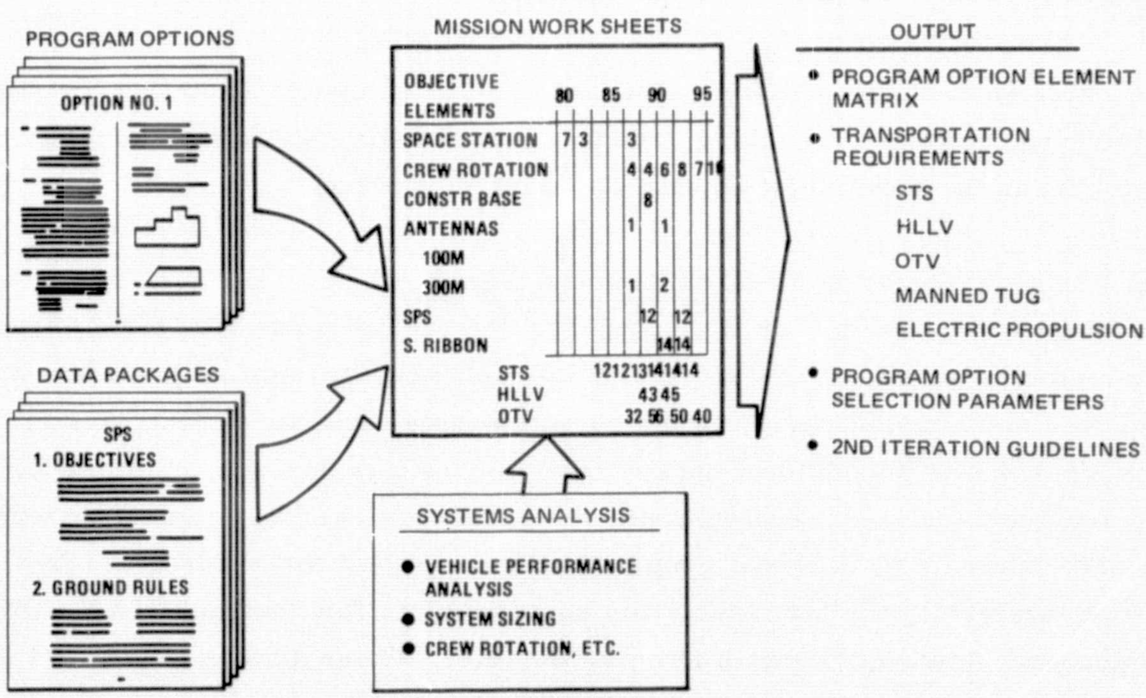


Figure 4-59. Program Option Transportation Analysis Methodology

Table 4-22 illustrates how the time-phased transportation requirements were calculated for each program option. A typical analysis shows launches totalling 251. The numbers across the top show crew size required as the mission progresses. In the early years, the placement of the Space Station modules and crew rotation and logistics flights use the Shuttle flights needed. Delivered modules and logistics allow the early portion (primarily R&D) of the program to be accomplished. Flight requirements increase as objective elements are delivered. Specifically, the construction base and SPS Pilot Plant require several launches. Implementation of the geosynchronous Space Station again requires Shuttle flight for the delivery and fueling of OTV's and Manned Tug. The yearly maximum number of flights varied from 10 to 236 for all options. Clearly, program schedules for the high launch rate options had to be reconsidered in both time and content to accommodate launch rate capabilities. These data were used to determine overall transportation requirements as an element of system cost.

The total Shuttle and HLLV flights needed for each program option are shown in Figure 4-60. The minimum required was No. 3C and 264 Shuttle flights and the maximum was No. 16A with 686. The flight spread and effect on the cost of each program option at $17.3M per flight is quite large (1.1 to 11.9B).

Required OTV-Cargo and OTV-Manned flights were calculated for each program option, as shown in Figure 4-61. The OTV-Cargo flight requirements are in two ranges. Most of the program options (34 of 45) required less than 10 OTV-Cargo flights for unmanned deliverables. The remaining 11 required a range of 29 to 50 flights. OTV-Manned Tug requirements to accomplish GEO crew rotation number from 15 to 38 for the 28 options that need it.

Clearly, the OTV cargo and OTV manned tug should be considered as a potential common vehicle because of the similarity of their performance requirements (mentioned earlier), their compatible flight schedules, and

Table 4-22

TYPICAL PROGRAM OPTION SHUTTLE FLIGHT

	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
	Crew Size				12	12	24	24	24	24	30	30	12/7	12/7	12/7		
Space Station (LEO)					7	7	3				4						
Crew Rotation (LEO)					4	4	8	8	8	8	10	10	4	4	4		
Space Station (GEO)												4					
Crew Rotation (GEO)												16	16	16	16		
Manned Tug												1					
Construction Base										8							
SPS Pilot Plant											12	10					
Transfer System												14	14				
SI Ribbon											2	3					
Radiotelescope								1			2						
30m Comm Antenna								1			1						
Depot												8					
OTV													1				
OTV Propellant													11				
Hangar										1							
					11	11	11	10	8	17	31	66	46	20	20		251

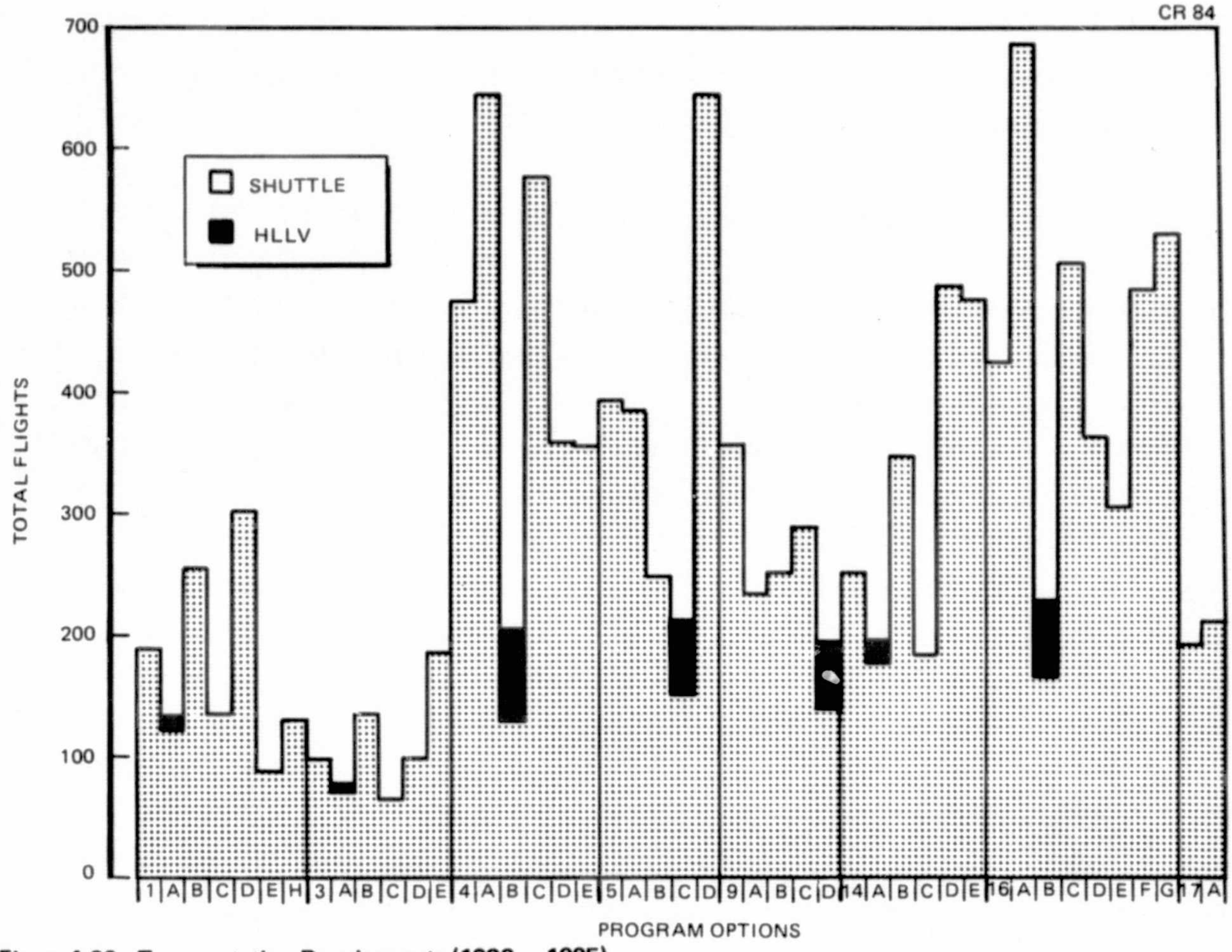


Figure 4-60. Transportation Requirements (1983 – 1995)

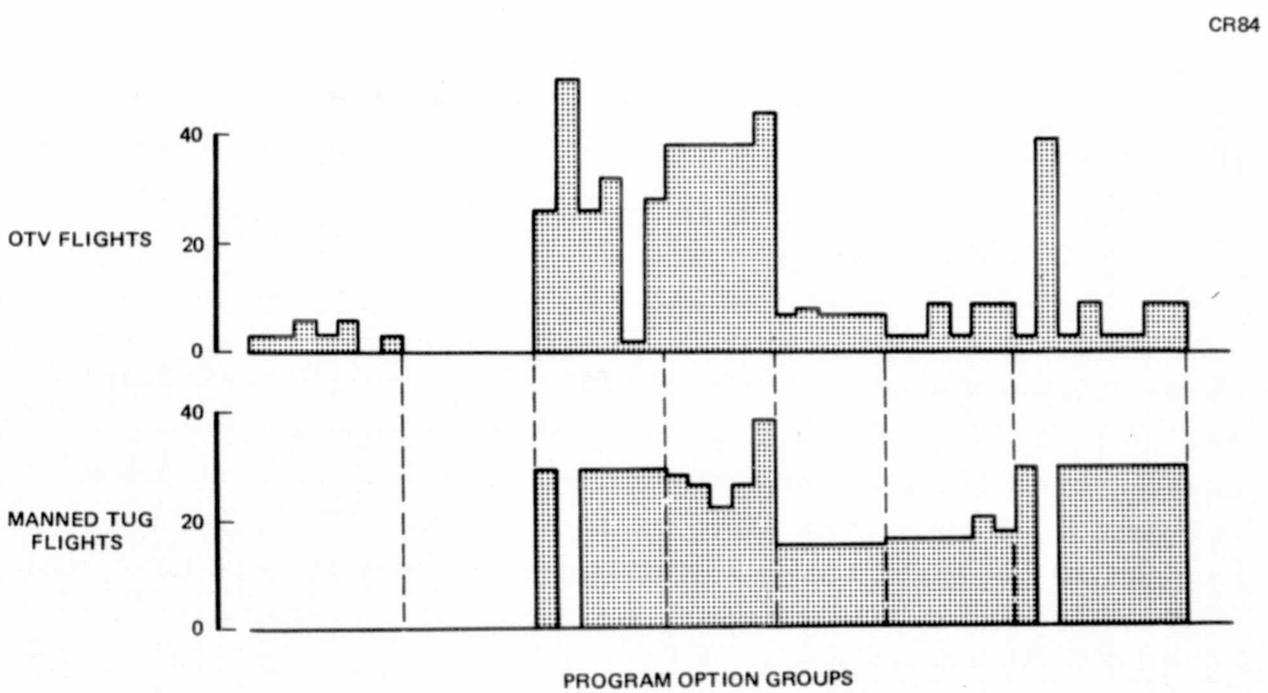


Figure 4-61. OTV/Manned Tug Flights (1983–1995)

the large number of options with a low number of OTV-Cargo flights needed (thus, questioning the economic viability of the OTV for these missions).

Launch rate requirements for each option were calculated for the program schedules initially assumed. The effect of launch rate capabilities on the program schedule of a typical program option (No. 14) is shown in Figure 4-62. A launch rate limit of 20 would require an inordinately long extension (up to 8 years) for some options. A 40-per-year launch rate capability would reduce the required extension to about 2 years. For this analysis the program was lengthened as needed to stay within the allowable launch rates.

The effect of launch rate capabilities of 20, 40, 60, and 80 per year on the implementation schedule of all 45 program options is shown in Figure 4-63. A 20-per-year capability would require schedule extensions of 5 years or more on about half (23 to 45) up the program options. A launch rate capability of about 60 per year is needed to keep the schedule extension to less than 5 years for all options. Program options must therefore be selected and defined with care to ensure launch rate compatibility. The need for HLLV is evident to reduce the rates for the high transport requirement options.

4.5.3 Major Transportation/Payload System Interfaces

Payload/transportation system interface designs selected will have a great effect on the overall complexity, cost, and ease of operations. The design goal is to minimize the interface relationship while maintaining those interfaces that are necessary to accomplish the mission, ensure safety, and that are an overall benefit.

Potential Space Station program interfaces with the transportation system are categorized in Table 4-23; as resources, environmental, and operational. The resources represent interface elements that can be used to advantage by prospective payloads should they be found to be desirable. The second category has to do with design constraints or "spec values" that

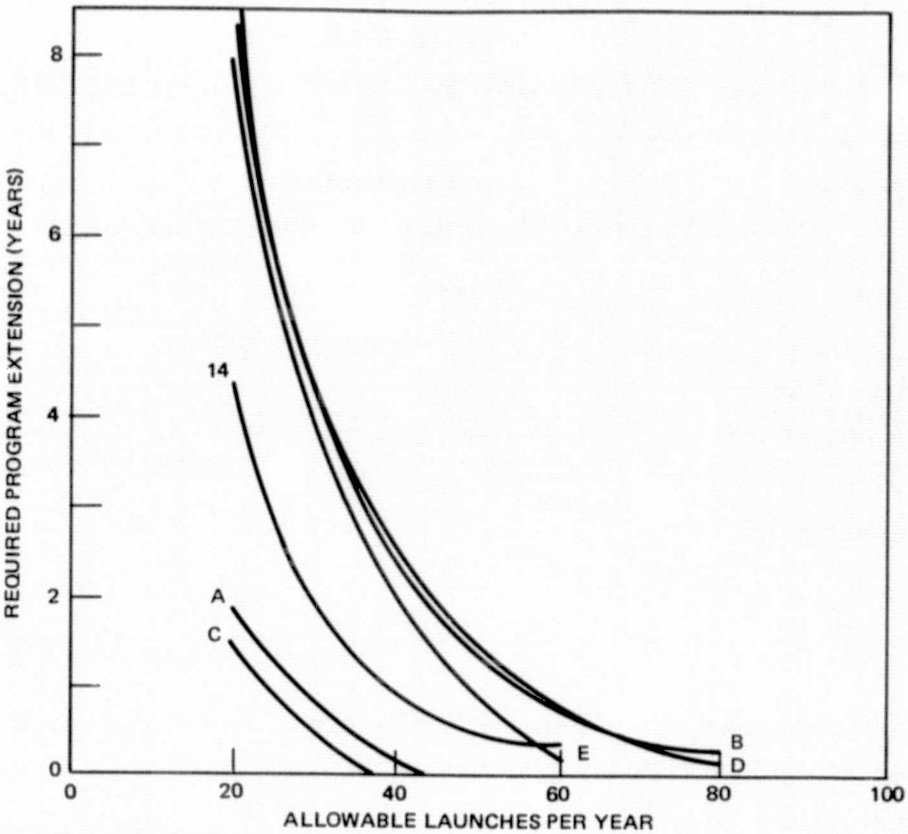


Figure 4-62. Launch Rate Effects, Option 14

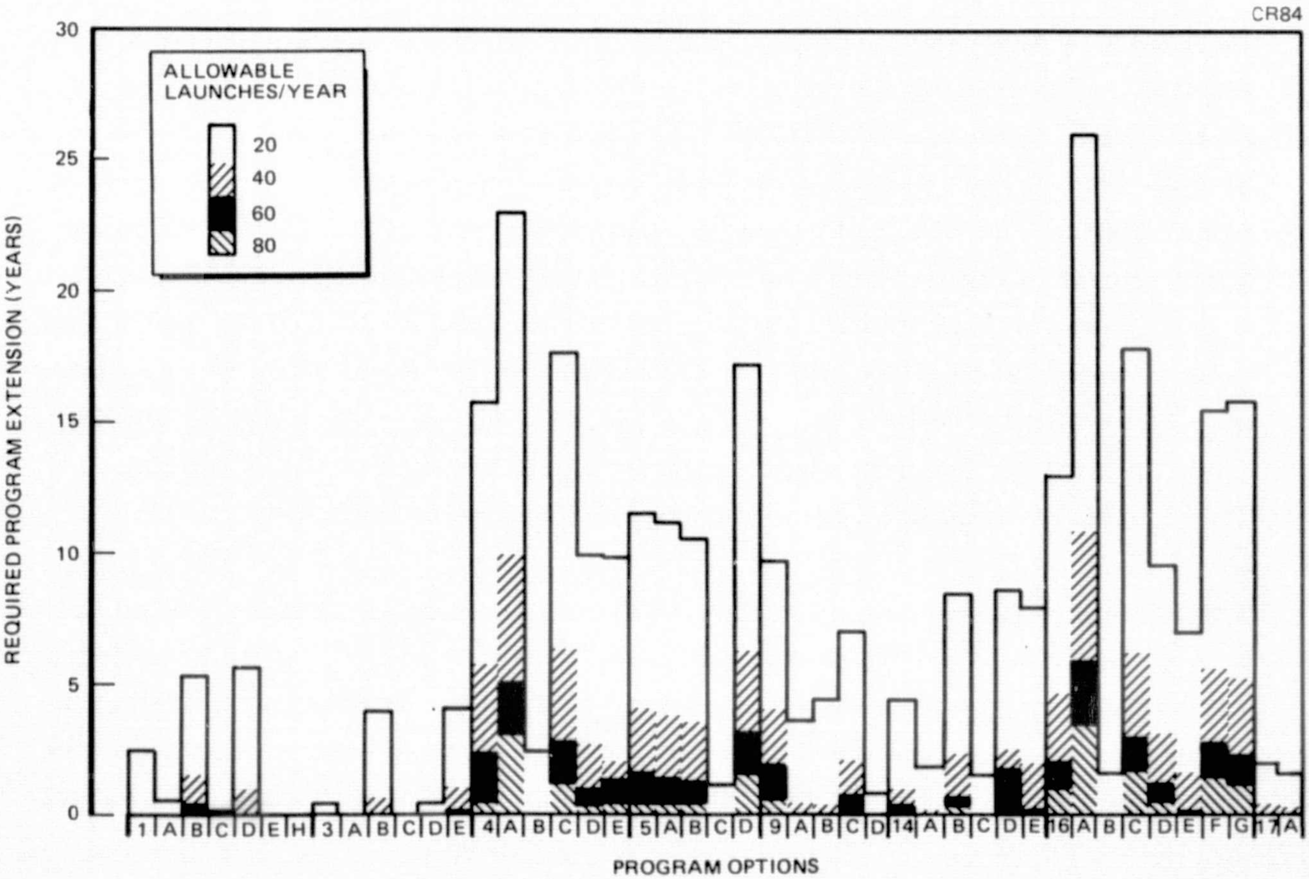


Figure 4-63. Effect of Launch Rate on Program Duration

Table 4-23

MAJOR TRANSPORTATION/PAYLOAD SYSTEM INTERFACES

Resources	Environment	Operational
(Design Goal: Minimize Interface Dependency)		
Attachments	Loads	Access
Power	Vibration/Acoustics	Launch Rate
Thermal Control	Acceleration	Abort
Purge, Vent, Dump	Thermal	Landing
Caution and Warning	Contamination	
Data Transmission		
Crew		

must be accommodated. In general, these are comparable with current launch vehicle characteristics. Operational interfaces are somewhat different because of the very nature of the transportation system, i.e., Shuttle.

Preliminary analysis of the payload cg constraints was accomplished for the allowable Shuttle payload cg envelope shown in Figure 4-64. It is derived from Shuttle pitch control capabilities during reentry and therefore, must be observed at the respective weight conditions present prior to reentry for either an abort or a normal landing. As shown, the center of the envelope is about 3m aft of the payload bay center. Thus, long homogeneous payloads will be restricted in weight. Maximum design weight (29,500 kg) and maximum planned landing payload (14,500 kg) are also shown. The payload bay also can be occupied by the docking module (1,713 kg x 2m long) or OMS kits (10m long with mass dependent on number used) as the mission requires. These must be accounted for in the cg envelope calculation.

The allowable payload cg envelope in terms of weight and length of a potential homogeneous payload is shown in Figure 4-65. As shown, an 18m homogeneous payload must not exceed 12,500 kg. If the docking module is used on a particular version, the maximum allowable remaining payload could be 16m long with a mass of 12,500 kg. Shorter payloads for both cases would allow

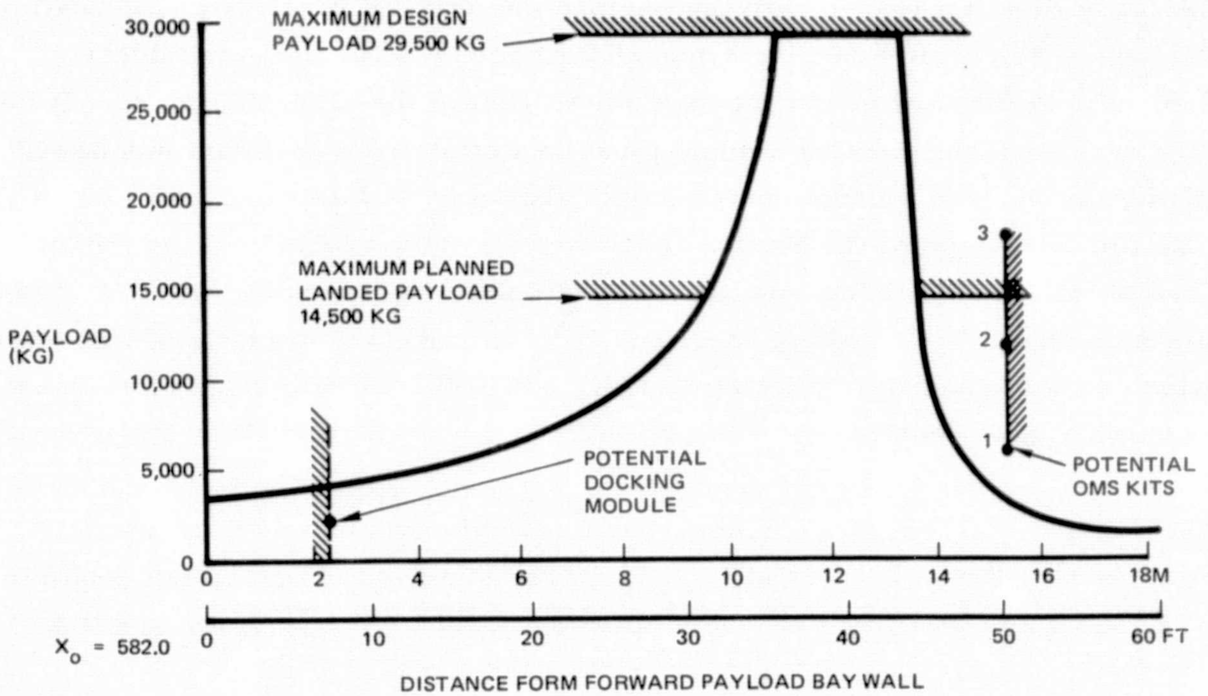


Figure 4-64. Allowable Payload CG Envelope

CR84

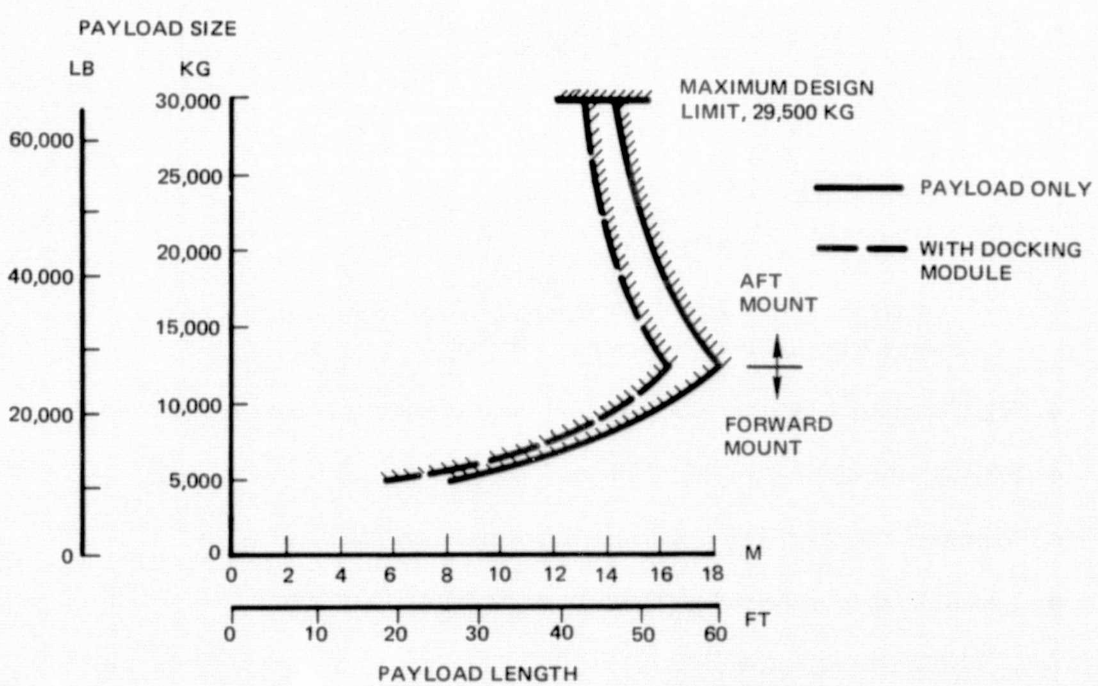


Figure 4-65. Module Design Envelope,Homogeneous Module

the mass to be increased with the payload mounted aft (against the aft wall of the bay). This would require a tunnel for access to the cabin (or docking module). A forward mount location would reduce the allowable mass. It may turn out that if the docking module must be flown on a significant number of flights the payload module design length should be reduced to 13 on 14m to take full advantage of the Shuttle capability. Future analysis of the module designs will consider their length requirements, cg locations, docking module flight compatibility, tiedown location, etc. In addition, operational consideration can influence the cg solution, i.e., aft RCS tank ballasting or removal of forward equipment.

The results of the Part 1 transportation analysis are summarized in Table 4-24. The large variation in required launches indicates the need for HLLV on some options, that some options should be scaled down, and that

Table 4-24

RESULTS AND CONCLUSIONS

- Program option transportation requirements determined
- Large variation in launch requirements

    Shuttle, 64 to 686
    HLLV, 6 to 76
    OTV, 2 to 254
    Manned tug, 15 to 38

- Relatively few OTV flights

    10 flights for 28 of 39 program options using OTV
    Depot should be reconsidered

- HLLV appears needed for "all objective" program options
- HLLV should be in 60,000 to 112,000 kg payload range
- Manned tug and OTV should be same vehicle
- Launch rate effects program schedule

    Schedules extended
    Up to 80 launches/year with no HLLV

- Shuttle cg envelope restricting

OTV-Cargo may not be viable as a single element of some of the options. The relatively small number of OTV-Cargo flights suggests that the depot definition be reconsidered. Similar OTV cargo and OTV manned Tug performance requirements and compatible missions and schedules suggests that they be the same basic vehicle to make best use of development expenditures.

The Shuttle-derived HLLV to be used for future option analysis should be in the 60,000 to 112,000-kg payload range.

As a goal, payload/transportation system interfaces will be kept to the minimum that can be used to advantage by the payloads. Analysis to date indicates that Shuttle payload cg envelope restrictions limit the full use of the Shuttle capability.

Section 5
PROGRAMMATICS

5.1 COST, SCHEDULES, AND FUNDING FOR PROGRAM OPTIONS

During Part 1 of the Space Station Systems Analysis Study, rough order of magnitude (ROM) cost and schedule data were compiled for each of the 56 different options. Special emphasis was placed on using methodology and procedures that identified the difference in costs between each of the various options. This emphasis on relative cost, rather than absolute, was implemented by using the following approaches.

First, not only were common ground rules and assumptions applied to all options, but care was used to assure that no option was artifically favored or penalized by biased assumptions or procedures. For example, development cost was determined for the total Space Station rather than assigned separately for each module. This assured that the cost of all required subsystems were fully accounted for, and prevented omitting part of the cost of developing a given subsystem because part of its cost had been prorated to a module (such as the CORE module) that was not included in each option.

Second, the cost of each hardware element used in any of the options was computed separately (outside any option) and recorded in a list of standard costs. These standard costs were used as building blocks to assemble the cost of each option. This procedure assured that the same cost was included in each option for the same effort. The only adjustment that was made to these standard costs was to reflect the impact, if any, of the interaction of a different combination of items within a given option. For example, in this part of the study, the same special tooling employed to build the large SPS Pilot Plant II is also used to build the large cluster array. Therefore, the cost added to an option to include the cluster array would be adjusted depending on whether the large SPS was also constructed in the same option.

PRECEDING PAGE BLANK NOT FILMED

Third, the transportation required to deliver items from earth to LEO or PEO, and the Shuttle flights needed to deliver propellant to LEO for transferring equipment to GEO, was also standardized by item.

Fourth, no learning curves were used in calculating multiple usage because this could introduce an artificial cost differential for accomplishing the same objectives on different options solely because of an arbitrarily assigned position or difference in sequence on the curve.

The cost of the hardware item and the effort required by each option were identified in the three major categories specified in the WBS: Space Station, mission hardware, and transportation. These three categories were segregated into initial program costs and total program costs as defined in the ground rules and assumptions.

The MDAC Modular Space Station Study was the major base for the costs assigned to the Space Station modules and hardware items. However, these costs were supplemented and modified by data from other sources, including data generated during the Manned Orbital Systems Concepts study, data obtained from the Skylab program, and information from the MDAC data bank, including factors and ratios traditionally used by MDAC. The detail cost data available from these sources was segregated into categories to facilitate determination of how module cost varied with subsystem content, and how subsystem cost varied with such parameters as module length, crew size or power requirements. The resulting cost estimating relationships (CER's) were used to determine the cost of each of the various Space Station modules (including the general purpose fabrication/construction facility) used in each of the options.

Mission hardware costs were estimated by using data from several sources depending on the hardware configuration. Costs for items that are similar to Space Station hardware were derived from module costs. They include such items as Depot docking modules and research labs. For tooling and jig-fixture items, such as the special fixture required for constructing the 300m antenna, costs were derived from structure CER's in the MDAC data bank. Costs for facility items, such as the silicon-ribbon and blanket fabrication process items constructed in space, such as antennas, and radiotelescopes were taken from Outlook for Space whenever possible. When data were not available, as in the case of the SPS array, costs were derived by engineering judgment based on data from Skylab, SEPS, and MDAC data bank.

Transportation costs were supplied by NASA. These costs included per flight costs for the Shuttle and a 135,000-kg gross payload HLLV. They also included development and unit costs for the HLLV and for a 29,000-kg payload OTV. All these costs were increased to 1977 dollars using factors in the table shown under the cost ground rules and assumptions. MDAC estimated the cost of a suitable payload shroud, and this was added to the development and per flight cost of the HLLV. Transportation costs included in each program option included the cost of any Shuttle and HLLV flight from earth-to-orbit and return. It included the cost of purchasing the HLLV and OTV's. The costs for OTV flights from LEO to GEO included only the cost of Shuttle (or HLLV) flights required to deliver the propellant from earth to LEO station.

