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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

Architectural Options and Selection

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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PREFACE

The McDonnell Douglas Astronautics Company has been engaged in a study for the National Aeronautics and Space Administration to determine Space Station needs, attributes, and architecture. The study, which emphasized mission validation by potential users, and the benefits a Space Station would provide to its users, was divided into the following three tasks:

- Task 1: Mission Requirements
- Task 2: Mission Implementation Concepts
- Task 3: Cost and Programmatics Analysis

In Task 1, missions and potential users were identified; the degree of interest on the part of potential users was ascertained, especially for commercial missions; benefits to users were quantified; and mission requirements were defined.

In Task 2, a range of system and architectural alternatives encompassing the needs of all missions identified in Task 1 were developed. Functions, resources, support, and transportation necessary to accomplish the missions were described.

Task 3 examined the programmatic options and the impact of alternative program strategies on cost, schedule and mission accommodation.

This report, which discusses architectural options and selection, was prepared for the National Aeronautics and Space Administration under contract NASw-3687 as part of the Task 2 activities.

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Section 1
INTRODUCTION AND SUMMARY

This report describes the approach, study results, and our recommendations for defining and selecting space station architectural options. The effort is a subtask of Task 2, Mission Implementation Concepts, of the space station Needs, Attibutes, and Architecture Study. Space Station System architecture, as used in this report, is defined as the arrangement of elements (manned and unmanned on-orbit facilities, shuttle vehicles, orbital transfer vehicles, etc.), the number of these elements, their location (orbital inclination and altitude), and their functional and performance capability (power, volume, crew, etc.).

Architectural options are evaluated based on the degree of mission capture versus cost and required funding rate. Mission capture refers to the number of missions accommodated by the particular architecture.

1.1 SCOPE AND PURPOSE

Space station system architecture is selected by establishing the optimum number, the orbital location, and the implementation date of on-orbit facilities. Figure 1-1 presents the variables involved in the selection process, some of the possible alternative mission scenarios, and the evaluation criteria. Both manned and unmanned facilities are considered because many missions, such as life science and R&D types, require manned assistance, whereas some others, such as stellar viewers, prefer to be isolated from any disturbances caused by man's presence. These facilities can be located at any number of orbital locations that can generally be grouped into a low 28.5-deg inclination, or higher inclinations of 57 deg or 90 deg, or sun-synchronous orbits.

Sequence of placement in orbit was determined to be a primary consideration because the introduction of mission support capability on orbit must coincide with mission needs concerning location, functional capability,

FIGURE 1-1.

MCDONNELL DOUGLAS

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ARCHITECTURE OPTION SELECTION

ARCHITECTURE VARIABLES

- Facilities
  - Manned Space Station
  - Unmanned Platforms
- Locations
  - 28 deg
  - 57 deg
  - Sun Sync
  - 90 deg
- Sequence of Placement in Orbit
- Capabilities
  - Crew Size
  - Pressurized Volume
  - Power
  - External Ports
  - Data Rate
  - Resupply

MISSION SCENARIOS

1 Prioritized Mission Model
2 Science/Applications Emphasis
3 Operations and Technology Emphasis
4 Commercial Emphasis

EVALUATION CRITERION

- Mission Accommodation Versus Cost

and capacity. The study identifies the key capabilities to include crew size, power, data rate, pressurized volume, number of and function for external ports, and resupply requirements.

Although the conceivable number of possible mission scenarios is limitless, several were identified that have particular significance, based on the needs of specific mission categories and priorities. The prioritized mission model treats all mission classes equally, but assigns priorities to individual missions, so the resulting architectures emphasize accommodation of those missions most likely to be implemented. Missions are considered accommodated when they are provided with the support needed to accomplish mission objectives.

1.2 APPROACH

Figure 1-2 shows the time sequence and relationships between the major overall study tasks performed. Task 1, Mission Requirements, defines potential space station system missions, validates them through consultation

FIGURE 1-2.

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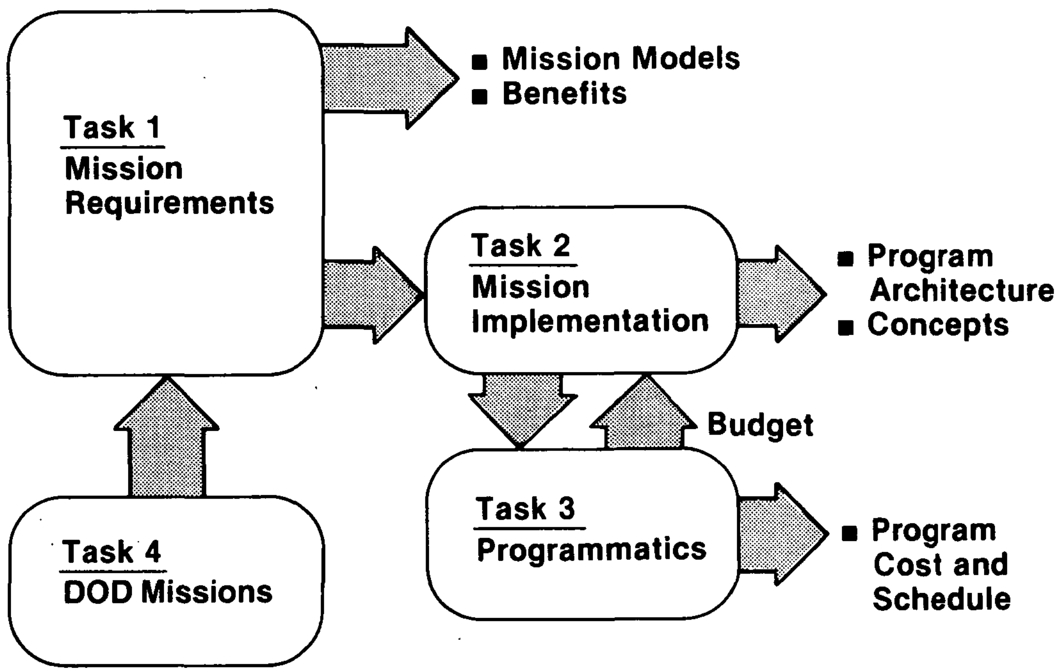
MDAC STUDY APPROACH



with their respective users, calculates the benefits achievable, and prioritizes the requirements to be imposed on the elements of the space station system. Initially, hundreds of potential missions are defined, but these are condensed to a final model of 88 missions. Forty-four separate parameters are identified for each of these missions, and this body of data establishes the functional and capacity requirements for the architectural options. This mission requirements data base is computerized to allow the data to be sorted in various time-phased sets according to needs for inclination, vehicle type (manned/unmanned), and priority group, see Figure 1-3. This computerized data base also allows the resources required of a particular architectural element (facility) to be summed by year.

In Task 2, Mission Implementation Concepts, architectural options are defined that are responsive to mission requirements. Initially, a 100% capture architecture is defined that could satisfy all mission requirements by providing the type and amount of mission resources needed at the various orbital locations in accordance with the mission schedules. This scenario

FIGURE 1-3.
MISSION DATA BASE

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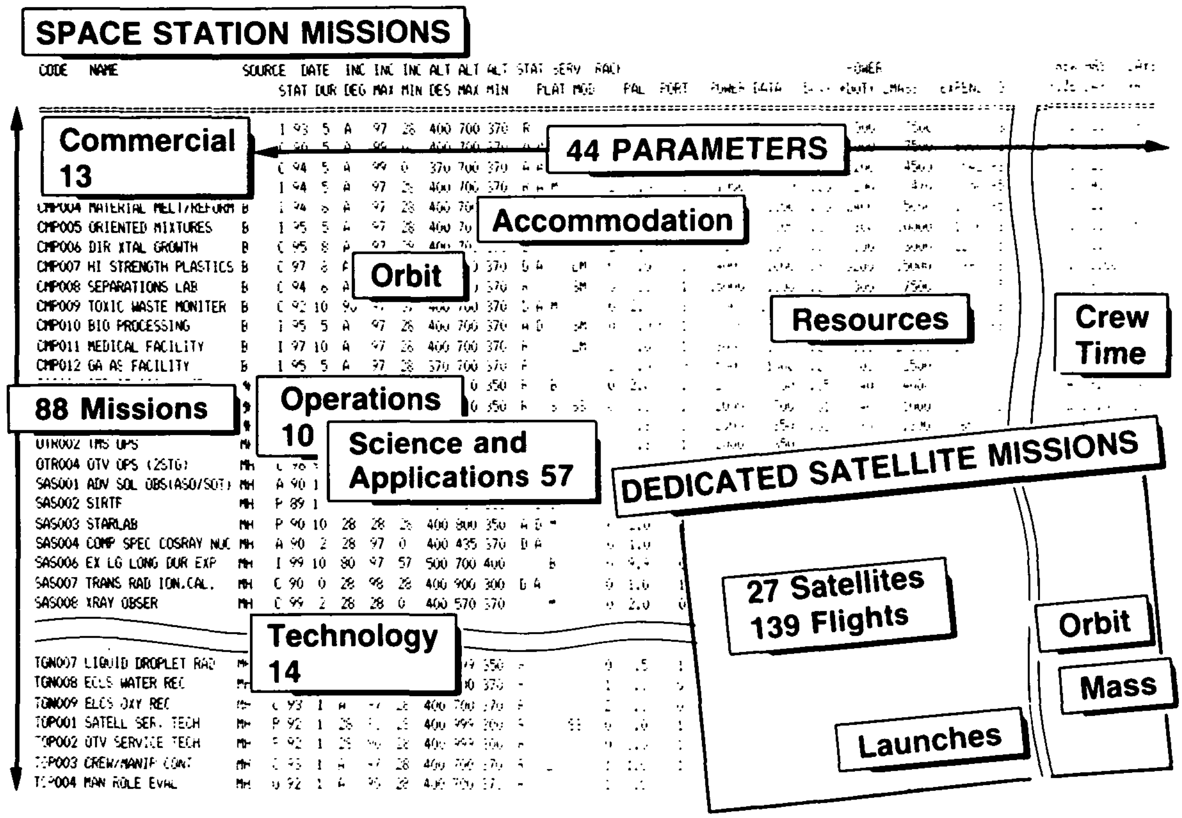

assumes that all the missions identified in the mission list will mature to the hardware phase according to the user's desires as reflected in the mission data base. The impact of the budget constraints is then applied to this very ambitious program to determine affordability.

Assuming the budget will not be available for the most ambitious architectural option, less costly architectures are defined. They consist of single-facility, dual-facility, and mission-emphasis architectures, which intially support only one or two classes of missions. Additionally, an intermittently manned concept is examined to evaluate a low-cost option for a reusable orbital transfer vehicle (ROTV) support facility.

Task 2, proceeds in parallel with Task 3, Programmatics, so that the architectures reflect realistic schedule and funding considerations.

All three tasks are highly computerized (see Figure 1-4), so that the data can be manipulated quickly and with multiple iterations. These computer programs, developed with company funds, are designed with compatible interfaces so that the mission requirements feed directly into the architectural definition program, with this output driving the cost and schedule estimating program.

FIGURE 1-4.

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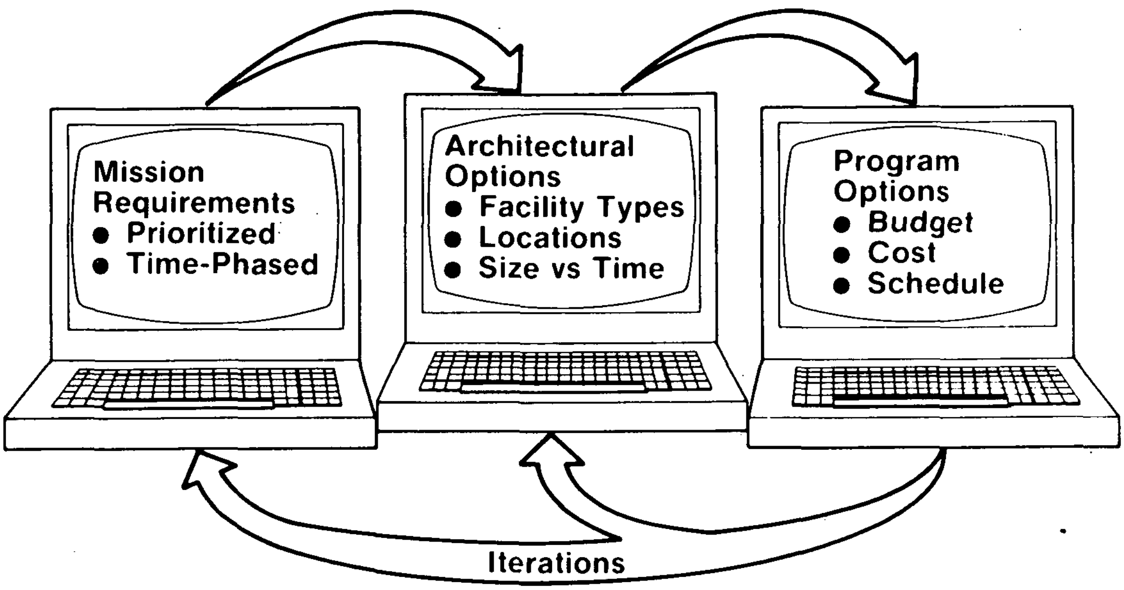
MDAC'S STUDY APPROACH



■ Computerized Analysis Allows
- Quick Response
- Multiple Iterations

Figure 1-5 shows the main features of the architecture analysis program. Input consisting of vehicle data, which establishes the architectural option, includes vehicle type (manned/unmanned), inclination, altitude, resupply period, etc. The type and amount of resources required are also input, including power needs, data transmission rates, weight and volume of mission equipment, etc.

The computer program calculates the major characteristics of the architecture with algorithms and orbiter performance capability relationships contained in the code. These calculations are performed iteratively because there is an interaction between the various elements being calculated. For instance, the size of the electrical power subsystem is affected by the size of the pump (power requirement) in the thermal control subsystem. On the other hand, pump size is related to total electrical power (cooling needs).

FIGURE 1-5.

SIMPLIFIED LOGIC DIAGRAM FOR ARCHITECTURE ANALYSIS PROGRAM

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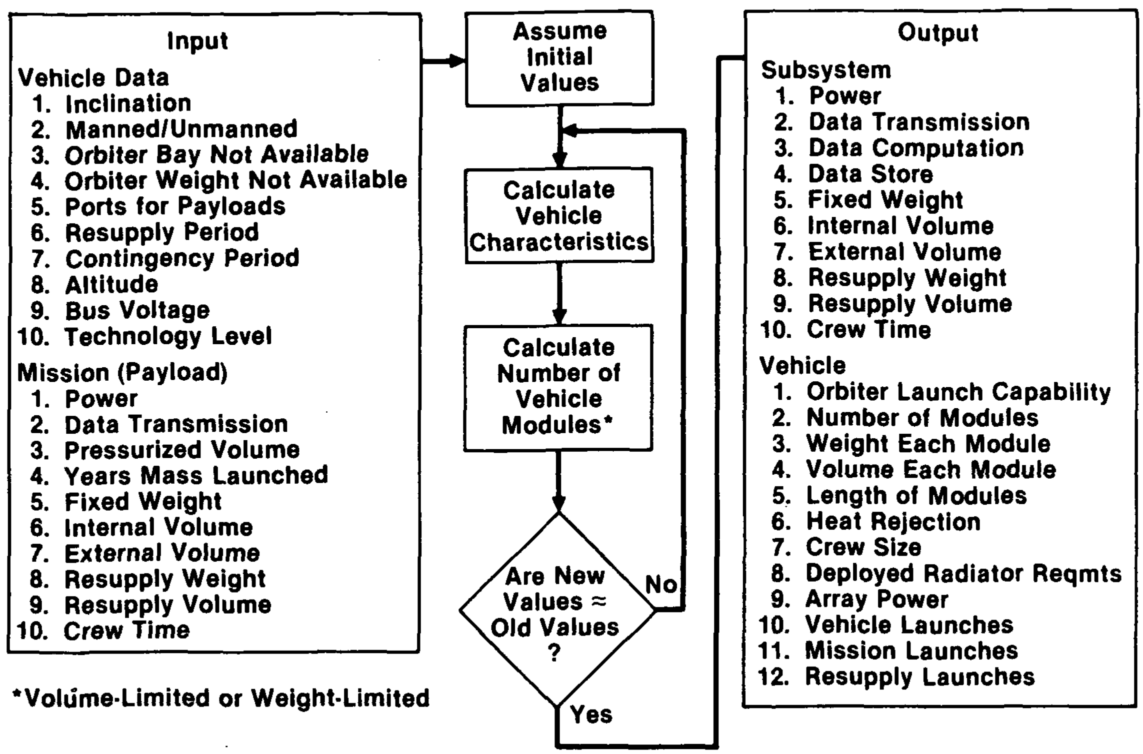

Characteristics are determined at the subsystem level in terms of power, data transmission, storage and computation, fixed weight, resupply needs, etc., (see Figure 1-6). Equipment and crew volume requirements are also calculated, and the total pressurized volume needed is determined. The size and number of modules required are then established based on orbiter launch-weight limits or available payload bay volume (whichever is the controlling factor).

Other key characteristics determined consist of crew size, housekeeping needs, total array power, heat rejection from integral and deployable radiators, and number of required launches for the station, mission equipment, and resupply.

FIGURE 1-6.
ARCHITECTURE ANALYSIS

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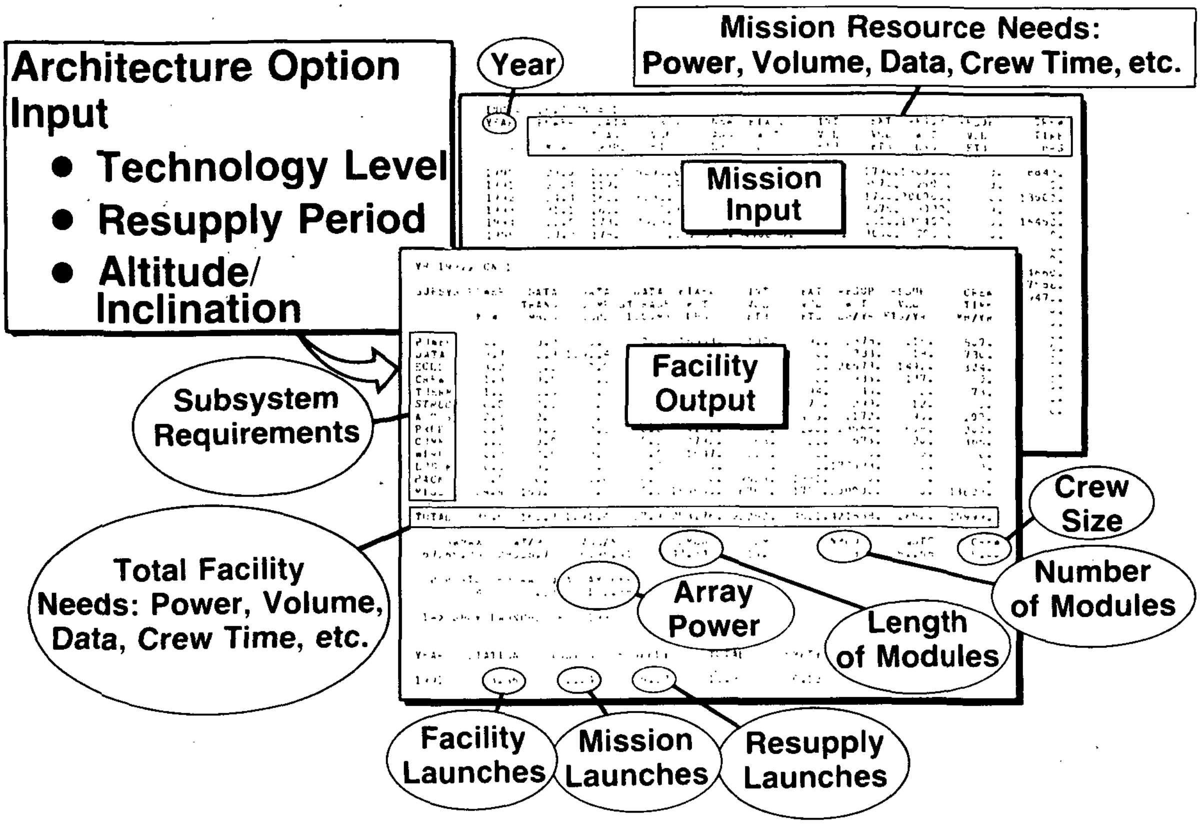

1.3 OVERVIEW OF RESULTS

As a first step, a 100% capture architecture is defined that provides near-optimum accommodation of the entire set of 88 missions. This architecture provides the majority of the missions with ideal accommodations in terms of orbit location, manned or unmanned facility, and resources available, such as power and data rates. Accommodation of some missions is slightly compromised by providing "second choices" regarding orbit location or facility type (manned or unmanned). This architecture, consisting of two space stations and two platforms, is more expensive than the other architectures considered and is not highly cost effective because it captures only a few additional missions at the cost of additional facilities.