Table 5-1 is a summary of the costs of Options 18-26. The table shows total cost, maximum peak year funding, and the year in which peak year funding occurs for the initial and total program for each of the options. The initial program includes the cost associated with those levels of objectives whose pace activities are initiated prior to 1986, and the 1986 and 1987 transportation/resupply costs (if any) associated with that effort. Total program cost includes the initial program cost as well as the cost of those space activities begun after 1985.

Figure 5-1 shows the schedule associated with Option 26. Similar schedules were developed for each of Options 18-26, and are included in the Appendix. Timelines shown for Option 26 are typical of the timelines used for other options except that this option includes a larger number of items than the others.

Timelines shown in Figure 5-1 were used to develop the funding distribution for each option. Figure 5-2 shows the annual and cumulative funding for

Table 5-1
TOTAL PROGRAM AND INITIAL PROGRAM COSTS
PROGRAM OPTIONS 18-26
($ MILLION)

COST ELEMENT	PROGRAM OPTION NO. 18	19	20	21	22	23	24	25	26
Total Program Cost									
• Total Program Cost	5849	7235	8847	11357	11544	15780	16403	16702	25179
• Peak Year Funding	905	1075	1327	1377	1564	2075	2457	1965	3513
• Year of Peak Funding	1984	1984	1985	1985	1985	1986	1990	1986	1991
Initial Program Cost									
• Initial Program Cost	5015	5097	5097	5097	5097	6296	7035	7030	6296
• Peak Year Funding	842	853	846	847	847	1168	1381	1463	1168
• Year of Peak Funding	1981	1982	1982	1982	1982	1983	1983	1983	1983

CR84

ACTIVITY	REQUIRED LAUNCHES	CREW SIZE	DURATION
DDT&E			
LAUNCH INITIAL SPACE STATION	LEO 14/1 GEO 17		
SPS DEVELOP AND TEST	0	2	24 MO
SPS PILOT PLANT 1	4	5	16 MO
SPS PILOT PLANT II CONSTRUCTION	9	10	15 MO
SPS PILOT PLANT II – LEO	22	4	36 MO
SPS PILOT PLANT II – GEO	16	2	24 MO
SPACE PROCESSING	0	5	12 MO
PROCESS OPTIMIZATION	0	2	12 MO
SILICON RIBBON/BLANKET PILOT PLANT	4	4	6 MO
COMMERCIAL PROCESSING PILOT PLANT	1	4	CONT
EARTH SERVICES–30M RADIOMETER	8	2	9 MO
100M RADIOMETER	1	4	18 MO
300M RADIOMETER–LEO	18	6	24 MO
300M RADIOMETER–GEO		1	2 MO
MULTIBEAM LENS–LEO	1	2	8 MO
MULTIBEAM LENS–GEO		1	2 MO
CROSS-PHASED ARRAY–LEO	13	6	18 MO
CROSS-PHASED ARRAY–GEO		1	2 MO
MULTIDISCIPLINE SCIENCE LAB–MAXIMUM	0	8	CONT
LIVING AND WORKING, LIMITED RESEARCH	0	1	CONT
EXTENSION RESEARCH	0	2	CONT
DEMONSTRATE TECHNIQUE		4	CONT
CONSTRUCTION SUPPORT	0	5	CONT
SPACE COSMOLOGICAL R&D			
COMPONENT DEVEL. & TEST	0	1	6 MO
MARK II RADIOTELESCOPE	1	4	6 MO
TEST OPERATIONS	0	1	2 MO
DEPOT – COMPONENT DEVEL. & TEST	0	1	12 MO
SMALL OTV DEPOT	2	7	CONT
LARGE OTV DEPOT	2	1	AS REQD
CLUSTER–MSPP	0	0	0
LARGE CLUSTER COMPONENT DEVEL.	0	2	6 MO
LARGE CLUSTER PILOT PLANT	86	20	6 MO
SENSOR – DEVELOP & TEST	0	1	CONT
FAB & EVALUATION	0	4	CONT

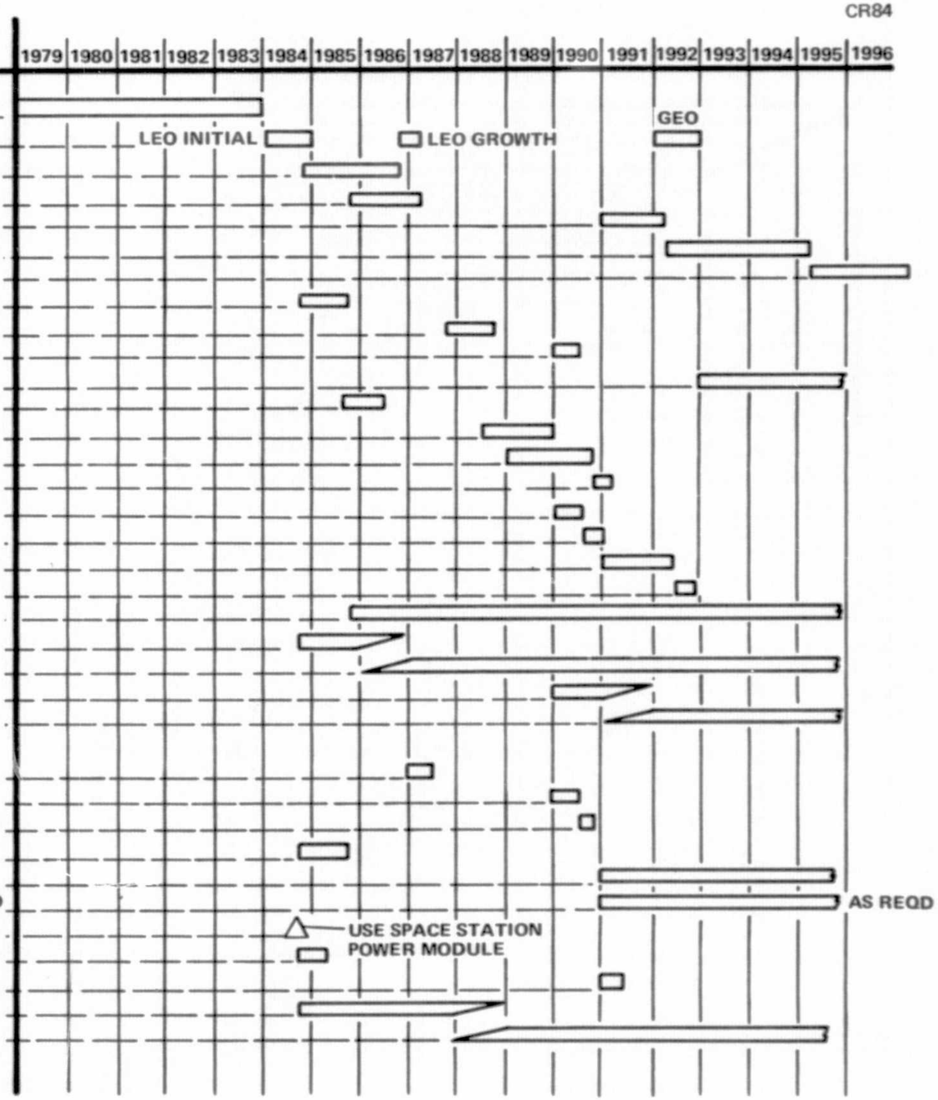


Figure 5-1. Option 26

CR84

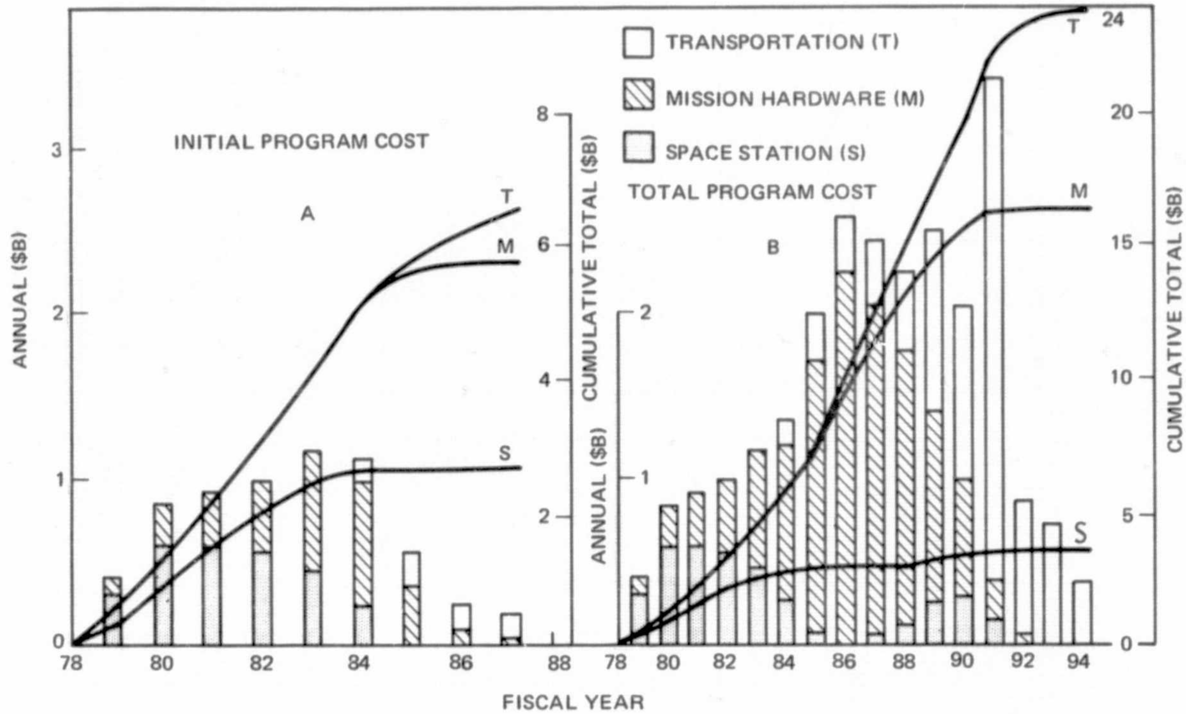


Figure 5-2. Candidate Option 26, Cost

The initial program of Option 26; Figure 5-2B shows the total program funding for the same option. The lower curve is the cumulative cost of the Space Station and mission hardware. The top curve is the cumulative cost of the Space Station plus mission hardware and transportation. More detailed cost information is presented in Volume 3, Book 2.

5.2 GROUND RULES AND ASSUMPTIONS

The ground rules and assumptions used for obtaining costs for Part 1 of the Station Station Systems Analysis Study are as follows:

1. Cost estimates are reported in constant fiscal mid-year (April) 1977 dollars.
2. As required, previous year dollars are escalated as follows:

CALENDAR	DDT&E		PRODUCTION		OPERATIONS	
MIDYEAR	% Increase	Cum	% Increase	Cum	% Increase	Cum
1970	5.0	153.4	5.5	162.8	6.2	161.4
1971	3.7	146.1	4.3	154.0	7.4	152.0
1972	3.9	140.8	4.5	148.0	6.3	141.5
1973	7.5	135.6	9.8	141.6	9.5	133.1
1974	10.0	126.1	10.9	129.0	6.4	121.6
1975	9.0	114.6	10.0	116.3	9.0	114.2
1976	5.1	105.1	4.7	105.7	4.8	104.8
FY1977		100.0		100.0		100.0

The foregoing data are based on DoD Deflators, " Office of the Assistant Secretary of Defense (Controller), February 4, 1974, DOD Escalation Indices "Defense Space Daily, " 8 July 1975; and "Price Level Indexes, " Defense Communications Agency Circular 600-60-1, Section F, Change 3, June 1975.

3. Funding distributions are in October 1 through September 30 fiscal years.
4. 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.
5. Cost estimates exclude NASA institutional costs, such as base support contractor personnel costs, civil service personnel salaries and allowances, and administrative support technical services.
6. NASA-furnished flight costs of $18.94M per Shuttle flight and $16.6M per HLLV flight, both in mid-FY 1977 dollars, are used.
7. Mission hardware costs reported in the Outlook for Space report are used when more recent data are unavailable.

8. The costs for each Program Option are grouped into three categories which in turn are divided into groups as follows:

- Space Station Project
  - Power module
  - Crew module
  - Control center
  - Crane module
  - CORE module
  - Station cargo module
  - Fabrication and assembly facility
- Mission Hardware Project
  - Special tooling
  - Items built in space
  - Items not specifically included in the Space Station or Transportation project costs
- Transportation Project
  - Orbital transfer vehicle (OTV)
  - Heavy lift launch vehicle (HLLV)
  - Shuttle flights

9. The emphasis is on relative costs rather than on absolute costs.
10. No learning curve has been used in Part 1. This minimizes the distortion induced by arbitrary placement of the units on a learning curve.
11. The cost estimates are developed in consonance with the latest JSC approved Work Breakdown Structure (WBS) and WBS dictionary.
12. The cost estimates assume no dedicated flight test hardware.
13. All flight crew and training costs not included in the Shuttle costs per flight or HLLV costs per flight are excluded from the total program costs.
14. It is assumed for funding purposes that the first available funding will be in Fiscal Year 1979.
15. It is assumed for scheduling purposes that the first Space Station launch will be in Fiscal Year 1984, and that the Growth Station will be initiated in Fiscal Year 1986.
16. The 1971 modular Phase-B Space Station costs are used as a base for deriving Space Station costs for this study.
17. Where any manned vehicle free-flying vehicle is required, a minimum of two vehicles are included to ensure that an alternate/rescue vehicle would be available.

Section 6
RESEARCH IMPLEMENTATION

Requirements for major Space research technology (SRT) in support of Space Station development will generally be identified during Part 2 and Part 3 after analysis of critical operations and the selection of primary Space Station concepts. Three preliminary candidate areas for SRT have surfaced during Part 1 objective analyses which will impact the initial station design. The areas are:

- General docking, berthing, and equipment-handling techniques.
- EVA operations, which are an intrinsic Space Station function in support of many objectives.
- Storage and transfer of propellants from the Space Station to a variety of vehicles on orbit.

Each of these areas will be evaluated in the succeeding months to determine the magnitude of the problems, alternate methods of resolution, and the scope of the requisite SRT activity.

6.1 GENERAL DOCKING, BERTHING, AND EQUIPMENT HANDLING

The orbiter docking capability will be evaluated in Part 2 to ensure that viable concepts are defined and to determine the design impact on those concepts. The chief area of concern to date is in the area of stability and control authority of the station/orbiter combination. This will be examined in the impending studies, and solutions recommended for x, y, or z axis docking.

Crane devices for moving and handling modules and other equipment are an integral part of this problem and will be analyzed.

Two types of cranes are candidates for SRT, a two-arm traveling crane and a single-arm monorail crane. Variations in the crane concept will include single-arm fixed location, single-arm module, two-arm mobile, and mobility concepts such as monorail and self-propelled or walking crane. The two-arm traveling crane configuration, shown in Figure 6-1, has several unique operational characteristics.

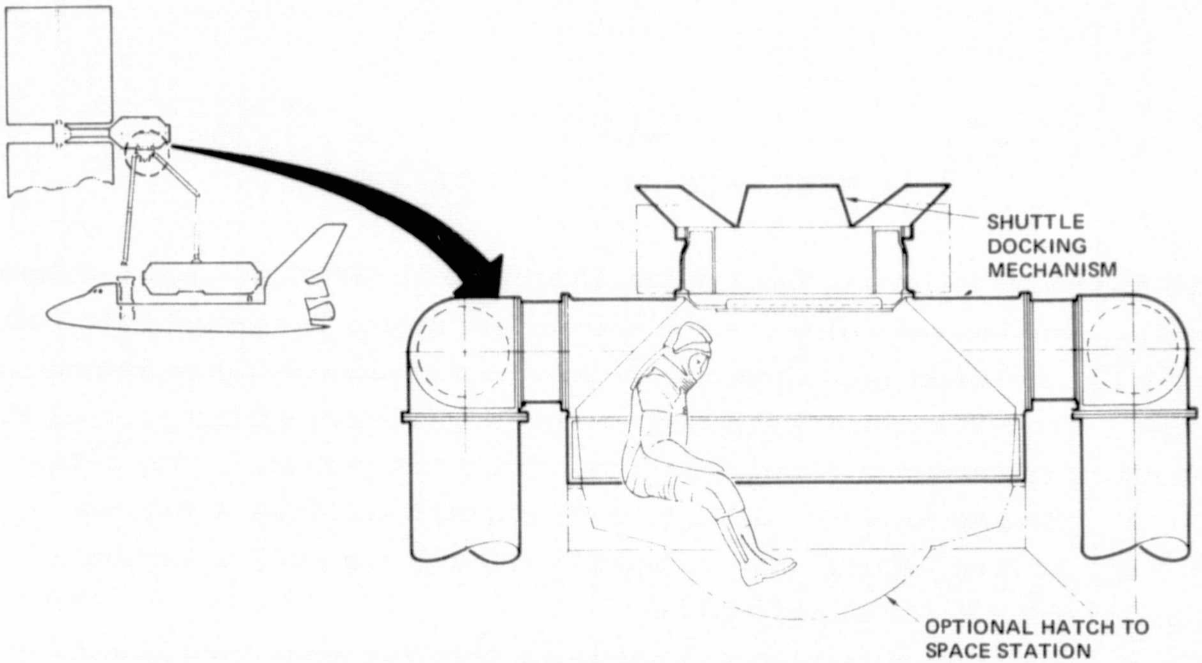


Figure 6-1. On-Board Two-Arm Crane Module

- It has the mobility to move to all extremities of the Space Station through the use of external attach points on the Space Station module's external surface.
- It can handle the exchange of cargo modules virtually without assistance.
- It can provide an airlock for EVA or crew transfer to the Orbiter at all Space Station berthing and docking ports. This has the important advantage of supporting crew rescue from a module by berthing the crane airlock to the Orbiter berthing port and removing the crew from an isolated module.
- It can supply the interface to the Orbiter.
- Initial layout and analysis of the crane arm structural stiffness determined that the stiffness ratio is about 10 times that of the Orbiter manipulator.

A need has also been evidenced for a small mobile unit to effect the transfer of smaller items of hardware and to aid in the assembly of objective elements. While this mobile unit is not an intrinsic part of the Space Station, it can be considered an extension since it is envisaged as providing life support functions for two Space Station astronauts. By exchanging end effectors a variety of tasks can be performed, from thermal bonding applications to cutting and repairing sheet metal. The unit should be capable of using the same sockets provided for the walking crane to acquire Space Station services as well as using them for anchors when employing its two small manipulator arms for other purposes.

6.2 EVA OPERATIONS

One of the significant design drivers of the Living and Working in Space objective is the development of a capability to work in the normal low-level background radiation environment and the high-intensity radiation accompanying solar flares in all orbits. Since EVA must become a standard mode of operation with many crewman performing tasks external to the Space Station for days or months at a time, SRT is indicated to determine how long a crewman may remain in space, the duration of his tour, and the length of his career as a function of the amount and type of radiation to be expected and the shielding provided by his space suit. For the Space Station itself, additional research on solar flares, the amount of high-intensity radiation impinging on it, and the predictability of arrival of the high-intensity radiation are needed for protective shell designs and/or storm cellars as well as the procedures for escape to lower orbit or earth.

It is also apparent that the conduct of EVA operations in an efficient manner requires that crew conditioning time be reduced or eliminated. This in turn will require a semi-hardsuit capable of holding near-atmospheric pressure while retaining the flexibility of soft suits. Provisions for ease of use and shielding should both be superior to current designs. This would preclude the Orbiter 5-psia pressure suit since it requires 2.5 hr of "denitrogenization" or "preoxygenation," consisting of breathing pure oxygen prior to decompression. Table 6-1 indicates that the probability of decompression sickness (dysbarism) is an unacceptable 10% without this period. However, a modest increase in suit pressure to 7 psia results in a risk of only 2%.

6.3 DEPOT OPERATIONS

The Space Station will employ several different vehicle types, all of which will require refueling. In addition to Orbital Transfer Vehicles (OTV's), many of the objectives will require the use of unmanned satellites controlled from the

Table 6-1

DYSBARISM RISKS

In Ascent From Sea Level Pressure (760 mmHg)

Risk %	Final Pressure (P_{B_2}) (psi)	(mmHg)	Denitrogenation Times (T_1)
1	10	517	None
	7	362	34 min
	5	259	3 hr 44 min
	3.5	181	7 hr 40 min
2	10	517	None
	7	362	None
	5	259	2 hr 40 min
	3.5	181	6 hr 24 min
5	10	517	None
	7	362	None
	5	259	36 min
	3.5	181	4 hr
10	10	517	None
	7	362	None
	5	259	None
	3.5	181	2 hr

station for applications such as observation, signal sources, targets, etc. Various one- and two-man astronaut mobility devices will also require refueling as a normal, everyday operation. Although the "Depot" objective is designed to conduct R&D for cryogenic propellant storage and transfer, additional SRT for the development of stores replenishment techniques appears necessary. Many aspects of transfer and storage control required by this objective will be required on a smaller scale during initial operations, i.e., screen systems, receiving tank thermodynamics and fluid dynamics, venting, multilayer insulation as vacuum bottle configurations, vapor-cooled shields. Research on the smaller quantities and tanks involved will contribute to both the Space Station design and the objective.

6.4 SYSTEM SRT ITEMS (INDEPENDENT OF INITIAL SPACE STATIONS)

Additional system SRT items have been identified which, while not necessarily mandatory for an initial Low Earth Orbit (LEO) Space Station, will be required for growth versions and stations in geosynchronous orbit. Some of these items are discussed briefly in the following paragraphs.

6.4.1 Stability and Control of Large Space Stations

Growth stations may consist of numerous modules and/or construction elements docked in serial fashion. This can result in an elongated vehicle, stations with large mass distributions which are some distance from the desired center of gravity, and/or large masses with their own active control systems. The methods for ensuring station stability in the presence of large off-axis applied forces, the manner in which control systems may be integrated as station growth occurs, and the adaptibility of control systems to variable demands require additional insight and potentially new systems.

6.4.2 Environmental Effects

A major concern in the design of a Space Station suitable for multimission capability is the radiation environment. The environment characteristics at LEO (low inclination), polar, and geosynchronous are not only different in terms of steady-state or background radiation and intermittent (solar cosmic ray) radiation but also in the variation and uncertainties in the respective levels. Further detailed data and system analyses are needed to define the environment, its varients and uncertainties, and to determine the design and operational techniques to accommodate them.

Another environmental concern is the buildup of charges on various segments of a station operating in geosynchronous orbit which may result in high-voltage arcing. A station immersed in the space environmental plasma may be expected to develop surface charges provided by primary plasma electron and ion arrivals as well as photo electrons released when sunlight illuminates its surface. To prevent potential charge differences from reaching arcing magnitudes, station configurations with low capacitance shapes and appropriate procedures for shielding and grounding must be developed. Docking of an arriving vehicle to an orbital facility at a higher potential is also of concern and methods to assure safety during this procedure must be developed.

6.4.3 Lightweight OTV

The importance of the OTV mass fraction, λ', was discussed in Section 4. The achievable design of a lightweight OTV must be confirmed by a thorough analysis to give confidence to the dependent Space Station Program elements. It appears that the orbit-based environment, low acceleration requirements, and new materials and components would allow a λ' approaching 0.92. This must be demonstrated.

6.4.4 Crew Rescue

For the station in a geosynchronous orbit, an additional concern is the time required for crew rescue in the event of a catastrophic malfunction. In general, the spacesuit and docked transport vehicles constitute the only independent means of life support external to the Space Station. Additional analysis is required to select from options such as additional standby transport, spacesuit supplementary life support systems, and inflatable shelters (presently being studied by JSC). The selected options should then be the subject of increased research support.

6.4.5 Contamination

Use of thrusters for attitude control, plume impingement by the Orbiter and/or OTV's, and the effluents of open-loop environmental control and life support systems will all result in the production of particulates and gases. The integrated product of these discharges in the vicinity of the Space Station will have a deleterious effect on earth and cosmos viewing in the long term and require the repeated cleaning of observation lenses and ports. Methods for reducing contamination levels by limiting their discharge, developing means of dispersal, or polarizing them for periodic collection are required.

6.4.6 Waste Disposal

Space crews of the size considered for the growth Space Stations will produce a large amount of waste. Methods for trash compaction and stowage must be developed to reduce the volume required to be transported back to earth.

Section 7
SUPPORTING STUDIES

A summary of Satellite power system (SPS) supporting studies is presented in this section and summarized in Figure 7-1. An initial objective of these studies was the definition of a candidate SPS development program with particular attention given to those activities best undertaken with support of a Space Station facility; the Space Station objective with respect to SPS is to provide a permanent space test capability for evaluation of the technical and economic feasibility of SPS. MDAC's company-supported study has concentrated on the definition of the major hardware development steps (pilot plants), while definition of early laboratory technology development tests and Space Station support of the pilot plants (as noted in the left-hand box of Figure 7-1) is within scope of the Space Station Systems Analysis Study work statement.

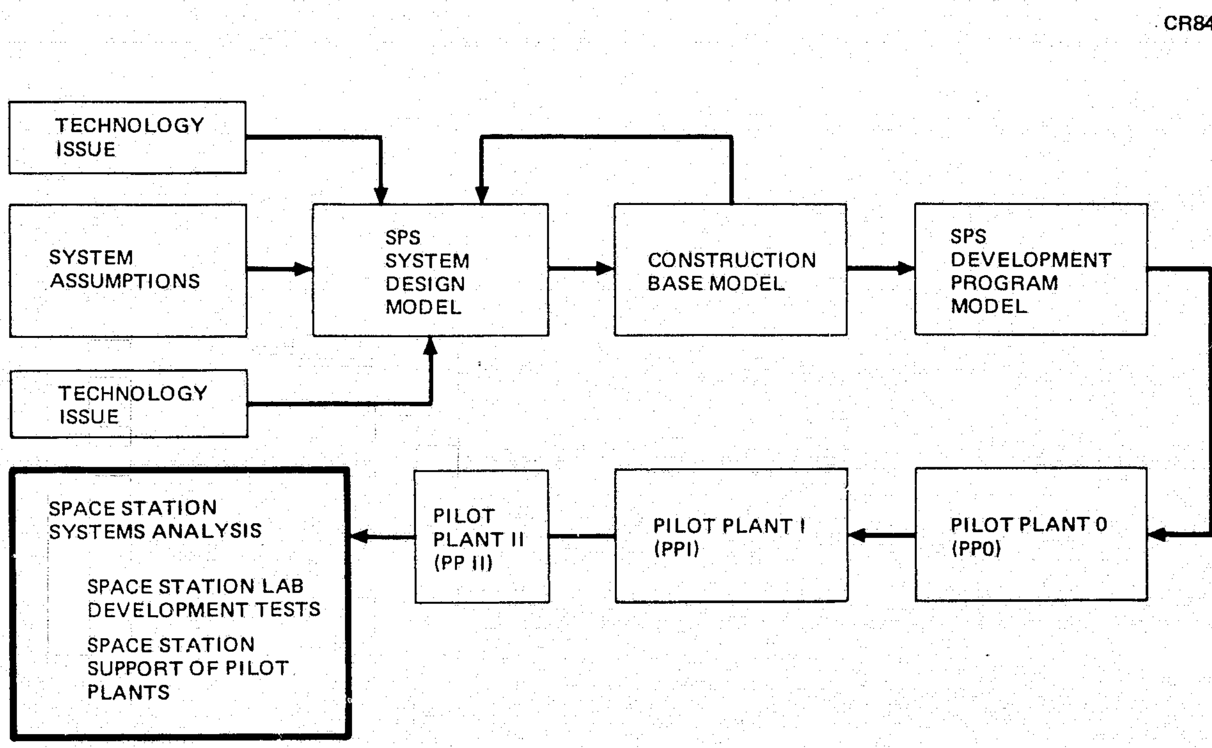


Figure 7-1. SPS Study Logic

The work subsequently defined in Sections 7.1 on SPS and SPS pilot plant structures and construction, and in 7.2 on orbital silicon ribbon and solar cell blanket production was MDAC-supported. Section 7.1 summarizes the SPS system configuration, the SPS development program and the definition of and rationale for key Space Station supported development hardware (e.g., Pilot Plants 0, I, and II). Data on the rationale and justification for an SPS, and the derivation of Space Station functional requirements are given in Volume 3, Book 1.

7.1 SATELLITE POWER SYSTEM

7.1.1 SPS Prototype/Production Configuration

This section presents the MDAC SPS assumptions and the system design model as shown in the first two blocks of Figure 7-1; this SPS discussion will provide the reader with a framework for subsequent discussion of Space Station supported pilot plant fabrication, construction and test. The SPS system assumptions are presented in Table 7-1, along with the reasons for their choice. The primary objective here is to derive a representative system development program model; consequently, no attempt has been made to define optimum system size or energy conversion processes (solar to electrical or electrical to microwave). In general, systems engineering problems have not been addressed unless they are germane to the Space Station functional requirements.

Table 7-1
SPS SYSTEM ASSUMPTIONS

Assumption Choice Based on:
- Data Base Adequacy
- Eliminating Effort Not Critical to Space Station Functions

Primary Assumptions:

Photovoltaic	(Data Base)
5 GW_e	(Not Critical)
Amplitron	(Date Base/Not Critical)
18M Antenna Panels	(Date Base/Not Critical)
2:1 Solar Collector	(Data Base)
10% Solar Cells	(Not Critical)
JSC System Efficiencies	(Not Critical)

The MDAC-derived SPS configuration, based on the above assumptions, is presented in Figure 7-2; it delivers 5,000 MWe at the ground rectenna output. The model SPS configuration is built of an assembly of large and small diameter tubes. The longitudinal center mast/power bus consists of four large cylindrical members (approximately 4.35m diameter) built up from the drums that house antenna components in the Orbiter cargo bay. The transverse "feeder line" power buses (solid lines) and nonconducting beams (dashed lines) are built of mirror and blanket drums which, in the Orbiter cargo bay, house the smaller ~ 12.7 cm (5 in) diameter columns of the solar collector troughs. The two collector arrays on either side of the central antenna are connected by the center mast only; no other structural connection is necessary.

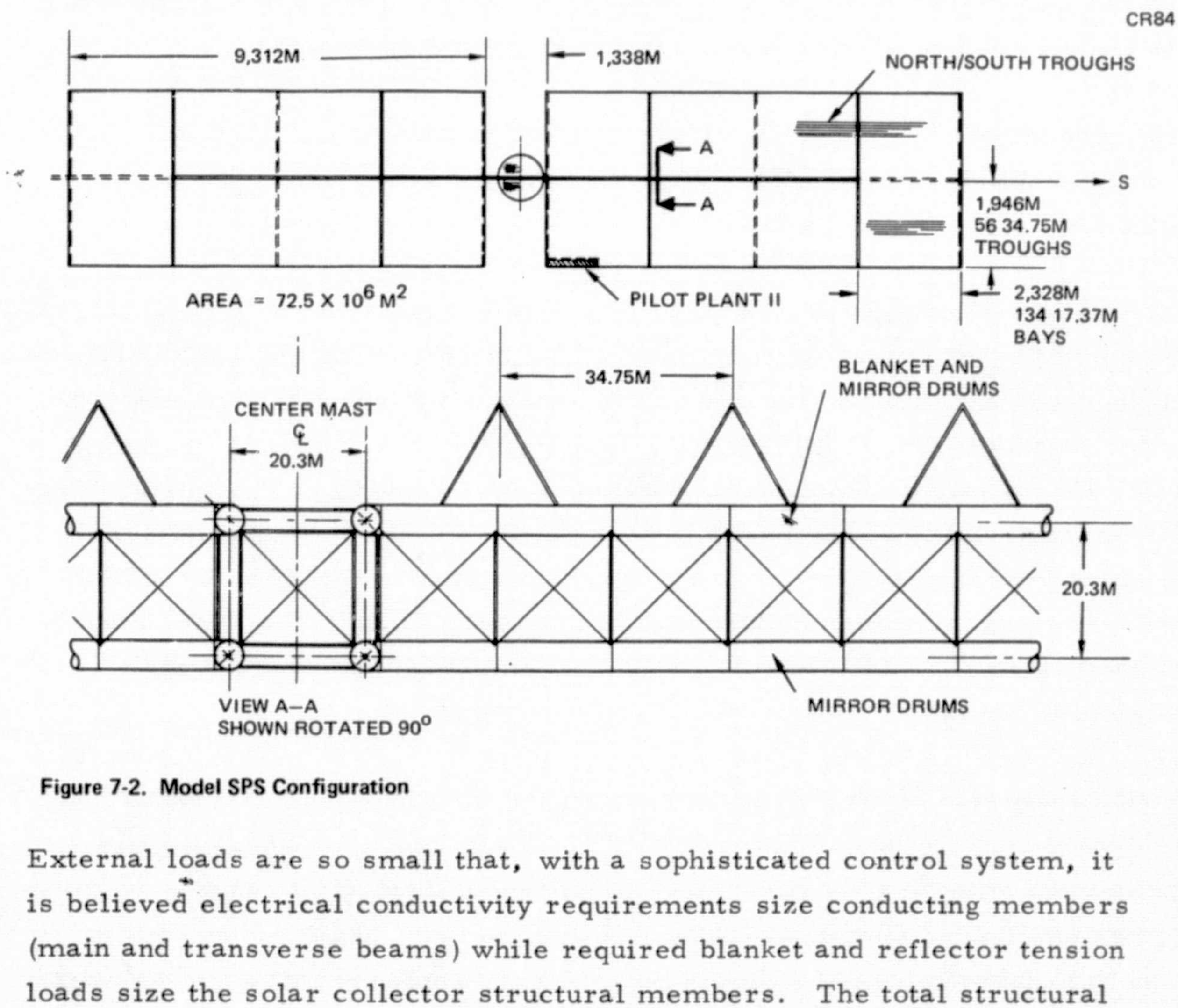


Figure 7-2. Model SPS Configuration

External loads are so small that, with a sophisticated control system, it is believed electrical conductivity requirements size conducting members (main and transverse beams) while required blanket and reflector tension loads size the solar collector structural members. The total structural weight of the 72.5 x 10^6 m^2 (780 x 10^6 ft^2) of solar collectors, transverse beams, and main beam is estimated at 12.7 x 10^6 kg (28 x 10^6 lb). Gross weight is significant in solar cell blanket, wave guide, and amplitron weight assumptions. Using 0.049 and 0.039 kg/m^2 (0.01 and 0.08 lb/ft^2) for the reflector and blanket respectively, total solar collector weight is 30.4 x 10^6 kg (67 x 10^6 lb). Antenna and gimbal system is estimated at 6.35 x 10^6 kg (14 x 10^6 lb). Assembly of the model SPS uses five shuttlecock construction bases similar to those discussed later. The antenna construction base also assembles the main beam while four solar collector bases assemble the transverse beams. Construction begins with the antenna and center mast. When the first 2133m (7000 ft) of mast is compelted on each side, the solar collector bases begin laying troughs, in a "single-pass-to-completion" process on each side of the continuously extending center mast. When this outmost 2328m (7638 ft) collector panel is complete, the collector construction bases continue the process, working in toward the antenna.

The size of the 17 MW_{RF} Pilot Plant II (PPII) solar array is shown in the lower left-hand corner of the right-hand solar array in Figure 7-2 to put pilot plant sizes in perspective.

The power distribution in the solar collectors is illustrated in Figure 7-3. To minimize I^2R losses, estimated at 6% in this configuration, wall thickness of the conducting drums increases as they progress toward the antenna. It is interesting to note that the pattern is quite similar to nature's original solar energy conversion system, the plant leaf. The solar cells are 17.37m (57 ft) long ribbons, approximately 10.2 cm (4 in.) in width, manufactured in space by machines similar to those recently studied for NASA by MDAC and discussed in Section 7.2 below. Completely open solar collector troughs allow rapid replacement of both the blanket and reflectors and eliminate potentially devastating solar cell shadowing problems.

A small segment of the SPS microwave power transmission system (MPTS) antenna is illustrated in Figure 7-4. The 17.4m long aluminum wave guide tubes with directly mounted amplitrons are formed into square segments on two transverse aluminum beams. These, in turn, are mounted to the carbon/polyimide tubular substructure by four adjustable jacks. The design and spacing of the solar array and antenna structural members allows the

CR84

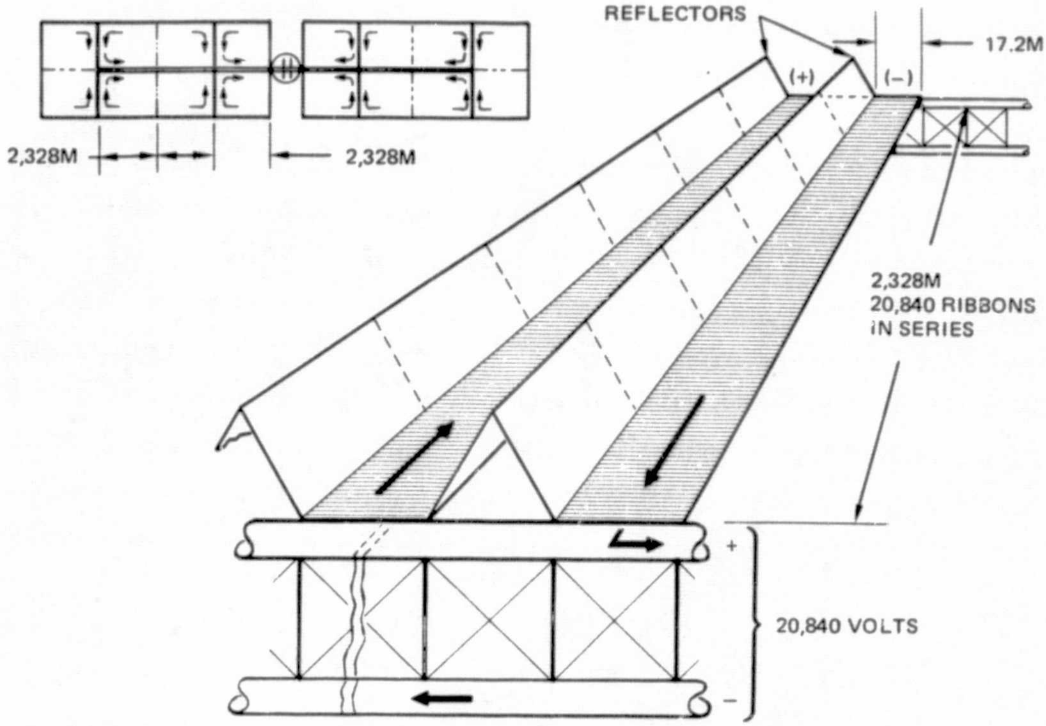


Figure 7-3. Solar-Cell Blanket Power Distribution

CR84

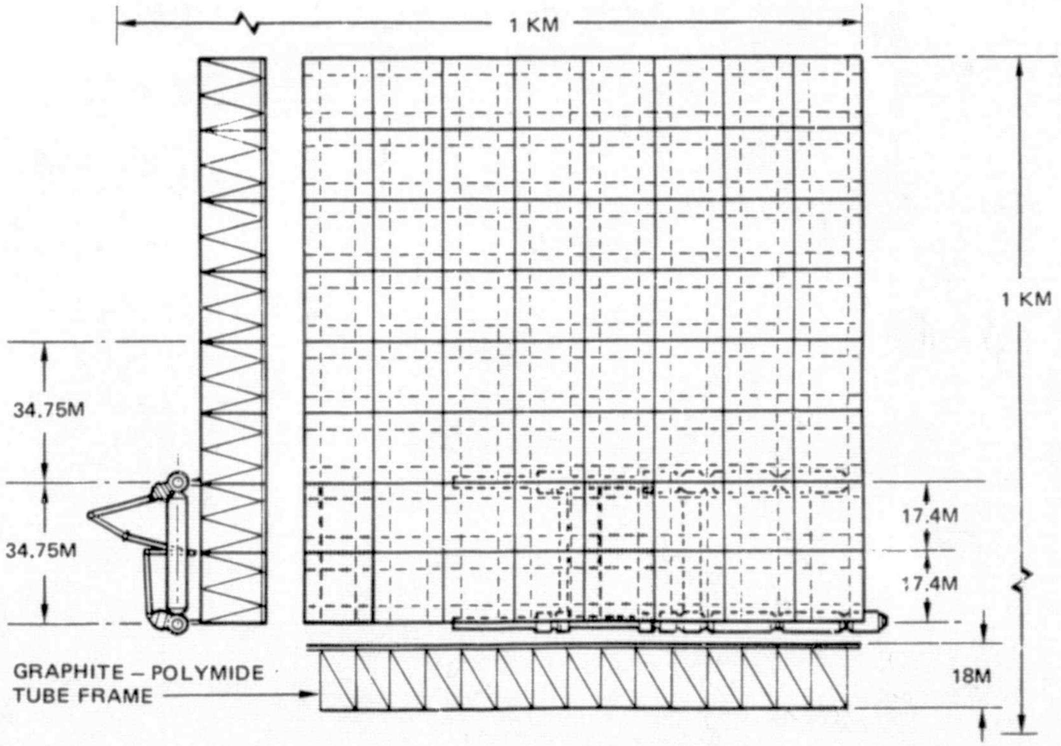


Figure 7-4. SPS Antenna

ORIGINAL PAGE IS
OF POOR QUALITY

construction base (shown attached to the antenna) to construct both the solar collector and the antenna. Figure 7-4 also depicts the 64 subarray (8 x 8 at 17.4m each) PPII antenna.

The solar array and antenna are tied together and the system completed with the addition of an antenna gimbal system (Figure 7-5) and the power transfer rotary joint (Figure 7-6). Moving the gimbal system aft "I" struts in or out (from the centerline) will pitch the antenna about the vehicle's East-West axis. Additionally, if the left-handed "I" strut is held fixed, and the right-hand one driven in synchronization with the one movable "V" strut a vernier adjustment is also available about the North-South axis. The gimbal system shown here expected to provide more precise antenna pointing and a lower gimbal system weight, as contrasted to a rotary joint system.

Power transfer from the solar collector to the rotating antenna requires a flow of some 300,000 amperes. If a conventional slipring-brush system is used, friction may prove a difficult problem, because accurate antenna pointing is required. The mercury-filled roller bearing concept shown here

CR84

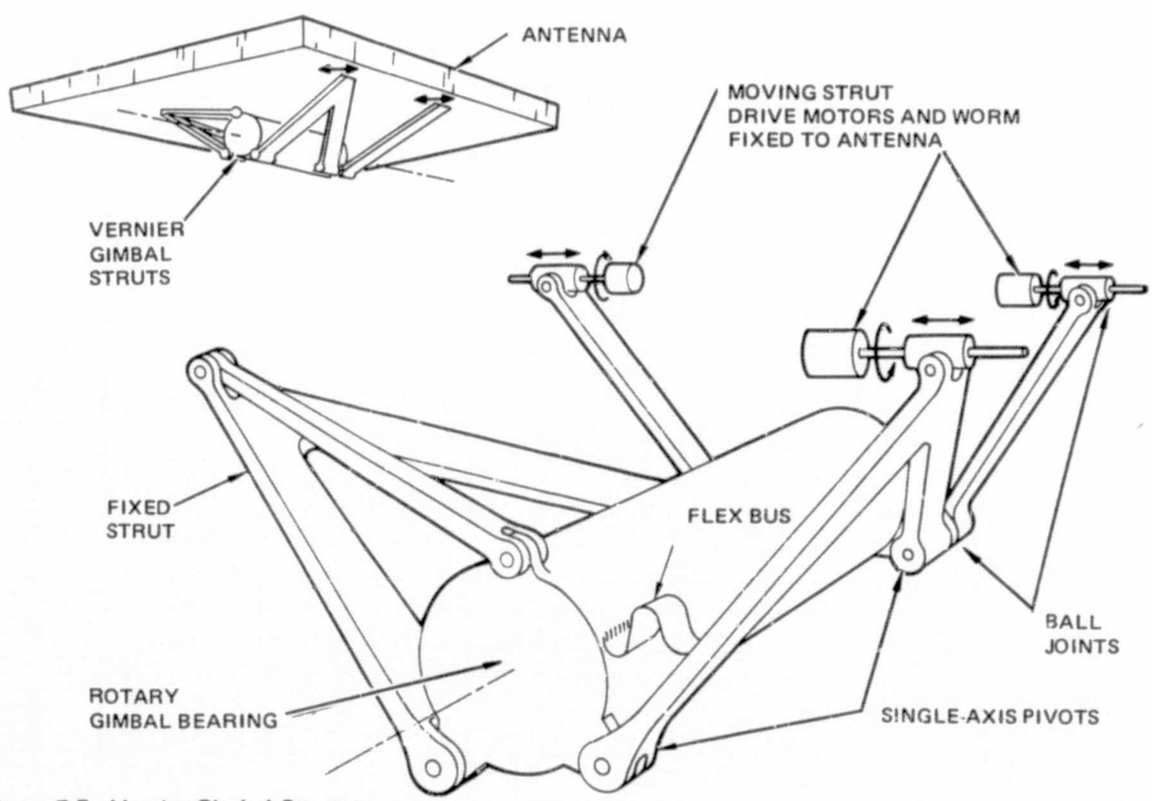


Figure 7-5. Vernier Gimbal Concept

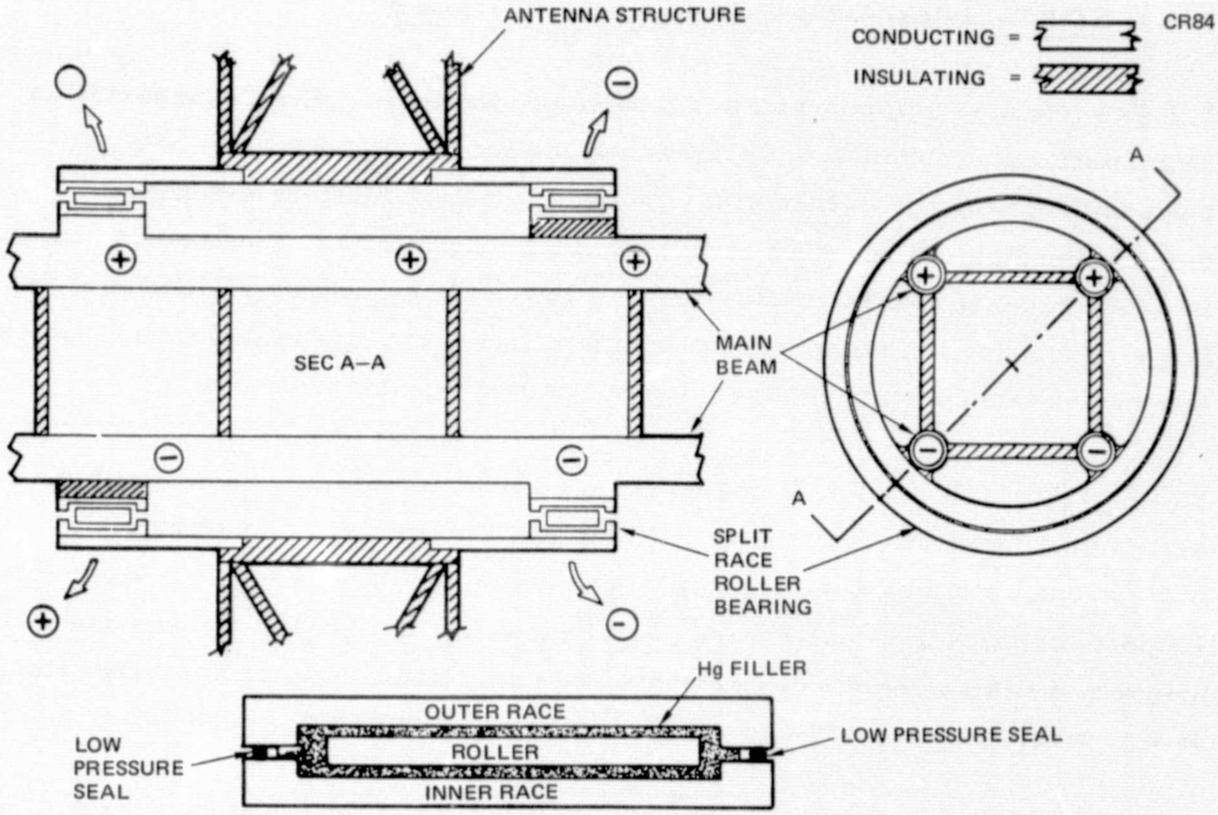


Figure 7-6. Low-Friction Brushless Power Transfer Bearing Concept

should provide relatively low friction, particularly since the very low vapor pressure of mercury would, in turn, require very low seal pressures. Environmental/safety considerations may be of concern with a mercury system.

With an ability to adjust antenna pointing about the East/West axis to set it for the receiving station(s) latitude, dynamic angular motion about this axis will be small (a few degrees). Thus, a flexural pivot may be used and power transfer problems across this axis are eliminated because of the flexible material serves as the conductor. While torque requirements of such a pivot will be high, the rates will be equal to the limit cycle frequencies of the main beam. As previously illustrated, these are very low, on the order of a degree per hour. Hence, actuator power is relatively low. For example, one horse power is equal to more than one hundred million foot pounds at a one degree per hour rate.

C.3

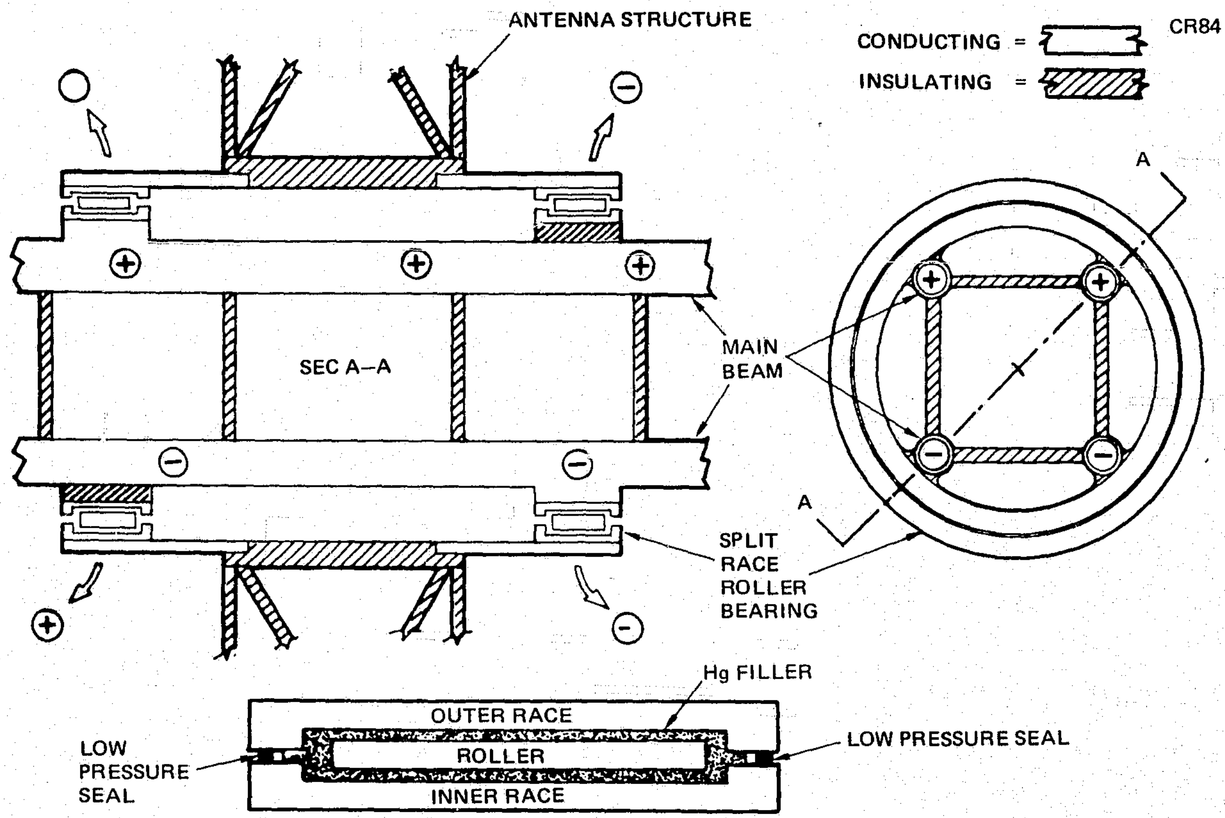


Figure 7-6. Low-Friction Brushless Power Transfer Bearing Concept

should provide relatively low friction, particularly since the very low vapor pressure of mercury would, in turn, require very low seal pressures. Environmental/safety considerations may be of concern with a mercury system.

With an ability to adjust antenna pointing about the East/West axis to set it for the receiving station(s) latitude, dynamic angular motion about this axis will be small (a few degrees). Thus, a flexural pivot may be used and power transfer problems across this axis are eliminated because of the flexible material serves as the conductor. While torque requirements of such a pivot will be high, the rates will be equal to the limit cycle frequencies of the main beam. As previously illustrated, these are very low, on the order of a degree per hour. Hence, actuator power is relatively low. For example, one horse power is equal to more than one hundred million foot pounds at a one degree per hour rate.

C 3

7.1.2 SPS Technical Issues/Configuration Rationale

7.1.2.1 Orbital Component Fabrication and Earth-to-LEO Transportation
Transportation represents the predominant recurring cost in an SPS production program. It is then clear that every effort must be extended to develop the lightest possible structure; ultra-lightweight structure is possible in space because orbital loads are very low. These considerations lead to large cross-section compression beams of very-low-average density, which introduces transportation cargo density and packaging problems.

While orbital fabrication of beams (e.g., metal forming of tubes and box beams and composite pultrusion of Graphite Polyimide, for example) is clearly one solution, such machines are complex and will require their own support logistics and maintenance and hence may not greatly reduce the total number of flights required. For this reason, MDAC undertook a brief study of achievable Orbiter payload weights using typical SPS components.

Figure 7-7 plots the total number of circular tubes necessary to fill all available Orbiter cargo volume and required aluminum wall thickness if their collective total weight equals 27,200 kg (60,000 lb). Typical optimum tube members for the SPS design discussed here are 12.7 to 15.2 cm (5 to 6 in.) diameter with a wall thickness of 0.038 cm (0.015 in.) or less. As indicated, total weight for such a one-diameter payload would be about 6,803 kg (15,000 lb). However, if the payload were made up of telescoping tubes with outside diameters of 13.83, 13.92, 14.01, and 14.10 cm (5.445, 5.480, 5.515, and 5.550 in.) respectively, and wall thicknesses of 0.038 cm (0.015 in.), the Orbiter would be fully used, allowing 2,268 kg (5,000 lb) for payload packaging. These chosen dimensions would allow 0.051 cm (0.020 in.) nominal clearance in telescoping and, assuming the optimum diameter is 13.97 cm (5.5 in.) at 0.038 cm (0,015 in.) wall thickness, differ little from the nominal optimum.

A mixture of SPS components can be used to increase payload density as shown in Figure 7-8. Typically, different size structural members are required, and this presents additional opportunities for "telescopic" payload assembly. In MDAC's SPS design, large cross-section area members are

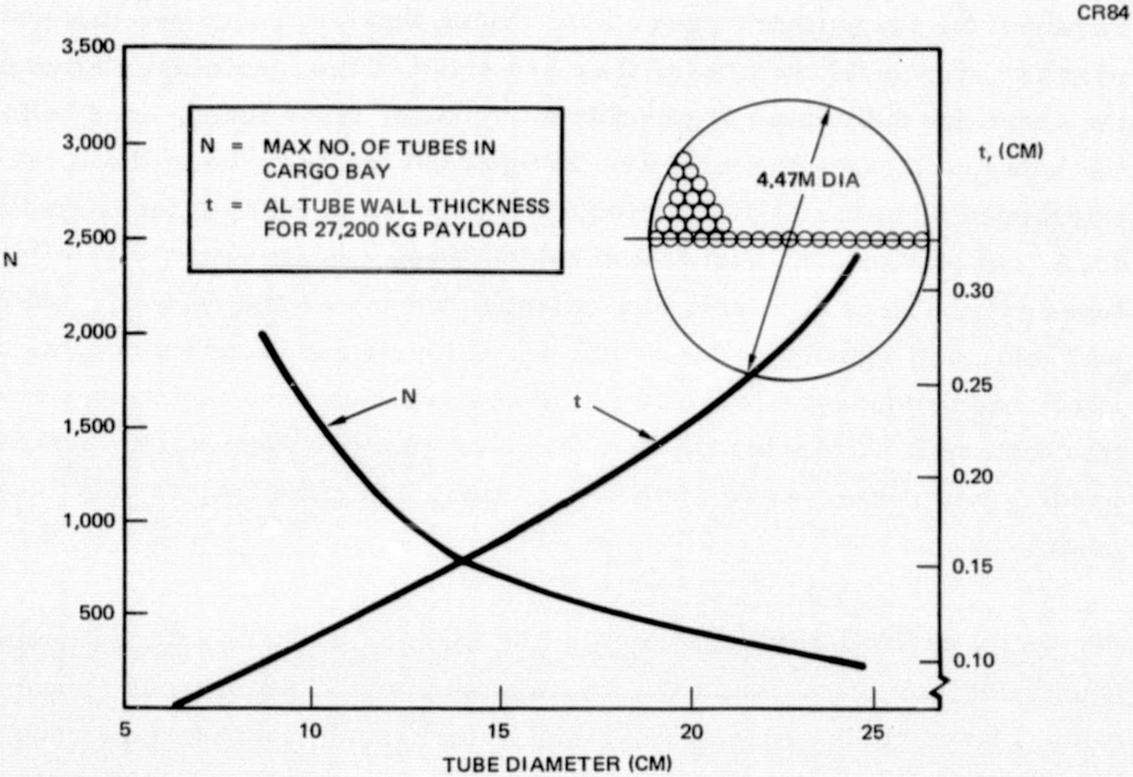
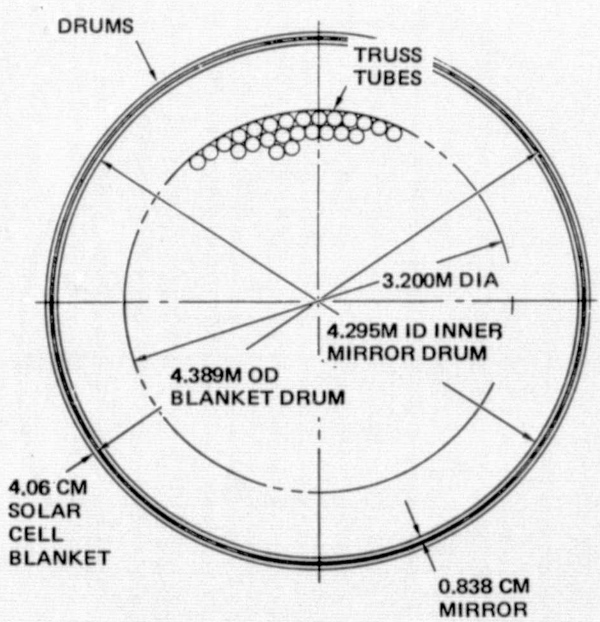
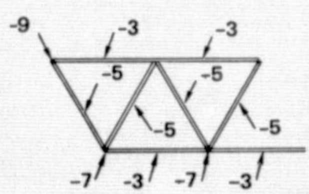


Figure 7-7. Tube Packaging

CR84



TRUSS TUBES	NO.	OD (CM)	t (MM)	IC (CM)
–3	512	12.70	0.381	12.62
–5	512	12.57	0.203	12.53
–7	256	12.48	0.254	12.43
–9	128	12.38	0.508	12.28



3 DRUMS PER LAUNCH

OD (M)	t (MM)	ID (M)
4.389	1.270	4.387
4.343	0.889	4.341
4.298	0.889	4.295

	WT (KG)
TRUSS	8,417
BLANKET	14,956
MIRROR	3,739
DRUMS	2,002
LAUNCH SUPPORTS	364
LAUNCH WEIGHT	29,478

Figure 7-8. Solar Collector Packaging

CR84

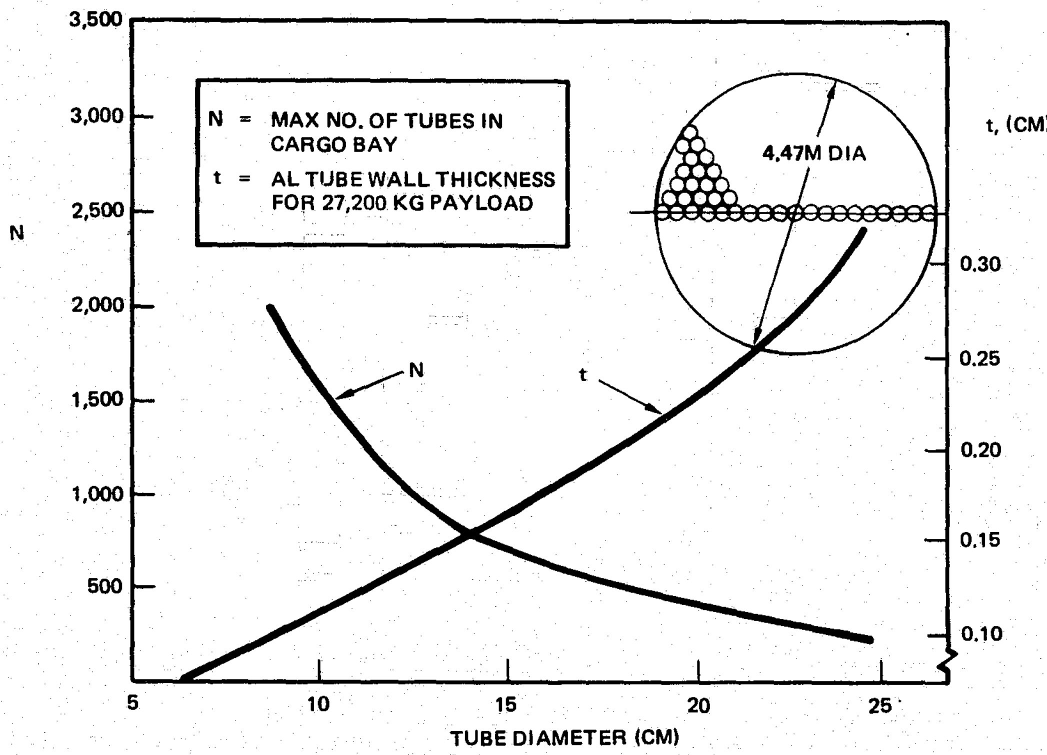
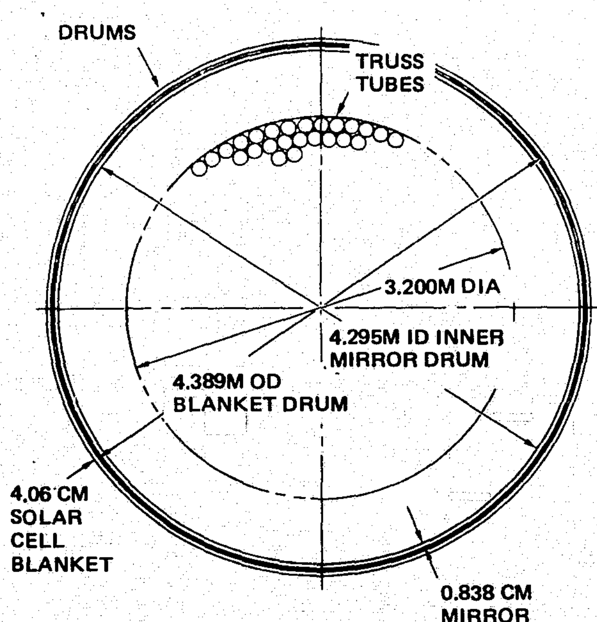
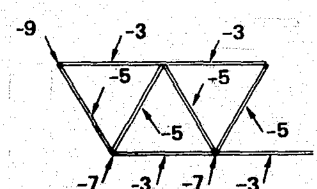


Figure 7-7. Tube Packaging

CR84



TRUSS TUBES	NO.	OD (CM)	t (MM)	IC (CM)
–3	512	12.70	0.381	12.62
–5	512	12.57	0.203	12.53
–7	256	12.48	0.254	12.43
–9	128	12.38	0.508	12.28



3 DRUMS PER LAUNCH

OD (M)	t (MM)	ID (M)
4.389	1.270	4.387
4.343	0.889	4.341
4.298	0.889	4.295

	WT (KG)
TRUSS	8,417
BLANKET	14,956
MIRROR	3,739
DRUMS	2,002
LAUNCH SUPPORTS	364
LAUNCH WEIGHT	29,478

Figure 7-8. Solar Collector Packaging

required for the primary power bus. Since these can also be employed as primary structural members, they are sized to the maximum diameter of the Orbiter's available cargo volume. Smaller truss tubes, used to form the solar collector channels, are then packed inside three of the large telescoped drums. As illustrated, 512 12.7 cm (5 in.) OD tubes contain 12.57 cm (4.95 in.) OD tubes and half of these contain slightly smaller tubes (see table). It is also convenient to wrap both the reflector material and solar cell blanket on the drums for shipping and launch since, as detailed later, the drums are also used in the construction base as fixtures to dispense this material. Wrapping the blanket on drums with appropriate straps and padding is a conservative method for transporting the fragile solar cells to orbit.