Several single- and dual-facility architectures are developed as a less ambitious solution. Results show that a single space station at 28.5 deg can satisfy 61% of the mission list with 100% accommodation of mission needs, and 73% of the mission list if 75 to 100% accommodation is acceptable. A dual-facility architecture with a space station at 57 deg and a platform at 28.5 deg increases mission capture to 89%. This architecture, however, has the drawback of not providing manned facility support for the ROTV at low inclination. A concept that provides intermittently manned ROTV support on the 28.5-deg platform is relatively low in cost and simple because manned attendance is provided from a berthed orbiter, thereby eliminating the cost of manned capability on the platform. This concept is shown in Figure 1-7. The crew in the orbiter will support the payload to ROTV mating, checkout, propellant loading, and launch. Because time lines for the ROTV mission will probably preclude crew involvement in the returning ROTV rendezvous and berthing operation, automatic ROTV docking will be required early in the program.

FIGURE 1-7.

ROTV SERVICE STATION CONCEPT

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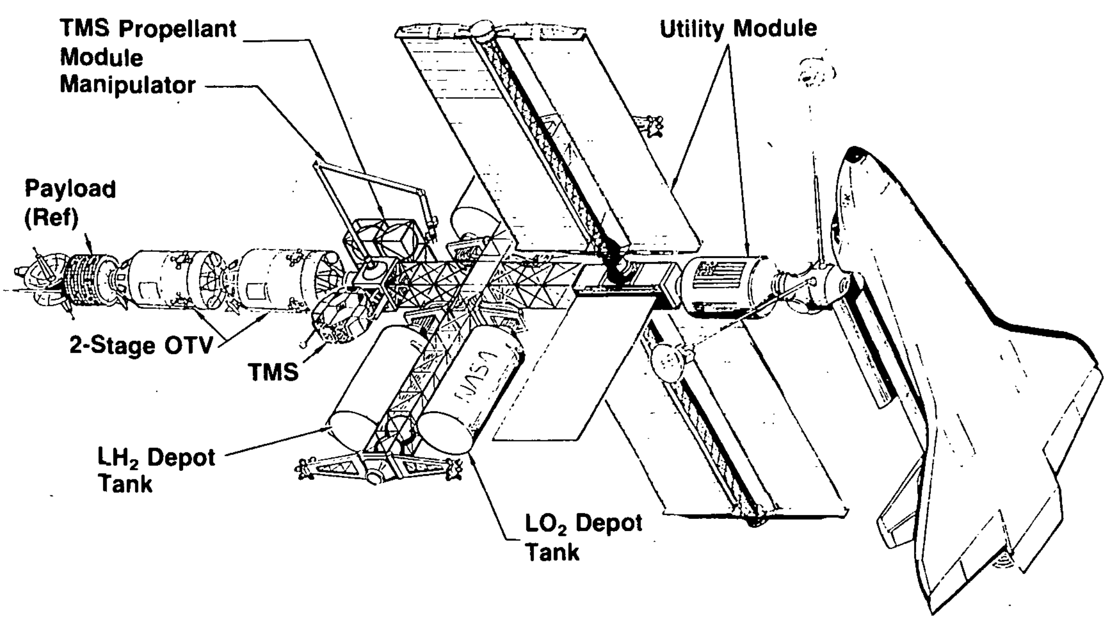
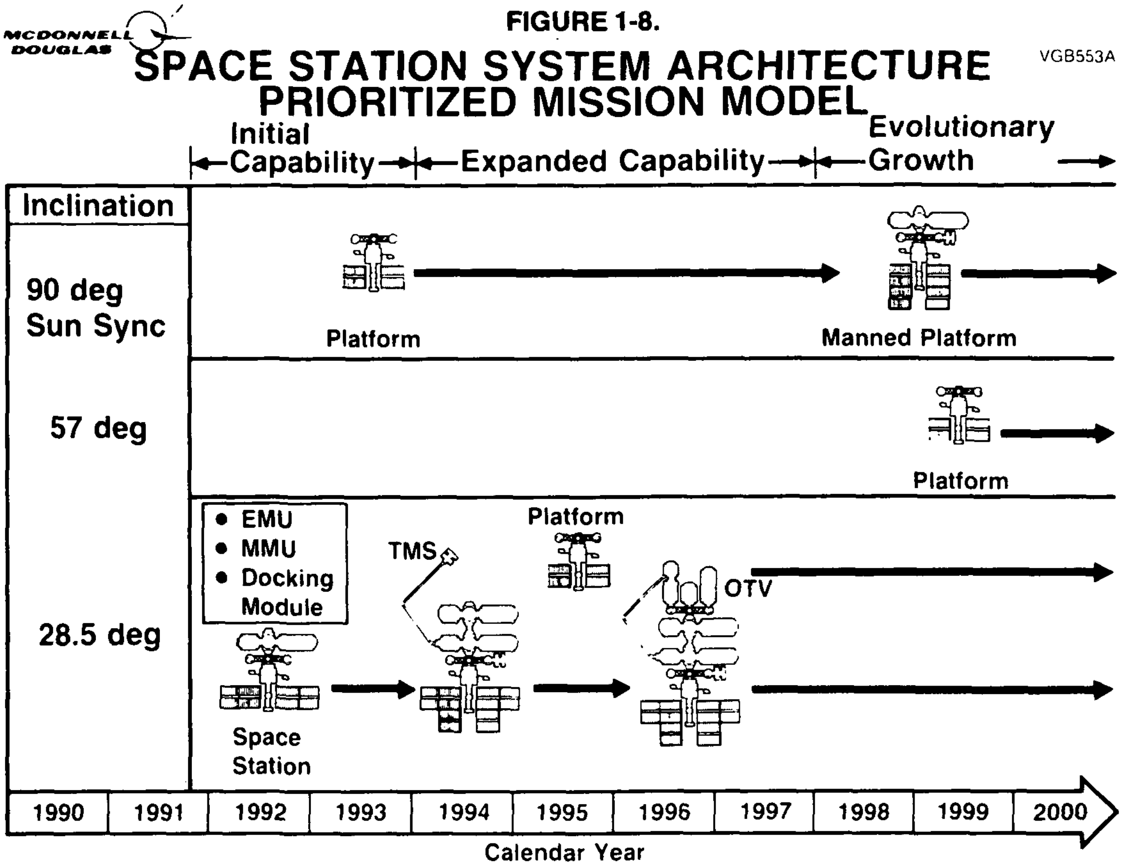


Budget-Constrained Architecture

Based on lessons learned with the architectural options discussed above, a budget-constrained option is defined that fully uses the cost-savings potential of a modular approach. This option, which provides on-orbit type, quantity, and location of mission-dedicated resources that nearly match requirements, is shown in Figure 1-8.

This architecture can provide nearly all the resources in the orbit locations desired except for a small deficit in power and pressurized volume in the early 1990s. Also, some commercial production missions are not accommodated during the 1994-to-1997 time frame because these missions are

FIGURE 1-8.



expected to be allocated to separately funded, commercially dedicated facilities. This budget-constrained architecture initially consists of a four-man space station at 28.5 deg and a platform in sun-synchronous orbit. In 1994, the station will be expanded to an eight-man capability, with TMS support. ROTV support will be added in 1996. Also, a second platform will be added at a 28.5-deg inclination in 1995.

Based on the projections of the identified mission list, a likely evolutionary growth path will add manned capability to the platform at sun-synchronous orbit and another platform at the 57-deg location. This growth is projected for the 1980-to-2000 time period.

Modular growth is considered essential for providing adequate on-orbit mission support in an affordable manner. The budget-constrained architecture is defined based on use of modular elements, chosen in size to minimize cost while meeting the incremental performance needs at the various orbital locations.

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Section 2
MISSION REQUIREMENTS SUMMARY

Key mission requirements can be expressed in terms of (1) the preferred type of space facility, i.e., manned or unmanned, (2) orbit location with regard to inclination and altitude, and (3) type and amount of resources needed, such as power, crew support, and data rates. Some mission requirements are nonspecific and can be met with a range of accommodations; for example, a material processing payload may accept any orbital inclination. On the other hand, many mission requirements are specific, such as a processing payload requiring a certain amount of electrical power.

The most probable list of mission types, schedule, and needed accommodations that a space station program should provide in the 1990s is shown in Table 2-1. Although many of these missions may be accommodated by alternative modes, such as the orbital or free-flying dedicated satellites, this list is representative of resources that should be provided by the space station system. This list of 88 missions is separated into four priority groups established to identify the missions most likely to become important missions for a space station system to accommodate. A priority of 1 is most important, a priority of 4 is the least important.

This range of acceptable accommodations is demonstrated in Figure 2-1, which gives inclination and facility type for the entire 88-mission list. The figure shows the number of missions accommodated by manned and unmanned facilities at low and high inclinations. Also indicated are the missions having nonspecific needs that can be accommodated in more than one way. For instance, there are 24 missions that must fly on a space station at low inclination. Additionally, 25 other missions can be added to this facility because they require a space station and have no specific inclination needs. There are other missions that can be accommodated on either a platform or space station at a low inclination: and still others that can accept any inclination. Both of these types of missions also can be accommodated by a

Table 2-1. Space Station Data Base (Page 1 of 2)

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Apr 27, 1983

STATUS
0=operational
P=planned
C=candidate
I=opportunity

ACCOMMODATION
R=required
D=desired
A=acceptable

S=supply
L=launch
M=maint/repair
B=assemb/build

VIEW
A=any
E=earth
I=inertial

M=multiple
S=solar
V=velocity
Z=anti earth

LEGACY
S=spacelab
0=other legacy

CODE	NAME	SOURCE	STAT	DATE	DUR	INC DEG	INC MAX	INC MIN	ALT DES	ALT MAX	ALT MIN	STAT PLAT SERV	MOD	RACK	PAL	PORT	POWER	DATA	POWER DUTY	#DUTY	LMASS	EXPEND	G	CODE	VIEW	CREW SIZE	HRS DAY	DAYS YR	BEN	SAVE CONS	SAVE RISK	BEN# CONS	SAV# RISK	PRIORTY	LEGACY
CIR001	MATERIALS RES FAC	MH	I	93	5	A	97	28	400	700	370	R	SM	0	.0	1	25000	10000	.20	5000	7500	10	-3	CIR001	A	2	2.00	60	23	7 21	27	161	567	2.00	
CMP001	ELECTROPHORETIC PRO	MS	C	90	5	A	99	0	400	700	370	A A M	SM	0	.0	1	15000	1000	.80	12000	7500	6000	-3	CMP001	A	1	2.00	50	29	9 21	30	261	630	1.00	0
CMP002	SILICON RIBBON MAN	MS	C	94	5	A	99	0	370	700	370	A A	SM	0	.0	1	15000	1000	.80	12000	4500	542	-3	CMP002	A	1	2.00	50	22	7 22	22	154	484	4.00	
CMP003	ELECTRONIC CIR ELEM	MH	I	94	5	A	97	28	400	700	370	R A M		2	.0	0	1000	10	.20	200	470	50	-5	CMP003	A	1	4.00	70	19	6 24	22	114	528	3.00	
CMP004	MATERIAL MELT/REFORM	B	I	94	8	A	97	28	400	700	370	R	SM	0	.0	1	12000	1000	.20	2400	5000	1000	-5	CMP004	A	1	2.00	260	22	7 20	23	154	460	4.00	
CMP005	ORIENTED MIXTURES	B	I	95	5	A	97	28	400	700	370	D A	SM	0	.0	1	1500	1000	.20	300	10000	1100	-3	CMP005	A	1	1.00	50	22	7 22	22	154	484	4.00	
CMP006	DIR XTAL GROWTH	B	C	95	8	A	97	28	400	700	370	D A		2	.0	0	500	1000	.20	100	3000	2200	-5	CMP006	A	1	1.00	260	21	7 24	22	147	528	3.00	
CMP007	HI STRENGTH PLASTICS	B	C	97	8	A	97	28	400	700	370	D A	LM	0	.0	1	4000	1000	.80	3200	15000	9999	-3	CMP007	A	1	1.00	260	22	7 22	23	154	506	4.00	
CMP008	SEPARATIONS LAB	B	C	94	6	A	97	28	400	700	370	R	SM	0	.0	1	15000	1000	.20	3000	7500	3000	-5	CMP008	A	1	8.00	200	23	8 18	25	184	450	4.00	
CMP009	TOXIC WASTE MONITOR	B	C	92	10	90	97	57	400	700	370	D A M		0	2.0	1	1000	12000	.30	300	1500	0	-3	CMP009	E	1	1.00	365	21	7 29	25	147	725	1.00	
CMP010	BIO PROCESSING	B	I	95	5	A	97	28	400	700	370	A D	SM	0	.0	1	15000	1000	1.00	0	30000	500	-3	CMP010	A	1	.10	365	20	7 24	23	140	552	3.00	
CMP011	MEDICAL FACILITY	B	I	97	10	A	97	28	400	700	370	R	LM	0	.0	1	3000	5000	.20	600	20000	5000	-2	CMP011	A	3	8.00	365	19	6 18	21	114	378	4.00	
CMP012	GA AS FACILITY	B	I	95	5	A	97	28	370	700	370	R		2	.0	0	5000	1000	.20	1000	2500	0	-3	CMP012	A	2	4.00	50	20	6 22	23	120	506	4.00	
OAI001	STRUCT ASSY & TEST	MH	C	95	99	28	28	28	400	700	350	R B		0	2.0	1	2000	700	.05	100	4000	0	0	OAI001	E	4	8.00	60	23	5 19	22	115	418	3.00	
OSR001	SAT SERV OPS	MH	P	92	99	28	28	28	400	700	350	R S	SS	0	.1	1	2000	700	.01	20	1000	0	0	OSR001	A	2	10.00	10	21	6 23	24	126	552	1.00	
OTR001	TMS OPS	MH	P	92	99	28	28	28	400	700	350	R L		0	.3	1	2000	350	.02	40	1300	650	0	OTR001	A	2	10.00	30	20	6 24	24	120	576	1.00	
OTR004	OTV OPS (2STG)	MH	C	96	99	28	28	28	400	700	350	R L		0	.3	1	3000	500	.07	210	1400	13000	0	OTR004	A	3	10.00	60	22	5 22	20	110	440	2.00	
SAS001	ADV SOL OBS(ASO/SOT)	MH	A	90	10	97	97	28	400	600	350	D A S		0	3.0	1	5000	2500	1.00	5000	12500	0	0	SAS001	S	2	1.50	365	24	6 24	26	144	624	1.00	S
SAS002	SIRTF	MH	P	89	10	57	57	0	400	430	350	A D S		0	3.0	1	1300	1000	.50	650	8103	12	0	SAS002	I	2	8.00	3	23	5 25	24	115	600	2.00	S
SAS003	STARLAB	MH	P	90	10	28	28	28	400	800	350	A D M		0	2.0	1	2220	7000	.80	1776	3280	0	0	SAS003	I	2	.57	180	23	5 24	24	115	576	2.00	S
SAS004	COMP SPEC COSRAY NUC	MH	A	90	2	28	97	0	400	435	370	D A		0	1.0	1	731	102	.98	716	3082	30	0	SAS004	Z	1	1.02	365	20	5 29	25	100	725	2.00	S
SAS006	EX LG LONG DUR EXP	MH	I	99	10	57	97	28	500	700	400	B		0	9.9	0	1	1	.00	0	99999	0	0	SAS006	A	2	11.00	1	21	3 28	21	63	588	4.00	
SAS007	TRANS RAD ION.CAL.	MH	C	90	2	28	98	28	400	900	300	D A		0	1.0	1	60	2	.98	59	2000	0	0	SAS007	Z	1	1.02	365	19	3 30	21	57	630	3.00	S
SAS008	XRAY OBSER	MH	C	99	2	28	28	0	400	570	370	A A M		0	2.0	0	900	1000	.00	0	3550	0	0	SAS008	I	2	9.00	2	20	4 28	22	80	616	3.00	
SAS009	SPACE TELESC	MH	A	85	15	28	28	28	600	600	600	M	SS	0	4.0	0	2100	0	.00	0	11070	0	0	SAS009	I	2	8.00	2	24	6 24	28	144	672	1.00	
SAS010	HIRES X&G-RAY SPEC	MH	C	90	2	28	45	0	400	500	350	D A M		0	.5	1	530	35	.80	424	1668	10	0	SAS010	I	2	7.00	1	20	3 28	21	60	588	4.00	S
SAS011	XRAY TIMING EXPL	MH	A	89	5	28	45	0	400	600	300	A A M		0	2.0	1	600	1000	.80	480	1000	0	0	SAS011	I	2	2.00	1	19	5 30	23	95	690	1.00	0
SAS012	SOLAR INT DYNAMICS	MH	C	91	5	98	98	57	575	575	300	A A M		0	3.0	1	800	0	.99	792	2600	0	0	SAS012	S	2	3.00	1	19	4 27	23	76	621	3.00	0
SAS013	ADV XRAY ASTROFAC	MH	P	91	15	28	28	0	500	600	400	M		0	5.0	0	2000	0	.00	0	11000	0	0	SAS013	I	2	13.00	1	23	5 25	22	115	550	1.00	
SAS014	LAMAR(HTM)	MH	C	92	10	28	28	0	400	435	200	A A S		0	4.0	1	3400	130	.80	2720	9516	18	0	SAS014	I	2	13.00	1	22	4 24	21	88	504	3.00	S
SAS015	VLBI	MH	C	89	10	57	98	45	400	600	350	A A B		0	2.0	1	900	12000	.50	450	1354	0	0	SAS015	I	2	3.00	1	19	5 28	23	95	644	2.00	S
SAS016	LRG DELP REFL	MH	C	95	10	57	57	28	700	800	400	M		0	10.0	0	3000	0	.00	0	20500	0	0	SAS016	I	2	13.00	1	22	4 25	21	88	525	3.00	
SAS017	GAMMA RAY OBS	MH	A	88	5	28	28	28	400	400	400	M		0	5.0	0	2000	0	.00	0	11000	0	0	SAS017	I	2	13.00	1	21	6 24	24	126	576	2.00	
SAS018	HIGH ENER ISO EXP	MH	P	90	2	57	98	57	400	900	300	D A		0	1.0	1	250	100	.98	245	2000	0	0	SAS018	Z	1	1.02	365	18	3 28	21	54	588	3.00	S
SAS019	SOLAR COR DYN	MH	P	93	2	A	97	28	400	900	300	A A M		0	3.0	1	1000	0	.50	500	3500	0	0	SAS019	S	2	3.00	1	18	4 30	21	72	630	3.00	0
SAS020	COSMIC RAY OBS	MH	C	98	5	57	97	57	400	400	400	D A S		0	5.0	1	2000	1000	.98	1960	18000	0	0	SAS020	Z	1	1.02	365	22	4 26	22	88	572	2.00	
SCM001	REMOTE SENSING RFI	MH	I	92	10	90	97	57	400	700	400	A D A		0	2.0	1	120	5	.05	6	2500	0	0	SCM001	M	2	3.00	1	18	4 28	21	72	588	4.00	
SCM002	ORB STANDARDS PACK	MH	I	90	10	57	97	57	400	700	350	D A A		0	.5	1	150	100	.05	8	100	0	0	SCM002	M	2	2.00	1	17	5 32	23	85	736	2.00	0
SCM003	COMM RESEARCH FAC	MH	I	92	15	57	97	57	400	999	300	R	SM	0	.0	1	5000	120000	.05	250	5000	0	0	SCM003	M	3	1.93	100	18	4 23	20	72	460	4.00	
SEE001	OCEAN PAYLOAD	MH	P	88	10	98	98	57	400	700	250	D A		0	3.0	1	1000	120000	.20	200	10000	0	0	SEE001	E	3	.85	365	28	7 23	24	196	552	2.00	0
SEE002	ATMOS COMP	MH	P	90	3	90	98	57	600	780	400	D A		0	2.0	1	4000	500	.01	40	2500	0	0	SEE002	M	2	11.00	4	21	5 25	21	105	525	3.00	
SEE003	UPPER ATMOS RES	MH	P	88	6	57	97	28	400	400	400	A A M		0	2.0	1	1339	18	.03	0	2367	0	0	SEE003	M	2	10.00	2	20	5 25	23	100	575	2.00	
SEE004	SPACE PLASMA PHYSICS	MH	P	88	5	90	97	57	400	500	250	A D		0	1.0	1	2665	7510	.10	267	3183	0	0	SEE004	M	2	10.00	2	20	4 25	22	80	550	2.00	S
SEE005	ZERO G CLOUD PHYSICS	MH	P	92	5	A	97	0	400	600	350	R		3	.0	0	1360	500	.02	27	474	10	-5	SEE005	A	2	4.25	50	26	5 28	23	130	644	3.00	S
TOTALS ARE=																	166426	312763			374016														
NUMBER OF MISSIONS=	44																																		