Beneficial payload mixtures can also be formed of MPTS antenna components. Illustrated in Figure 7-9 is the total complement of amplitrons, wave guides, wave guide cross beams, screw jacks, and substructure required for a 109 x 126m portion of the antenna. These components are packaged inside six telescoped main beam (power bus) tubes.

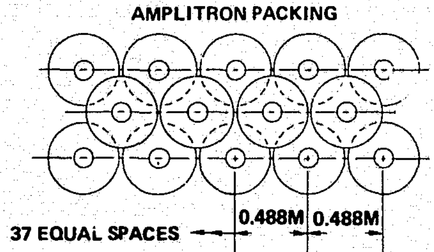
CR84

ITEM	WT (KG)	NUMBER	WEIGHT PER LAUNCH(KG)
① AMPLITRON	1.615	3,956	6,387
② WAVEGUIDE	5.22	910	4,750
③ SUPPORTS	3.807	405	1,542
④ CROSS BEAM	60.0	12	720
⑤ SCREW JACK	11.3	21	237
⑥ CONDUCTOR	1,811	6	10,870

LAUNCH SUPPORTS (ASSEMBLY JIGS) 4,535 KG

29,041 KG

AMPLITRON PACKING



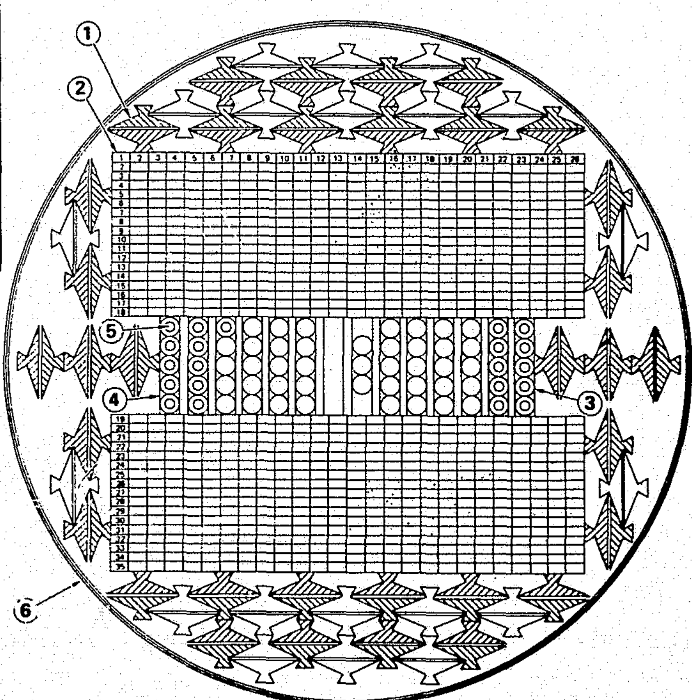


Figure 7-9. Antenna Packaging

Amplitrons, in this configuration, are packaged on individual linear pallets that serve as tooling jigs during amplitron to wave guide assembly. This feature and other associated packaging requirements account for the 4,535 kg (10,000 lb) estimated launch support weight.

The payloads of Figures 7-8 and 7-9 have uniform weight distribution with length, and would exceed the Orbiter's forward CG limit with these payload densities (which can be reduced for shuttle compatibility). However, some form of new HLLV would be employed for production of SPS vehicles, and these remain valid demonstrations that high payload densities can be achieved with ground-fabricated components. This CG situation will not impose an excessive penalty for Orbiter use to construct the SPS pilot plant, because assembly will likely take place above the Orbiter's maximum payload altitude (which limits payload) and relatively few flights are required. Hence, for this early test operation, payload density is not a severe problem. In addition, system development risk is improved with high quality, ground-fabricated waveguides, which can more easily be made to the precise tolerances needed.

In conclusion, high average payload densities can be achieved with ground-fabricated structural components without significantly compromising the objective of structural efficiency if logistics considerations are kept in mind during SPS design. High density packaging of SPS components – on the order of 80-241 kg/m^3 (5-15 lb/ft^2) – is possible, although some "unpacking" and on-orbit logistics problems are created. It is difficult to predict the qualitative result of an accurate cost trade study of ground vs orbital component fabrication; the tradeoff is dependent on: (1) support requirements for orbital component fabrication, (2) the characteristics of HLLV, and (3) the detailed SPS design. Elimination of an orbital component fabrication requirement reduces the initial SPS development cost and the MDAC study assumes ground fabrication of components. Orbital fabrication capability can be later introduced into the production program if desirable.

One of the construction/assembly techniques frequently proposed for consideration in large-scale structures is represented by the numerous designs for folding, deployable beams. Generally, the folding requirement results in a relatively poor strength-to-weight ratio.

Figure 7-10 compares the weight of an optimized cylindrical column (monocoque) with that of a deployable boom developed by the Able Engineering Corporation. While this clever device is one of the efficient designs, it still weighs some 60 to 70% more than the optimum column when sized to the same compressive load. The required deployment canister could be reused in repetitive operations, hence its weight cannot be counted in this comparison.

7.1.2.2 SPS Control System/Solar Collector Structural Design Interactions

Typical practice in automatic control of flexible vehicles requires significant body bending modes to have frequencies of approximately 10 times major control input frequencies. As structural loads on orbit are quite small — dictated more by such requirements as blanket/reflector tension and electrical conductivity than by external loads — bending frequencies of large structures of minimum weight can usually be expressed in cycles per day. Thus the fundamental frequency of a minimum-weight SPS may be quite close to that of the gravity gradient torque, the predominant external force. Previous studies have established that conventional control practice would require

CR84

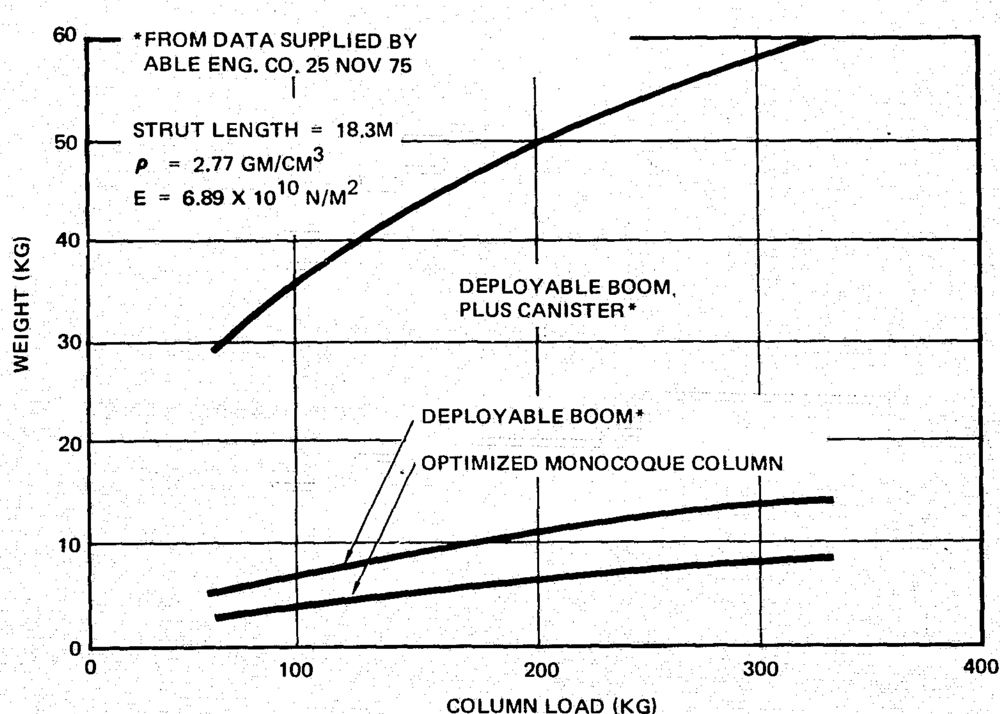
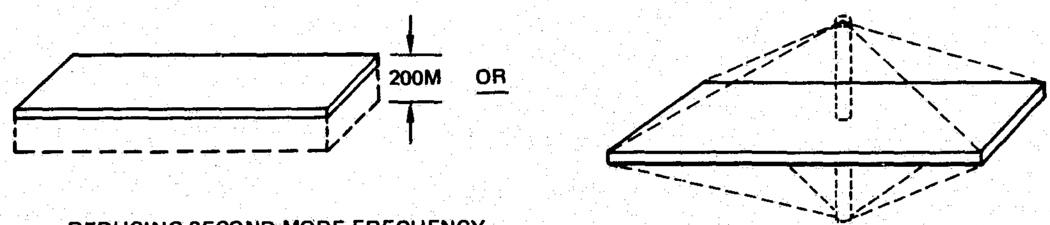


Figure 7-10. Deployable Boom vs Optimum Monocoque Column

solar collector structural framework depth to be nearly 200m, or a king post and cable brace system used as depicted in Figure 7-11. Not only would these alternatives add weight to the system, they would also significantly complicate the assembly process.

CR84

- "CURRENT PRACTICE" SOLAR COLLECTOR BENDING FREQUENCIES REQUIRE PLATFORM DEPTH OR KING POSTS AND CABLE BRACING



REDUCING SECOND-MODE FREQUENCY TO APPROXIMATELY 10^{-2} RAD/SEC REQUIRES DEPTH ⟶ 200M

- EITHER SOLUTION INCREASES ASSEMBLY PROBLEMS AND SOLAR COLLECTOR WEIGHT

Figure 7-11. SPS Solar Collector Control System/Structural Design Interactions

A brief examination of the trade between control propellant required to balance gravity gradient torques and the weight of a counter balance boom should be investigated. Booms of very light weight may also be used to reduce control propellant consumption by extending the attitude control motors away from the vehicle. The desirability of either approach requires further analysis.

Conventional control systems applied to a flexible platform tend to excite the first antisymmetric bending mode as shown in Figure 7-12. With an attitude control feedback system, it is difficult to avoid an unstable structural oscillation if the frequency of this mode is near the major frequency content of attitude control commands. Advanced control techniques can suppress body bending by distributing the control force or actively countering the bending. It is also possible to stabilize very flexible systems with a conventional control system using distributed feedback systems.

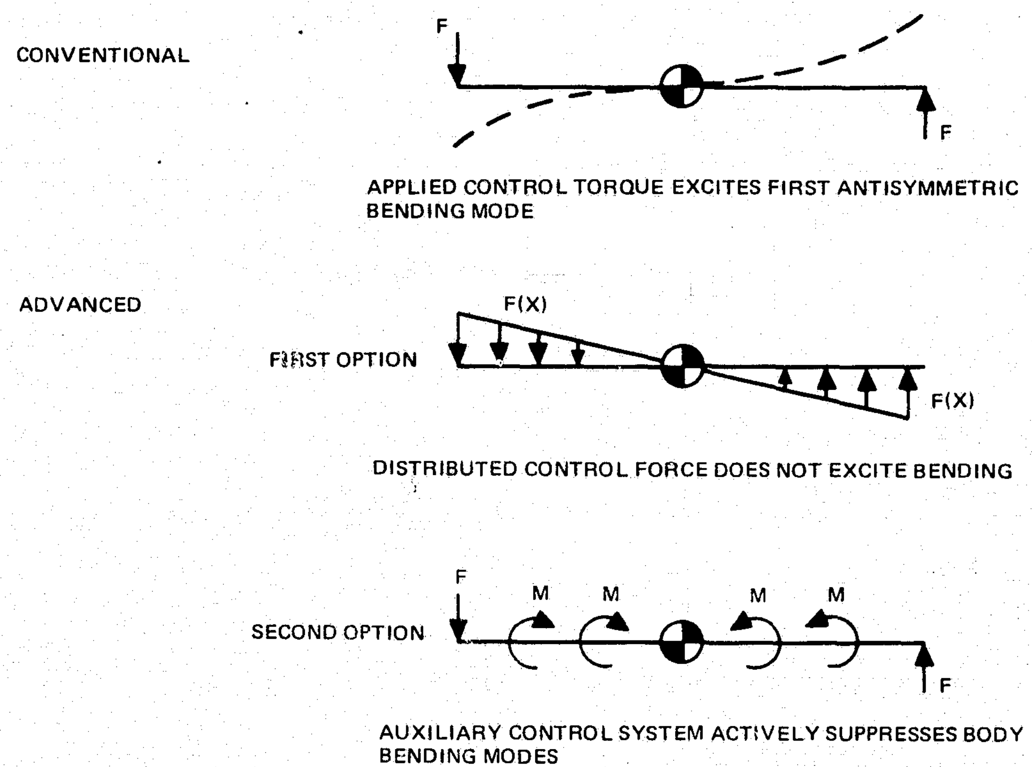


Figure 7-12. SPS Solar Collector Attitude Control Techniques

To investigate the possibility of employing minimum depth structure SPS solar arrays, bending characteristics, derived from a minimum-weight SPS design (17m deep, 6,700m long, and 3,350m wide) were employed in a fundamental two-dimensional control analysis; Table 7-2 summarizes the assumptions and results. The control system was conventional, but featured feedback of bending moment from antinodal points on the solar collector. In practice, this could be achieved through differential strain measurements. The vehicle can be successfully controlled, in the GEO environment, and it was concluded that the resulting limit cycles and elastic deformations were acceptable for a photovoltaic solar collector.

One of the interesting results of this control study is the illustrated response to a step command as shown in Figure 7-13. The exceptionally low gain that may be used (over one hour to achieve 90% of a command) simplifies the control problem since elaborate computational schemes can be used to smooth feedback information and shape commands.

Table 7-2

CONTROL SIMULATION, FLEXIBLE SOLAR ARRAY

Math Model
- 22,000-Ft Uniform Beam
- Natural Bending Periods: 1st = 3.6 Hr
  - 2nd = 1.29 Hr
  - 4th = 0.40 Hr
- Two Dimensional
- 1% Structural Damping

Attitude Control
- Conventional with Bending Feedback
- Digital Control, 120-Sec Sample Period

Bending Feedback Control
- First Antisymmetric Mode (2nd Fundamental)
- Senses Radius of Curvature

Results to Date
- Stable Control
- Gravity Gradient Disturbance Error ≥ 1%

CR84

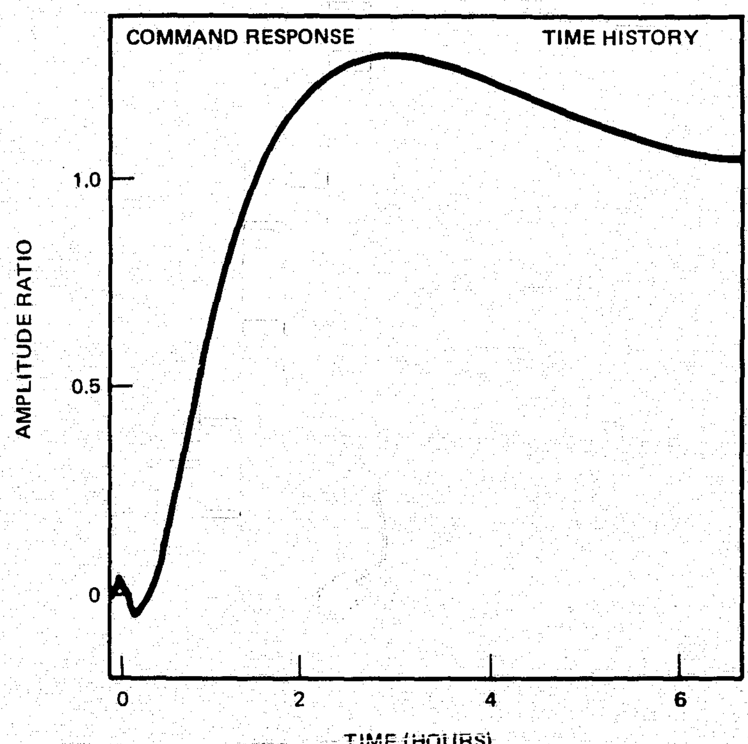


Figure 7-13. SPS Solar Collector Response to Step Command

In conclusion, the control of very flexible solar cell arrays in GEO is feasible. Fundamental bending frequencies of 6 to 7 cycles per day are practical. The ability to control very flexible configurations can be used to reduce gravity gradient bias on the configuration by increasing its north-to-south length. However, power distribution losses (or increased weight of the power bus) tend to limit collector length.

7.1.2.3 LEO vs GEO Construction

Assembly of the SPS in LEO appears to be desirable because it reduces the total mass transported to GEO (eliminates the Construction Base requirements in GEO) and, further, it offers the possibility of SPS electrical "self power" to GEO with attendant savings in propellant weight. While a greatly increased gravity gradient and aerodynamic drag is associated with the LEO environment, these problems do not appreciably affect the SPS system concept if assembly is in a streamlined, gravity-gradient-stabilized attitude. The structural design is dictated by other factors and control of a very flexible vehicle is feasible as noted above. However, as previous studies have pointed out, orbital transfer times typically associated with maximum efficiency ion propulsion systems (4-8 weeks) significantly degrade exposed solar cells, because of the time spent in the proton Van Allen belt; this factor tends to preclude photovoltaic self power.

Since electric propulsion power is proportional to the product of specific impulse and thrust, the vehicle's thrust-to-weight ratio may be increased and transfer times reduced by adopting a thruster design that operates at lower temperature (specific impulse). With a hydrogen working fluid, pure resistance-heated jets can produce specifics of about 800 sec, and arc-heated jets with magnetic accelerators can work with reasonable efficiency at specifics in the range of 1,000 to 1,500 sec. While these figures are much lower than that possible with very high voltage ion accelerators, they represent efficiencies much greater than chemical engines. In typical SPS designs, self power acceleration approaching 10^{-2} g's is then possible.

Figure 7-14 presents the radiation dose received by solar cells during LEO to GEO transfer as a percentage of that received during 30 years of operation in GEO. As can be seen, a thrust-to-weight ratio of about

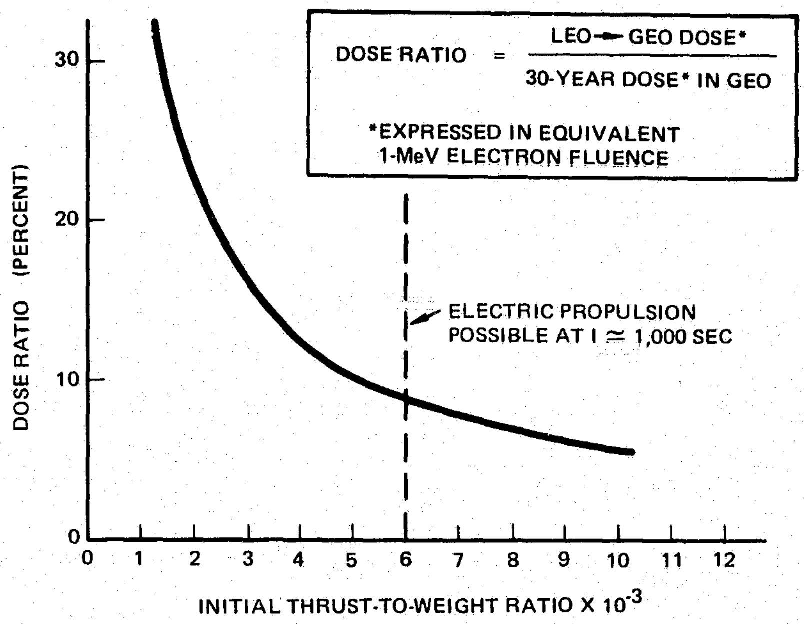


Figure 7-14. Accumulated Radiation During Leo-to-Geo Transfer

5×10^{-3} reduces the transfer dose to 10% of the operational dose. This is, of course, due to the reduction of transfer time. (For reference, a thrust-to-weight ratio of 1.5×10^{-3} results in a 77-hr transfer.)

A significant reduction of dose received during transfer is possible by chemically augmenting the electrical propulsion. Figure 7-15 presents the proton dosage for two-step transfers (in which the initial chemically augmented thrust-to-weight ratio is 5×10^{-2} and the sustaining electric propulsion second step T/W is 1.5×10^{-3}) as a function of altitude attained during the first step. In each case, the vehicle achieves circular orbit at the transition point by chemical propulsion.

While additional work must be done to optimize either of the two appraoches to orbital transfer outlined previously, it is clearly possible to reduce transfer times (and the transfer dose) to acceptable levels and still achieve significant propellant savings through the use of self power. Hence, self-powered LEO to GEO propulsion is believed feasible. The transfer dosage

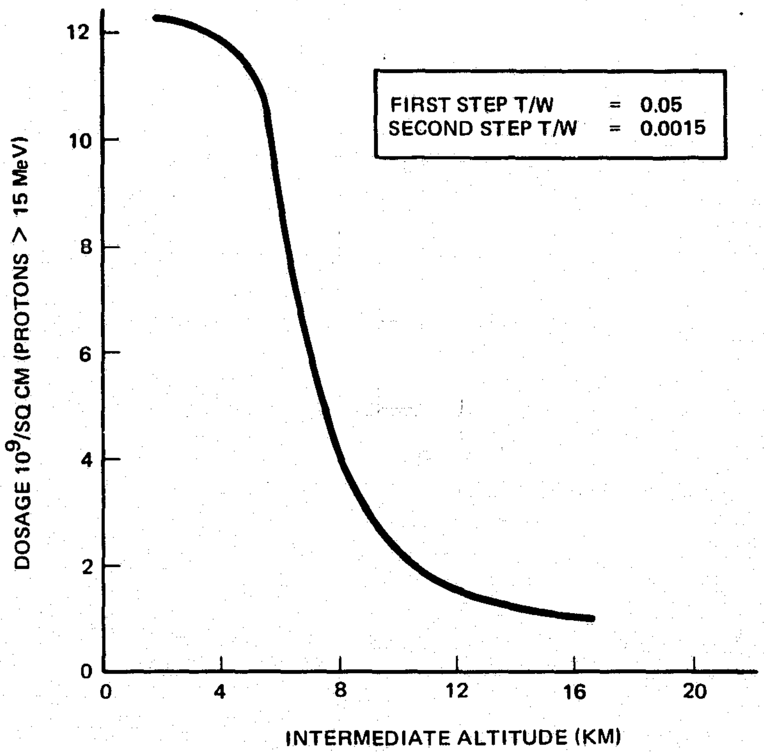


Figure 7-15. Dosage During Two-Step Leo → Geo Transfer

is < 10% of the 30-yr total mission dose. Magnetoplasmadynamic (MPD) and hydrogen resistojet propulsion systems are the propulsion systems of interest. Chemical augmentation of self-powered electric propulsion reduces solar cell degradation. MDAC's structural analysis indicates that thrust-to-weight ratios on the order of 10^{-2} can be achieved without a significant increase in structural weight. The MDAC study assumes LEO construction, although final assembly in GEO is an option.

7.1.3 SPS Construction

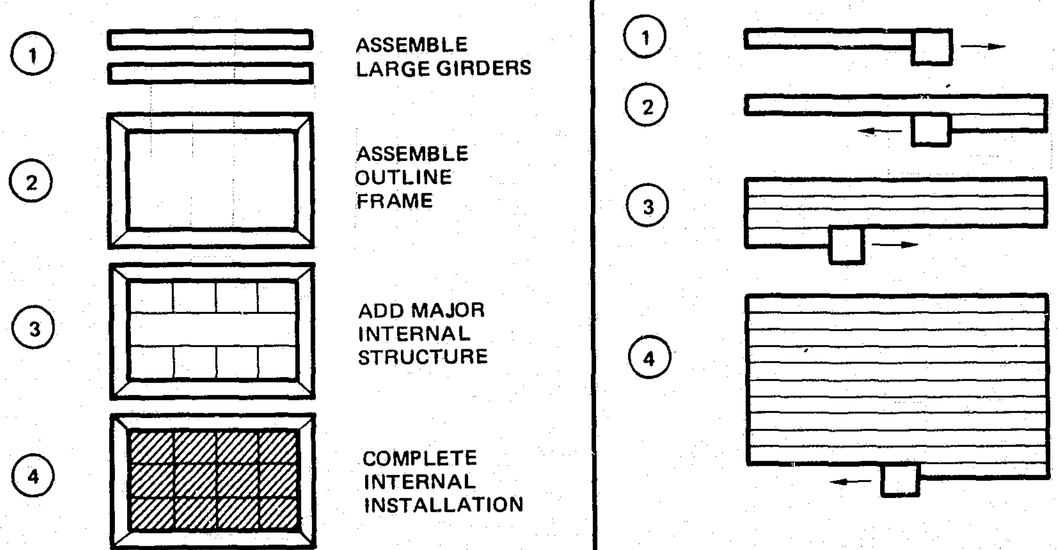
Generalized construction/assembly techniques are illustrated in Figure 7-16. It is worth noting that the "framing" technique finds greatest application where geometry is necessarily complex. Some modern construction of large office or apartment buildings (repetitive geometry) has evolved into a process resembling the shuttlecock. A central crane (supported by the building itself) moves back and forth, erecting one layer of frame on another as followup crews finish lower-floor installations before the upper framework is completed.

FRAMING

SIMILAR TO CONSTRUCTION OF LARGE TERRESTRIAL BUILDINGS

SHUTTLECOCK

SIMILAR TO WEAVING OF TEXTILE OR ROAD CONSTRUCTION



ADVANTAGES

ALLOWS SIMULTANEOUS, PARALLEL OPERATIONS ON DIFFERENT PARTS OF STRUCTURE

RELATIVELY SIMPLE TOOLING REQUIREMENT

DISADVANTANGES

REQUIRES DOCKING OF LARGE, HIGH-INERTIA COMPONENTS

DIFFICULT TO AUTOMATE

ADVANTAGES

DOES NOT REQUIRE DOCKING OF HIGH-INERTIA COMPONENTS

ADAPTABLE TO AUTOMATION

"SINGLE-PASS COMPLETE" OPERATION

DISADVANTAGES

COMPLEX TOOLING PROBLEM

Figure 7-16. SPS/Large Space Structures, Generic Construction Techniques

It is concluded that framing techniques are best adapted to the proposed type of space structure, but that a shuttlecock or continuous flow process may prove economical where production can amortize the tooling investment. A photovoltaic SPS is particularly adaptable to the shuttlecock process because the solar arrays and microwave antenna can be designed with a repetitive structural geometry.

7.1.4 SPS Structure/Construction Design Ground Rules

The following structure design and construction ground rules have been adopted for the MDAC prototype/production SPS:

A. Shuttle Compatibility - Shuttle compatibility allows full-scale structural/assembly experiments, to be pursued early in the development without the added fiscal burden of a new launch vehicle program. While it would require more than a thousand Orbiter flights, assembly of the prototype SPS is also be possible with the existing Shuttle system.

B. Producibility by Design - The design uses a "single-pass-to-completion" shuttlecock type of construction tooling for both the antenna and solar collector. Commonality of tooling is an objective.

C. Design for Indefinite Life - All components subject to a wearout phenomena are designed for orbital replacement. In particular, the solar reflectors and blanket are replaceable using the original construction tooling.

D. Structural Components Produced on Earth - Earth surface fabrication components are primarily viewed as a means of reducing initial development costs, since early development of orbital beam forming/fabrication machines is not required. However, continuing experimental technology work during SPS development would be pursued to determine if orbital fabrication is profitable for SPS production.

E. Minimum Structure Approach - Structure is initially designed without an overall bending stiffness requirement for control stability. However, dynamic deflections must be a strong criteria, particularly on the antenna, because angular deformations seriously affect overall system efficiency.

7.1.5 SPS Development Program Model

The SPS development program model is discussed in this section. This model drives the SPS Space Station support requirements and largely revolves around a series of component/subsystem and integrated Pilot Plant systems.

The SPS development program must be geared to evaluate six major technical and economic issues as follows:

A. Fabrication, operation, and control of large structural arrays.

B. Designs for large-scale solar energy collector/distribution systems; integrated system performance in the space environment.

C. RFI effects produced by large-scale microwave power transmission systems on, for example, space communication systems and radio astronomy.

D. Large, high-voltage structure and electronic components in the space plasma/environment.

E. Interactions between the atmosphere/ionosphere and large-scale microwave power transmission systems.

F. Prototype SPS manufacturing processes and the associated man-machine productivity, which is fundamental to SPS production costs.

The above issues are the basis of SPS development program functional requirements.

An overview of the SPS development program is presented in Figure 7-17. The portion of the SPS development program of interest for early Space Stations relates to those activities necessary to verify basic concepts, feasibility, and costs, and leading to a system development decision in 1987. A spectrum of development activities, ranging from ground tests to large-scale space pilot plants, must be considered; the candidate approaches to resolution must be those for which this is either the only practical, or the most cost-effective solution by virtue of the unique capability of Space Station (e. g., long-duration, complex activities requiring man's presence, and the space environment). These selections must be made in the context of the total SPS program as shown.

The functions for the three phases of Space Station activity are noted on the chart. The Pilot Plant I (PPI) integrated system evaluation provides the primary basis for the 1987 development decision. PPII is constructed as

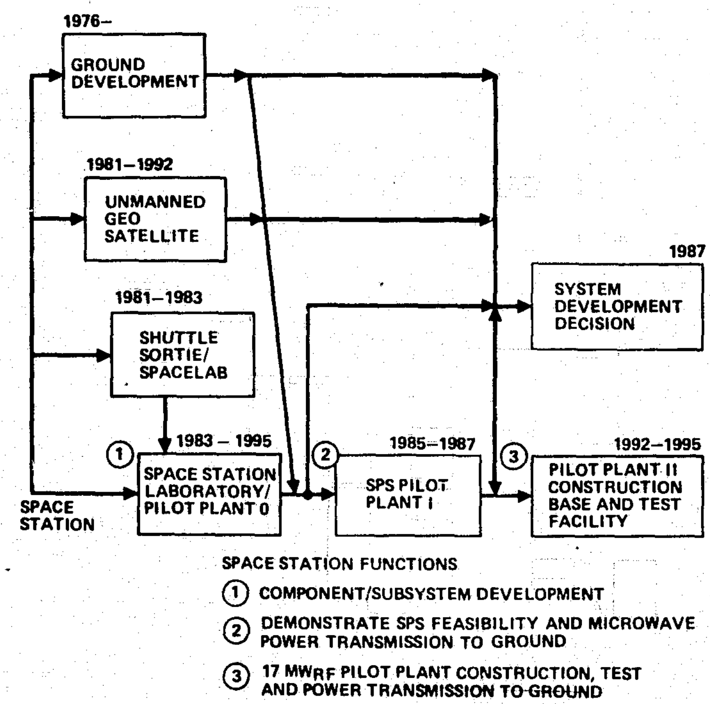


Figure 7-17. SPS Development Program

part of the development program subsequent to 1987 as depicted, and its construction is initiated concurrent with the SPS Preliminary Design Review. PPII might be considered as an alternative to PPI in the 1985 time period if early SPS funding permits.

In postulating the test activities that allow an orderly SPS development program, it is most important to identify the tests chronologically with respect to major program milestones. Clearly, a test designed to provide data for a rational choice between two different structural concepts has little value if it occurs after the program critical design review. Such work is ideally accomplished during program definition, or at least prior to PDR.

If we assume that the SPS objective is a prototype system by 1995-2000, technology work aimed at supporting major system decisions should be largely completed in 1985. In this event, most Space Station effort will be in support of test and qualification of the selected subsystems rather than evaluation of alternative concepts.

Figure 7-18 presents an overview of the Space Station role in support of SPS development and the three SPS objective element development articles: Pilot Plant 0 (PP0), Pilot Plant I (PPI), and Pilot Plant II (PPII), which correspond to the lower three boxes of Figure 7-17. The figure also shows the relationship of the objective elements to the resolution of the six critical SPS issues/functional requirements.

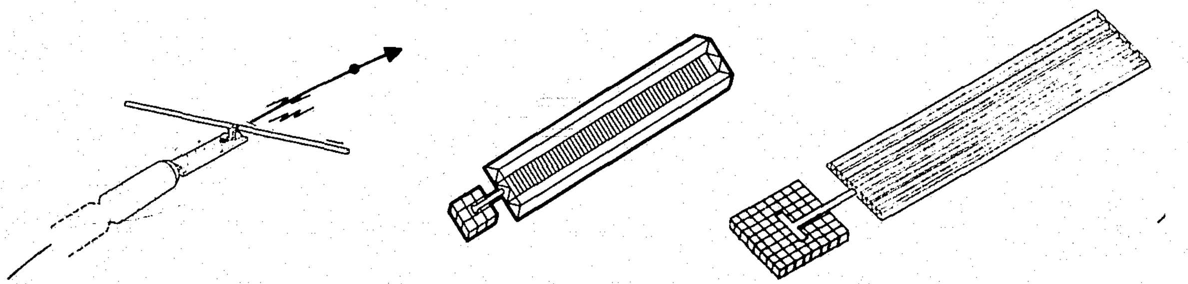
In order to resolve the above issues, major space structures are required. The Space Station can act as the factory to produce these structures on orbit and support their testing. The first objective element (component development) is a laboratory-scale investigation of component subsystem technology, and man-machine investigations of elementary fabrication and assembly tasks. It features a pallet-mounted, 85.8m long tapered linear-array antenna used for orbit-to-orbit testing to evaluate phase control, beam quality, and RFI aspects of microwave power transmission. Because of the setup and tear-down time required, these tests are most efficiently performed on a Space Station.

Concurrent component development tests will also produce a 52 x 52 meter section of solar collector structure; the solar collector and 85.8m antenna together comprise PP0, which is operated in LEO and perhaps GEO.

The SPS Pilot Plant I objective element involves: (1) fabrication and assembly of a 2.24 MWe solar array, (2) fabrication/assembly of a 1.72 MW_{RF} microwave antenna, and (3) orbit-to-orbit and orbit-to-ground testing. PPI provides an early demonstration of concept feasibility and engineering data for the SPS prototype design upon which future design and cost estimates can be firmly based. The PPII phase involves the fabrication/construction and test of a 17-MW_{RF} pilot plant. PPII is a "partial prototype" of the SPS and is constructed using a construction base that demonstrates prototype production methods and processes and develops construction, operation, and repair procedures by experience under realistic conditions. Figure 7-19 presents a summary of the buildup of decision-making information with completion of various PP0 and PPI elements for the six issues/functional requirements.

The following subsections define characteristics of the three SPS objective elements (PP0, PPI, and PPII) and the associated test operations and rationale.

OBJECTIVE: PROVIDE A PERMANENT SPACE TEST CAPABILITY FOR EVALUATION OF THE TECHNICAL AND ECONOMIC FEASIBILITY OF SPS



SPACE STATION LABORATORY R&D (1983–1995)

SPS (1985–1987) PILOT PLANT I

17 MW_{RF} PILOT PLANT II (1992–1995)

EVALUATE MAN-MACHINE PRODUCTIVITY IN LARGE-SCALE SPACE CONSTRUCTION
- PRODUCTION METHODS, RATES, COST, QUALITY, AND O&M
- SIMULATE PROTOTYPE/PRODUCTION SPS

DETERMINE COMPONENT/SUBSYSTEM/INTEGRATED SYSTEM PERFORMANCE
- MICROWAVE SYSTEM PERFORMANCE (E.G., STRUCTURAL/THERMAL, PHASE CONTROL, AND RFI)
- ORBIT-TO-ORBIT AND ORBIT-TO-GROUND POWER TRANSMISSION
- POWER SOURCE LIFE AND PERFORMANCE

SUPPORT SPS DEVELOPMENT DECISION

FUNCTIONAL REQUIREMENTS

EVALUATE ON-ORBIT FABRICATION OF LARGE STRUCTURES

EVALUATE INTERACTIONS OF HIGH-VOLTAGE STRUCTURES IN SPACE PLASMA

EVALUATE PROTOTYPE MANUFACTURING PROCESS AND MAN'S PRODUCTIVITY

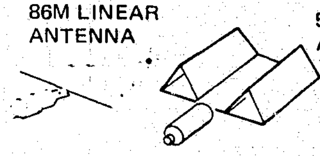
EVALUATE LARGE-SCALE SOLAR ENERGY SYSTEM DESIGN/INTEGRATED SYSTEM PERFORMANCE

EVALUATE RFI EFFECTS

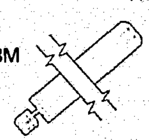
EVALUATE EFFECTS OF POWER TRANSMISSION ON IONOSPHERE

OBJECTIVE ELEMENTS

• COMPONENT DEVELOPMENT/PILOT PLAN 0



• PILOT PLANT I (1.72 MW_{RF})



• PILOT PLANT II (17 MW_{RF})

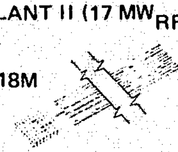


Figure 7-18. Satellite Power System

CR84

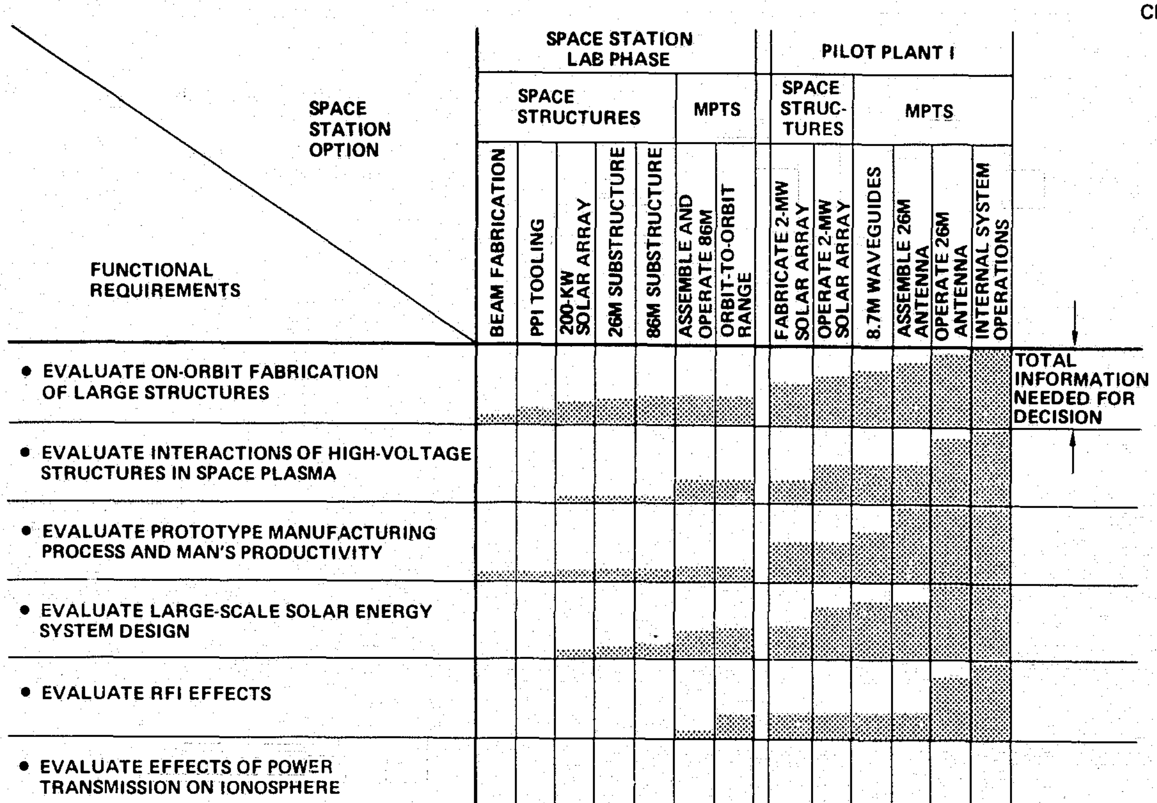
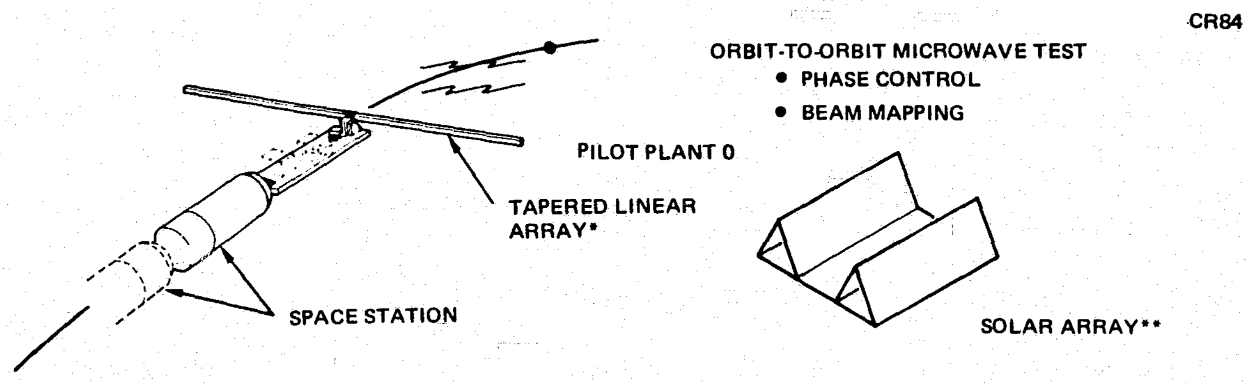


Figure 7-19. System Development Logic

7.1.5.1 Space Station Laboratory Component/Subsystem Development and PP0

Typical component and subsystem laboratory scale development activities are presented in Figure 7-20; two activities are depicted by the sketch and others are listed. The orbit-to-orbit microwave test beams power from a tapered linear array to another satellite, at about 120-km range, which maps the beam field strength and provides the pilot beam for phase-control tests. This technique allows nearly continuous, controlled, tests to proceed rather than the ocassional opportunities (dictated by orbital mechanics) associated with use of fixed, ground based, instrumentation. The 12-section waveguide portion of the tapered linear array is 6 cm x 12 cm x 85.8m; it is power-density tapered to provide six steps of power density by means of increasingly long waveguides, each fed by a single RF generator.

The Space Station fabrication and assembly module is employed to construct the 52m length of solar collector channel using full-scale components (structure reflector, and solar blanket). In addition to representing a realistic evaluation of components and large scale structure designs, this array



OTHER TYPICAL COMPONENT/SUBSYSTEM DEVELOPMENT

- WAVEGUIDE/RF AMPLIFIER ASSEMBLY AND CHECKOUT
- EVA AND CONSTRUCTION TOOLS/DEVICES — MAN's PRODUCTIVITY
- STRUCTURAL JOINTS/JOINING
- STRUCTURAL COMPONENT FABRICATION
- MICROWAVE TUBE CONTAMINATION EFFECTS
- SOLAR CELL/BLANKET AND MIRROR SAMPLE TESTS (E.G., SILICON AND GaAs)
- RFI MEASUREMENTS/COUNTERMEASURES

*0.06 X 0.12 X 86M; 60 KW_{RF}

**52 X 52 X 15M; 217 KWe

Figure 7-20. SPS Laboratory Development Tests

supplies 217 kW_e for other activities. Since repeated system test operations will span a period of months, the long-duration general-purpose fabrication/assembly, control, and data capabilities of the Space Station are suited for the purpose. Appropriate RFI environment measurements are made and protective measures investigated (e.g., screens between the antenna and the Space Station). The impact of microwave system operation on Space Station, Shuttle, and other NASA and military communications is of concern, particularly during the later, higher power test phases.

The waveguide lengths for a 10-dB taper in 10 steps for the Raytheon prototype SPS ($18m^2$ subarrays) are: 1.8, 2.0, 2.25, 2.57, 3.0, 3.6, 4.5, 6.0, 9.0 and 18.0. The 85.8m tapered linear array discussed herein uses 6 of the above 10 steps as follows: 1.8 + 3.6 + 4.5 + 6.0 + 9.0 + 18.0 = 42.9. The total length involves 2 sets of the above waveguides and is 2 x 42.9 = 85.8m for the 12-section array. A sketch of this antenna system, which has been selected as a representative tapered linear array, is presented in Figure 7-21; this size antenna was selected because it is less expensive and requires less power (76 kWe) from the Space Station power module than the full 20-section

CR84

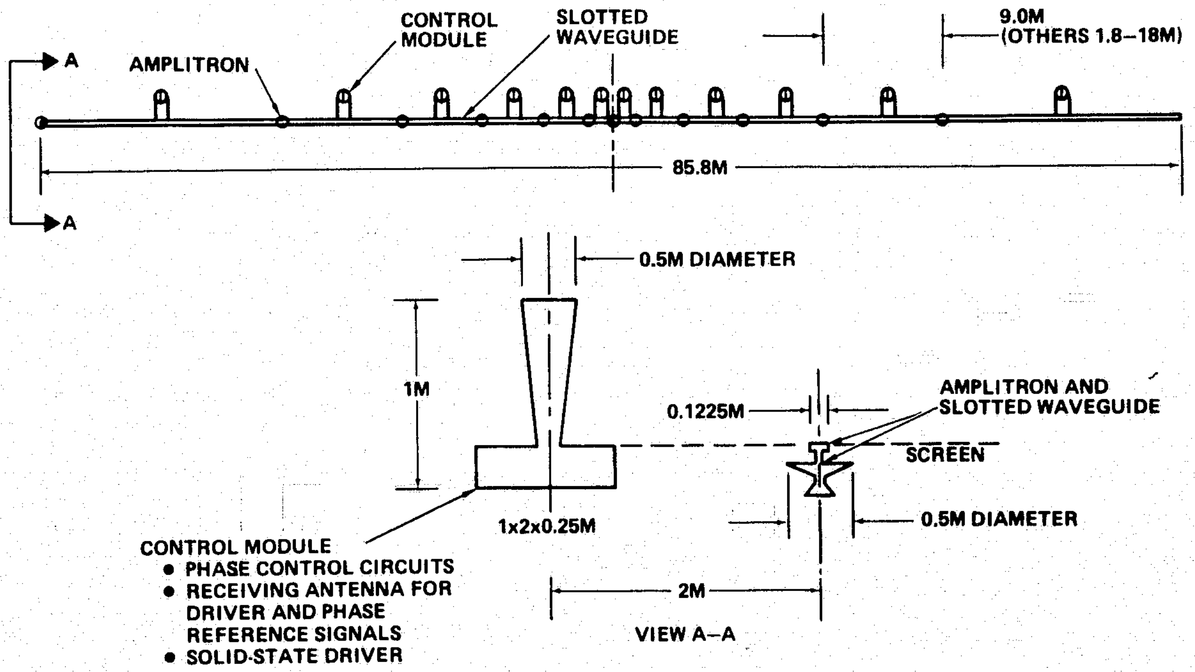


Figure 7-21. Tapered Linear Array (12 Active Sections – 60 KW_{RF})

array, which is 105m long. Operation of the 85.8m array should not impose excessive requirements on the Space Station power source and will adequately demonstrate phase control, beam quality and fabrication/assembly/checkout procedures. The long slender waveguides require a rigid support structure and sophisticated mounting arrangement for the waveguides, RF generators, screens and related phase-control modules. Each of the 12 sections requires a phase control module and an RF generator (e.g., amplitron).

Operation of the tapered linear array in space is necessary because of problems of operating the open tube RF generators in the earth's atmosphere and ground reflection effects on beam patterns. The far field distance is 120 km. Problems with LEO-to-ground angular rates, and time on-target lead to the need for an orbit-to-orbit antenna range.

Operation of the tapered linear array in GEO is highly desirable, because of:

1. Continuous antenna and solar array operation in the GEO plasma/ environment over day-night and the 11-year solar cycle.

2. No angular accelerations.

3. Operation with the pilot beam through the atmosphere/ionosphere through day and night cycles.

4. Possible operation through heated ionosphere (using HF up-beam heating of the proper ionosphere locality.

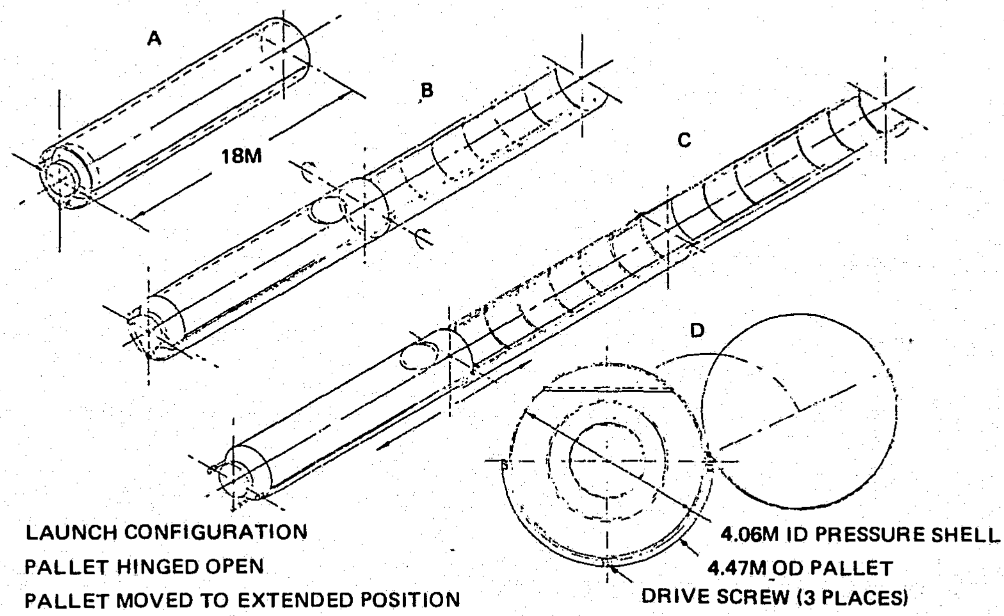
5. The actual thermal environment. Such a test provides a good demonstration of phase control, pointing/focusing, and GEO environment interactions.

The above GEO test could be accomplished using the 52 x 52m solar array as a power source for (1) chemically assisted self-powered electric propulsion, and (2) the GEO power source. The Space Station role is fabrication, assembly, checkout, LEO test/evaluation, and launch support for the GEO transfer. GEO operation would be basically unmanned, although later GEO Space Stations could contribute inspection and repair benefits.

The ensuring discussion explains the fab and assembly module and its use in constructing the 52 x 52m PP0 solar array. The module shown in Figure 7-22 is configured to serve as a general-purpose space construction facility suitable for the assembly and deployment of large structures. It is equipped with provisions for roll forming, welding, and diffusion bonding to permit space fabrication of structural elements from sheet stock. Hatches on the end and side berthing ports, and an inflatable seal engaging the hinged end bulkhead permit the module to be launched pressurized to provide shirtsleeve access for removal of launch restraints after berthing.

The module is unpressurized during operation and houses no ECLS equipment, but can be sealed and pressurized for shirtsleeve maintenance, repair, or modification of the equipment is contains. Air revitalization during these periods is through the umbilicals at the berthing port.

A frame and stringer stiffened pallet that is 4.47m (176 in.) OD is mounted on the outside of the 4.064m (160 in.) ID pressure shell on three acme threaded drive screws. The split pallet hinges open and can be moved aft on the drive screws approximately 17.68m (58 ft) to form a work platform that is 35.36m (116 ft).



A LAUNCH CONFIGURATION
B PALLET HINGED OPEN
C PALLET MOVED TO EXTENDED POSITION WITH 3 DRIVE SCREWS
D PRESSURE BULKHEAD HINGED OPEN

Figure 7-22. Fabrication and Assembly Module

While the use of the fabrication and assembly module is intended to be general purpose, it can be used to deploy a full-size segment of SPS solar collector. To do this, a jig is erected on the pallet as shown in Figure 7-23A, from structural elements fabricated within the module and positioned with the crane berthed at the side port. All the material for the jig and the solar collector it deploys can be launched within the module.

The jig is mounted on tracks on the pallet and fittings on the pressure shell. The structural elements for one bay of a solar collector trough are located in the jig and joined. The pallet is then retracted on the drive screws and cross beams of the assembly in the jig engaged by attach pins on the deployment beams on pallet. The pallet is then extended moving the assembly out of the jig. During this extension, the rolls of mirror and solar cell blanket unwind and the blanket and mirror edges are attached to the collector longerons. A second bay of the collector is then located in the jig, attached to the bay previously deployed, and the process repeated.

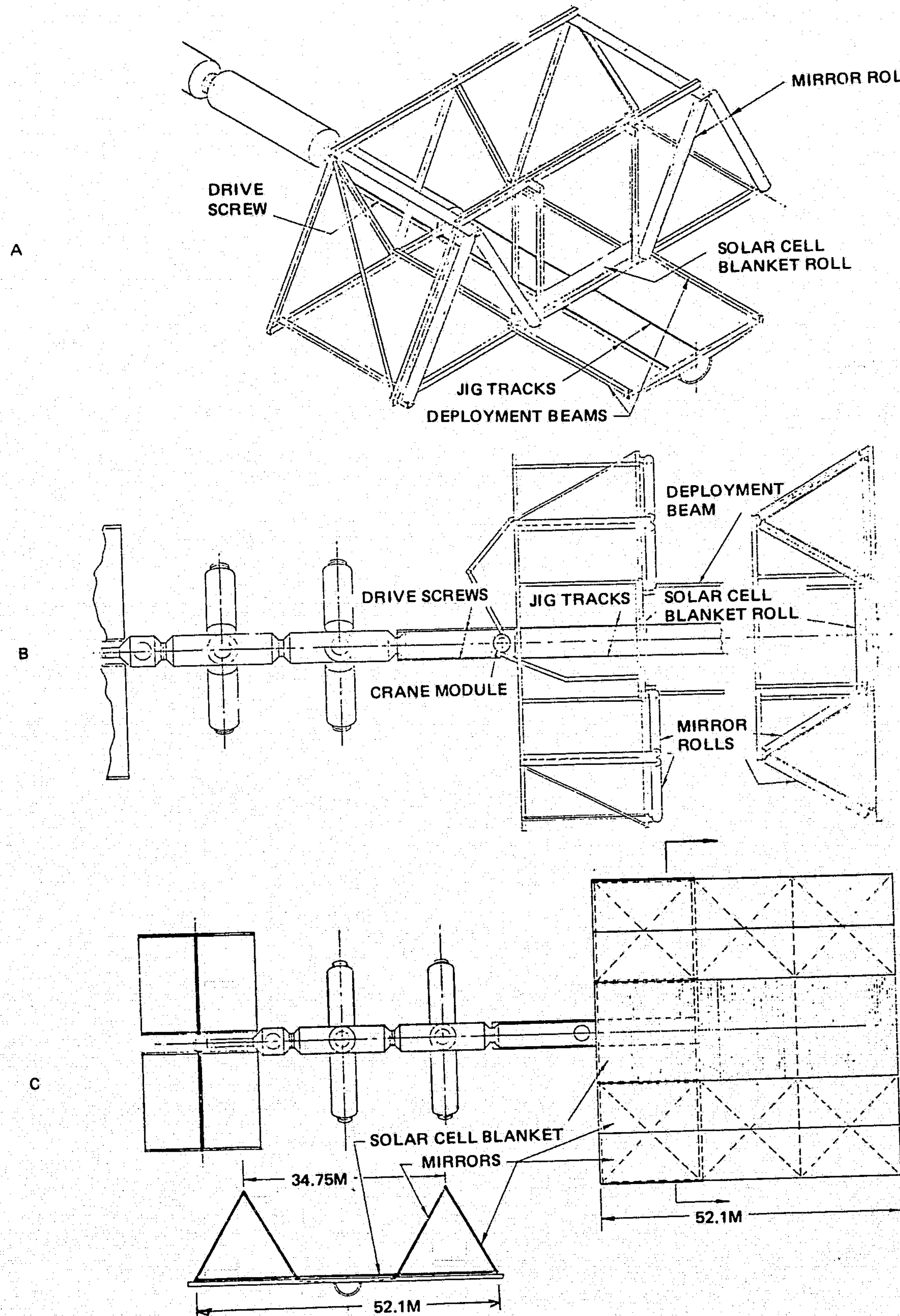


Figure 7-23. Early Structural Assembly Test

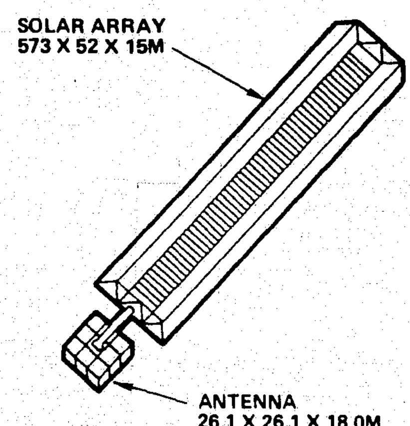
The crane module used to erect the jig and position the structural elements of the collector is shown in the plan view in Figure 7-23B. The segment of solar collector with three bays deployed is shown in Figure 7-23C. In this view, the jig elements which shade the collector have been removed and stored in the module and aft section of pallet, and the pallet has been retracted bringing the last bay of the collector up against the end of the pressure shell.

7.1.5.2 Pilot Plant I (PPI)

A summary of the functions and characteristics of PPI is presented in Figure 7-24. PPI contains the essential design features of the prototype SPS. Fabrication and construction techniques are also similar, but without the degree of special tooling and automation that would be used for PPII and the prototype SPS. PPI provides an integrated system feasibility demonstration with respect to fabrication, construction, operation and system performance.

It should be noted that the active area of the solar array is considerably less than the total projected area, because of: (1) the outer mirror slopes of the side reflectors, and (2) solar cells are not installed on the last 17.37m at

CR84



FUNCTION
- TEST PROTOTYPE DESIGN CONCEPT
  - FAB AND CONSTRUCTION PRODUCTIVITY
  - INTEGRATED PERFORMANCE
    - STRUCTURAL/THERMAL DISTORTION
    - MICROWAVE/PHASE CONTROL/RFI
- GROUND POWER TRANSMISSION DEMO
- POWER FOR OTHER APPLICATIONS

CHARACTERISTICS
- ANTENNA POWER, 1.72 MW_{RF}
- ARRAY POWER, 2.24 MWe
- ONE SUBARRAY, MAXIMUM POWER DENSITY

	WEIGHT (1,000 KG)	FLIGHTS
ANTENNA	5.4	FRACTION
SOLAR ARRAY	9.8	FRACTION
	15.2	< 1

Figure 7-24. SPS Pilot Plant I

either end of the trough due to solar cell shadowning by the end braces. The trough "peak-to-peak" dimension is 34.75m (vs overall width of 52.11m). The active length is 538.5m. The active area is 538.5m x 34.75m = 18,710m^2 vs a total projected area of 573.2m x 52.11m = 29,870m^2. The antenna consists of nine subarrays, each 8.7m square.

A critical aspect of the microwave system is the fabrication/assembly and thermal/structural performance of the maximum power density subarrays; demonstration of these aspects is considered a mandatory SPS development test. For this purpose, the full-scale subarry and supporting substructure should be employed.

The antenna power required to test, at maximum power density, one subarray of a nine-subarray antenna is shown as the straight line of Figure 7-25 as a function of the dimension of one side of a square subarray. MDAC has selected, with assistance of Raytheon, an 8.7 by 8.7m subarray as representative; the resulting power requirement is 1.719 MW_{RF} and 2.238 MWe at the solar array. The 8.7m subarray is a candidate for the prototype

CR84

- PILOT PLANT I MUST SUPPORT SYSTEM DEVELOPMENT DECISION IN 1987
- PILOT PLANT II MUST PROVIDE FIRM COST AND MANUFACTURING DATA FOR FULL-SCALE PLANT

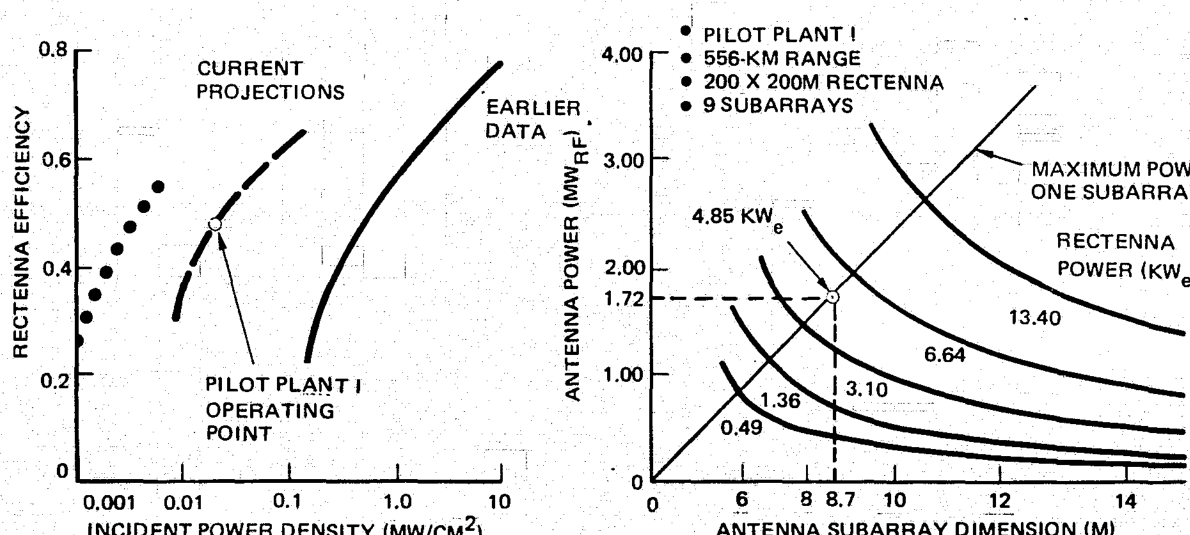


Figure 7-25. Pilot Plant Sizing Rationale

and production SPS's, although the Raytheon MPTS study for LeRC showed a 2-7% capital investment advantage in 18m subarrays. The 8.7m size is essentially consistent with JSC SPS in-house studies, which selected a 10m square subarray, and requires considerably less power for a full-power density test than the 18m dimension of Raytheon's studies. The 8.7m size is one-half the shuttle bay length, which is compatible with ground-fabricated waveguides for PPII and the SPS prototype.