Table 2-1. Space Station Data Base (Page 2 of 2)

MCDONNELL DOUGLAS ASTRONAUTICS HUNTINGTON BEACH
Apr 27, 1983

STATUS
O=operational
P=planned
C=candidate
I=opportunity

ACCOMMODATION
R=required S=supply
D=desired L=launch
A=acceptable M=maint/repair
B=assemb/build

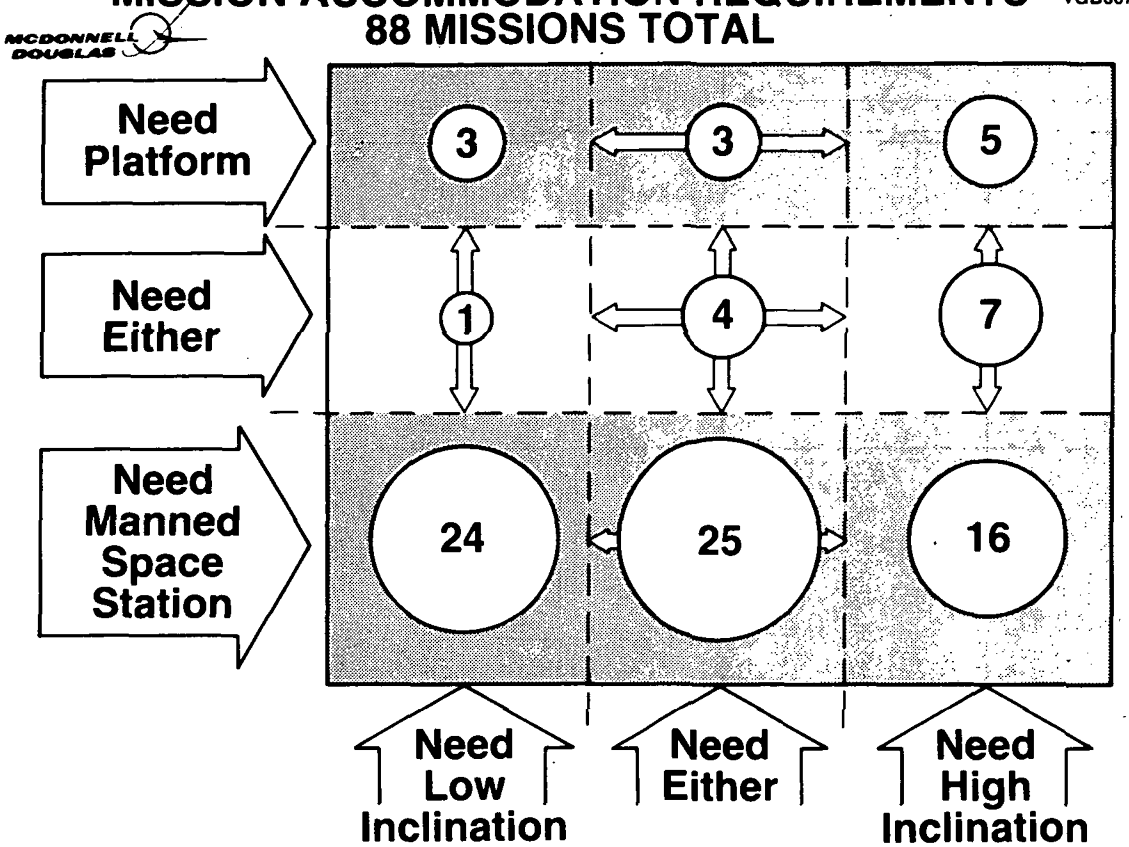
VIEW
A=any M=multiple
E=earth S=solar
I=inertial V=velocity
Z=anti earth

LEGACY
S=spacelab
O=other legacy

CODE	NAME	SOURCE	STAT	DATE	DUR	INC DEG	INC MAX	INC MIN	ALT DES	ALT MAX	ALT MIN	STAT	SERV	PLAT	RACK MOD	PAL	PORT	POWER	DATA	DUTY	POWER *DUTY	LMASS	EXPEND	G	CODE	VIEW	CREW SIZE	HRS DAY	DAYS YR	BEN	SAVE CONS	SAVE RISK	BEN* CONS	SAV* RISK	PRIORTY	LEGACY
SEE006	MET. RES. PKG	MH	P	92	10	57	97	57	500	800	400	R				0	1.0	1	1200	14	.20	240	1500	0	0	SEE006	E	3	.85	365	24	5	25	20	120	500	3.00
SEE007	ATM DYNAMICS&RAD	MH	C	93	5	90	97	57	400	600	350	D	A	M		0	2.0	1	5000	2500	.10	500	2300	0	0	SEE007	M	2	13.00	1	25	5	25	22	125	550	2.00	S
SEE008	OP CIVIL MET	MN	O	88	10	98	98	98	833	870	830	A	A	M		0	1.0	1	415	2700	.99	411	700	0	0	SEE008	E	2	5.00	2	22	5	26	24	110	624	2.00	O
SEP001	SAR	MH	P	84	10	90	97	57	400	700	250	A	A	M		0	1.0	1	6486	120000	.20	1297	1876	0	0	SEP001	E	1	.51	360	26	6	25	25	156	625	1.00	O
SEP002	MULTISPECT LIN ARRAY	MH	P	89	5	98	98	57	705	705	400	D	A	S		0	.5	1	500	250000	.20	100	315	0	0	SEP002	E	1	.51	360	24	5	29	23	120	667	1.00	
SEP003	MAG FIELD MAPPER	MH	P	89	5	97	97	57	300	400	300		A	L		0	.5	1	120	230	.99	119	890	0	0	SEP003	E	2	13.00	1	17	3	30	24	51	720	4.00	
SEP004	PASS MICROWAVE RAD	MH	P	92	2	90	99	45	465	900	300	A	D			0	2.0	1	1200	200	.20	240	475	0	0	SEP004	E	2	3.00	1	22	5	29	22	110	638	1.00	
SEP005	LARGE FORMAT CAMERA	MH	P	90	5	90	97	57	250	500	180	R				0	.2	0	1	1	.20	0	70	0	0	SEP005	E	1	1.00	13	24	6	30	26	144	780	1.00	S
SEP006	IMAGE SPECTROMETER	MH	C	95	10	97	97	50	400	700	250	A	D	M		0	1.0	1	500	100000	.20	100	1938	0	0	SEP006	E	1	1.02	180	20	5	29	22	100	638	2.00	S
SEP007	LUMINESCENCE DET	MH	C	94	2	98	98	57	400	800	200	A	A			0	.1	0	150	2500	.20	30	60	0	0	SEP007	E	1	1.02	180	18	4	32	20	72	640	3.00	
SEP008	LASER RANGING	MH	P	89	15	90	97	57	400	600	300	D	A			0	.1	0	500	10	.20	100	185	0	0	SEP008	E	2	2.00	1	17	4	33	24	68	792	3.00	O
SEP009	LANDSAT D-D'	MH	O	82	15	98	98	98	705	705	705	A	A	M	SS	0	.0	1	750	0	.00	0	1600	0	0	SEP009	E	2	9.00	1	21	6	27	24	126	648	1.00	O
SEP010	RADAR ALT	MH	C	92	10	90	98	57	400	800	350	D	A	M		0	.2	0	100	2500	.20	20	100	0	0	SEP010	E	2	3.00	1	20	4	30	23	80	690	1.00	O
SEP011	ACT FLUOR SPECT	MH	C	95	10	90	98	57	400	500	250	D	A	M		0	1.0	1	2000	40000	.20	400	1900	0	0	SEP011	E	1	1.02	180	17	3	27	19	51	513	4.00	
SEP012	PLAN SPECT TELE	MN	I	90	10	A	98	28	400	999	250	D	A	M		0	2.0	1	3000	50000	.80	2400	3000	0	0	SEP012	I	2	.58	40	21	4	25	21	84	525	3.00	S
SEP013	IR SPECT	MN	I	91	10	A	98	28	400	999	250	D	A	S		0	2.0	1	3000	50000	.80	2400	8100	0	0	SEP013	I	2	.67	40	20	4	27	21	80	567	3.00	
SEP014	FAR IR SPECT	MH	I	95	10	28	57	28	700	999	400		A	M		0	10.0	1	3000	50000	.80	2400	20000	0	0	SEP014	I	2	.58	40	20	4	25	20	80	500	4.00	
SEP015	EXTRA SS DET	MH	I	92	20	28	28	28	500	600	400	D	A	M		0	2.0	1	3000	100	.80	2400	3000	0	0	SEP015	I	1	1.14	180	20	4	26	19	80	494	4.00	
SEP016	PLANETARY PROC LAB	MH	I	99	10	A	98	28	400	999	250	R			SM	0	.0	1	1000	500	1.00	1000	2500	1	0	SEP016	I	1	8.50	50	21	3	24	18	63	432	4.00	S
SLS001	PRIMATE EXP FAC	MH	P	95	10	A	98	28	400	98	350	R			LM	0	.0	1	4000	50	1.00	4000	1700	0	-3	SLS001	A	2	1.53	360	22	4	26	25	88	650	2.00	S
SLS002	PLANT BIO/LS FACIL	MH	P	92	10	A	97	28	400	700	350	R			SM	0	.0	1	4400	50	1.00	4400	1800	0	-5	SLS002	A	2	3.00	12	23	5	27	23	115	621	2.00	S
SLS003	RODENT EXP FACIL	MH	P	92	10	A	97	28	400	700	350	R			SM	0	.0	1	4200	50	1.00	4200	1600	0	-4	SLS003	A	3	.78	360	23	4	26	25	92	650	2.00	S
SLS004	ORB QUARANTINE	MH	I	99	1	28	57	28	400	700	350	R			SM	0	.0	1	1700	50	.10	170	6600	0	0	SLS004	A	1	4.00	30	16	3	26	20	48	520	4.00	
SLS005	EXP MED TREAT FAC	MH	I	95	10	A	97	28	400	700	350	R			SM	0	.0	1	1000	50	1.00	1000	3200	0	-3	SLS005	A	2	4.00	30	18	3	27	23	54	621	4.00	
SLS006	HUMAN EXP FAC	MH	P	92	10	A	97	28	400	700	350	R			SM	0	.0	1	2900	50	1.00	2900	3000	1	-3	SLS006	A	5	1.00	52	24	4	28	27	96	756	2.00	S
SMP001	MATERIALS PROC LAB	MH	C	92	10	A	97	28	400	999	300	R			LM	0	.0	1	12000	10	.50	6000	5500	0	0	SMP001	A	3	4.00	100	26	7	22	25	182	550	2.00	
SMP002	MATERIALS EXP CARR	MH	C	90	10	A	99	0	ANY	999	300	A	D			0	2.0	1	10000	500	.80	8000	13600	30	0	SMP002	A	2	6.50	26	25	7	23	25	175	575	2.00	
SMP003	MATERIALS EXP ASS	MH	P	88	10	A	99	0	ANY	999	300	A	A			0	1.0	1	4000	6	.50	2000	2215	0	-5	SMP003	A	2	6.50	26	23	7	27	24	161	648	1.00	O
SMP004	WAKE SHIELD EXP	MH	I	90	1	A	97	0	400	700	350	R				0	1.0	1	500	10	.20	100	600	0	0	SMP004	V	2	5.00	10	16	3	33	24	48	792	4.00	
SMP005	ULTRAVACUUM FAC	MH	I	95	10	A	97	0	400	700	350	D	A			0	1.5	1	3000	10	.50	1500	1200	0	0	SMP005	V	3	5.00	26	18	3	31	24	54	744	4.00	
TFM001	LASER COMM&TRACK DEV	MH	I	92	1	28	97	0	400	999	300	R				0	.5	1	1000	10	.05	50	200	0	0	TFM001	M	2	3.00	20	14	4	28	23	56	644	4.00	
TGN001	LSS CONTR EXP	MH	C	93	1	28	90	0	400	999	300	R				0	2.0	1	500	0	.02	10	600	0	0	TGN001	A	1	1.00	30	18	4	28	24	72	672	3.00	
TGN002	ZERO G ANT RANGE	MH	I	92	1	28	90	28	400	999	300	R				0	2.0	1	1000	1	.04	40	1000	0	0	TGN002	V	2	8.00	10	21	5	25	25	105	625	2.00	
TGN003	MATERIALS&COAT TECH	MH	I	92	5	28	97	28	400	600	300		D	M		0	1.0	1	100	0	.01	0	1400	0	0	TGN003	A	2	4.00	10	15	4	32	26	60	832	4.00	
TGN004	TETHER DYNAMICS	MH	C	94	1	28	97	0	400	600	300	R				0	.5	1	1000	0	.01	10	250	0	0	TGN004	E	2	4.00	30	18	4	31	24	72	744	3.00	
TGN005	LRG STRUCT CONSTR	MH	C	94	1	28	57	28	400	999	350	R				0	2.0	1	500	1	.03	15	600	0	0	TGN005	E	3	8.00	60	21	5	23	24	105	552	1.00	
TGN006	FLUID STORE&MANAG	MH	C	92	1	28	97	28	400	999	300	R				0	3.0	1	500	0	.02	10	9000	0	0	TGN006	A	1	4.00	30	17	4	28	24	68	672	1.00	
TGN007	LIQUID DROPLET RAD	MH	I	94	1	28	97	0	400	999	350	R				0	.5	1	200	0	.01	2	400	0	0	TGN007	A	1	4.00	30	15	4	32	23	60	736	4.00	
TGN008	ECLS WATER REC	MH	C	93	1	A	97	28	400	700	370	R				1	.0	0	150	10	.01	2	80	0	0	TGN008	A	1	.15	180	14	5	33	25	70	825	2.00	
TGN009	ELCS OXY REC	MH	C	93	1	A	97	28	400	700	370	R				2	.0	0	500	10	.01	5	100	0	0	TGN009	A	1	.14	180	18	5	29	22	90	638	2.00	
TOP001	SATELL SERV TECH	MH	P	92	1	28	90	28	400	999	300	R			SS	0	.0	1	1000	0	.05	50	500	0	0	TOP001	A	2	8.00	60	19	5	26	25	95	650	1.00	
TOP002	OTV SERVICE TECH	MH	P	92	1	28	90	28	400	999	300	R				0	3.0	1	1500	0	.05	75	500	0	0	TOP002	A	2	4.00	60	18	5	26	23	90	598	1.00	
TOP003	CREW/MANIP CONT	MH	C	93	1	A	97	28	400	700	370	R		L		1	1.0	1	150	10	.06	9	550	0	0	TOP003	A	2	4.00	60	18	4	29	23	72	667	3.00	
TOP004	MAN ROLE EVAL	MH	O	92	1	A	90	28	400	700	370	R				1	.0	0	50	5	.03	2	100	0	0	TOP004	A	1	1.00	260	22	5	30	26	110	780	1.00	
TOTALS ARE=																			87772	672138			106804															
NUMBER OF MISSIONS=	44																																			

FIGURE 2-1.

MISSION ACCOMMODATION REQUIREMENTS
88 MISSIONS TOTAL



space station at low inclination. Those missions that have nonspecific needs can also be shifted to other facilities and inclinations.

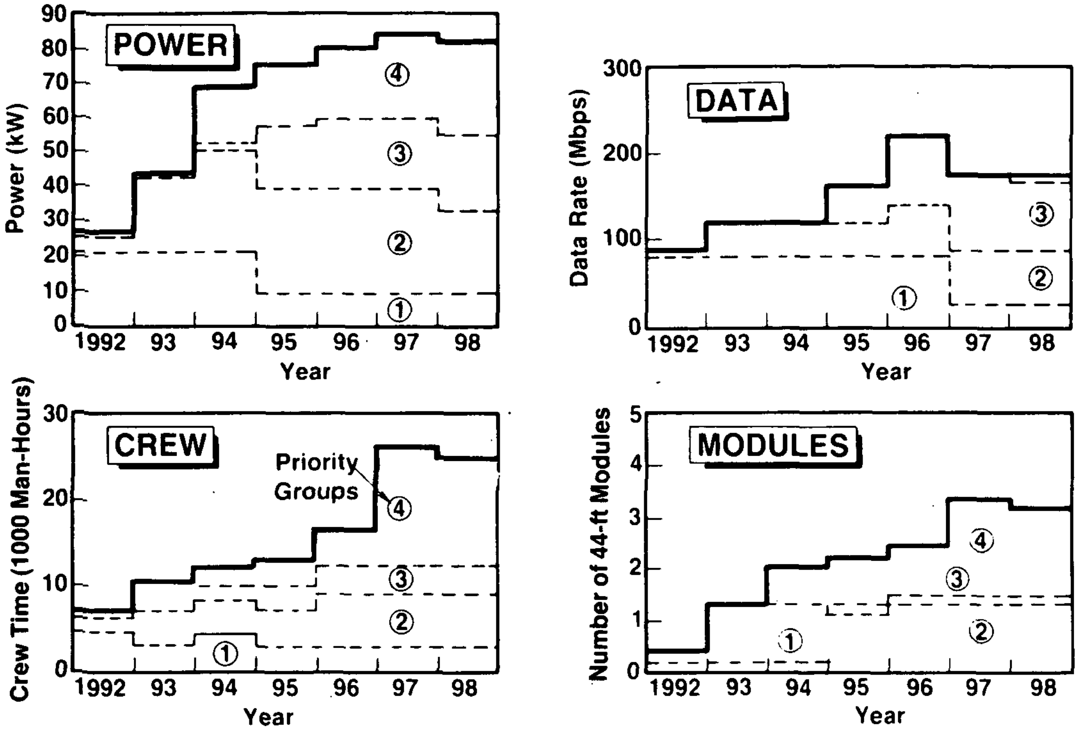
One-hundred-percent capture requires manned space stations at low and high inclinations, and platforms at low and high inclinations. A single space station at low inclination has the highest accommodation (54 missions); a space station at high inclination (52 missions) is next.

Total mission resource requirements are given in Figure 2-2 in terms of average electrical power and data rate, crew time, and pressurized volume needs. The figure also gives resource needs by priority level. Missions of higher priority tend to be more mature and therefore occur earlier in the program, as indicated by the figure showing that nearly all the 1992 missions are of the first or second priority level.

FIGURE 2-2.

TIME-PHASED PRIORITIZED MISSION REQUIREMENTS

VGB817



The mission model indicates that resource needs decrease slightly after 1997. This is primarily because less mission information is available for this more distant time period. Actually, we expect mission requirements to expand in this time period.

Resource needs for special-emphasis missions are given in a similar format in Figures 2-3, 2-4, and 2-5 for science and applications, operations and technology, and commercial missions.

Science and applications missions are characterized by high data rates, power, and crew needs, and relatively low resupply needs. The high power and crew needs are due primarily to the large number of missions of this class--57 out of the total of 88 missions.

Missions emphasizing operations and technology require low data rates and power, but have high crew needs and very high resupply needs after the ROTV operations start in 1996.

FIGURE 2-3.