A test antenna should also contain a number of subarrays to establish (1) structural/thermal edge effects in such a test, and (2) productivity/learning curve data. A 26.1 x 26.1m antenna design using nine 8.7 x 8.7m panels has been adopted for the above reasons, coupled with a reasonable ground power transmission demonstration capability as discussed below.

Recent data has indicated that rectenna efficiencies, at low-incident power levels, are much higher than originally estimated (the center, dashed efficiency curve of Figure 7-25). Hence, judicious use of of 1.719 MW_{RF} power can provide a reasonable LEO-to-ground-power transmission demonstration (e.g., approximately 4.85 kWe rectenna power output for a 200 by 200m rectenna at a range of 556 km) with a nine-subarray antenna. Estimated rectenna efficiency is 48% at 0.253 mW/cm^2. Figure 7-25 also shows the effect of antenna power and subarray size on rectenna power output for design points other than 8.7m subarrays at 1.72 MW_{RF}. The 4.85 kWe can light a small auditorium with a reasonable size rectenna.

The right-hand rectenna efficiency curve of Figure 7-25 is based on tests of the element developed for the JPL Goldstone tests, and has heretofore been used for rectenna design purposes. In the past, 1.0 mW/cm^2 has typically been taken as the minimum useful value for rectenna design purposes. The center curve is a Raytheon projection based on current laboratory technology development work for LeRC. Still further improvement in efficiency may be achieved at low power density by increasing the number of rectenna elements in series as shown by the left-hand dotted curve; however, current concepts make this configuration highly directional. The two left-hand curves are of considerable interest for PPI and PPII ground transmission demonstrations.

Test objectives include (1) antenna beam quality and RFI data, (2) closed-loop beam steering (phase control), (3) thermal distortion data on both antenna and solar collector, (4) control of the large, flexible array, (5) evaluation of the structural design, reflector and solar blanket quality, and other parameters after many light/dark cycles, (6) startup and shutdown procedures during light/dark transients. Antenna and RFI measurements would use the orbit-to-orbit system developed for the earlier linear array tests.

The PPI power source is also available for other applications, such as electric propulsion, space processing, or construction.

PPI construction is accomplished in a fashion similar to that described for PP0. Figure 7-26 shows the use of two fabrication and assembly modules to drive a jig similar to the one described earlier. Another view of this jig producing the PP0 solar array is shown in Figure 7-27. The fabrication and

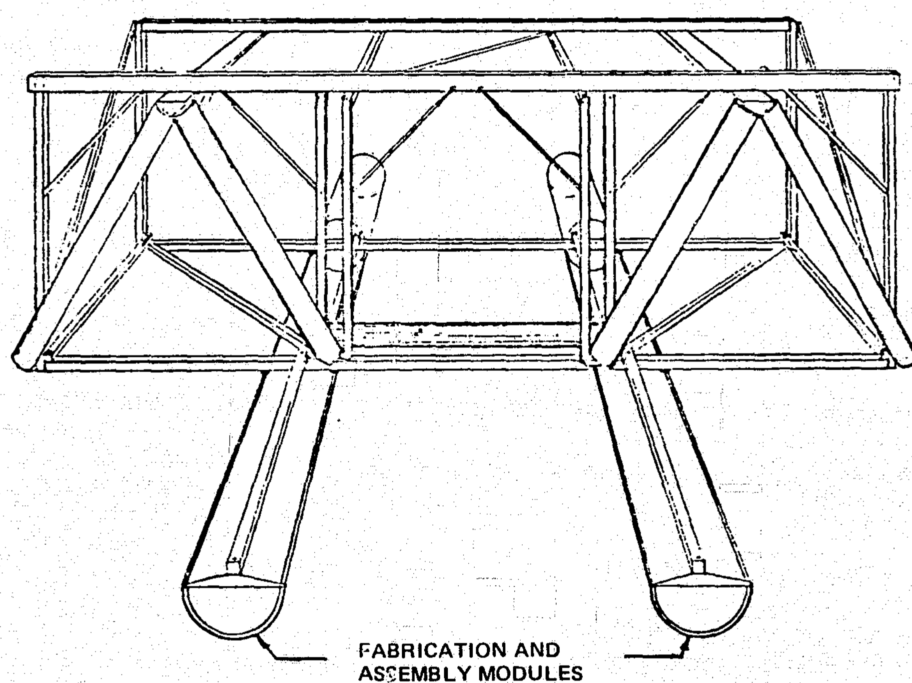


Figure 7-26. Construction Base Jig Configured for Pilot Plant I

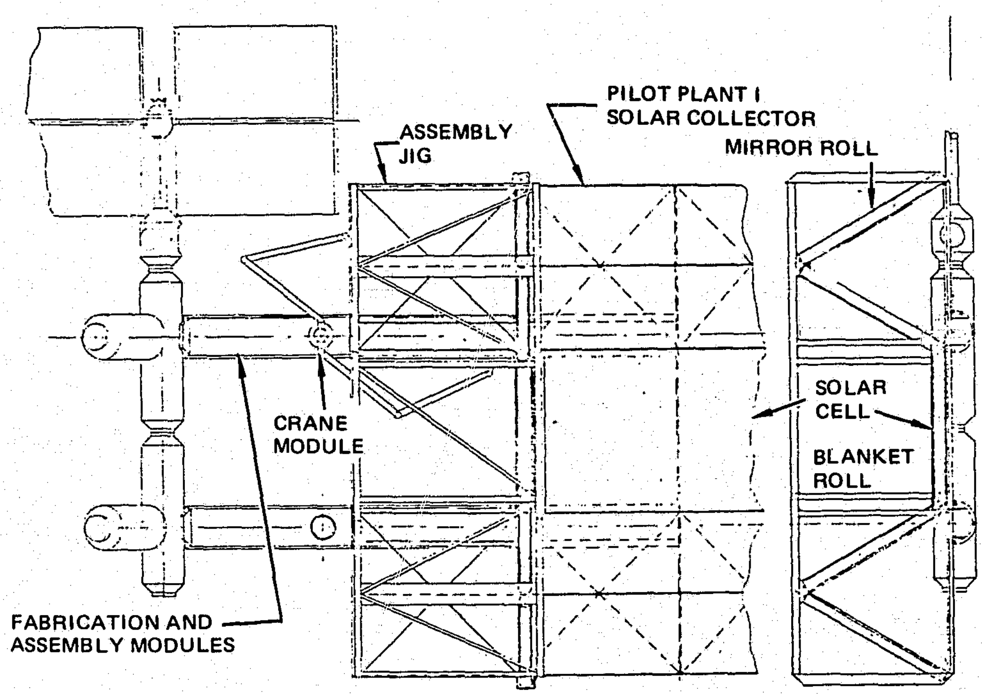
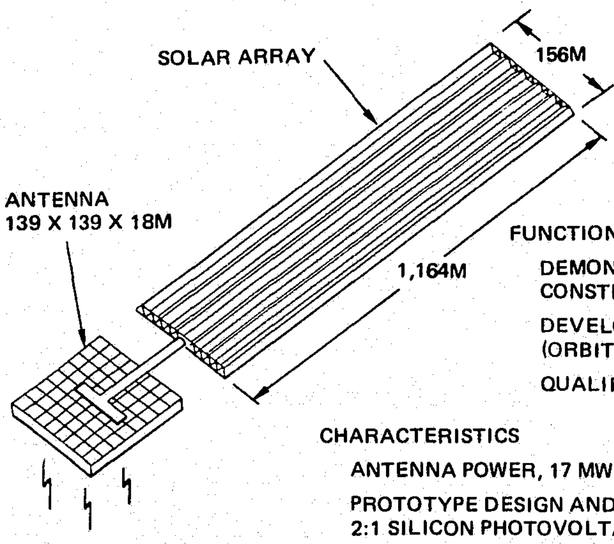


Figure 7-27. General-Purpose Construction Base

assembly modules may be placed at other Space Station locations if preferred, for example, at the end opposite the power module.

7.1.5.3 Pilot Plant II (PPII)

PPII features a 64-subarray (8 x 8 at 17.4 x 17.4m each), 17-MW_{RF} antenna, and 21-MWe power source as shown in Figure 7-28. PPII is considered a "partial prototype" because it employs the same design features and construction methods as the SPS prototype; it is fabricated by a construction base that is assembled with the aid of the Space Station and supported by the Space Station during the construction and operations phases. The primary functions of PPII are given on the chart; it offers a realistic integrated system test of the construction cost/productivity and quality, operation, and system performance of a prototypical SPS. Subsystem qualification tests include (1) structural (thermal cycling and thermal distortion), (2) electronic (antenna beam quality and beam steering/focus), (3) attitude control system, and (4) operational procedures (power up/down and repair/maintenance).



FUNCTION

DEMONSTRATE MANNED PRODUCTIVITY AND PROTOTYPE CONSTRUCTION PROCESSES

DEVELOPMENT AND PERFORMANCE TESTING (ORBIT-TO-ORBIT AND ORBIT-TO-GROUND)

QUALIFY PROTOTYPE SPS CONCEPTS AND SUBSYSTEMS

CHARACTERISTICS

ANTENNA POWER, 17 MW_{RF}

PROTOTYPE DESIGN AND CONSTRUCTION, PARTIAL PROTOTYPE

2:1 SILICON PHOTOVOLTAIC EXAMPLE

	WEIGHT (1,000 KG)	FLIGHTS
CONSTRUCTION BASE LOGISTICS	64	8
SOLAR ARRAY	60	4
ANTENNA	186	8
	310	20

Figure 7-28. SPS Pilot Plant II Model

Figure 7-29 is a layout of PPII. It should be noted that for the same reasons as PP0, the active solar array area is 1,129m x 139m = 156,900m^2 whereas the total projected area is 1,164m x 156m = 181,600m^2. The PPII configuration duplicates full-scale prototype solar array and antenna structure with the exception of the solar array center mast and transverse solar collector beams. Evaluation of these items would be performed by separate tests using the construction base that assembled PPII. The construction base tooling is representative of that used in production. Full-power density is required on at least one or two subarrays, with a sufficient total number of subarrays and total power to avoid excessive edge effect, for evaluation of antennas thermal distortion. However, since the full-scale subsystem can be assembled and tested on the ground, a scaled gimbal may be used.

The PPII antenna was shown earlier (Figure 7-4) and is further illustrated in Figure 7-30 with its scale-model gimbal system. The rotary joint (mercury filled roller bearings) is sized for Orbiter transportation in an assembled condition (4.27m diameter x 15.2m long).

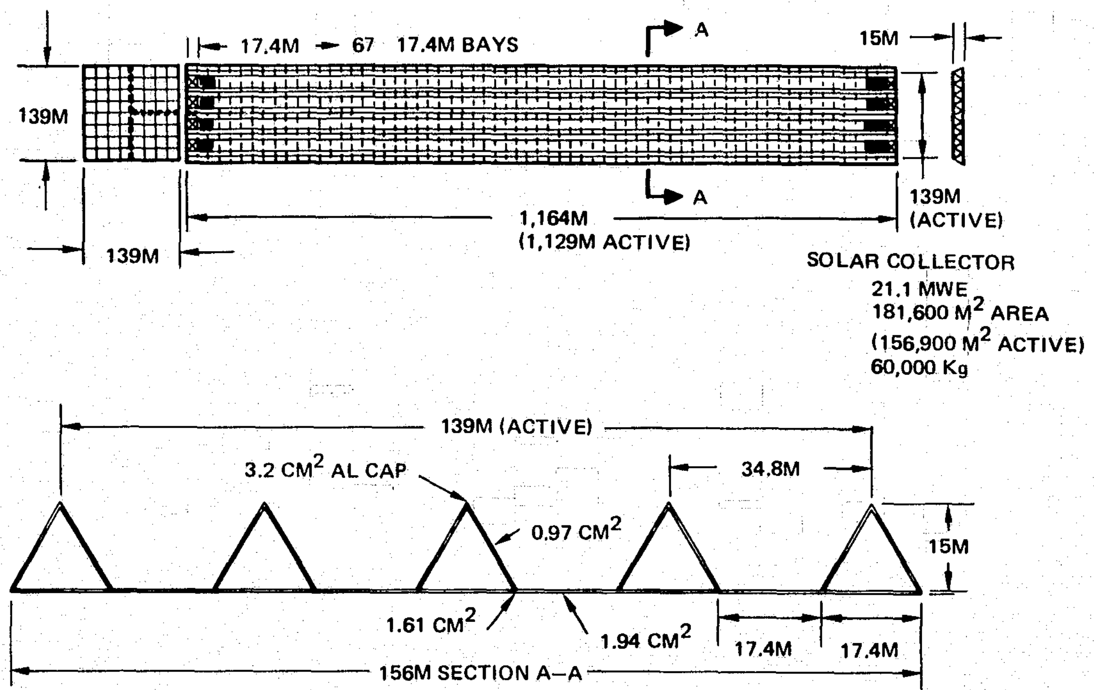
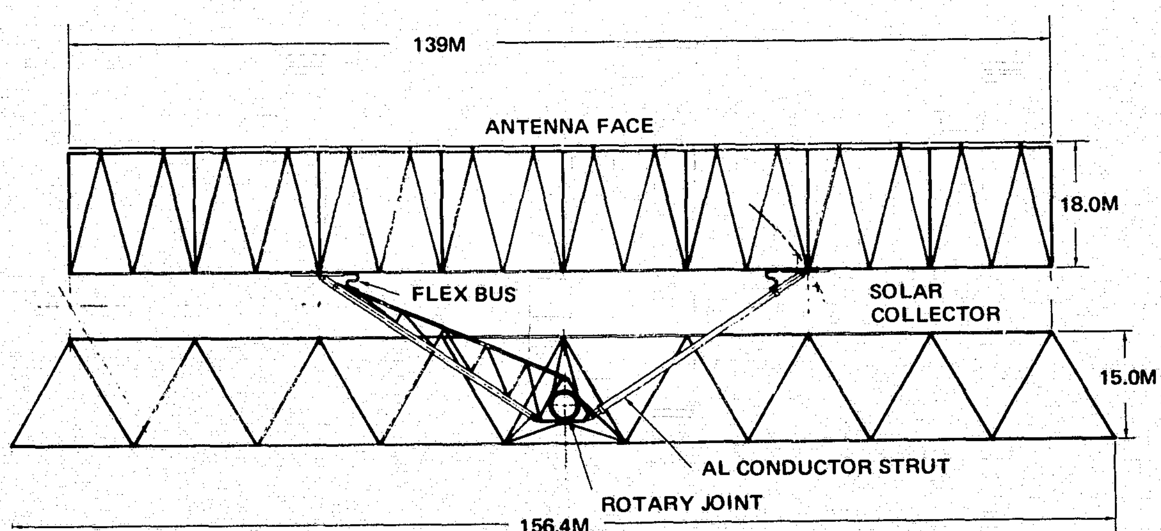


Figure 7-29. SPS Pilot Plant II Configuration



ORIGINAL PAGE IS OF POOR QUALITY

Figure 7-30. SPS Pilot Plant II Antenna – Antenna Vernier Pitch/Roll Pointing Provisions

As noted on Figure 7-28, a total of 20 Shuttle flights are dedicated to the launch of PPII hardware and its construction base. Late in the PPII Program (circa 1994-5), the base would be placed synchronous orbit. This provides a realistic demonstration and test of transportation technology necessary for the prototype, and SPS operational experience with the prototype structural/ electrical/electronic configuration in synchronous orbit; the GEO plasma interaction is size and geometry dependent. Further, it can even provide a ground power-transmission demonstration from GEO. Recent rectenna information indicates that 30% efficiency can be obtained with 0.001 mW/cm^2 power density by coupling a number of rectenna elements in series per diode. Thus, not only could power from synchronous orbit be demonstrated, but also the critical closed loop pointing/tracking of the ground rectenna by a large orbital antenna under realistic conditions.

An isometric of the PPII construction base, which duplicates the prototype construction process, is presented in Figure 7-31. As in many simple concepts, detailed implementation of the Shuttlecock construction base becomes complex in detail. Primarily the base consists of a jig, to align

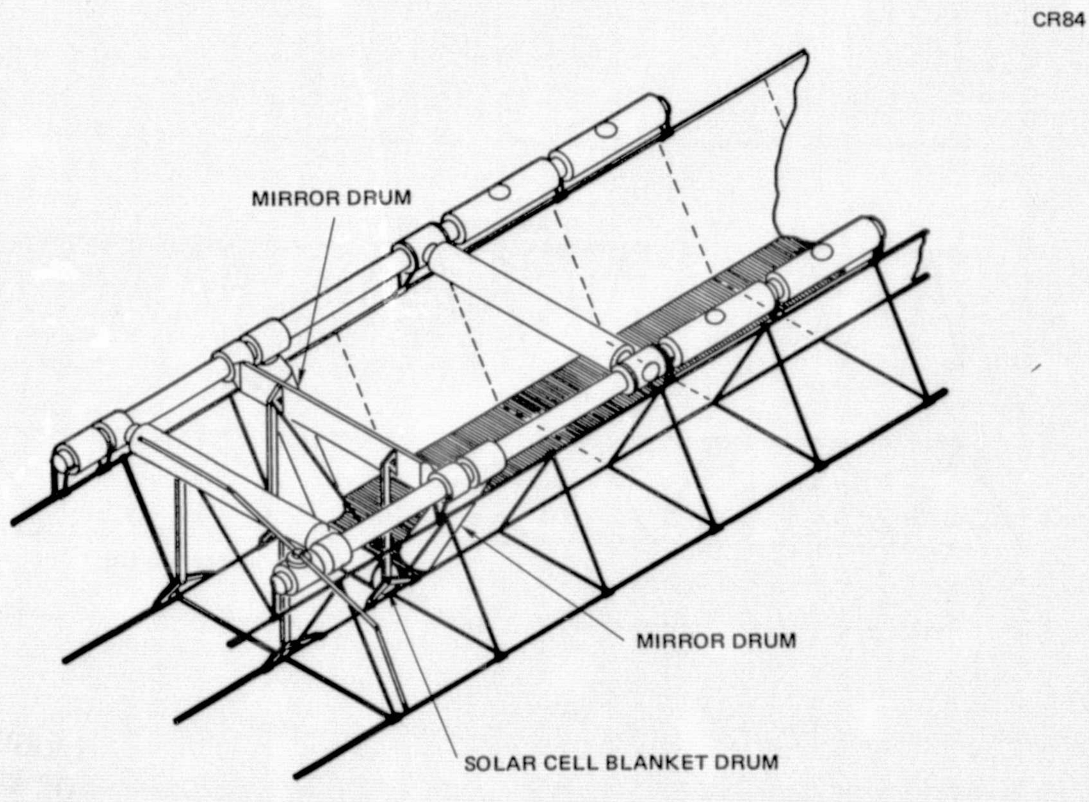


Figure 7-31. SPS Construction Base

the solar collector structural members as they are assembled, and a means of "walking" this jig along and across the individual collector channels. As shown, the base is progressing from right to left with tube assembly performed in its forward portion. Reflector and solar cell blanket drums are located behind the tube assembly jigs. The two pairs of modules at the right are standard Space Station elements with "walking shoes" attached. Power modules (not shown) are attached to their lateral docking ports.

As configured, the construction base has a "JANUS" (two faced) characteristic, while traveling either forward or backward. When it travels from left to right, the drums dispensing reflector sheets and solar cell blankets are repositioned to the left of (behind) the tube assembly jig.

A layout of the PPII construction base concept is illustrated in Figure 7-32. The major elements are:

A. Rotatable mirror drum mount.

B. "D-section" module mounting assembly.

CR84

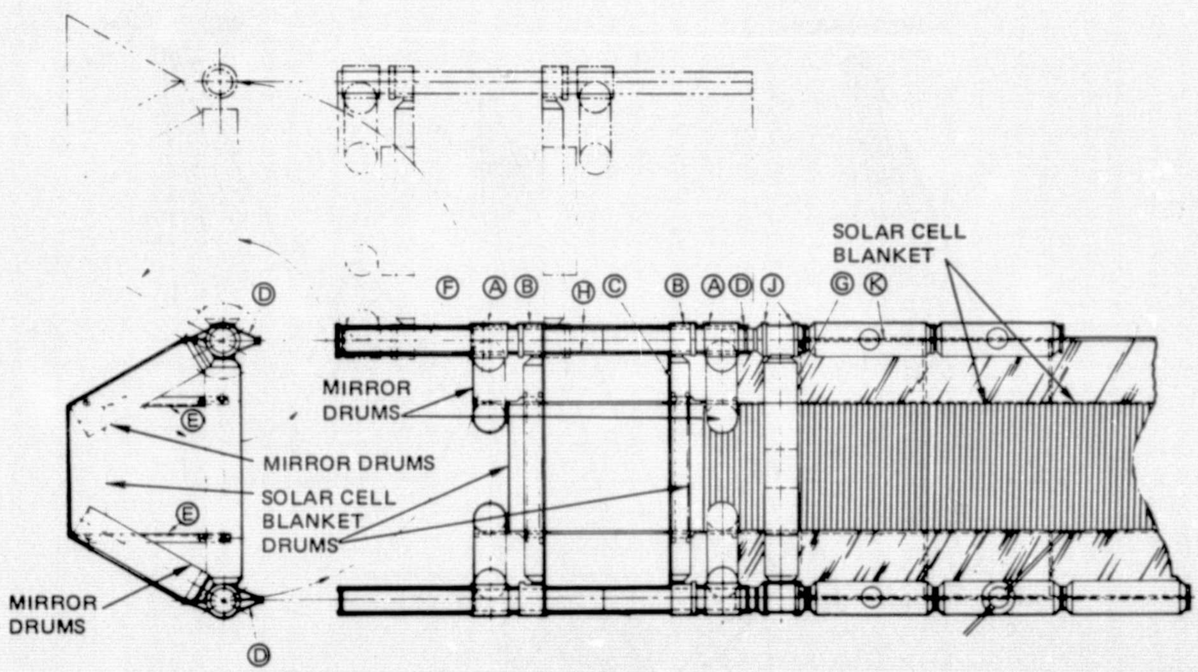


Figure 7-32. Pilot Plant Construction Base

C. "D-section" module with tube storage racks.

D. Drive screw mounting frames.

E. Truss jig arm/conveyor and blanket drum mount.

F. Telescoping jig arm (pressurizable).

G. Telescoping torque module (pressurizable).

H. Drive screw (3 segments).

J. Rotatable joint with inflatable seals.

K. Two-segment drive screw.

The ensuing series of figures explain the operation and assembly of the PPII construction base. Movement of the construction base across the solar collector channels is accomplished by rotation of the jig arm portion of the base with respect to the station portion (and vise versa), as shown in Figure 7-33. The tube assembly jig with its attached solar cell blanket drum has been simplified in this drawing for clarity by eliminating one of the transverse "D" section modules.

Figure 7-34 illustrates the complete "cross channel walk" sequence of the construction base. After finishing the second trough, station modules are

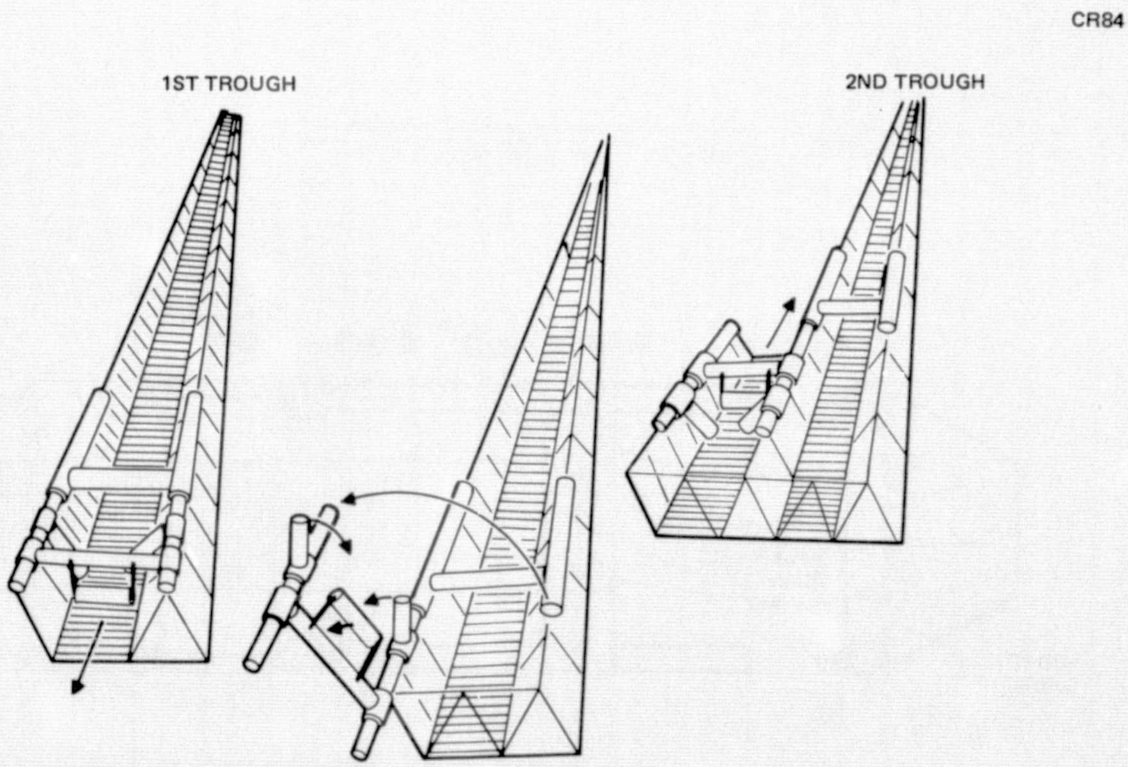


Figure 7-33. Pilot Plant II Construction Base Sequence

CR84

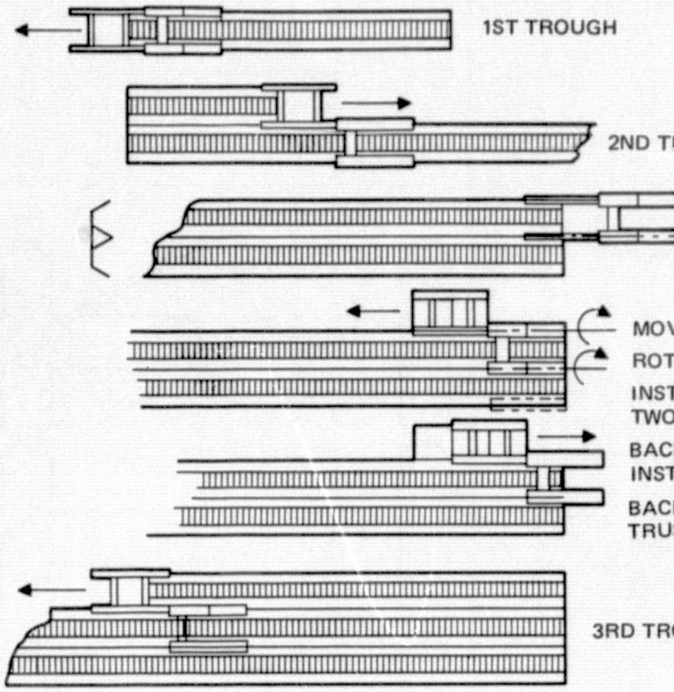


Figure 7-34. Construction Sequence

rotated to align again with the jig modules. The assembly then moves from right to left until station module walking shoes can again engage the second trough. With the station remaining attached to the second trough, the jig modules are rotated into the third trough position. Several bays of tubing for the third trough are then laid (without blanket or reflectors) to complete the right-hand end of the third trough's structure. The construction base then moves from left to right to attach reflector and blanket to the completed bays and resumes bay structural assembly at the appropriate point.