SCIENCE AND APPLICATIONS MISSION NEEDS

VGB829

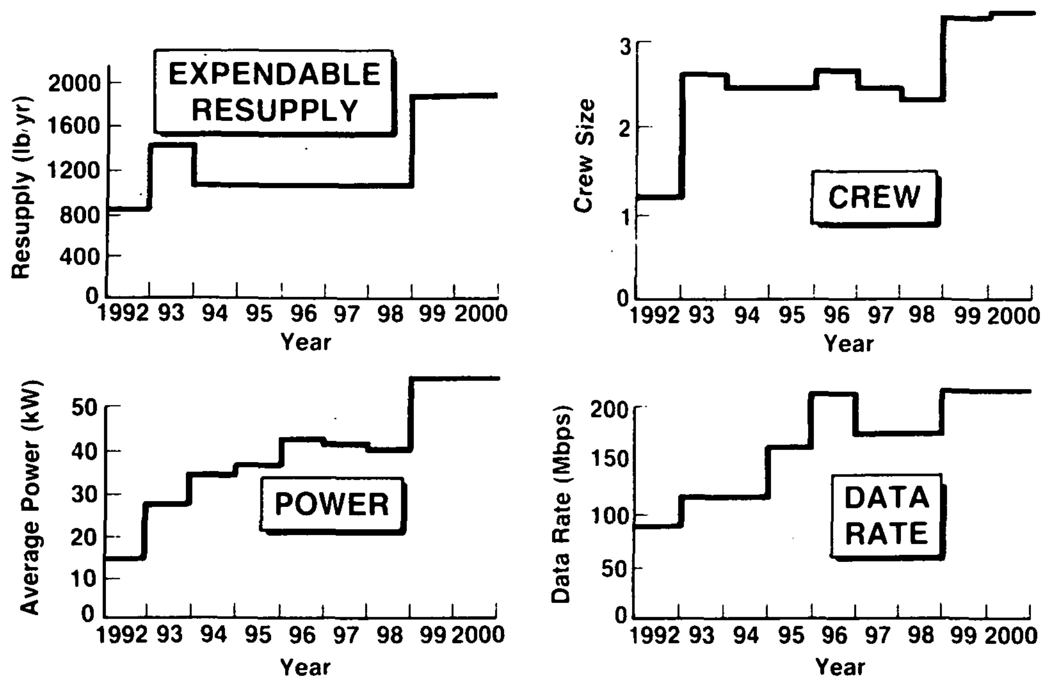


FIGURE 2-4.

OPERATIONS AND TECHNOLOGY MISSION NEEDS

VGB833

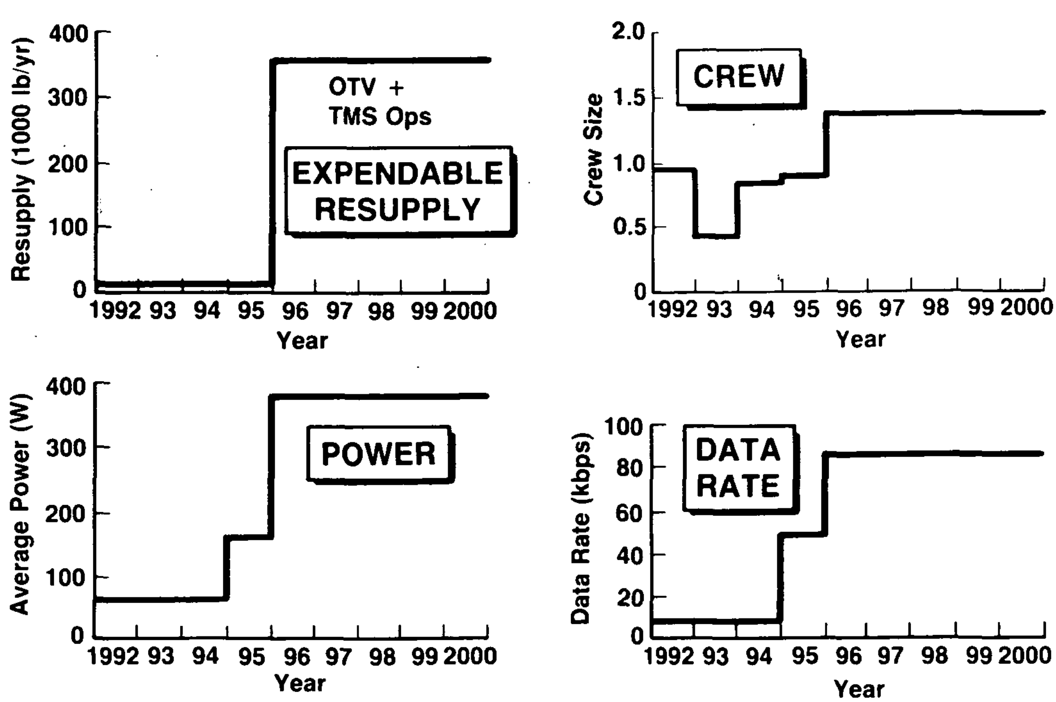
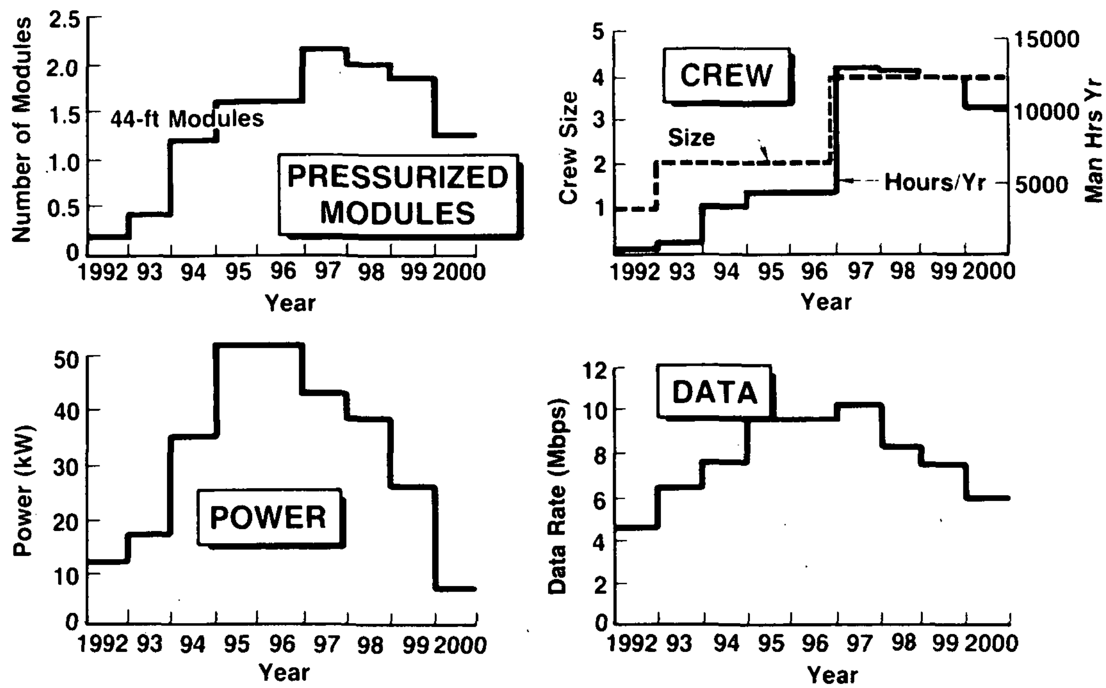


FIGURE 2-5.

VGC212

COMMERCIAL MISSION NEEDS

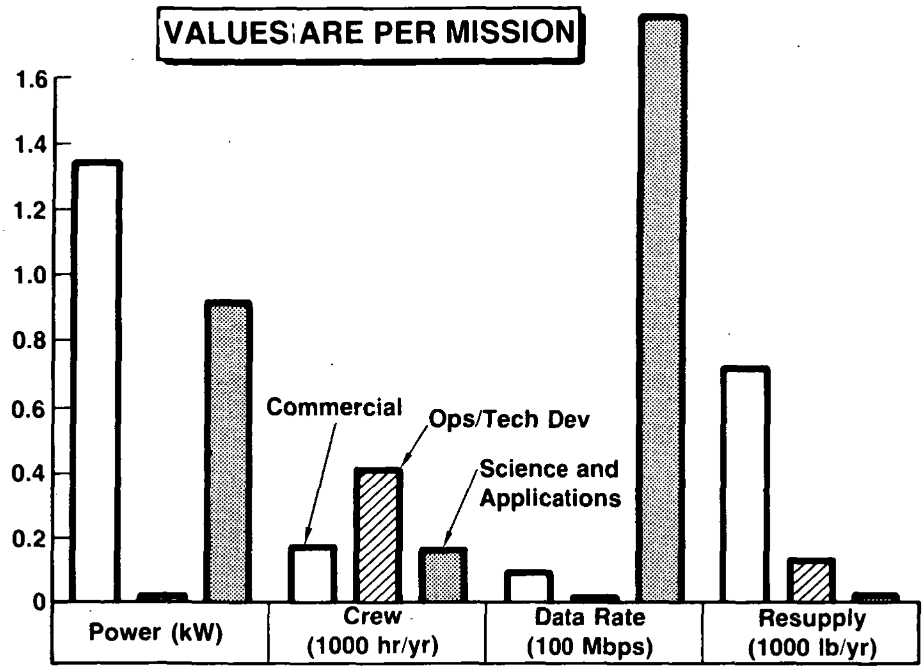


Commercial missions require high power, crew, and pressurized volume for material processing. Data rates are low inasmuch as only control and monitoring functions need to be provided. Expendable resupply is large, consisting of the materials to be processed in space and then returned to Earth.

The relatively different resource needs can be seen in Figure 2-6, which considers the average needs per payload for the various mission classes. Results agree with the conclusions for total mission class needs given above.

FIGURE 2-6.

RESOURCE REQUIREMENTS FOR DIFFERENT MISSION TYPES



Section 3
ARCHITECTURAL OPTIONS

This section defines several architectural options that accommodate different percentages of the 88 missions defined in the previous section. The most ambitious architecture (the 100% capture architecture) consists of the facilities required to provide optimum or near-optimum accommodation of all the missions. In anticipation that this 100% capture architecture will add facilities (and cost) that result in only limited additional mission capture, several single- and dual-facility architectures are defined that represent a more cost-effective approach.

The 100% capture architecture and the single- and dual-facility architectures represent the extremes in the possible sizes of space station programs: the most probable program will lie somewhere between them. This intermediate architecture is presented as the budget-constrained architecture that accommodates a high percentage of the mission in a cost-effective manner.

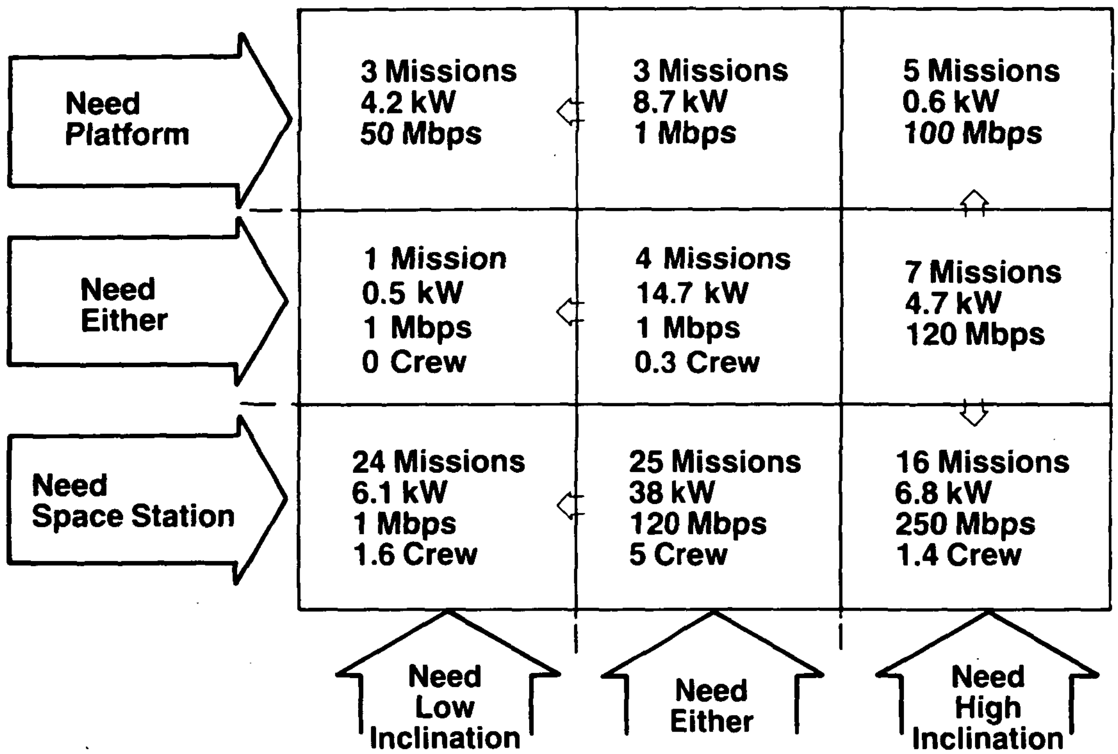
3.1 100% CAPTURE ARCHITECTURE

Based on location requirements and resource needs given in Figure 2-1 (Section 2 of this volume), requirements for a 100% capture architecture can be formulated. Space stations are required at 28.5-deg and sun-synchronous inclinations, and platforms are needed at 28.5 and 90 deg. Total resources required include 85 kW (average) of electrical power, an average data rate of 230-mbps, 27,000 man-hours per year of crew time for mission support, and the equivalent of three 44-ft-long modules for pressurized volume.

These total resources are allocated to the four facilities as indicated in Figure 3-1. Note that several options are available for many of the missions; e.g., some missions can be accommodated on either a platform or space station, and some missions can be accommodated at either high or low inclinations. These missions are allocated to the facilities in such a way as to minimize operational complexity and cost. That is, they are placed at the lowest

FIGURE 3-1.
MISSION RESOURCE NEEDS FOR 100% CAPTURE ARCHITECTURE

VGD942



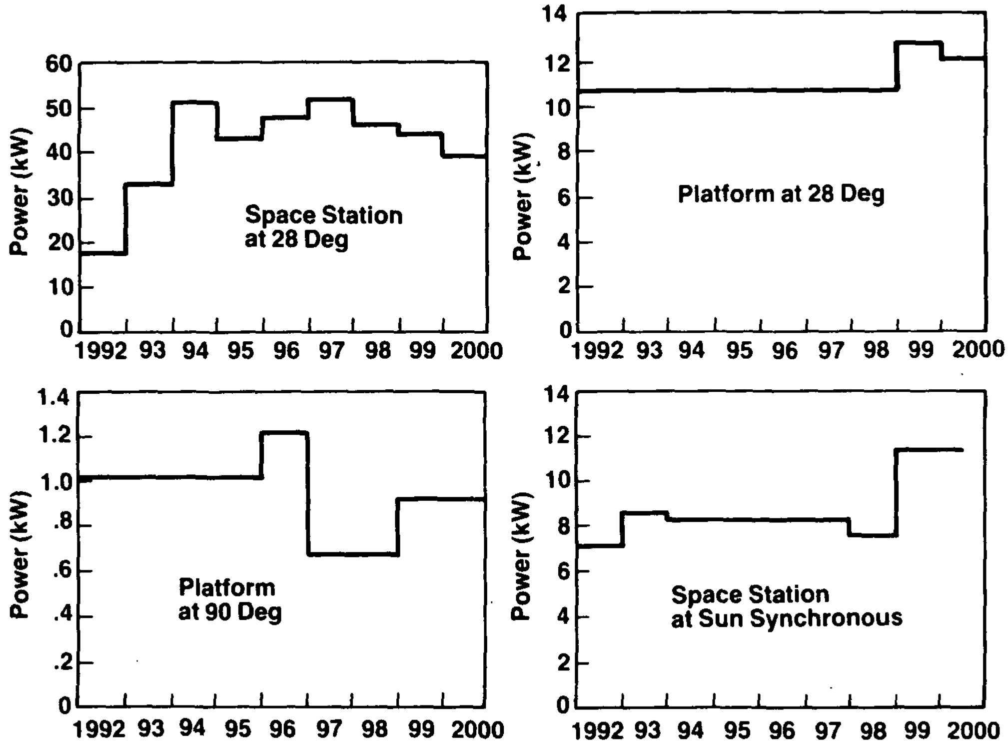
inclination they will accept in order to take advantage of maximum orbiter launch performance and are placed on space stations to focus logistics traffic and fully use the on-board crew for attending to the missions. The arrows in Figure 3-1 indicate the allocation of the missions with alternative means of being accommodated.

A review of time phasing of these resource requirements indicates that some capability is needed in all four facilities in the first or second year of the program. As an example of this, Figure 3-2 is a schedule of the electrical power needs for missions using the four facilities.

The facility characteristics of the 100% capture architecture are given in Tables 3-1 to 3-3. The space station at 28.5-deg inclination is a facility for a crew of seven and consists of four basic modules. Orbiter launches for these modules are bay-volume-limited rather than weight-limited. Total power for the facility is 57.8 kW, of which 16.5 kW are used by subsystems and 51.3

FIGURE 3-2.
MISSION POWER NEEDS FOR 100% CAPTURE ARCHITECTURE

VGD943



kW are allocated for mission use. The station is launched in four launches (not including logistics modules). Based on 90-day resupply, the basic station will require about 15,000 lb/resupply of expendables. This corresponds to a 30-ft module with a total weight of 25,000 lb per resupply.

The characteristics of the small station located at sun-synchronous inclination are given in Table 3-2. This facility has two crew members, provides 11.5 kW to missions, and requires 11.2 kW for subsystems. Three orbiter launches are required to launch the basic station because orbiter launch capability for this orbit is only 19,856 lb after accounting for the 6,000-lb docking module. The modules, therefore, must be designed for light weight (18,573 lb) and small size (34 ft long). Resupply for the basic station consists of 6000 lb every 90 days, which amounts to a total weight, including structure, of 10,000 lb and a length of 12 ft per resupply.

Table 3-3 gives the characteristics of the 28.5-deg platform, which provides 12.9 kW to missions and consumes 3.3 kW in power for subsystems. The total platform weight of 25,800 lb can be launched with a single orbiter

Table 3-1. 100% Capture Architecture - Space Station at 28.5-Degree Inclination

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	30168.	185.	162.	5017.	240.	672.
DATA	3.8	0.5	1805.2	39.1	3147.	79.	0.	758.	19.	730.
ECLS	3.9	0.0	0.0	0.0	12103.	710.	0.	35961.	1961.	377.
CREW	1.5	0.0	0.0	0.0	5821.	3365.	0.	1309.	262.	0.
THERM	2.2	0.0	0.0	0.0	7820.	27.	157.	78.	4.	73.
STRUC	0.0	0.0	0.0	0.0	40621.	600.	85.	406.	16.	0.
A C S	2.7	0.0	0.0	0.0	8619.	16.	545.	2580.	113.	200.
PROP	0.3	0.0	0.0	0.0	3841.	0.	176.	12197.	535.	200.
COMM	2.1	0.0	0.0	0.0	2686.	60.	20.	647.	19.	365.
WIRE	0.0	0.0	0.0	0.0	2794.	261.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	111266.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	12418.	2292.	0.	0.	0.
MISS	51.3	50.0	0.0	0.0	200000.	7000.	500.	100000.	0.	21100.
TOTAL	67.8	50.5	1805.2	39.1	317620.	24721.	3938.	270218.	3169.	23717.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	29405.11	5776.04	45.26	14.00	4	90.48	7.00

P PORTS	DEP RAD Q	ARRAY PWR
6	0.00	178.01

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1990	4.00	4.12	4.02	12.14	0.86

Table 3-2. 100% Capture Architecture - Space Station at Sun-Synchronous Inclination

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	10131.	57.	54.	1714.	206.	389.
DATA	3.4	0.1	521.0	11.3	2824.	71.	0.	680.	17.	730.
ECLS	2.1	0.0	0.0	0.0	4613.	306.	0.	12743.	786.	243.
CREW	1.2	0.0	0.0	0.0	2496.	1368.	0.	374.	75.	0.
THERM	0.7	0.0	0.0	0.0	2643.	11.	58.	26.	1.	73.
STRUC	0.0	0.0	0.0	0.0	23249.	400.	75.	232.	9.	0.
A C S	1.4	0.0	0.0	0.0	4143.	16.	261.	1240.	56.	200.
PROP	0.3	0.0	0.0	0.0	1824.	0.	70.	6065.	212.	200.
COMM	2.2	0.0	0.0	0.0	2699.	61.	20.	650.	20.	365.
WIRE	0.0	0.0	0.0	0.0	1098.	174.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	23607.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	6361.	1076.	0.	0.	0.
MISS	11.5	250.0	0.0	0.0	50000.	2500.	1000.	10000.	0.	4370.
TOTAL	22.7	250.1	521.0	11.3	105721.	11325.	2614.	57331.	1381.	6570.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
25856.30	18573.68	4054.14	34.07	14.00	3	30.28	2.00

P PORTS	DEP RAD Q	ARRAY PWR
4	0.00	59.66

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1990	2.81	2.06	2.22	7.09	0.91

Table 3-3. 100% Capture Architecture - Platform at 28.5-Degree Inclination

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	7086.	37.	39.	1186.	201.	328.
DATA	1.0	0.0	2.6	0.1	827.	21.	0.	199.	5.	365.
ECLS	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
CREW	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
THERM	0.4	0.0	0.0	0.0	3382.	2.	60.	34.	2.	0.
STRUC	0.0	0.0	0.0	0.0	8299.	0.	55.	83.	3.	0.
A C S	1.2	0.0	0.0	0.0	3512.	16.	220.	1051.	47.	200.
PROP	0.3	0.0	0.0	0.0	1309.	0.	42.	4497.	129.	200.
COMM	0.4	0.0	0.0	0.0	489.	11.	4.	118.	4.	180.
WIRE	0.0	0.0	0.0	0.0	929.	116.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	8518.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	2203.	840.	0.	0.	0.
MISS	12.9	50.0	0.0	0.0	50000.	0.	1000.	5000.	0.	0.
TOTAL	16.2	50.0	2.6	0.1	75833.	2406.	2259.	20686.	391.	1273.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	25832.86	6351.99	49.00	14.00	1	21.38	0.00

P PORTS	DEP RAD Q	ARRAY PWR
0	13.47	42.51

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1990	1.30	0.41	0.76	2.47	0.53

flight. Platform resupply is about 7200 lb/year, which consists primarily of orbit-keeping propellant and replacement of electrical batteries.

The platform located at a 90-deg inclination is a small unit in the Eureka or multimission spacecraft (MMS) category. Mission-dedicated electrical power is 1.2 kW, and the total bus power is estimated at 2.0 kW. This platform can easily be launched with a single orbiter flight, with considerable performance remaining for co-manifesting of additional cargo.

3.2 IMPACT OF BUDGET/SCHEDULE CONSTRAINTS

Implementation of the 100% capture architecture will probably be impacted by available budget rates and by schedule considerations. Based on historical NASA budget trends and program commitments, MDAC has projected an available budget. From this analysis, it has been determined that an annual space station budget of about $1.3 billion in 1984 dollars can be phased into the NASA budget plan without significant increase in annual NASA funding. This also allows a significant increase in budget for science and applications missions. Based on this availability and the estimated total cost of the 100% capture architecture, the time schedule for the program can be estimated.

Table 3-4 gives a top-level cost breakdown for the 100% capture architecture. The costs given assume that each hardware element is developed

Table 3-4. Cost Breakdown for 100% Capture Architecture

Item	Cost (Billions of 1984 dollars)
Space station at 28 deg	5.87
Space station at sun synch.	2.67
Platform at 28 deg	0.45
Platform at 90 deg	0.43
OTV	1.30
TMS	0.30
Ground support equipment	0.20
Spares/refurbishment	.53/yr
	11.22 billion
	.53 billion/yr

on the most efficient schedule. Longer or shorter schedules would have an additional cost impact. It is also assumed that the procurement approach and contracting arrangement selected permit maximum realization of the commonality and standardization opportunities. Total cost from the table amounts to $11.22 billion, excluding operations costs, which will start being incurred at each facility IOC.

An additional schedule restriction occurs due to the rate at which the program can build up. A typical efficient buildup is shown in the left portion of Figure 3-3 - a linear buildup to the funding limit over a 3-year period. The funding curve shown in the figure is a typical total cost expenditure curve for the space station program. After the controlled buildup, the rate is constant at the funding limit. Operations costs will start occurring during the middle part of the program, which reduces the funding available for hardware. Near the end of the program, a 3-year winddown period is shown that, like the controlled buildup, is essential to an efficient program. A funding rate equal to operational costs, including spares and refurbishment costs, is shown after the hardware phase. Remaining funds will be available for other programs after this phase.

The right portion of Figure 3-3 shows the impact that annual funding rate has on total program schedule. For the projected $1.3-billion-per-year rate, the 100% capture architecture would not be implemented until mid-1997. This schedule would not adequately meet mission needs, as shown in Figure 3-4.

MCDONNELL DOUGLAS

FIGURE 3-3.
ANNUAL FUNDING CONSTRAINT ON 100% CAPTURE ARCHITECTURE

VGD944

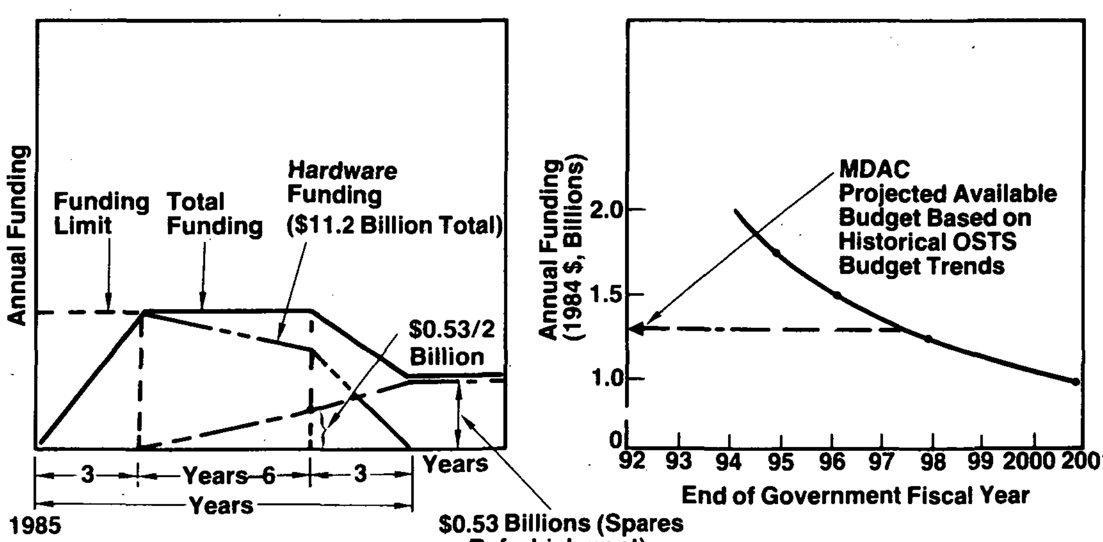
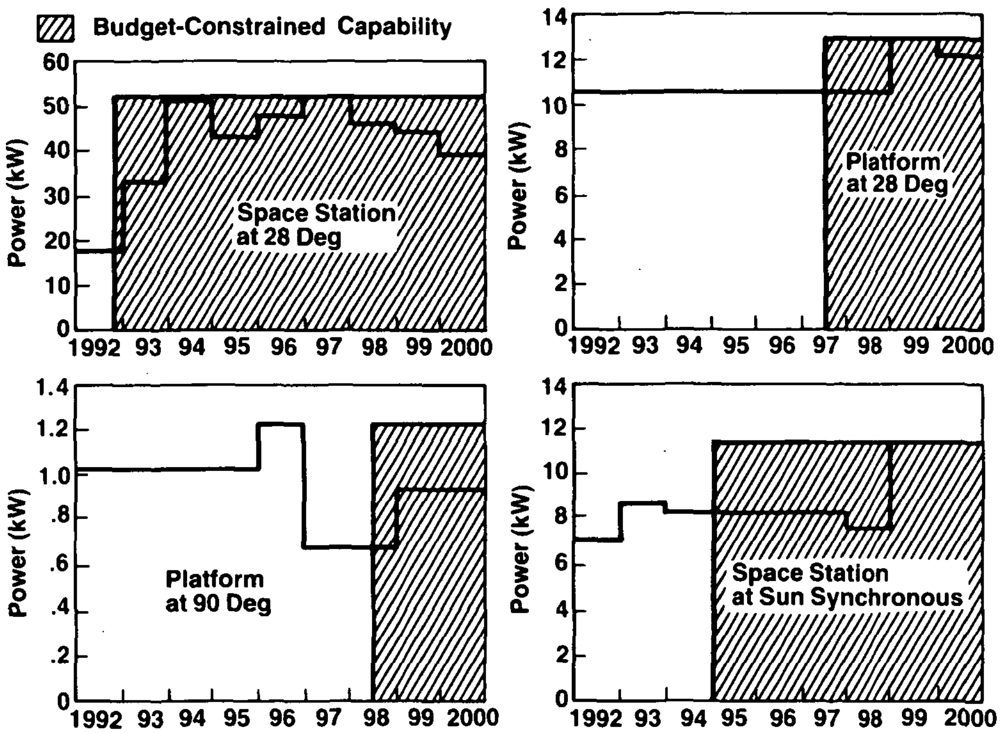


FIGURE 3-4.

MISSION POWER CAPABILITY FOR 100% CAPTURE ARCHITECTURE

VGD945



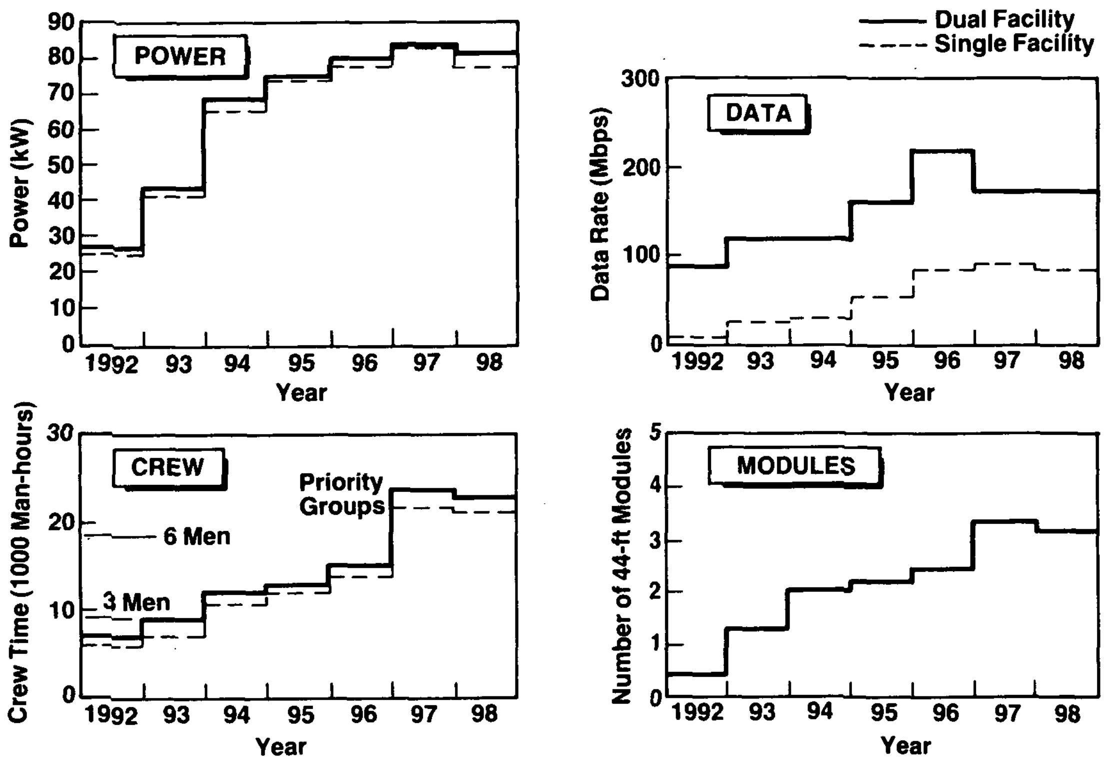
3.3 SINGLE- AND DUAL-FACILITY ARCHITECTURES

As shown in the previous section, the cost for the 100% capture architecture precludes implementation of the architecture on a schedule coinciding with mission needs. Several approaches can be used to reduce hardware cost and thereby enable more resources to be made available to support missions. These include designing for modularity to reduce nonrecurring cost, and reducing the number of facilities provided. This section considers the latter--specifically, single and dual facilities.

Figure 2-2 of the previous section presented the most competitive single- and dual-facility architectures with regard to total missions captured. The first of the three most promising architectures from the figure consists of a single space station at a 28.5-deg inclination. This concept can potentially capture 64 missions (73%). Specific resources that must be provided are shown in Figure 3-5 along with those for dual facilities. Power and crew requirements are slightly less than for dual facilities; the number of pressurized modules is identical. Data rate is considerably less for the

FIGURE 3-5.
TIME-PHASED MISSION REQUIREMENTS SINGLE AND DUAL ARCHITECTURES

VGD946



28-deg single facility because it does not capture several science and applications missions that require very high data rates.

As can be seen from Figure 3-5, resource requirements are moderate initially, but they more than double over the duration of the program. This leads to the rationale that the architecture should not be designed initially for the maximum requirements, which occur years later. Therefore, the architecture is defined to consist of an initial concept for the first few years (1992 to 1993), which is expanded in 1994 to meet the needs of the 1994-to-2000 time frame.

Table 3-5 defines the architecture of the single facility at an inclination of 28.5 deg for the initial version, and Table 3-6 shows it for the growth version. The initial version is a four-man space station supplying 41 kW for missions and 15.3 kW for facility needs. The basic facility consists of three modules that weigh 31,500 lb each. Four orbiter launches will be required for the pressurized and unpressurized portions of the basic station.

Table 3-5. Definition of Single-Facility Architecture - Initial Version

YR 1993, CN 1

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	24410.	146.	135.	4176.	232.	612.
DATA	2.8	0.3	1036.2	22.4	2352.	59.	0.	567.	14.	550.
ECLS	5.0	0.0	0.0	0.0	6714.	555.	0.	12502.	935.	200.
CREW	1.2	0.0	0.0	0.0	3972.	2026.	0.	748.	150.	0.
THERM	1.9	0.0	0.0	0.0	9827.	69.	214.	98.	5.	73.
STRUC	0.0	0.0	0.0	0.0	31300.	400.	75.	313.	13.	0.
A C S	2.2	0.0	0.0	0.0	6862.	16.	433.	2054.	90.	200.
PROP	0.3	0.0	0.0	0.0	4807.	0.	227.	15138.	691.	200.
COMM	1.9	0.0	0.0	0.0	2366.	53.	18.	570.	17.	275.
WIRE	0.0	0.0	0.0	0.0	1827.	216.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	234616.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	9963.	2204.	0.	0.	0.
MISS	41.0	100.0	0.0	0.0	140000.	12470.	2268.	299000.	0.	10300.
TOTAL	56.3	100.3	1036.2	22.4	234438.	25972.	5574.	569781.	2145.	12411.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	31479.29	6001.05	46.72	14.00	3	74.92	4.00

P PORTS	DEP RAD Q	ARRAY PWR
4	5.38	147.87

-> SHOW LAUNCH FOR 1993

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1993	3.48	3.08	8.47	15.04	0.96

Table 3-6. Definition of Single-Facility Architecture - Growth Version

YR 1997, CN 1

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	47266.	294.	248.	7633.	267.	830.
DATA	3.1	0.5	1809.2	39.1	2544.	64.	0.	613.	15.	550.
ECLS	6.8	0.0	0.0	0.0	9415.	743.	0.	19270.	1395.	203.
CREW	1.7	0.0	0.0	0.0	5774.	3365.	0.	1309.	262.	0.
THERM	3.4	0.0	0.0	0.0	18840.	121.	349.	188.	9.	73.
STRUC	0.0	0.0	0.0	0.0	50304.	1000.	105.	503.	20.	0.
A C S	4.2	0.0	0.0	0.0	13688.	16.	867.	4097.	177.	200.
PROP	0.3	0.0	0.0	0.0	2170.	0.	88.	7114.	267.	200.
COMM	2.0	0.0	0.0	0.0	2529.	57.	19.	609.	18.	275.
WIRE	0.0	0.0	0.0	0.0	5029.	281.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	714235.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	14386.	3352.	0.	0.	0.
MISS	82.0	100.0	0.0	0.0	400000.	20820.	2930.	979000.	0.	22400.
TOTAL	103.5	100.5	1809.2	39.1	557559.	41147.	7957.	*******	2432.	24731.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	26259.79	3937.12	33.31	14.00	6	137.63	7.00

P PORTS	DEP RAD Q	ARRAY PWR
10	13.76	271.74

-> SHOW LAUNCH FOR 1997

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1997	4.84	3.08	25.79	33.71	0.29

The growth version provides support for a seven-man crew and an increase in total mission power from 41 kW to 82 kW. Three additional modules are required for the growth version. Both versions of the single-facility architecture are current technology.

Tables 3-7 to 3-9 define the dual-facility architectures that locate a space station at an inclination of 57 deg and a platform at a 28.5-deg inclination. The initial space station considered in Table 3-7 supports a crew of four and provides 30 kW to missions. It weighs about 10,000 lb less than the single-facility space station because it supplies 11 kW less power to the missions. The growth version, shown in Table 3-8, consists of five modules with pressurized sections that are 37.6 ft long. The platform facility provides 15 kW to the missions. This facility may require two launches for implementation because of the volume associated with ten external ports and associated structure.

The architecture that locates a space station at 28.5 deg and a platform at sun-synchronous orbit is nearly identical to the dual-facility architecture presented in the previous paragraph. One major difference is that the platform will be placed at sun-synchronous orbit, which requires substantially less orbiter launch capability (reduced from 61,265 lb to 19,856 lb, after accounting for the orbiter docking module). Review of Table 3-9 for the platform shows, however, that the number of launches is determined on the basis of orbiter bay size limits rather than on orbiter launch weight limits, so the platform definition is not affected. Mission launches and resupply launches will increase for the sun-synchronous platform, however, because in many cases these will be established on the basis of orbiter lifting capacity.

Table 3-7. Definition of Dual-Facility Architecture - Initial Space Station at 57-Degree Inclination

YR 1993, CN 1

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	19561.	116.	107.	3335.	223.	547.
DATA	2.8	0.3	1035.9	22.4	2358.	59.	0.	568.	14.	550.
ECLS	5.0	0.0	0.0	0.0	6714.	555.	0.	12502.	935.	200.
CREW	1.2	0.0	0.0	0.0	3958.	2026.	0.	748.	150.	0.
THERM	1.5	0.0	0.0	0.0	7272.	61.	177.	73.	4.	73.
STRUC	0.0	0.0	0.0	0.0	30067.	400.	75.	301.	12.	0.
A C S	2.1	0.0	0.0	0.0	6483.	16.	409.	1940.	85.	200.
PROP	0.3	0.0	0.0	0.0	4048.	0.	187.	12827.	569.	200.
COMM	1.9	0.0	0.0	0.0	2392.	54.	18.	576.	17.	275.
WIRE	0.0	0.0	0.0	0.0	1621.	214.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	128010.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	9678.	1948.	0.	0.	0.
MISS	30.0	116.0	0.0	0.0	132000.	8530.	2700.	150000.	0.	9300.
TOTAL	44.8	116.3	1035.9	22.4	216474.	21709.	5622.	310880.	2008.	11345.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
52611.80	28157.85	5911.74	46.14	14.00	3	59.78	4.00

P PORTS	DEP RAD Q	ARRAY PWR
4	0.00	117.77

-> SHOW LAUNCH FOR 1993

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1993	3.46	2.47	5.91	11.84	0.16

Table 3-8. Definition of Dual-Facility Architecture - Growth Space Station at 57-Degree Inclination

YR 1997, CN 1

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	40397.	250.	215.	6638.	257.	774.
DATA	3.1	0.5	1807.9	39.1	2574.	64.	0.	620.	16.	550.
ECLS	6.8	0.0	0.0	0.0	9415.	743.	0.	19270.	1395.	203.
CREW	1.6	0.0	0.0	0.0	5757.	3365.	0.	1309.	262.	0.
THERM	3.0	0.0	0.0	0.0	16234.	109.	310.	162.	8.	73.
STRUC	0.0	0.0	0.0	0.0	45666.	800.	95.	457.	18.	0.
A C S	3.0	0.0	0.0	0.0	9774.	16.	619.	2925.	127.	200.
PROP	0.3	0.0	0.0	0.0	1943.	0.	76.	6426.	231.	200.
COMM	2.1	0.0	0.0	0.0	2664.	60.	20.	642.	19.	275.
WIRE	0.0	0.0	0.0	0.0	3862.	268.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	416113.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	13642.	2670.	0.	0.	0.
MISS	70.0	218.0	0.0	0.0	234000.	20820.	3780.	556000.	0.	21000.
TOTAL	89.9	218.5	1807.9	39.1	372287.	40138.	7785.	*******	2333.	23275.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
52611.80	27657.36	4594.94	37.59	14.00	5	119.70	7.00

P PORTS	DEP RAD Q	ARRAY PWR
8	8.77	236.10

-> SHOW LAUNCH FOR 1997

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1997	4.65	2.47	19.21	26.34	0.66

Table 3-9. Definition of Dual-Facility Architecture - Platform at 28-Degree Inclination

YR 1993, CN 1

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	8160.	43.	44.	1362.	203.	352.
DATA	1.0	0.0	2.9	0.1	834.	21.	0.	201.	5.	365.
ECLS	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
CREW	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
THERM	0.5	0.0	0.0	0.0	3910.	2.	66.	39.	2.	0.
STRUC	0.0	0.0	0.0	0.0	12719.	0.	65.	127.	5.	0.
A C S	1.4	0.0	0.0	0.0	4197.	16.	264.	1256.	56.	200.
PROP	0.3	0.0	0.0	0.0	2119.	0.	85.	6959.	259.	200.
COMM	0.4	0.0	0.0	0.0	518.	12.	4.	125.	4.	180.
WIRE	0.0	0.0	0.0	0.0	832.	100.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	21049.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	1733.	1056.	0.	0.	0.
MISS	15.0	100.0	0.0	0.0	75000.	0.	3240.	20000.	0.	0.
TOTAL	18.6	100.0	2.9	0.1	108289.	1926.	4824.	51118.	534.	1297.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	16644.44	1481.85	17.36	14.00	2	24.55	0.00

P PORTS	DEP RAD Q	ARRAY PWR
2	16.27	48.81

-> SHOW LAUNCH FOR 1993

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1993	1.67	1.65	0.78	4.10	0.90

3.4 BUDGET-CONSTRAINED ARCHITECTURE

The previous paragraphs define various architectural options, and it was determined that the 100% capture architecture adds facilities that only slightly increase mission capture. The program cost is driven by the need for two space stations and for four total facilities. Although the single and dual facilities are less budget constraining, mission support is limited regarding orbit locations and facility types provided.