Construction base assembly is a complex process involving use of the walking crane and telescopic modules. The new modules in each build up sequence (illustrated in Figure 7-35) are shaded. The transverse modules docked to the Space Station are not essential to the construction base function, but are included to indicate that the construction base can also undertake work on other objectives. The sequential buildup steps shown in the figure are as follows:

1. Remove the rotary joint modules from the PIDA.
2. Berth the rotary joints; move the power module to lateral port.

CR84

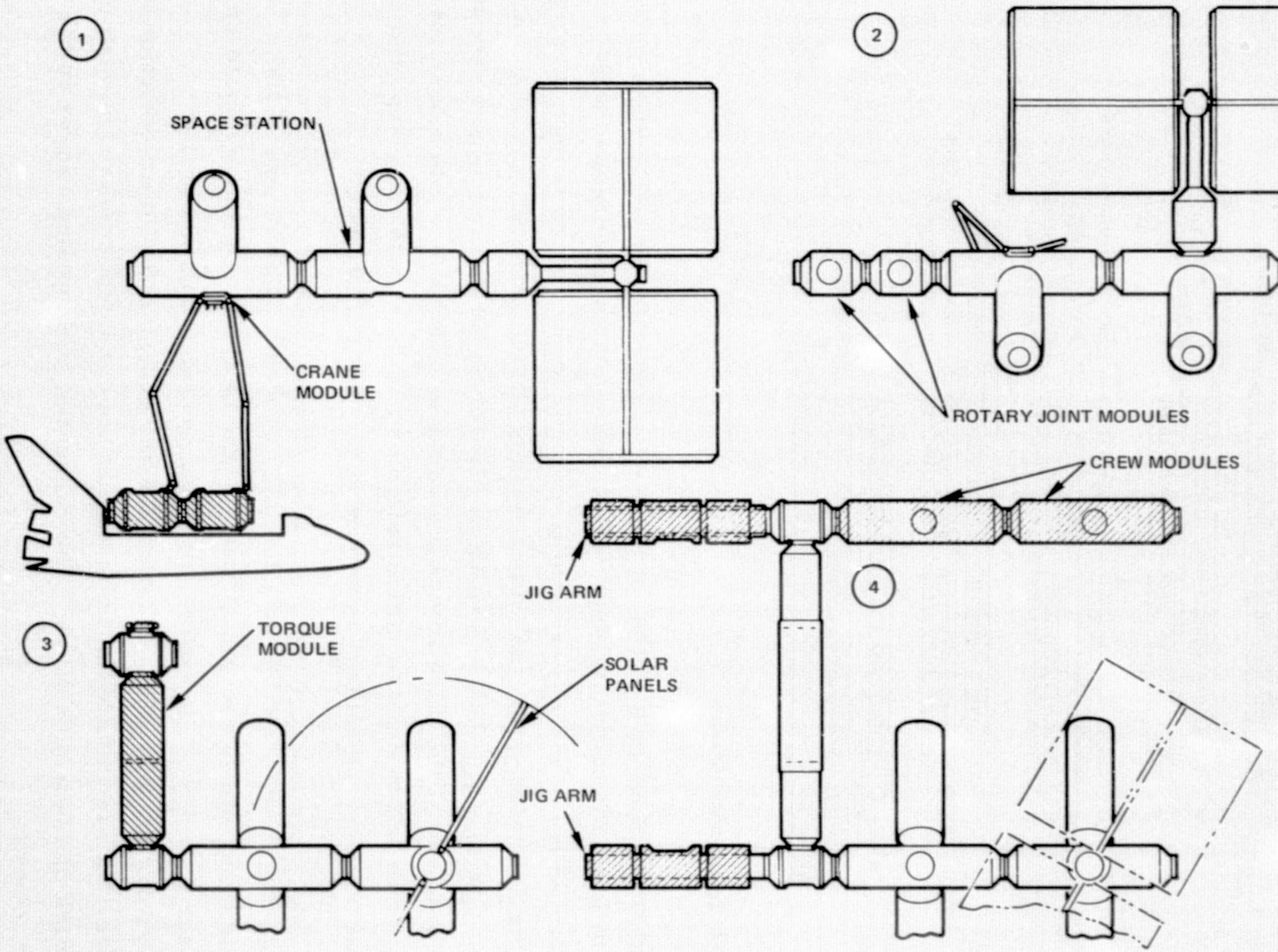


Figure 7-35. Pilot Plant II Construction Base Assembly Sequence (Sheet 1 of 3)

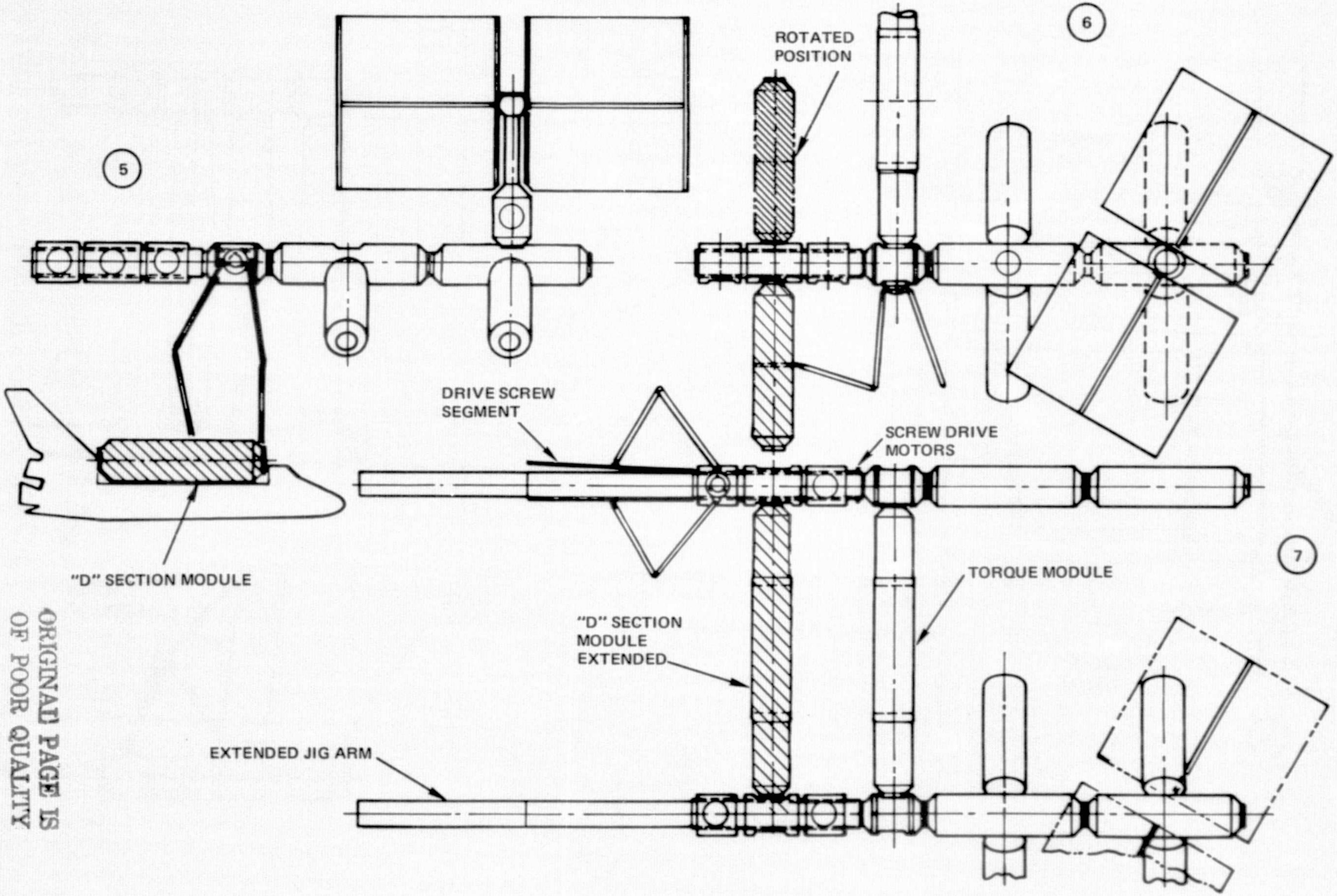


Figure 7-35. Pilot Plant II Construction Base Assembly Sequence (Sheet 2 of 3)

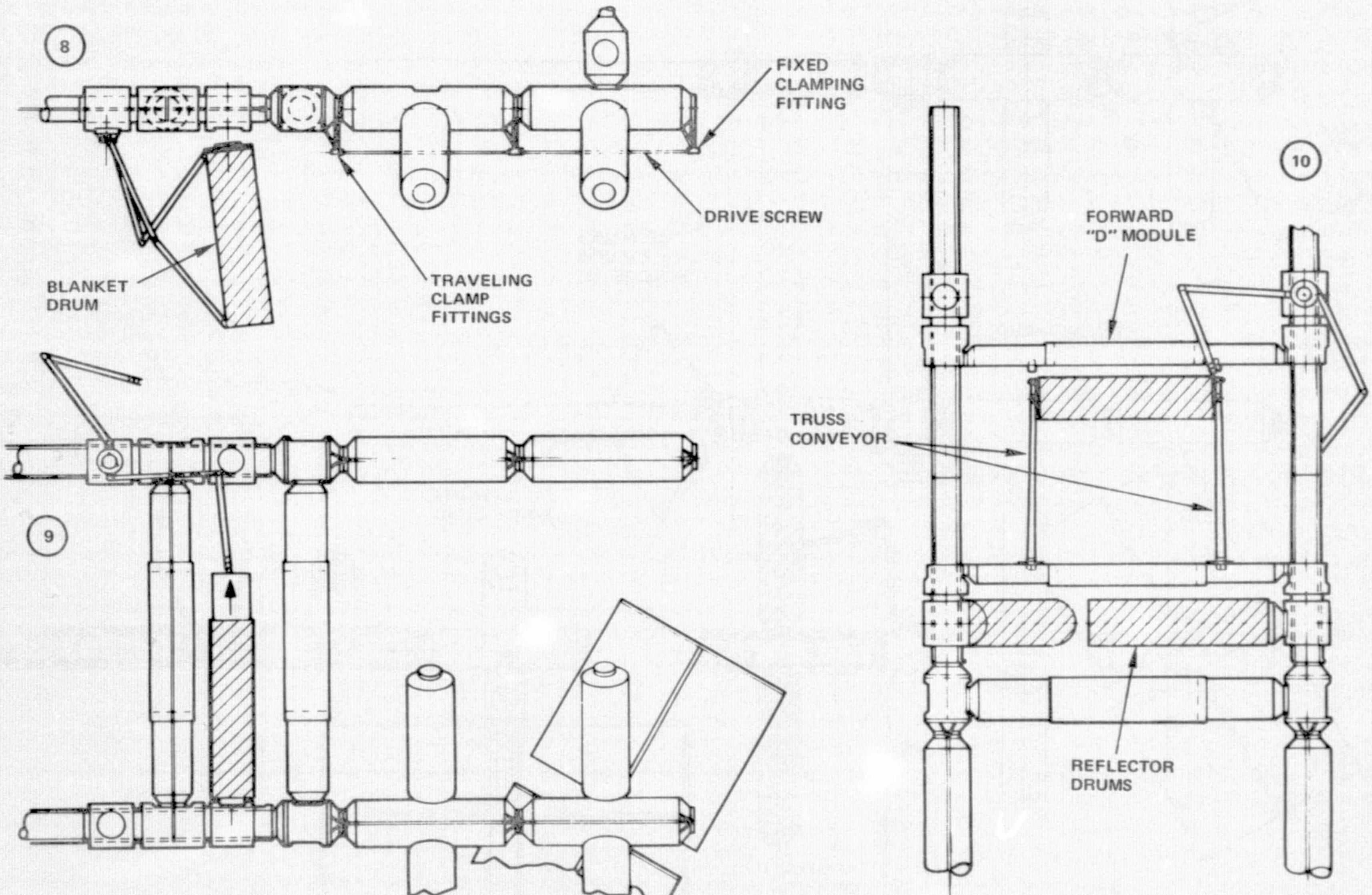


Figure 7-35. Pilot Plant II Construction Base Assembly Sequence (Sheet 3 of 3)

3. Offload and berth the torque module; move one rotary joint.
4. Offload and berth the first and second jig arms; attach two additional station modules; deploy the telescoped torque module.
5. Off-load the "D-section" modules, which contain truss tube jigs.
6. Berth the "D-section" module and rotate it to a position parallel to the torque module (Note that the second jig arm and second pair of station modules are not shown in this view).
7. Extend the telescoped "D-section" modules to berth in the second jig arm; extend the telescoped jig arms; install the acme thread drive screw segments.
8. Offload the telescoped blanket and mirror drums and berth them on the mirror drum port. Install the "walking shoes" and the drive screw on the station modules.
9. Remove the inner mirror drum and install it at the opposite port.
10. Separate the "D-section" modules with the drive screws; erect the truss jig (stored in the D's); remove the truss tubes from the blanket drum and place them in the "D" module racks; remove the blanket drum from the second reflector drum and mount it on the truss jig.

It is important to note that the Construction Base just described builds not only PPII, but it is also the Construction Base for prototype and production SPS's, using multiple units.

7.2 SILICON RIBBON AND SOLAR CELL BLANKET PRODUCTION PLANT

Recent interest in new concepts for space power generation has stimulated an investigation into solar energy conversion into electrical energy with photovoltaic cells and transmission of energy by microwave to earth. This MDAC-funded study was directed toward building a manufacturing facility in earth orbit which will produce large quantities of solar cells and assemble them into lightweight solar cell blankets. These blankets will be assembled onto a satellite solar power station which converts solar energy directly into electricity.

McDonnell Douglas Astronautics Company - East recently completed a NASA funded study, "Feasibility Study of Commercial Space Manufacturing," report MDC E1400, dated 20 December 1975 (Reference 7-1). The objective of this study was to identify servicing and transportation requirements, determine major cost factors, and establish the technical and economic feasibility and aid in understanding the implication of space manufacturing.

The model product used in the above study was silicon ribbon, commonly used for integrated circuit production on earth. Space manufacturing of this silicon ribbon was found to be technically and economically feasible under the groundrules and assumptions used in the study:

7.2.1 Groundrules

The following groundrules were used in this study of space-produced solar cell blankets for the satellite power station:

A. All orbital operations will be supported by Space Station.

B. Space Station(s) for the manufacturing base(s) will be sized to meet the production requirement.

C. Space Station support for the test facility in 1987 will be limited to 10 men (12-man station).

D. Space Station support for an operational facility in 1995 is as required.

E. EVA may be used but is undesirable in the operational facility.

F. All facilities and tests will be Shuttle-compatible.

G. Solar blanket support drum diameter is to be determined.

H. The concept is based on ribbon processor design described in MDAC-E Report MDC E1400.

I. Requirements are:

1. Produce finished rolls of solar cell blankets similar to A. D. Little concept (References 7-2 and 7-3).
2. Individual blanket dimensions are 15m x ≈3.3 km at a bus voltage of 20,000V.
3. Assumed production rates at 10% efficiency

   1985 – 4.5×10^4 m^2.

   1987 – 2.7×10^5 m^2.

   1995 – 3.7×10^6 m^2/yr.

   2000 – 1.9×10^7 m^2/yr.

7.2.2 Study Approach

The approach for this study is to take the results of the feasibility study (Reference 7-1) and determine the necessary modifications to the silicon ribbon processor to meet the requirement established by the study groundrules. The silicon plant configuration of the study was a single free-flying assembly which was periodically resupplied by the Space Shuttle (Figure 7-36). Raw material is two polycrystalline silicon rods which are simultaneously fed into the furnace melt chamber where heat from the solar collector (while exposed to the sun) or heat from the radiant heaters (while in the eclipse) maintains a melt at the rod junction. Silicon ribbon is pulled from the melt and drawn through a shaper. The ribbon is monitored during shaping and as it leaves the pull chamber. A thin carrier tape is added to the ribbon after it passes through the reject and reseed chamber and together they continue onto the take-up storage reels.

The shaping device selected for the feasibility study was a radio frequency (RF) shaping coil which required a significant amount of power for shaping. There is also some question whether very thin (~0.1 mm) crystals can be formed by using this RF technique. This thickness is desirable for production of large quantities of ribbon as required in Task 1, because the crystal growth rate increases significantly as the ribbon thickness is reduced (Reference 7-4). A 0.1-mm thick ribbon will grow at the rate of approximately 7.6 m/hr as compared to the 1.9 m/hr of 0.4-mm-thick ribbon. Another consideration is the availability of Space Station crewmen to provide maintenance and servicing more frequently than postulated in the report cited in Reference 7-1. Therefore, an adaption of the silicon ribbon growth through a sharp-edged die technique is used for this study (Reference 7-4). Die replacement would probably be required on a frequent and scheduled basis (~30 days) due to potential die erosion.

The silicon ribbon solar cell manufacturing facility will be launched in modular sections and assembled in space adjacent to the manned orbital facility (OF). Several ribbon manufacturing facilities will be assembled to provide solar cell ribbon for each solar cell blanket assembly module.

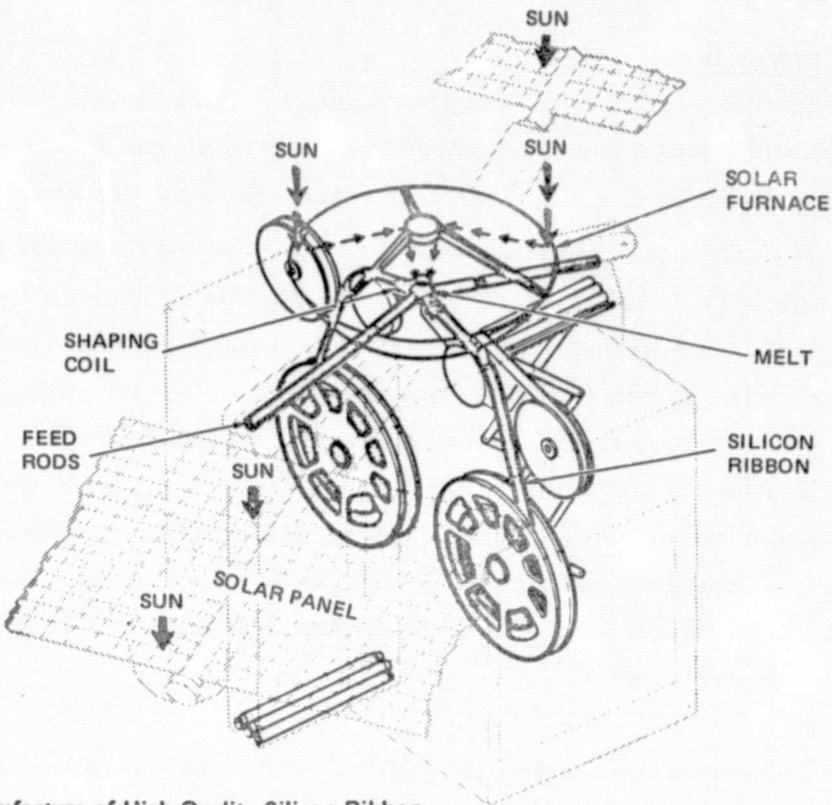


Figure 7-36. Manufacture of High-Quality Silicon Ribbon

7.2.2.1 Production Rates

The solar cell power output is highly dependent on cell efficiency. As shown in Figure 7-37, the silicon ribbon production rate can be reduced considerably by using the space-produced cells, which have higher efficiency. Figure 7-37 is a plot of the production rate requirements specified in the ground rules. For example, in 1995, the production rate must reach about 37 million square meters of solar cells operating at 10% efficiency or about 21 million square meters of space-processed solar cells operating at 18% efficiency.

7.2.3 Silicon Ribbon Solar Cell Process

The solar cell process described in the Reference 1 study can be modified as shown in Figure 7-38. Boron-doped polycrystalline feed rods are used to form and maintain the melt. The seeds are introduced and the crystal drawn through the shaping die, forming a boron-doped 0.1 x 76 mm ribbon. While still hot (~600°-700°C), the ribbon is drawn through a phosphene gas chamber where phosphorus is diffused to a depth of approximately 0.1 μm into the

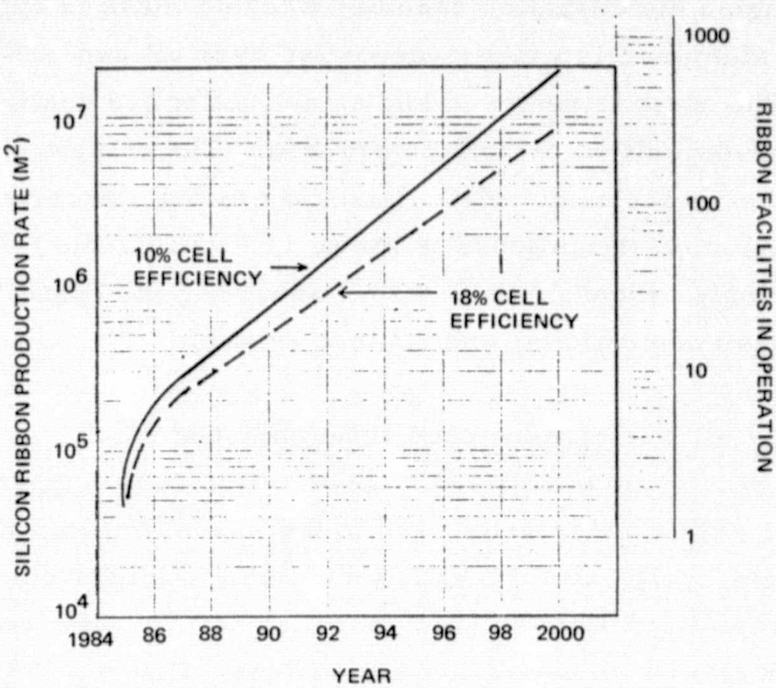


Figure 7-37. Silicon-Ribbon Production

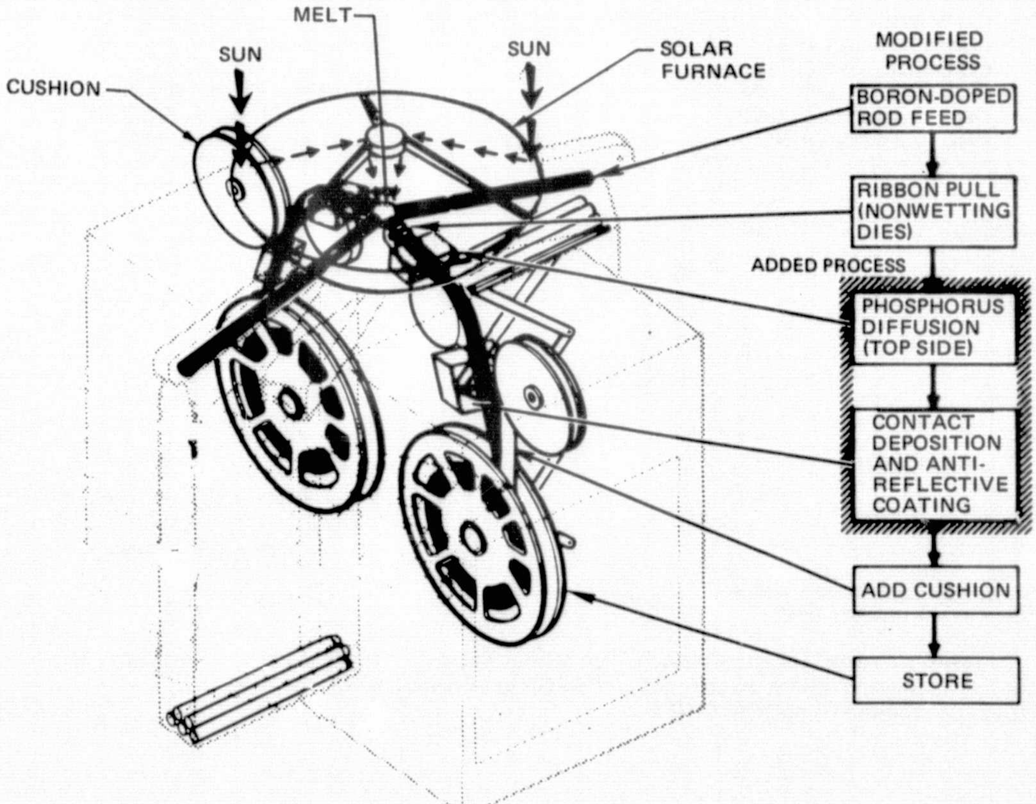


Figure 7-38. Manufacture of High-Quality Silicon-Ribbon for Solar Cells

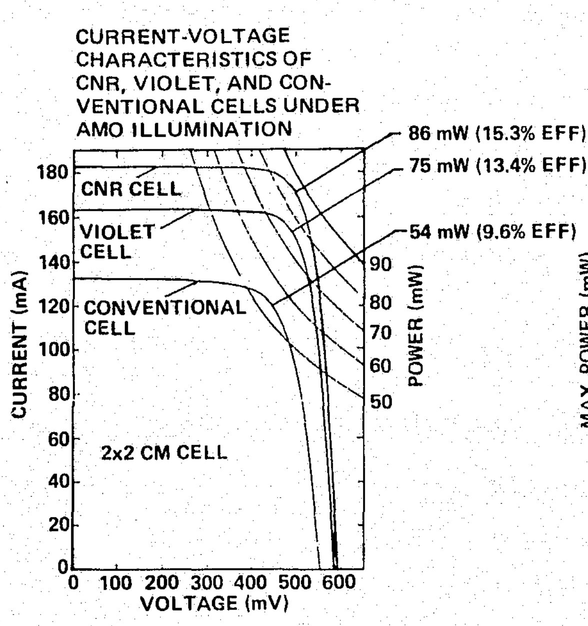
ORIGINAL PAGE IS OF POOR QUALITY

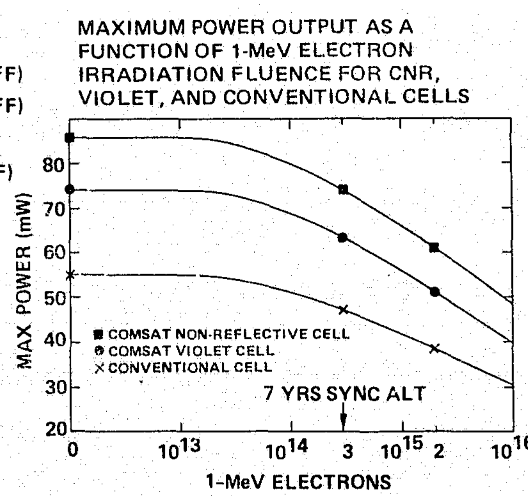
top surface, forming a solar cell diode. This continuous diode is then passed through a metallization chamber where a mask is applied to the top surface and aluminum is vacuum-deposited over all exposed top and bottom surfaces. The mask is removed and an antireflective coating is applied using a vapor-deposition or roll-on process. The complete solar cells are stored on take-up reels in a manner similar to that described in Reference 7-1. (A block diagram of the process is shown in Figure 7-38.) The power requirement for a single processor is 2.4 kW, assuming the Space Station supplies the power, communications, and attitude control.

7.2.4 Solar Cell Performance and Efficiency Gain

Ideally, the silicon solar cell can have an efficiency of approximately 22%. Conventional silicon solar cells used in the space program achieve a conversion efficiency of 9 to 11%. The most notable improvements in efficiency have been obtained with the "violet" and Comsat Nonreflective Cell (CNR) silicon solar cell as reported (Reference 7-5). Figure 7-39 compares the efficiency and power associated with the conventional, violet, and CNR cells.

CR84





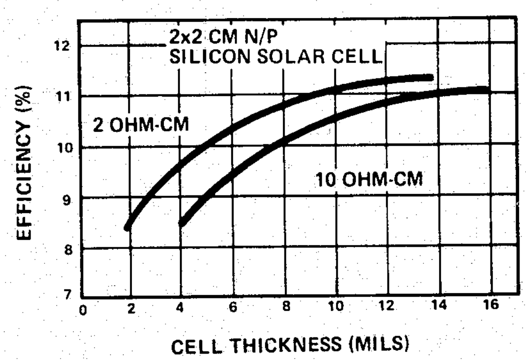
REF: HAYNOS, ALLISON, ARNOT AND MEULENBURG, "THE COMSAT NONREFLECTIVE (CNR) SILICON SOLAR CELL: A SECOND GENERATION IMPROVED CELL," COMSAT LABORATORIES

Figure 7-39. Improvements in Silicon Solar Cells

To date the violet and CNR cells have not been used as the primary power source for spacecraft. The figure indicates an upward trend in the performance of silicon solar cells. Extensive research and development is in progress to improve further the performance of silicon solar cells. Figure 7-40 shows typical characteristics for the conventional silicon solar cell. The thicker cell with low base resistivity (2 ohm-cm) provides the highest efficiency. However, at the expected fluence levels the power output of the thin cell is equal to that of the thick cell. Thus, the thin cell with low resistivity results in the lightest system.

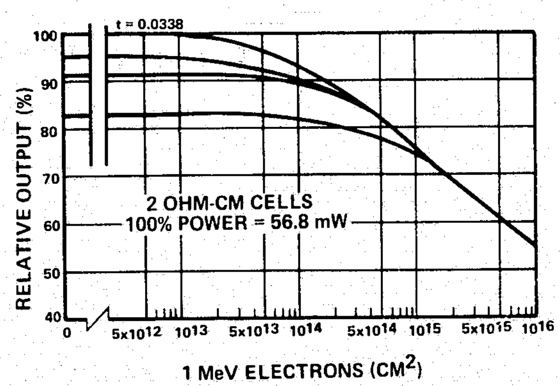
Reference 7-6 states that a large improvement in cell efficiency comes from increasing the available voltage. If the base resistivity can be reduced from the typical 10 ohm-cm to 0.01 ohm-cm, a 50% increase in open-circuit voltage will result. A practical efficiency of 19.7% is projected for the 1985 cell.

CR84



2 OHM-CM CELLS PROVIDE HIGHEST EFFICIENCY

REF: E. L. RALPH, "PERFORMANCE OF VERY THIN SILICON SOLAR CELLS," HELIOTEK RESEARCH PAPER B118A



AT THE EXPECTED FLUENCE LEVELS THIN CELL POWER OUTPUT IS EQUAL TO THICK CELL

REF: CURTIN AND STATLER, "REVIEW OF RADIATION DAMAGE TO SILICON SOLAR CELLS"

Figure 7-40. Solar Cell Characteristics

Reference 7-7 states that the greatest solar cell conversion efficiency gains will be obtained from improved functions and control of the base resistivity. Skylab experiments in space processing of crystals (Reference 7-8) showed that dopant diffusion and homogeneity, as well as uniform resistivity characteristics, were material property improvements which could be obtained from space processing. These experimental results indicate that the required solar cell improvements can be obtained from space processing; therefore, it is postulated that an 18% conversion efficiency is a practical space processing goal.

7.2.5 Silicon Ribbon Facility - Shuttle Installation

A layout was made to determine the number of solar cell processors that could be launched in the Space Shuttle; the result is shown in Figure 7-41. A dedicated mission would provide a Shuttle launch for a silicon ribbon solar cell manufacturing facility. The mission would launch a module capable of producing 108,000 m^2 of 76-mm wide solar cells per year. This production rate is based on pulling 0.1 mm thick x 76-mm wide ribbon through non-wetting dies at a rate of 7.6m per hour (extrapolating from Reference 7-4).

CR84

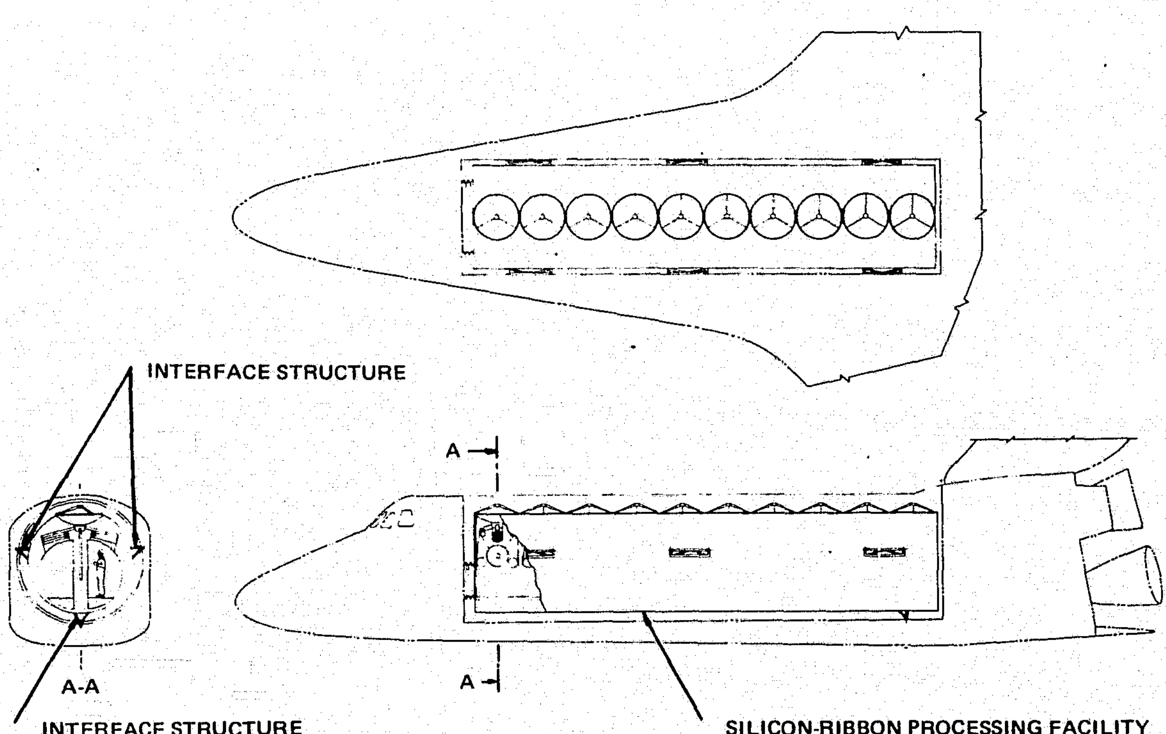


Figure 7-41. Silicon-Ribbon Facility Shuttle Installation

The annual production rate is achieved by operating at 93% productivity, 360 days per year, 24 hours a day:

$$\text{ANNUAL RATE} = 15\,\frac{\text{m}}{\text{hr}} \times 10 \text{ FURNACES} \times 24\,\frac{\text{hrs}}{\text{day}} \times 360\,\frac{\text{day}}{\text{yr}} \times 0.93 \text{ PRODUCTIVITY}$$

$$\times\ 76\text{mm width} = 108,000\ \text{m}^2$$

The power and attitude control would be provided by the Space Station. The power requirements of each solar cell processor are shown in Table 7-3.

7.2.6 Solar Cell Plant Size

The solar cell plant size is dependent on annual production requirements. The ratio of the assembly plant floor area to the annual production is about 2/3 m^2/m^2 per year. For example, an annual solar cell production of 37 million m^2 would require 400 facilities assembled together forming a plant plan area of 24,000 m^2. A multifacility is assembled with an interconnecting tunnel to each facility for material retrieval and resupply. Figure 7-42 shows a conceptual solar cell plant assembly connected to a solar cell blanket module. There are seven facilities, each containing ten solar furnaces and solar cell processors. Each solar cell facility has crew access tunnels down each side for material removal, resupply, and equipment maintenance. Each facility is interconnected and attached to the solar cell blanket assembly module through an airlock. The solar cell production facility is designed for unmanned operation, with servicing every 30 days. Thus, a 3.5×10^4 N/m^2 pressure level is assumed. The plant assembly as shown will produce 756,000 m^2 of solar cell ribbon. The sketch in the upper left hand corner of Figure 7-42 shows the relative size of the plant when attached to a typical Space Station (e.g., manned orbital facility).