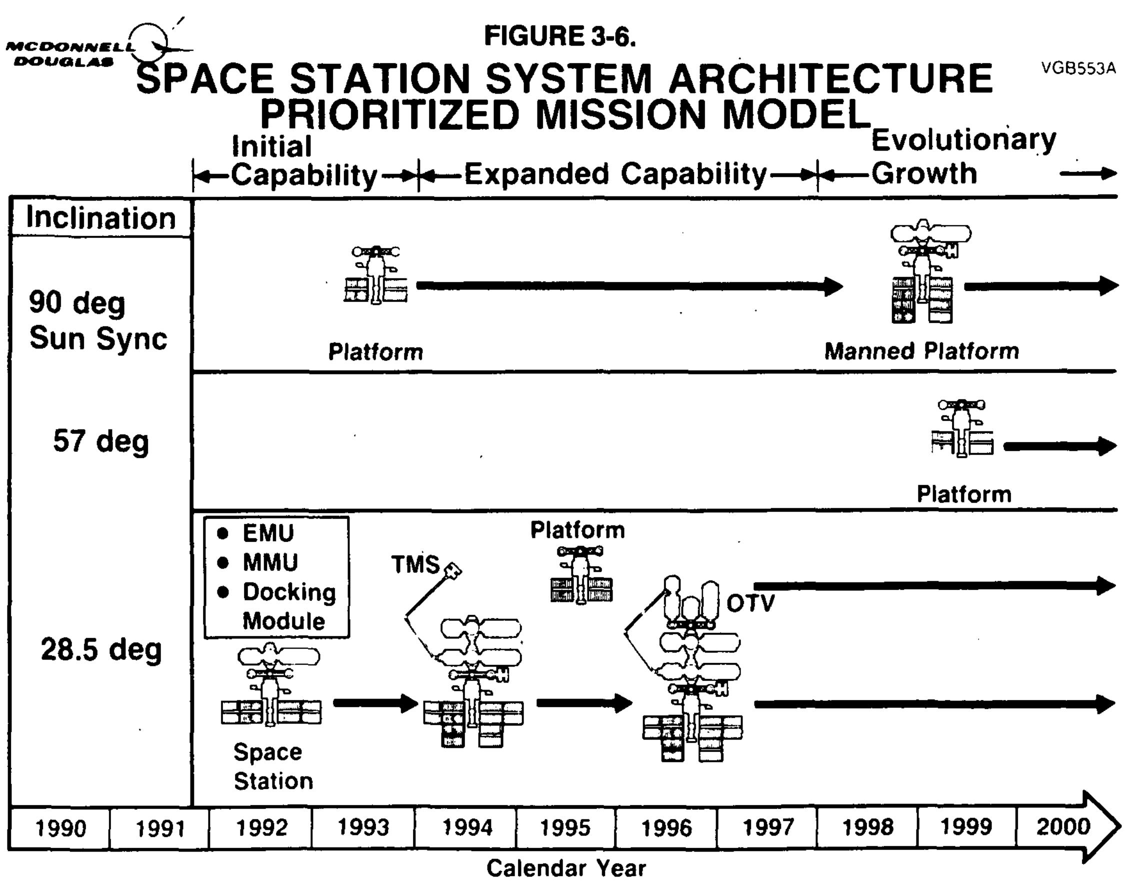
In this section, lessons learned from earlier architectural option studies are applied to the definition of a budget-constrained architecture that provides relatively generous resources to missions early in the program and evolves to meet expanding needs as the program progresses.

3.4.1 Description

The architecture shown in Figure 3-6 is responsive to the missions identified in the study while it also takes into account anticipated budget rate availability and efficient production rates of space station and platform elements.

FIGURE 3-6.

SPACE STATION SYSTEM ARCHITECTURE PRIORITIZED MISSION MODEL



Initially, this architecture places a four-man space station into a 28-deg orbit and provides 25 kW to payloads. This is primarily an R&D facility supporting science and applications, operations and technology development, and early commercial missions, such as an EOS early production facility. EMUs and MMUs are provided for general-purpose EVA tasks.

After about a year, a small platform is placed in sun-synchronous orbit, primarily to support science and applications missions requiring full Earth-surface coverage. This platform provides about 15 kW to payloads and a high data rate of 300 mbps. A data rate of 250 mbps is required by some payloads; however, efficient use of the TDRSS dictates the 300-mbps data rates.

The space station at 28 deg is expanded in about 1994 to support an eight-man crew and to provide 40 kW for the missions. Also, a crane, TMS, and TMS servicing are added between 1992 and 1994 to retrieve and service satellites. This addition of resources is necessary as the role of the space station emerges from primarily an R&D facility to an operations and commercial endeavor. This process is continued in 1995, when a platform is launched into a 28-deg inclination, providing additional amounts of power (15 kW for missions) to establish a relatively benign atmosphere for material processing and commercial production facilities. This platform also provides for science and applications missions that need the lower inclination orbits.

In the 1996 time frame, the space station is expanded once again to provide ROTV support. The facility at this point supports a wide base of support to R&D, early commercial development, and operations.

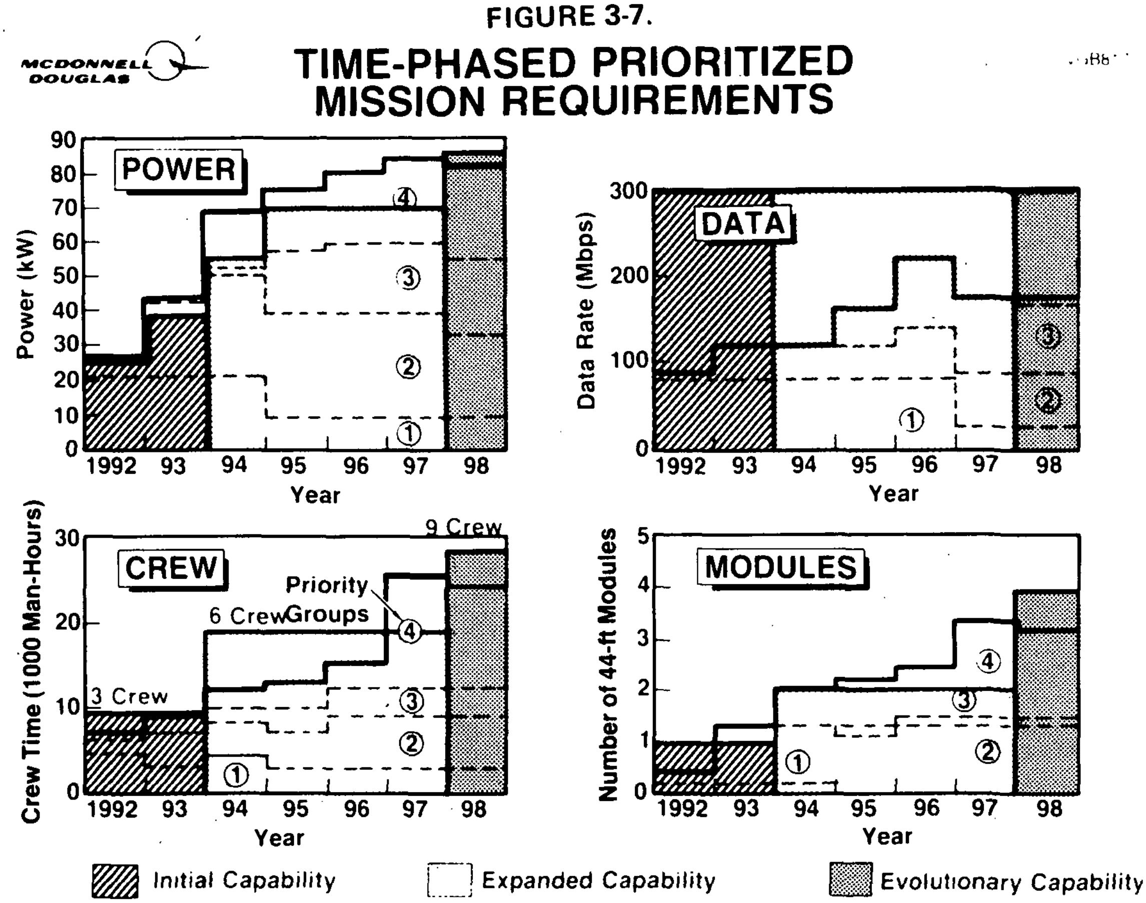
Also shown in the figure are predicted evolutionary growth needs for the 1998 time period and beyond. The platform at sun-synchronous orbit is expanded by adding manned capbability. This entails expanding the power subsystem and adding, as a minimum, a habitability module, laboratory module, docking or core module, and logistics module. The docking module acts as the second independent pressurized volume and contains a separate independent life support system as backup to the primary system contained in the habitability module.

A small platform, essentially identical to the platform at 28.5 deg, is placed at a 57-deg inclination. This facility expands the number of orbit locations where mission support is provided.

3.4.2 Performance

Figure 3-7 shows the performance provided by the architecture described in the previous paragraphs. The initial space station implemented in late 1991 provides 25 kW of power, a three-man crew (9360 man-hrs/yr), and 300 mbps of data rate for mission support. As can be seen from Figure 3-6, this more than meets crew data management and module volume needs for the first year. Power for the first year is slightly below the demand.

FIGURE 3-7.
TIME-PHASED PRIORITIZED MISSION REQUIREMENTS



The resources added by the sun-synchronous platform in 1993 provide an additional 15 kW of power for missions and also provide another 300-mbps data system. With the addition of this facility, sufficient data rate and crew are available for mission support; however, there is a small deficit in power and module volume.

Expansion of the space station in 1994 provides an additional 15 kW of electrical power, bringing the total to 55 kW on orbit. This is adequate power to meet Priority 1, 2, and 3 missions, but some Priority 4 missions cannot be fully accommodated by the facilities in this architecture. The expansion of the space station meets all identified crew time needed by missions through the year 1996. Some deficit in pressurized module volume exists from 1995 through 1997.

The addition of another platform in 28.5-deg orbit increases to 70 kW the total electrical power available to missions in 1995. Addition of evolutionary facilities in 1998 raises available mission resources to values greater than identified needs.

In summary, the budget-constrained architecture meets nearly all identified mission needs except for some Priority 4 missions in the middle program years. These missions are primarily commercial production missions. Definition of these missions is relatively soft and hinges largely on the success of earlier R&D activity that occurs in the early 1990s. If these commercial missions do evolve, they are expected to be profitable ventures, in which case the on-orbit supporting resources will be separately funded by the sponsoring organizations. It is, therefore, rational to exclude these mission needs from the NASA-funded architecture.

3.4.3 Characteristics

Characteristics for the budget-constrained architecture are given in Tables 3-10 to 3-12. The data in these tables give values for total volume and weight, assuming the modules are of equal length and weight. The impact of separating these needs into specialized modules, such as utility and habitability modules, is considered in the following section on modularity considerations. The technology level used in this definition corresponds to current technology.

Characteristics for the initial four-man space station are given in Table 3-10. Bus power level is 40.1 kW, subsystems consume 15.1 kW, and 25 kW are available to missions. The facility consists of three modules and has a total weight of 79,200 lb and a total volume of about 22,000 cu ft.

Table 3-10. Definition of Budget-Constrained Architecture - Initial Four-Man Space Station

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	17562.	104.	96.	2988.	219.	517.
DATA	2.9	0.3	1036.1	22.4	2394.	60.	0.	577.	14.	550.
ECLS	5.0	0.0	0.0	0.0	6714.	555.	0.	12502.	935.	200.
CREW	1.2	0.0	0.0	0.0	3951.	2026.	0.	748.	150.	0.
THERM	1.3	0.0	0.0	0.0	5132.	60.	116.	51.	3.	73.
STRUC	0.0	0.0	0.0	0.0	29487.	400.	75.	295.	12.	0.
A C S	2.3	0.0	0.0	0.0	7301.	16.	461.	2185.	96.	200.
PROP	0.3	0.0	0.0	0.0	2556.	0.	108.	8290.	329.	200.
COMM	2.0	0.0	0.0	0.0	2557.	58.	19.	616.	18.	275.
WIRE	0.0	0.0	0.0	0.0	1537.	213.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	117776.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	9577.	1752.	0.	0.	0.
MISS	25.0	300.0	0.0	0.0	176000.	8532.	1000.	140000.	0.	10000.
TOTAL	40.1	300.3	1036.1	22.4	255190.	21600.	3628.	286028.	1776.	12015.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	26396.81	5864.40	45.84	14.00	3	53.52	4.00

P PORTS	DEP RAD Q	ARRAY PWR
4	0.00	105.33

-> SHOW LAUNCH FOR 1990

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1990	3.16	2.18	4.25	9.59	0.41

Table 3-11. Definition of Budget-Constrained Architecture - Expanded Capability Eight-Man Space Station

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	26412.	162.	141.	4378.	234.	627.
DATA	3.2	0.5	2063.3	44.6	2650.	66.	0.	638.	16.	550.
ECLS	7.4	0.0	0.0	0.0	10204.	796.	0.	21525.	1549.	204.
CREW	1.5	0.0	0.0	0.0	6422.	3812.	0.	1495.	299.	0.
THERM	2.0	0.0	0.0	0.0	8558.	98.	161.	86.	4.	73.
STRUC	0.0	0.0	0.0	0.0	40217.	600.	85.	402.	16.	0.
A C S	2.5	0.0	0.0	0.0	8016.	16.	507.	2399.	105.	200.
PROP	0.3	0.0	0.0	0.0	5243.	0.	250.	16464.	761.	200.
COMM	2.2	0.0	0.0	0.0	2773.	62.	21.	668.	20.	275.
WIRE	0.0	0.0	0.0	0.0	2580.	263.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	663640.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	13212.	2331.	0.	0.	0.
MISS	40.0	300.0	0.0	0.0	176000.	24576.	1000.	900000.	0.	26000.
TOTAL	59.1	300.5	2063.3	44.6	289076.	43664.	4496.	*******	3004.	28129.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	28268.93	5856.95	45.79	14.00	4	79.11	8.00

P PORTS	DEP RAD Q	ARRAY PWR
6	0.00	155.14

-> SHOW LAUNCH FOR 1991

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1991	4.12	2.18	23.96	30.26	0.74

Table 3-12. Definition of Budget-Constrained Architecture - Platform at Sun-Synchronous Inclination

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	8098.	42.	44.	1351.	203.	350.
DATA	1.0	0.0	2.7	0.1	845.	21.	0.	204.	5.	365.
ECLS	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
CREW	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
THERM	0.5	0.0	0.0	0.0	3880.	2.	65.	39.	2.	0.
STRUC	0.0	0.0	0.0	0.0	12695.	0.	65.	127.	5.	0.
A C S	1.2	0.0	0.0	0.0	3534.	16.	222.	1058.	48.	200.
PROP	0.3	0.0	0.0	0.0	2445.	0.	102.	7951.	311.	200.
COMM	0.5	0.0	0.0	0.0	564.	13.	4.	136.	4.	180.
WIRE	0.0	0.0	0.0	0.0	832.	100.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	32105.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	1733.	1006.	0.	0.	0.
MISS	15.0	300.0	0.0	0.0	44000.	0.	2000.	35000.	0.	0.
TOTAL	18.4	300.0	2.7	0.1	76892.	1927.	3509.	77970.	578.	1295.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
25856.30	16446.23	1482.42	17.36	14.00	2	24.35	0.00

P PORTS	DEP RAD Q	ARRAY PWR
2	16.10	48.41

-> SHOW LAUNCH FOR 1992

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1992	1.66	0.73	3.02	5.40	0.60

Unpressurized equipment is equivalent to about 30 ft of orbiter bay. Slightly more than three launches, therefore, will be necessary for IOC, precluding a logistics module.

The eight-man station has a bus power of 59.1 kW, providing 19.1 kW to subsystems and 40 kW to missions. Based on a 60-hr crew work week, subsystems require the attention of one crewman for about two-thirds of the scheduled work time; thus, approximately seven crewmen are available for mission support and other houskeeping attention.

The eight-man station weighs 113,100 lb and contains 23,430 cu ft of pressurized volume. The equivalent of one additional launch is required to expand the capability from the initial four-man station to that of this eight-man one.

Table 3-12 presents the top-level characteristics for the platform located in a sun-synchronous orbit. This definition is identical to that of the platform at a 28.5-deg inclination. This facility provides 15 kW to missions and requires 3.4 kW for subsystem support. The power for the subsystem platform represents 18% of the total bus power, as compared to 32% for the four-man space station. This difference is primarily due to crew support needs.

Array power increments are chosen based on modularity considerations; a 50-kW nominal size is chosen for the platforms. Two of these modules are needed for the four-man station; an additional module is added for the eight-man station.

3.4.4 Modularity Considerations

The space station system is assembled in orbit from modular elements because limitations of size, weight, and volume are imposed by the shuttle orbiter. These restrictions dictate that modules, in their transport configuration, be no larger than 174-in. OD and 53.25 ft long, and be compatible with orbiter lift capacity to the orbital inclination and altitude.

As illustrated by Figure 3-8, a typical space station architecture consists of a manned facility, which is expanded in orbit to accommodate increased power, crew, and functions, plus three unmanned platforms. One of the platforms is expanded to become a manned facility over a period of approximately 6 years. Each of the four facilities contains some or all of the same subsystem elements, which vary only in capacity.

The keystone for the buildup of any of these space station facilities is the first module in orbit. This module must be self-sufficient as a free-flyer until other modules are added to expand or complete the facility. The initial module is designated the utility module. It contains all the subsystems required for a free-flying satellite and, when sized properly, all the utility functions for an unmanned platform. The utility module must contain, as a minimum, solar array, electrical power subsystem, attitude control subsystem, thermal subsystem, communications and data management subsystem, and structural and mechanical subsystem, providing berthing and docking ports.

A standard set of elements can be used to construct all the required facilities, when the modular elements of the space station system are properly designed and sized, and the subsystems they contain are modularized.

Modular Element Sizing

By establishing the total space station system architecture and the buildup sequence, the largest, the smallest, and the increment size can be derived for each facility function. For example, the architecture for the prioritized mission model requires the initial space station to have a solar array producing 106 kW. The initial unmanned platform uses an array producing 53 kW. The high-inclination platform initially requires a 53-kW array and expands to require a 106-kW array. For this architecture, the basic utility module is sized to accommodate a 106-kW array, with the capability, through the use of modular electrical power subsystem elements, of being expanded to a 159-kW array or reduced to a 53-kW array.

Similarly, for the habitation module, the architecture defines the crew buildup in increments of four. A standard habitat module provides crew accommodations for four crew members and 4, 8, and then 12 crew members as habitation modules are added. These modules are identical structurally and in crew accommodation features; however, options in subsystems and interior furnishings are tailored to specific needs. For example, the first habitat module contains a command-and-control console for the space station, which is not be required for the second habitat module on the same facility.

Modular Element Requirements

Figure 3-8 illustrates the modular buildup for the prioritized mission model of space station system architecture. A total of 16 modular elements is required to assemble a total of four facilities in three separate orbit locations over a period from 1992 to the year 2000. Eight new modular elements are required for the first manned space station in 1992. Three additional new elements are required in 1994, and an additional four new elements in 1996. The time-phasing of new elements starts over a period of 5 years, minimizes leading-edge funding requirements, and makes the space station system compatible with limited annual funding. The total quantities of each modular element to satisfy architecture requirements range from one to six.