7.2.7 Solar Cell Blanket Assembly

An expanded view of the solar cell blanket assembly is shown in Figure 7-43. A preassembled substrate is used, composed of 0.4mm of printed etched passivated copper bus deposited on 0.2 mm of FEP and 0.2 mm of Kapton. Perforations in the FEP and Kapton allow welding of the bus to the contacts of the cell. A protective overcover of 0.4mm of FEP is bonded to the cell. Figure 7-43 also shows a cross-section of the solar cell blanket which uses wraparound contacts for connecting the top of the cell to the bottom (N-to-P contacts).

Table 7-3

RIBBON SILICON SOLAR CELL PROCESS FACILITY POWER REQUIREMENTS

Equipment	Qty	Power (Watts)	Duty Cycle (%)	Total Sun	Average Eclipse (Watts)
Ribbon Processor					
Electronics (Control & Monitor)	1	200	C	200	200
Motor and Control	2	50	C	100	100
Radiant Heater	1	3080	38		1170
Die Thermal Control	1	100	C	100	100
Solar Cell Processor					
Dopant Diffusion Chamber	2	50	C	100	100
Contact Deposition Chamber	2	50	C	100	100
AR Coating	2	20	C	40	40
Thermal Control					
Subsystem Louver Cont	6	5	C	30	30
Subsystem Heaters	2	100	10		20
Electrical Power					
Control and Monitor	1	100	C	100	100
Distribution Losses (4%)				31	78
Subtotal				801	2038
Contingency (20%)				160	408
Total Bus Power				961	2446

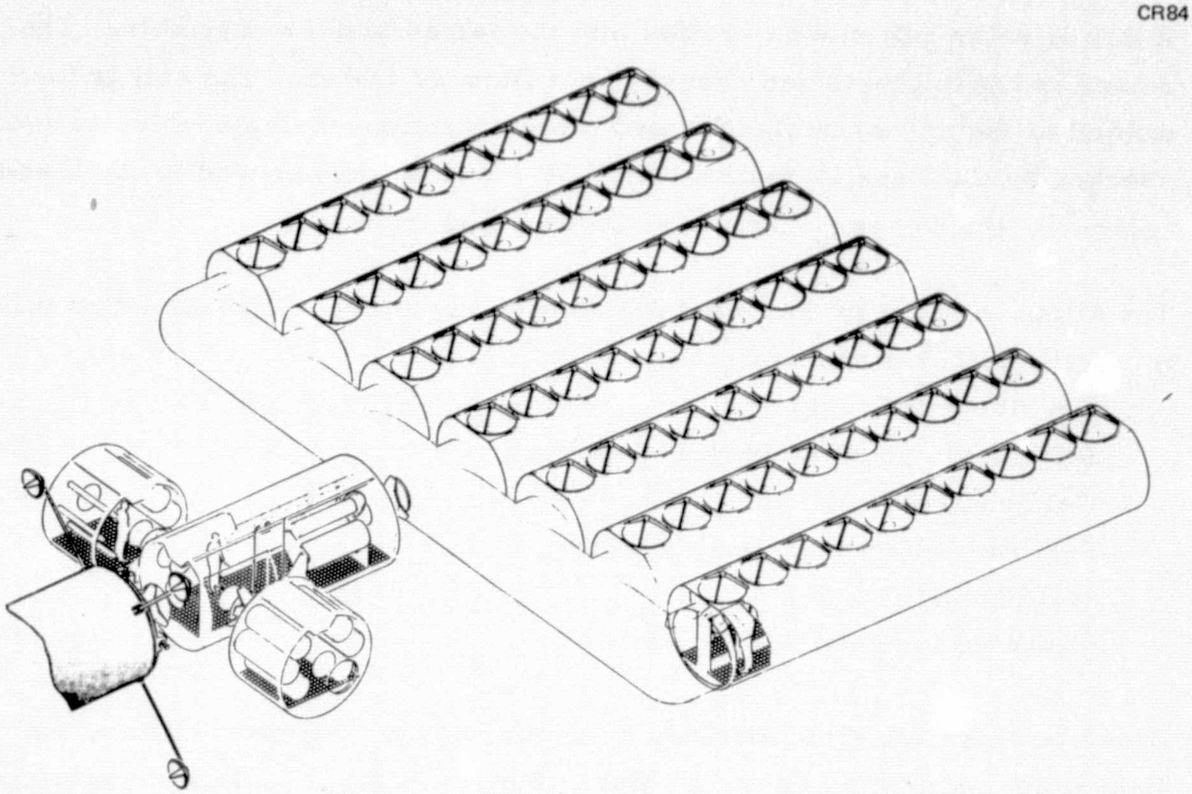


Figure 7-42. Solar Cell Assembly Plant

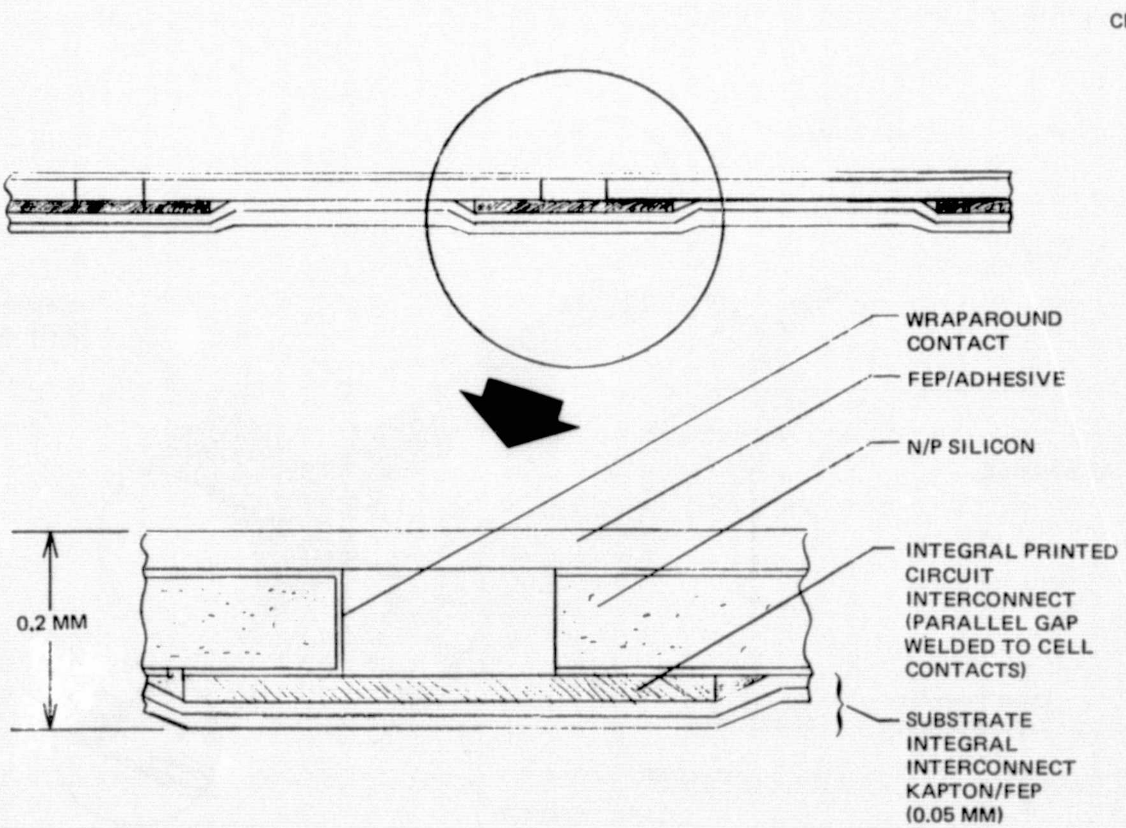


Figure 7-43. Solar Cell Blanket

ORIGINAL PAGE IS OF POOR QUALITY

A sketch of the solar cell blanket assembly scheme is shown in Figure 7-44. Reels of solar cell ribbon are fed into the tester/welder assembly. The ribbon is cut to length and checked by a Dark IV tester. The cell is then welded to the preassembled printed circuit Kapton substrate which is again checked by the Dark IV tester. An FEP cover is then bonded to the blanket before the blanket is rolled up for storage and transport.

The allocated time (in seconds) for blanket assembly was assumed as follows:

Pull out 2.9 meters of ribbon	3
Cut ribbon to length	1
Test 2.9 m section (Dark IV test)	1
Weld contacts each centimeter	2
Test welded section (Dark IV test)	1
Roll blanket	2
Allocated for each 76-mm strip	10 sec

Based on this time allocation and a 24-hour day at 95% productivity, the blanket assembly module can produce 620m per day of 2.9m wide solar cell blanket. This is equivalent to 1,800 m^2 each day, which will yield 650,000 m^2 per year based on a 360-day year.

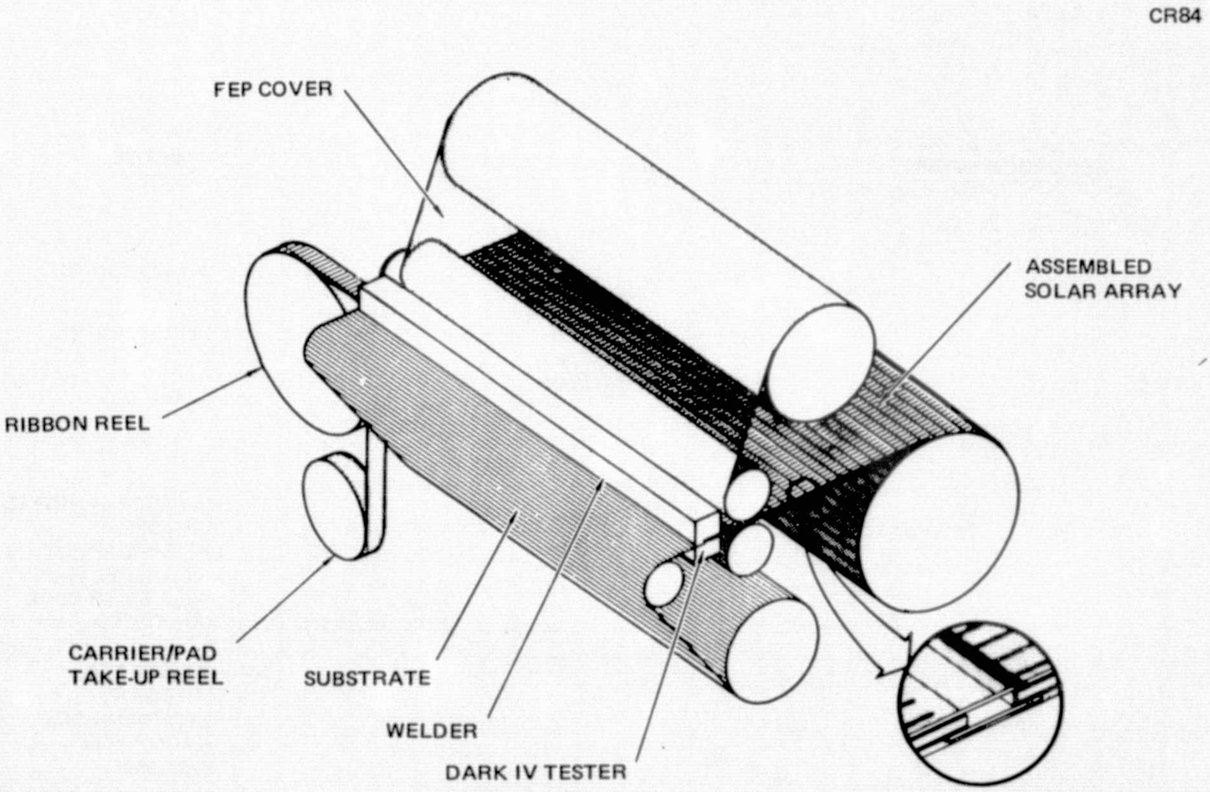


Figure 7-44. Assembly of Silicon-Ribbon Solar Cell Blanket

7.2.8 Blanket Assembly Module

The inboard profile of the blanket assembly module is shown in Figure 7-45. The module is 4m in diameter and 9.6m long. It contains the blanket assembly equipment, control panel, storage provision for ribbon reels, preassembled substrate, and storage for finished blankets. Shirtsleeve environment is provided for two crewmen who monitor the blanket assembly process and reload the blanket assembly equipment. The module operates on 2.2 kW of power and weighs 18,700 kg (including expendables) at launch. Figure 7-46 shows the blanket assembly module attached to the Space Station. On each side of the blanket assembly module is a material module. These modules are used for storage and transport of blanket materials and finished blanket. The configuration in Figure 7-46 shows the blanket assembly module attached to the habitability module (HM) of the Station.

7.2.9 Solar Cell Blanket Installation

Installation of the solar cell blankets for the satellite power station is shown in Figure 7-47. The solar cell blankets are rolled out on the blanket support structure of the SPS. Adjacent edges are attached by an extended blanket joining member. The ends of the blankets are rolled out laterally with the edges connected with the extruded joining member and the bus connection at the ends as shown in the figure.

7.2.10 Research and Development Schedules

The research and development schedule leading to an operational solar cell and blanket production facility by 1985 is shown in Figure 7-48. Sounding rocket and ground experiments will be used through 1980 for perfecting the ribbon shaper, sizing the solar furnace, selecting materials, and developing the process monitor and control. A Shuttle pilot sortie will be flown in 1982 to prove out the process apparatus. A free-flyer pilot plant for solar cell manufacturing will be launched in 1983. A blanket assembly pilot plant sortie will be flown on a Shuttle in 1983. Solar cell and blanket production facilities will be launched in 1985.

7.2.11 Cost and Economic Analysis

An order-of-magnitude cost and economic evaluation is presented to provide some basis for comparison of ground manufacture and launch-to-orbit of solar array blankets versus space on-site manufacture of the cells and

CR84

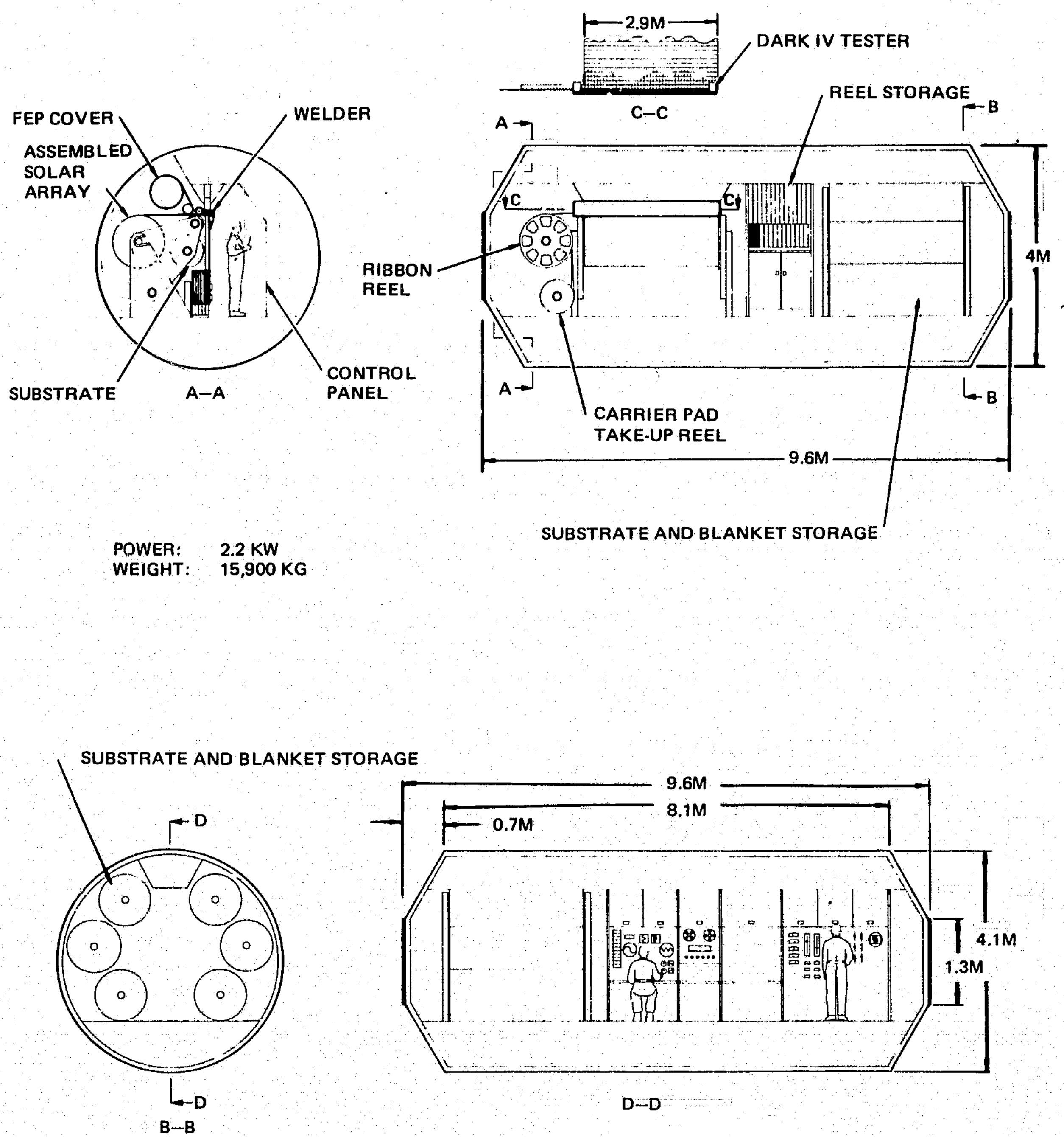


Figure 7-45. Silicon-Ribbon Solar-Cell Blanket Assembly Module

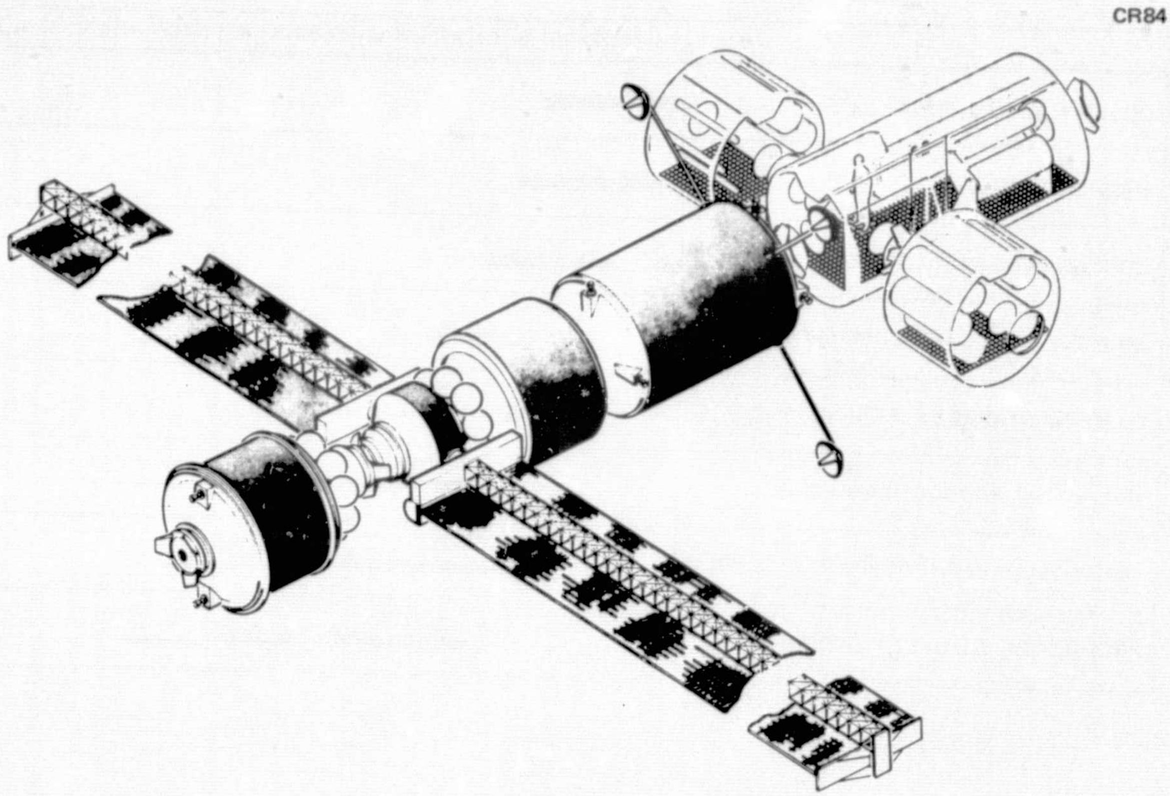


Figure 7-46. Solar Cell Blanket Assembly

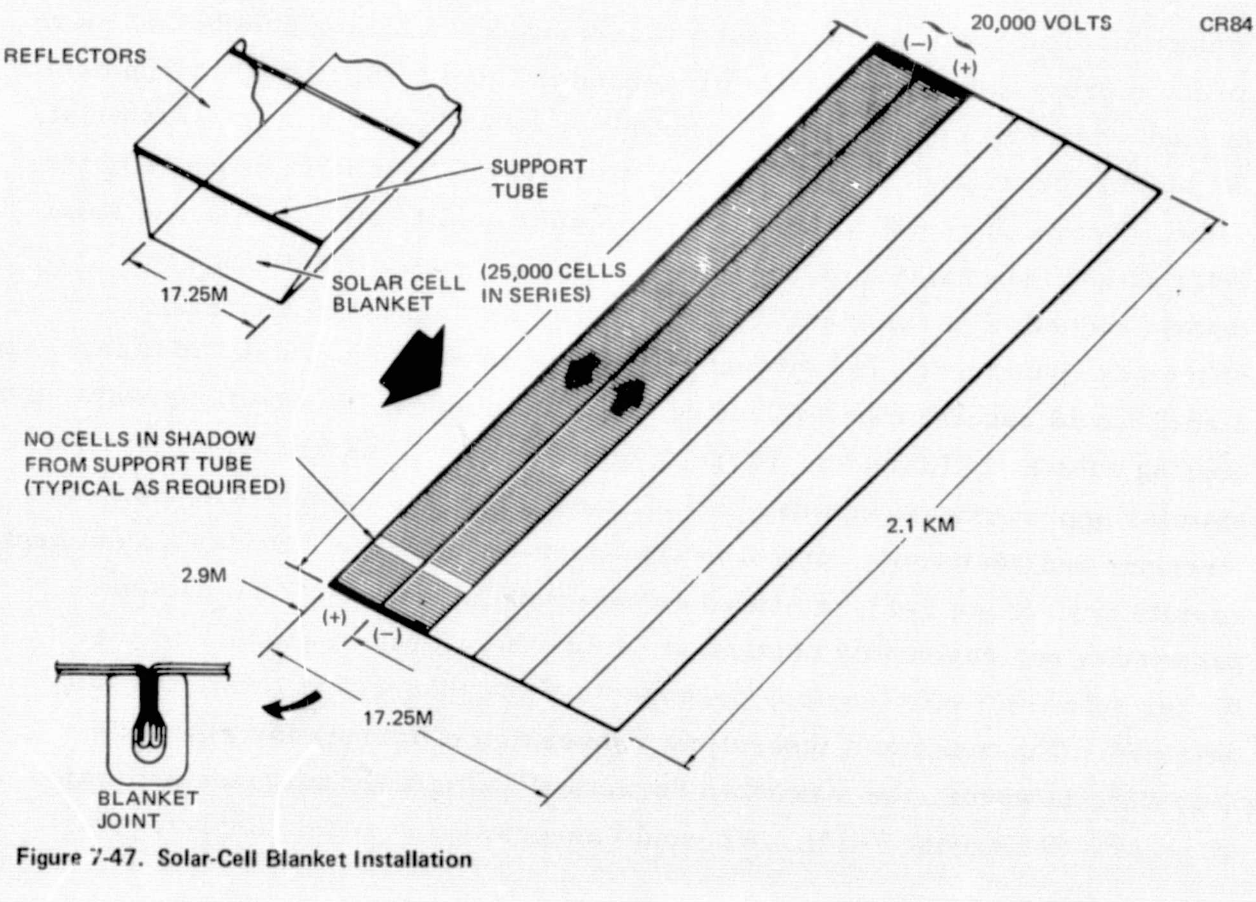


Figure 7-47. Solar-Cell Blanket Installation

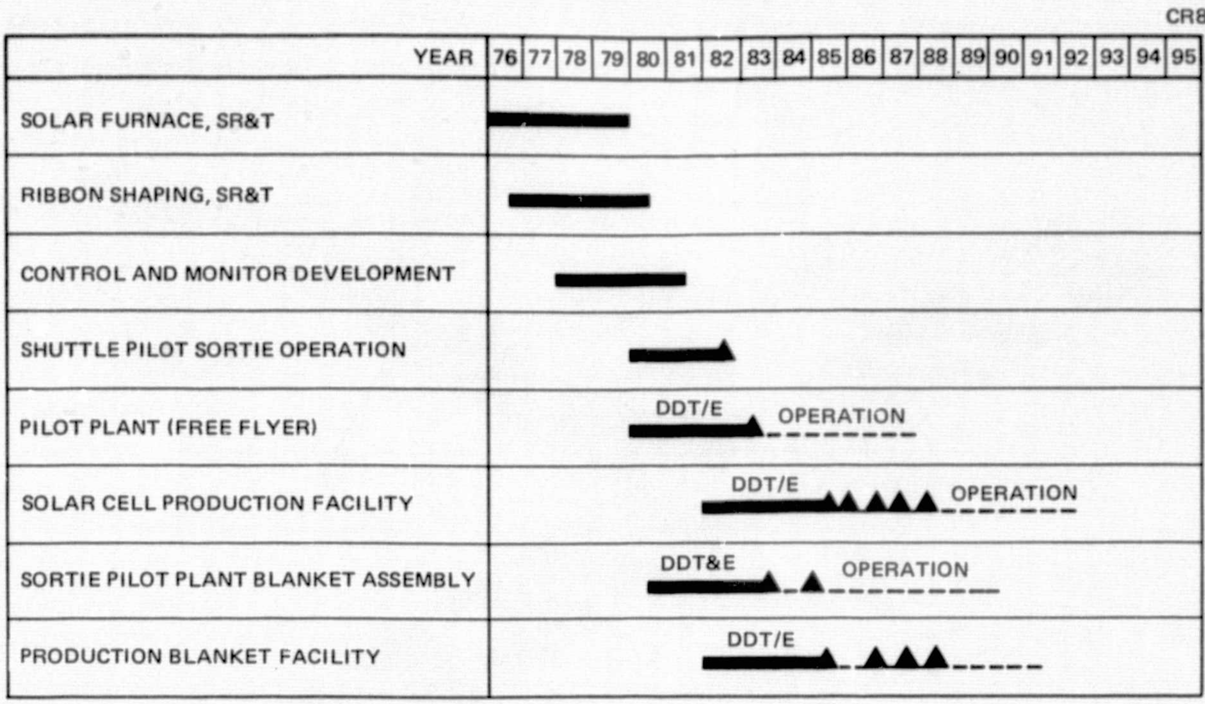


Figure 7-48. Research and Development Schedule

blankets. The rationale for space processing is the higher quality and more uniform properties of materials processed in the microgravity environment. In each case, the cost of launching either finished blankets or raw material for blanket production for similar quantities of solar cells is essentially the same. The savings will come from the higher quality space-produced solar cells rather than earth-produced cells. For example, predictions for mass-production of solar cells on earth are based on a 10% conversion efficiency (References 7-9 through 7-12), and production of cells of higher efficiency would require more selective processing and assembly of blankets, thus costing substantially more. There is an indication (Reference 7-5) that substantial improvements in solar cell efficiency can be obtained with improved junctions and resistivity control of the boron-doped layer. Skylab experimental results (Reference 7-13) indicated substantial improvements in material properties and resistivity control; it could, therefore, be postulated that higher solar cell efficiencies, perhaps near the theoretical limit, can be obtained. The maximum theoretical conversion efficiency for silicon is near 22%; however, the maximum "practical" efficiency has been estimated at 17-20% (Reference 7-14). We would assume then for this analysis that space manufacturing can routinely produce solar cells with a conversion efficiency of 18%. The economic benefit will then come from the reduction in solar cell area required for a given power requirement. This area reduction is a direct ratio of the efficiencies (10%/18%, or 0.56) and will result in lower quantities of material, thus lower launch costs. There will also be a power station construction benefit in lower time, labor, and structure costs; however, that analysis is beyond the scope of this study.

7.2.12 Economic Comparison

A summary of the cost factors for both ground and space construction is shown in Table 7-4. For comparison purposes, the factors are shown as $/kW.

Table 7-4
COST FACTOR SUMMARY

Power kW	Ground ($/kW) Cell	Ground ($/kW) Blanket	Ground ($/kW) Total	Space ($/kW) Cell	Space ($/kW) Blanket	Space ($/kW) Total
100,000	2,470	1,620	4,090	1580	730	2310
1,000,000	2,470	1,620	4,090	1190	466	1656
5,000,000	2,470	1,620	4,090	1116	446	1562

The constant values in the ground costs can be explained by the fact that the material expense (including launch cost) dominates the cell costs, and the blanket assembly costs are at a constant $\$1,140/m^2$. As can be noted, the space manufacturing costs are lower by factors of 2 or more.

An evaluation of the cost factors was also made on the basis of the $0.50/W cost projection made by ERDA for 1985 production of 10%-conversion-efficiency solar array blankets. Table 7-5 shows the cost elements for various power levels at this $0.50/W value. As noted in the table, the cost per kW is still significantly higher for ground-processed solar array blankets than for the space-manufactured blanket even if this $0.50/W value is achieved. It would appear from this rough analysis that there is a significant economic benefit accruing from space manufacture of solar array blankets.

Table 7-5

COST FACTORS - ERDA PROJECTIONS

Power kW	Blanket $M	Transportation $M	Material $M	Total $M	$/kW
100,000	50	206	16	272	2,720
1,000,000	500	2,060	160	2,720	2,720
5,000,000	2,500	9,956	791	13,247	2,649

7.3 REFERENCES FOR SECTION 7

7-1. Feasibility Study of Commercial Space Manufacturing, MDC E1400, 1975. McDonnell Douglas Astronautics Company-East.

7-2. Glaser, Peter E., Solar Power via Satellite, Astronautics & Aeronautics, August 1973.

7-3. Glaser, Peter E., The Satellite Solar Power Station: An Option for Energy Production on Earth, AIAA 1975.

7-4. Silicon Ribbon Growth by a Capillary Action Shaping Technique, IBM Quarterly Tech Progress Report #1, August 1975.

7-5. Haynes, J., Allison, J., Arndt, R. and Menlenberg, A. The Comsat Nonreflective Silicon Solar Cell: A Second Generation Improved Cell, International Conference on Photovolatic Power Generation, Hamburg, Germany, September 25-27, 1974.

7-6. Benning Ralph. The Role of Solar Cell Technology in the Satellite Solar Power Station, Heliotek/Spectrolab Divisions of Textron Inc.

7-7. Cohn, R. E., NASA Objectives for Improved Solar Power Plants, tenth IECEC Record.

7-8. Proceedings of 3rth Space Processing Symposium, Skylab Results, April 30-May 1, 1974, Huntsville, Ala.

7-9. Feasibility of Low Cost Silicon Solar Cells, Dow Corning, Report No. E-538, 17 May 1972.

7-10. Feasibility of Automated Silicon Solar Cells, Spectrolab, NAS 3-18566, October 1975.

7-11. Automated Array Assembly RCA, Contract No. 954352, March 1976.

7-12. Space-Based Solar Power Study, NAS 8-31308, Grumman, August 1975.

7-13. Proceedings of 3rd Space Processing Symposium, MSFC April 30 - May 1, 1974.

7-14. Eleventh IEEE Photovoltaic Conference.