FIGURE 3-8.

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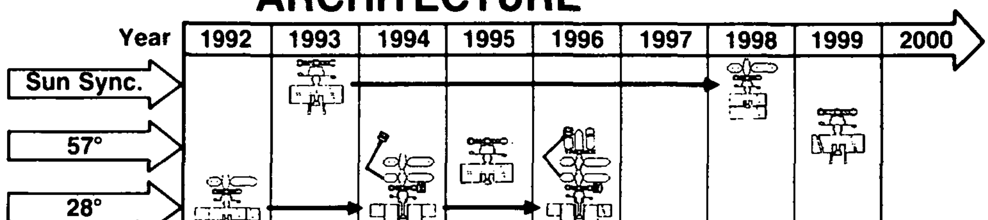
MODULAR BUILDUP IN SPACE STATION ARCHITECTURE



Modular Element \ Facility	1	2	1A	3	1B		2B	4	Total Modules
1. Orbiter Docking Module	1	1							2
2. EMU/MMU Casting	2		2				2		6
3. Utility Module	1	1	*	1			*	1	4
4. Propulsion Module	2	2		1				1	5
5. Payload Support Module	1	1		1				1	4
6. Docking Module	1		1				1		3
7. Habitability Module	1		1				1		3
8. Logistics Module	2						2		4
9. Laboratory Module	1		1				1		3
10. ROTV					1				1
11. LH_2 Storage Module					1				1
12. LO_2 Storage Module					1				1
13. Cryo Transfer Module					2				2
14. TMS Prop Module			1				1		2
15. TMS			1						1
16. RMS (Space Crane)			1						1
New Elements Total	8	0	3	0	4	0	0	0	

*Electrical Power Subsystem Expansion

Modular Element Definition

Figure 3-9 illustrates the 16 modular elements to construct the baseline architecture.

1. Orbiter Docking Module: This element provides the physical and functional interface between the orbiter and all orbiting space stations and platforms. It consists of a pressurized docking-berthing interface that protrudes out of the orbiter cargo bay. The module is located aft of the orbiter crew compartment at Station Xo 619 and attaches to provide pressurized access through the Spacelab tunnel adapter. The preliminary definition of the module has been completed. Two modules are required as a minimum: one for operation out of Florida for low-inclination orbits and one for operation out of California for polar orbits.

2. EMU/MMU: The existing extravehicular mobility unit, in combination with the manned maneuvering unit, is used by space station-based crew members to perform spacecraft servicing and aid facility buildup and maintenance. Four of these modular elements are required for the initial and expanded capability architecture.

FIGURE 3-9.

SS SYSTEM STANDARD MODULAR ELEMENTS

VGD941

	Element	Characteristics
1	Orbiter Docking Module	
2	EMU, MMU	
3	Utility Module	■ Array Pwr 50 to 150 kW ■ Thermal 75 to 225 kW ■ Com/Data Mgt 300 Mbps ■ Attitude Control
4	Propulsion Module	
5	Payload Support Module	■ 14 Unpressurized Ports
6	Docking Module	■ 6 Pressurized ■ 27 Ft Long
7	Habitability Module	■ 27 Ft Long ■ Crew of 4
8	Logistics Module	■ 27 Ft Long
9	Laboratory Module	■ 44 Ft Long
10	OTV	
11	LH_2 Storage Module	
12	LO_2 Storage Module	
13	Cryo Transfer Module	
14	TMS Propellant Module	
15	TMS	
16	RMS	■ 100-Ft Reach ■ 7 Deg of Freedom ■ 37.5-Lb Tip Force

3. Utility Module: The utility module is the first element to be placed in orbit for the buildup of a manned space station or an unmanned platform. Designed to accommodate a 106-kW solar array nominally with expansion capability in orbit to 159 kW, it may also be launched with a 53-kW array for use on smaller unmanned facilities. The module also contains a thermal control system sized to be compatible with electrical power; a communications and data management system with a 300-mbps data rate; an attitude control system designed to stabilize the projected complete facility; and a structural and mechanical system providing a two-axis solar array gimbal, support structure, and one to three berthing and docking ports. A total of three of these modular elements is required for the initial and expanded capability architecture.

4. Propulsion Module: The propulsion module is an interchangeable module containing tankage, thrusters, propellant distribution system, and valving to provide orbit-keeping thrust for the space station. Interfaces are provided for berthing and docking mechanism electrical power and data management. One module is required for each facility.

5. Payload Support Module: This truss-type composite structure is 44 ft long with a 5-ft square cross section. It mounts up to 14 berthing and docking interfaces. It contains the utilities distribution for the thermal control system coolant, electrical power and communications, and the data management data bus, and provides these functions at each berthing interface. Three modules are required for the initial and expanded capability architectures.

6. Docking Module: The docking module consists of a pressurized cylindrical structure 10 ft in diameter and 27 ft long, with berthing and docking ports on each end, and four radial ports. All ports are supplied and interconnected with the subsystem functions of thermal control, communications and data management, and electrical power. The interior is equipped with some crew accommodation and environmental control and life support (ECLS), lighting, and handrails. The initial and expanded architecture require two docking modules.

7. Habitability Modules: The habitat module has a 174-in. OD, is 27 ft long, and contains accommodations for four crew members. The outside surface serves as a combination meteoroid shield and radiator. Berthing and docking interfaces at both ends of the module provide interfaces with all subsystem

functions. This module also contains an ECLS subsystem. Two habitability modules are required for the initial and expanded capability architecture.

8. Logistics Module: The logistics module is a pressurized cylindrical structure with a 174-in. OD and is 27 ft long. Berthing and docking ports are provided on each end, with pressurized access through both. It contains tankage for liquid and gaseous expendables and internal racks for storing packaged materials. Two of these exchangeable modules are required to support each space station.

9. Laboratory Module: The laboratory module is a pressurized cylindrical structure 174-in. OD and 44 ft long. It has an integral meteoroid shield-radiator and berthing and docking ports at each end. Each of the ports interfaces with the electrical power, data management, and thermal distribution systems. The module contains internal structural racks to mount payloads; contains crew accommodations in the form of lighting, handholds, foot restraints, etc.; and provides general-purpose laboratory equipment. Two laboratory modules are required for the expanded-capability space station at 28-deg inclination.

10. ROTV: The reusable orbital transfer vehicle is a two-stage vehicle, both stages of which are equal in size. It is capable of transferring a payload of 8800 lb from the space station at 28.5-deg inclination to synchronous orbit and returning. Our analysis shows that one vehicle should accommodate geosynchronous launch traffic through the year 2000.

11. LH_2 Storage Module: This module serves as an on-orbit storage tank for LH_2 either transported by the orbiter or scavenged from the external tank. It is a special insulated vessel that forms part of the ROTV refueling system. The tank has an outside diameter of 174-in. and is 25 ft long. One module is required.

12. LO_2 Storage Module: The LO_2 storage module is the same as the LH_2 module, except its tank is 19 ft long and contains LO_2.

13. Cryogenics Transfer Module: The cryogenics transfer module is an exchangeable double tank that contains both LH_2 and LO_2. It has a 174-in. OD and is 11.3 ft long. Propellants may be transferred to this tank during transport in the orbiter. The full module is then exchanged for an empty one on the space station, and the empty one is returned to Earth. The propellants from the full tank are then transferred to the storage modules on the space station. Two modules are required.

14. TMS Propellant Module: The TMS propellant module is an exchangeable module containing propellants for the TMS. The module has a 174-in. OD and is 6 ft long. Two modules are required.

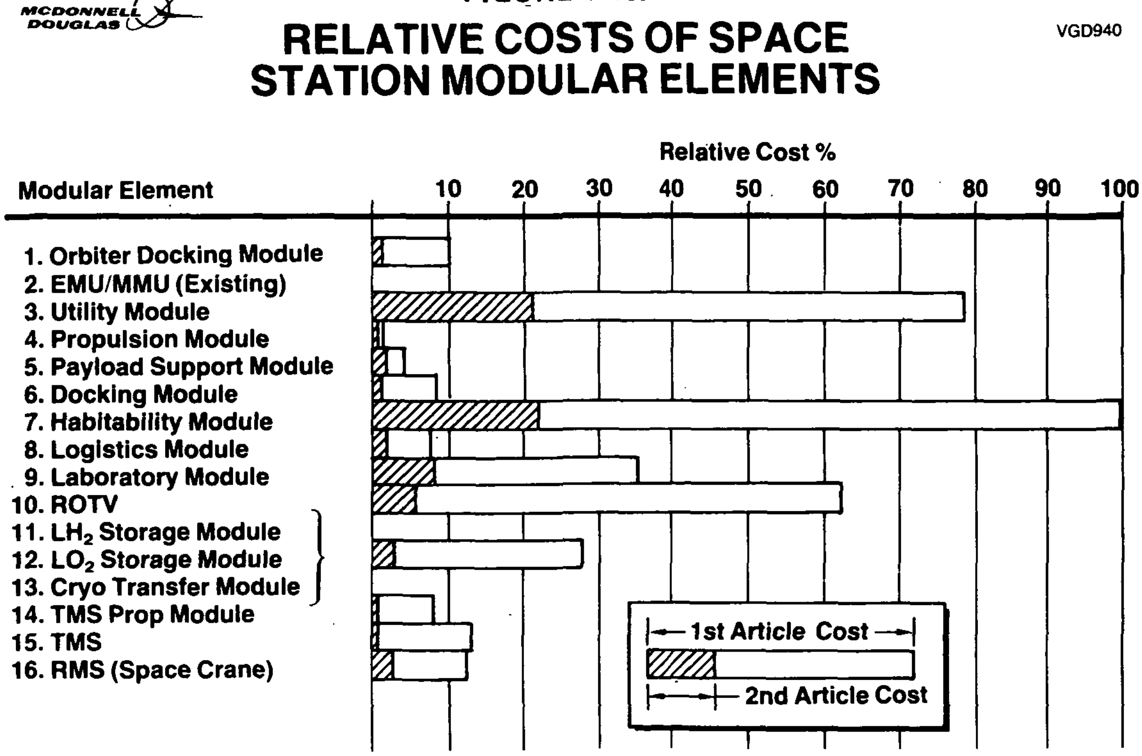
15. TMS: The teleoperator maneuvering system has a 154-in. OD and is 37 in. long. One TMS is required.

16 RMS (Space Crane): The RMS for use on the space station is a self-contained unit with a 100-ft reach, 7 deg of freedom, and a tip force at full extension of 37.4 lb. It provides handling capability for servicing satellites and for ROTV operations. One RMS is required.

Cost Impacts

The concept of standard modular duplication is essential to producing a space station system in a cost-effective manner. Figure 3-10 illustrates the cost of the first article of each module relative to the most expensive one. The most costly of the elements is the habitability module, with the utility module a close second. The figure also illustrates the cost of producing the second unit of a design relative to the first unit cost, showing that the cost of design, development, and qualification of the first article can range from 1.9 to 10 times the cost of a second such article.

FIGURE 3-10.
RELATIVE COSTS OF SPACE STATION MODULAR ELEMENTS



Section 4
MISSION EMPHASIS ARCHITECTURES

The architectures discussed in this section emphasize a particular mission class or combination of classes, including science and applications, operations and technology, and commercial emphasis missions. Also, an architecture is presented for a low-cost (intermittently manned) concept that is particularly attractive if early ROTV implementation is desired or if ROTV support is needed in an architecture containing no space station at 28.5 deg. Requirements for these special-emphasis missions are presented in Section 2 of this volume.

4.1 SCIENCE AND APPLICATIONS EMPHASIS ARCHITECTURE

A review of requirements for this architecture from Figure 2-6 shows these mission needs are characterized by crew sizes of one to three, high data rates up to about 200 mbps average with 250 mbps peak for individual missions, power ranging from 14 kW to about 57 kW, and moderate resupply needs. These mission requirements tend to increase during the 1992-to-2000 time span, but about one-half of the maximum needs are required early.

As shown in Figure 4-1, the architecture to satisfy this special-emphasis area consists of a four-man space station at sun-synchronous inclination and a 37-kW platform at 28-deg inclination. This architecture can capture 100% of the science and applications missions with the resources assigned to it. The space station provides 25 kW of mission power and a high data rate (250 mbps peak) as required by the multispectral linear array (SEP002 in Figure 2-1), which is located on the station. A relatively large number of mission-dedicated ports is provided, which constitute points of attachment and utilities connections for pallet-type mission equipment. Pressurized laboratory space is also provided for the portions of the mission equipment requiring it.

FIGURE 4-1.

SCIENCE AND APPLICATIONS EMPHASIS ARCHITECTURE

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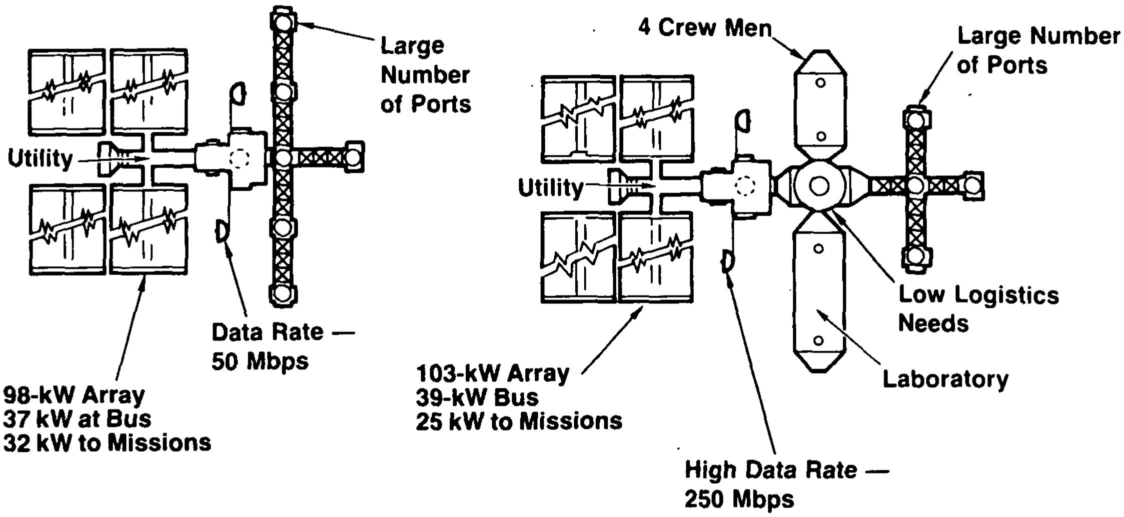
LOCATION:
PLATFORM AT 28-DEG INCLINATION
SPACE STATION AT SUN-SYCHRONOUS ORBIT



The space station is supplemented by a platform in a 28-deg orbit, which provides a large number of unpressurized mission-dedicated ports and 32 kW of electrical power to the missions. A lower data rate of 50 mbps is provided in this facility, which satisfies the needs of this mission set.

4.2 OPERATIONS AND TECHNOLOGY EMPHASIS ARCHITECTURE

Requirements for this special-emphasis architecture feature relatively low data rates and power, moderate crew sizes up to a two-man level, and very high expendable resupply in the ROTV era starting in 1996. During the period of 1992 to 1995, development missions will be conducted for the OTV and TMS, and then later in the time period TMS operations will commence. Also technology development missions occur during the first 2 years; therefore, the resource needs are low (see Figure 2-6). A step increase of resources occurs when ROTV operations are introduced in 1996, and expendables increase to 360,000 lb/yr for cryogenic propellants.

The architecture for this special-emphasis mission area is shown in Figure 4-2 and consists of a three-man space station located at 28.5-deg inclination. A total of 11.3 kW of bus power is provided, of which less than 1 kW is mission power and the rest is consumed by on-board subsystems. A low-data-rate data management system is provided along with an RMS for supporting operations such as EVA, grappling returning ROTVs and TMSs, during rendezvous berthing operations, and transferring propellant tanks, payloads, and associated equipment. Payloads, propellant tanks, and ancillary equipment are stowed on a structural member that contains unpressurized docking ports and electrical, thermal, and data utilities.

FIGURE 4-2.

OPERATIONS AND TECHNOLOGY EMPHASIS ARCHITECTURE

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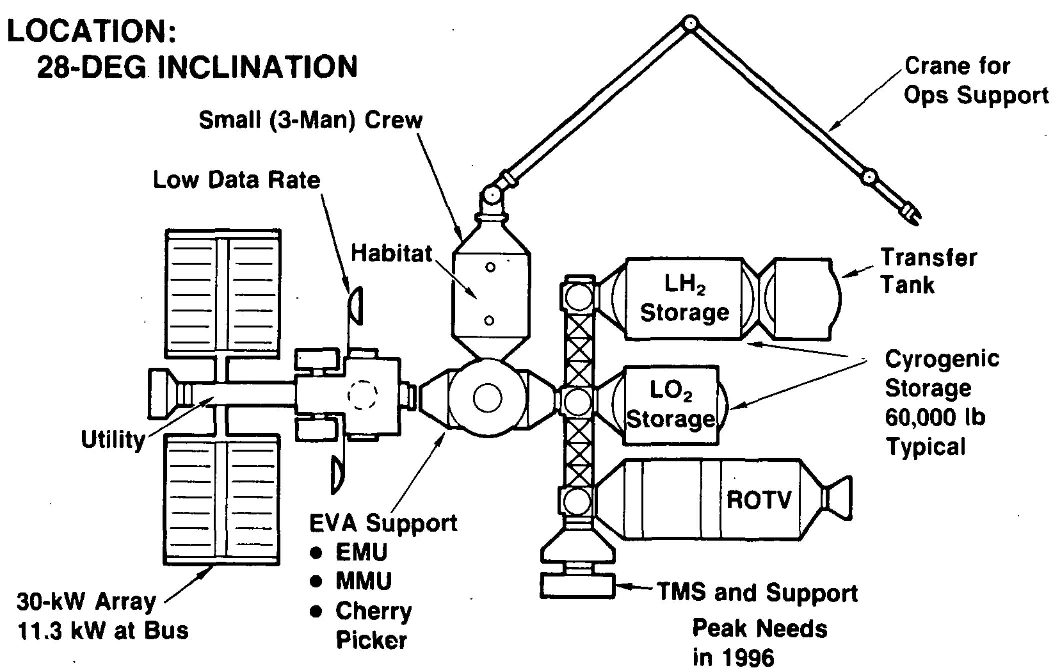

This architecture represents a design point concept that considers only the needs of operations and technology missions and is not cost optimized. Section 4.4 presents other concepts that are initially low-cost, unmanned versions that can later evolve to support other mission classes.

4.3 COMMERCIAL EMPHASIS ARCHITECTURE

Time-phasing of commercial mission needs is similar to that of operations in that early missions are primarily of an R&D nature and are characterized by rather low resource needs (see Figure 2-7). Initially, electrical power is only about 12 kW, but later it builds to above 50 kW in 1997. Data rate remains low, as needed to support control and monitoring functions.

Resource needs as shown in Figure 2-7 reach a peak in the 1995-to-1997 time period and then decline after that period. This is because less mission definition is available for the latter time period. In reality, an increasing need for resources to support commercial needs is expected, as commercial application matures to the production era.

The commercial-emphasis architecture, shown in Figure 4-3, consists of a five-man space station at 28-deg inclination and a 28-kW platform at 57-deg inclination. The space station supplies 28 kW to commercial missions from a design that has 47 kW at the bus. Missions with needs for a large resupply of expendables will be placed on this facility at 28 deg in order to maximize orbiter launch capability.

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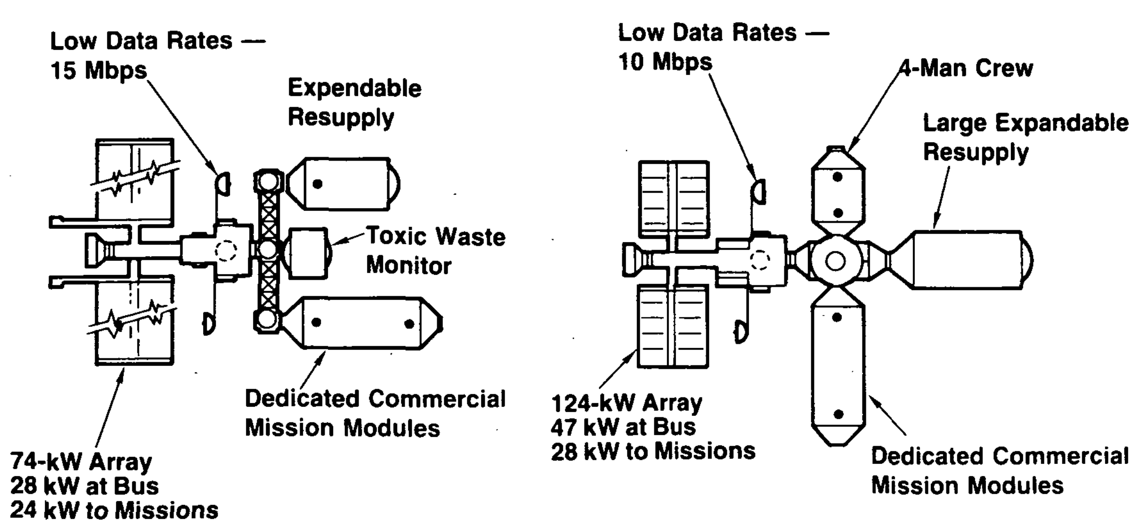
FIGURE 4-3.

VGB827

COMMERCIAL EMPHASIS ARCHITECTURE

LOCATION:
PLATFORM AT 57-DEG INCLINATION
SPACE STATION AT 28-DEG INCLINATION



The platform is placed at a 57-deg inclination to support the toxic waste monitor, which requires high-inclination viewing of the Earth. Both facilities have low data rates of 10 and 15 mbps.

An attractive alternative to this architecture consists of several smaller platforms, with dedicated platforms for each individual user. This secures proprietary rights for the user and assists in assigning user charges.

4.4 INTERMITTENTLY MANNED OPERATIONS CONCEPTS

This section discusses two low-cost, intermittently manned (orbiter tended) space platforms, i.e., the ROTV support platform and the ROTV multimission platform (Section 4.4.2). Both these concepts have a predominantly operational flavor (H_2/O_2 ROTV base/depot and satellite servicing). The only functions the first concept performs are ROTV basing, fueling, checkout, and launch, along with the related functions of payload storage, stacking, and checkout. The second concept in addition to performing the same functions as the first also accommodates satellite servicing, a variety of attached missions (primarily commercial), and a variety of attached missions that require pointing (primarily science and applications).

An additional benefit accrues in going to the growth concept: the associated increased traffic gives more opportunities to use payload topping propellant and may make it possible to bring up large quantities of H_2 and O_2 at a reduced transportation cost.

4.4.1 ROTV Support Platform

The ROTV support platform, whose only function is to support a space-based ROTV program (as noted above), is employed if (1) there is a strong desire for an early (approximately 1991), low-cost H_2/O_2 ROTV system, or (2) a low-cost ROTV base is needed in the mid-1990s in conjunction with a manned space station at high inclination (e.g., 90 deg).

This section discusses: (1) the nature of the assumed ROTV system to be accommodated; (2) the resulting requirements imposed on the ROTV support platform, and (3) platform characteristics, performance, and operations.

4.4.1.1 ROTV Mission Model/Operations Scenario. As commercialization of space expands, the demand for higher performance and more efficient, cheaper launch services is expected to increase. At present, the Shuttle is the only reusable launch vehicle in operation. The upper stages currently available and those in development are basically expendable stages. Development of a cryogenic ROTV promises improvements in both performance and economy over current and planned expendable stages. For maximum economy, this system will be placed in low Earth orbit and will remain in orbit to be fueled, serviced, and subsequently launched from a space facility. Based on current cost and traffic estimates, this system appears economically viable and may be considered as a candidate for commercial development and operation. Table 4-1 is a projected traffic model for geosynchronous missions in the 1990s that are candidate payloads for a reusable upper stage. An ROTV sized for an 8820-lb payload and equipped for multiple payload delivery up to this total, offers major operating cost advantages in comparison with the projected inventory of expendable stage alternatives. By combining delivery missions where possible, a total of 39 ROTV flights from LEO to GEO are needed to accommodate the 100-mission profile. This mission model represents a conservative estimate of only 13 missions per year, a number that could easily double if more optimistic traffic projections prove correct.

Table 4-1. Dedicated Satellite Traffic Model

CODE	NAME	#LAUNCHES PER YEAR 90	91	92	93	94	95	96	97	98	99	10 YR TOTAL 00	INC DEG	ALT KM	MASS KG
XAS012	SIMULT ASTRO EXP	1	0	0	0	0	0	0	0	0	0	1	0	GEO	2000
XAS013	FAR UV SPECT EXP	1	0	0	0	0	0	0	0	0	0	1	0	GEO	1000
XCM001	INTELSAT VI	2	1	2	2	0	0	0	0	0	0	7	0	GEO	2004
XCM002	INTELSAT VII	0	0	0	0	1	2	3	2	0	0	8	0	GEO	3636
XCM004	TEL	0	0	0	0	1	0	0	0	0	0	1	0	GEO	702
XCM005	WESTAR	0	0	2	1	0	0	0	0	0	0	3	0	GEO	626
XCM006	TDRS/ADV WESTAR	0	1	0	1	1	1	1	0	0	0	5	0	GEO	2273
XCM007	SATCOM	0	0	1	1	1	1	0	0	0	0	4	0	GEO	895
XCM008	SBS	0	1	0	0	1	1	1	0	0	0	4	0	GEO	550
XCM009	GALAXY	0	0	1	1	0	1	0	0	0	0	3	0	GEO	632
XCM010	SYNCOM	0	0	0	0	0	2	1	2	0	0	5	0	GEO	1314
XCM011	GSTAR	0	0	0	0	0	1	1	1	0	0	3	0	GEO	702
XCM013	STC	0	0	0	2	2	2	0	0	0	0	6	0	GEO	702
XCM014	DBS	2	0	0	0	0	2	2	2	0	0	8	0	GEO	1136
XCM016	DATA TRANS	1	0	0	1	0	1	0	1	0	0	4	0	GEO	636
XCM017	BANKING	0	0	1	0	0	1	0	0	0	0	2	0	GEO	636
XCM018	MAIL	0	1	0	1	0	1	0	0	0	0	3	0	GEO	636
XCM019	SATCOL	0	0	0	1	1	0	1	0	0	0	3	0	GEO	715
XCM021	TELESAT	1	0	2	0	1	0	0	1	0	0	5	0	GEO	702
XCM022	CHICOMSAT	1	0	0	0	1	1	0	1	0	0	4	0	GEO	702
XCM023	PALAPA	0	1	0	1	0	0	1	0	0	0	3	0	GEO	632
XCM024	MISC	0	1	1	0	1	1	0	0	0	0	4	0	GEO	702
XCM025	NATO	0	0	0	0	0	1	1	0	0	0	2	0	GEO	432
XCM026	TRACK/DATA ACQUISIT	0	0	1	0	0	0	0	0	0	0	1	0	GEO	3000
XEE004	GEO OP/ENV SAT	0	0	1	0	0	0	0	1	0	0	2	0	GEO	874
XEP001	GEOS	2	0	0	0	2	0	0	2	0	0	6	0	GEO	400
XXX002	INSAT	0	1	0	0	1	0	0	0	0	0	2	0	GEO	591
	Total Missions:	11	7	12	12	14	19	12	13	0	0	100			117798 (259,700 lb)

Based on the analysis reported in MDC 0535 "OTV/TMS Utilization", a two-stage ROTV capable of multiple payload deployment is selected as the basis for determining ROTV support requirements. The associated mission profile is illustrated in Figure 4-4. Based on a design condition of delivering 8820 lb to GEO with zero return to the space base, the two-stage ROTV requires a total of 27,600 lb of H_2/O_2. To minimize ROTV development, the two stages are assumed to hold equal amounts of propellant (13,800 lb). This two-stage ROTV accomplishes the traffic model identified in Table 4-1 with a flight rate of six per year (excluding DOD missions).

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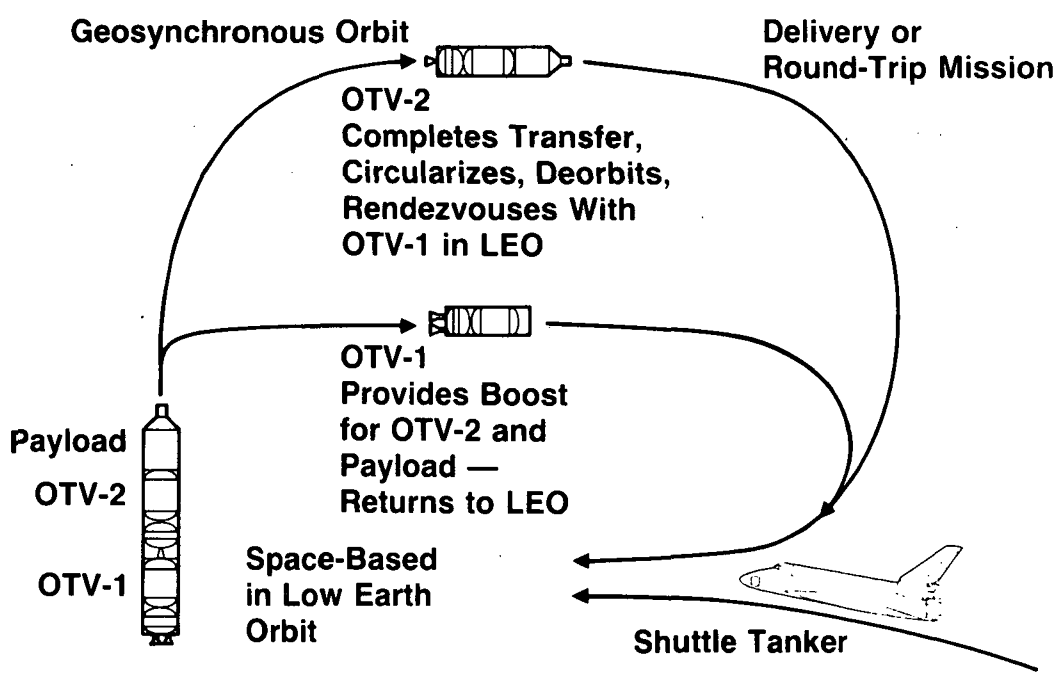
FIGURE 4-4.

VGB691

OTV MISSION PROFILE



4.4.1.2 Functions and Requirements. The functions of and requirements for the ROTV support platform are summarized in Table 4-2. The primary requirement for this application is for a low-cost, space-based ROTV system; this implies an intermittently manned space platform (orbiter tended).

Table 4-2. ROTV Support Platform Requirements

Function	Requirements
ROTV flights/year	6
Berthing/stacking/propellant module transfer	Manipulator; berthing space and ports/attachment latches
ROTV launch checkout and control	Manned supervision
ROTV recovery	Automatic/unsupervised
On-orbit crew support	Intermittent at assembly/checkout/ launch (200 MH/mission)
Usable H_2/O_2, lb/yr	23,600/141,000
Cryo H_2/O_2 storage	Exceed single mission need 909 day hold - minimum boiloff
Electrical power	
- Standby (unmanned)	2.5 kWe average
- Peak (operations)	7 for a few days
Orientation/stability	Stability for rendezvous
Growth potential	For larger platform and/or permanently manned station

The nominal ROTV flight rate is six missions per year, based on clustered payloads and the requirements of Table 4-1; this rate might grow to 12 flights per year. The nominal propellant use rate is 23,600 lb of H_2 and 141,600 lb of O_2 per year, excluding boiloff and other losses. The platform cryogenic depot (storage) tanks must be adequately sized and have sufficient hold capacity with reasonable boiloff to provide mission flexibility and growth potential. As a minimum, the capacity should exceed the needs of one ROTV mission.

Payload and ROTV support requirements include room attachments and equipment for (1) payload cluster and fuel transfer from the orbiter, (2) storage, (3) payload stacking, (4) ROTV servicing and fueling, (5) checkout and launch control, and (6) ROTV recovery without on-orbit manned support (to maximize mission flexibility and minimize orbiter stay-time and operations cost). An important requirement relates to the capability to grow to a much larger platform or to a permanently manned space station.

4.4.1.3 Description and Operations. The ROTV platform makes maximum use of hardware common to other space station facilities.

- Configuration. Figure 4-5 shows the ROTV support platform configuration. The concept incorporates a ground-assembled, space-deployed, support beam, and a 2.5-kW utility module, which supplies the necessary subsystems (e.g., power, and guidance, navigation, and control).

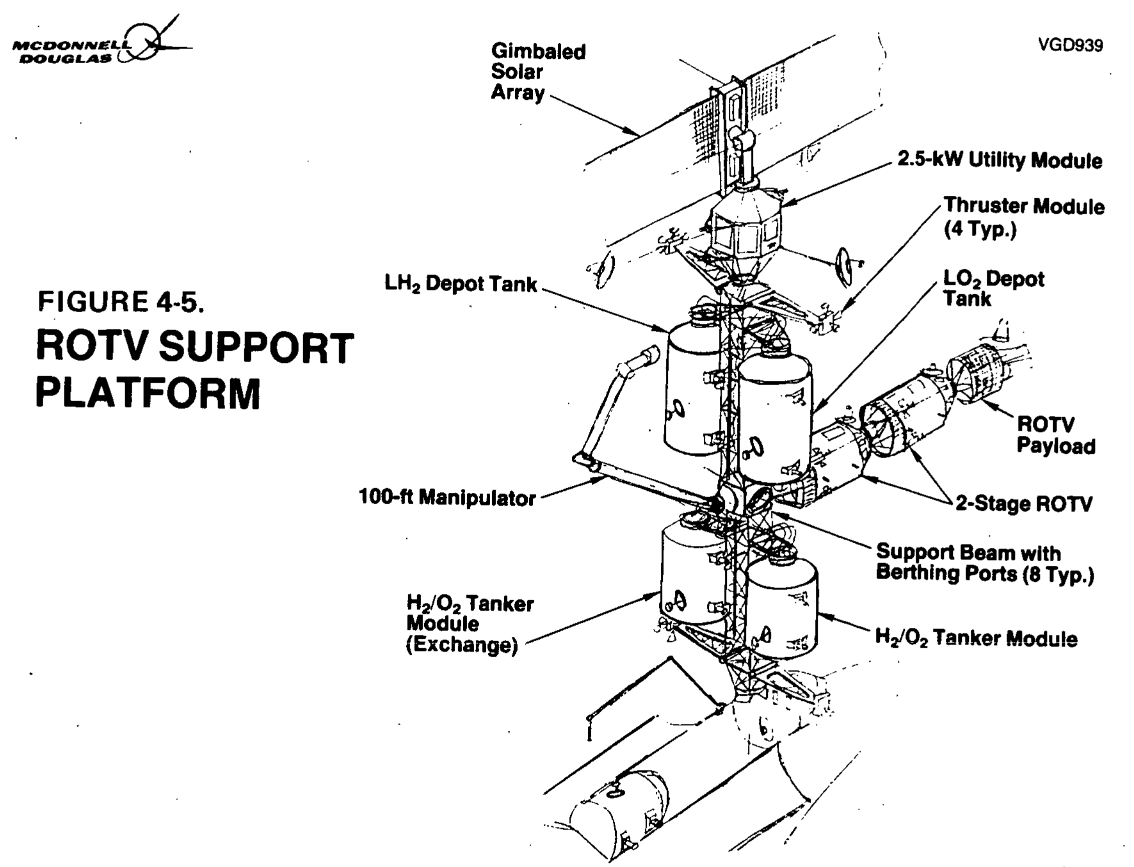


FIGURE 4-5.
ROTV SUPPORT PLATFORM

Resupply LO_2/LH_2 propellant is stored in depot tanks delivered by the orbiter and berthed to the support beam using two orbiter-type longeron latches and one keel fitting. Swing-away umbilical panels attach the LO_2/LH_2 tanks to the service station. Berthing ports for up to six ROTV payloads plus the two-stage ROTV are incorporated.

- Characteristics. Table 4-3 summarizes the characteristics of the ROTV support platform and presents related remarks and rationale. An H_2 vapor shield is used to minimize boiloff from both the H_2 and the O_2 tanks; hence, the H_2 depot tank contains excess LH_2. The depot tanks are maximum size for one orbiter launch (together) and can accommodate almost two ROTV maximum missions for orbiter manifesting flexibility. Although it is likely that zero-g screen devices can be used for propellant acquisition and

Table 4-3. ROTV Support Platform Characteristics

Function/Item	Selected Approach	Remarks/Rationale
H_2/O_2 storage, lb	11K/42K; H_2 vapor shield	Depot tanks in one launch (44 ft.). Flexibility - 2 ROTV missions; low boiloff (H_2); 10^{-4} g's for settling.
Berthing/stacking/cryo tank transfer	100 ft, 7 DOF manipulator	On tracks; growth; low cost; based on RMS
ROTV launch check-out/control	Orbiter aft flight deck	Low cost, maximum use of orbiter
ROTV recovery	Automatic; laser range/attitude	Flexible, low cost; laser range resolution/accuracy
Crew support mode	Orbiter tended at assembly/checkout/launch	Early, low cost
Electrical power	Solar array and regen fuel cell	low cost/commonality; Peaks - fuel cell or orbiter
Orientation/stability	Gravity grad./thruster control	Low cost; thrusters for brief special operations
Growth potential	Multiple ports (Esp. ±X and ±Y)	Growth in four directions

transfer, a conservative approach is tentatively selected for this function (10^{-4} g for 60 min).

The initial platform is equipped with a track-mounted, 100-ft manipulator having 7 deg of freedom to provide maximum mission support and growth capability. Station growth capability is achieved by providing docking ports at either end of the X-axis (long axis) and the $\pm$Y-axis at the center of the platform.

The use of an orbiter-tended manning mode, at least early in the program, makes maximum use of the orbiter's capabilities and is a low-cost solution inasmuch as the orbiter must bring up H_2/O_2 and payloads anyway. Special control provisions are needed in the orbiter aft flight deck for servicing, fueling, stacking, checkout, and launch.

- Communications and Data Management Subsystems. The communications and data management subsystems provide RF communications between the station and TDRSS, shuttle, and TOVs. The communication links provide command and data transfer capability. A global positioning system receiver/processor is included to provide information regarding orbit position. When the orbiter is berthed with the station, hardwire interfaces are provided for commands, data, and television video signals to support the control of the ROTV, payloads, and station activities from the aft flight deck of the orbiter. Minimal data management capability is provided onboard the station to support between-mission housekeeping of the ROTV and to support payload and ROTV checkout, mating, and deployment. A major technical challenge is to develop the docking sensor and the associated control capability to support automatic or remotely controlled ROTV recovery and docking. The docking sensor is envisioned as a laser ranging implementation, with ancillary data provided by GPS, onboard attitude measurement systems, and other available sources.

- Electrical Power Subsystem. The electrical power subsystem uses components employed by other facilities in the space station architecture. It features a foldup, flexible substrate solar array on a two-axis gimbal system. The two-wing array is a short version of the PEP/space platform array. A regenerative fuel cell/electrolysis cell system is used for energy storage. The fuel cell can be used in a primary mode for emergencies and peak loads during man-tended periods. Oversize power transmission cables are provided for growth.

• Guidance, Navigation, and Control. Attitude control system (ACS) requirements for the ROTV support platform are minimal. The vehicle's attitude and altitude rates must be compatible with ROTV and orbiter berthing and release. During other operations, solar array pointing is the primary requirement. Accuracies on the order of several degrees and rates of about one-tenth of a degree per second are adequate for platform operations. Momentum storage devices, therefore, are not used on the initial facility for attitude control. The vehicle will be allowed to attain a stable-equilibrium, Earth-referenced attitude, which aerodymamic, gravity gradient, and gyroscopic torques will maintain. Thrusters are used for rate damping, maneuvering, and special operations. The solar array is gimbaled to maximize solar incidence. Sun sensors and horizon sensors are used for measuring attitude, and a three-axis gyro package is used for short-term attitude reference and angular rate measurement. An ACS interface electronics package is also used.

• Reaction Control Subsystem. The primary functions of the reaction control subsystem (RCS) are to control (1) attitude during brief periods of special operations (e.g., orbiter rendezvous), (2) orbit-keeping, (3) acceleration for H_2/O_2 settling for transfer, and (4) postmission deorbit. In general, these functions require very high reliability and should be accomplished by a system independent of the operational propellant depot. The primary candidates for the RCS are N_2H_4 and an independent gaseous H_2/O_2 system; N_2H_4 is selected tentatively because it is a flight-proven, low-volume, and low-cost system.

The hydrazine propulsion system is integrated into the deployed support beam. The four thruster modules are mounted on swing arms to minimize plume impingement concerns and maximize platform control.

• Structural and Mechanical. The support beam is a long graphite epoxy telefold design 2.0 m x 2.0 m x 25.0 m (6.55 ft x 6.55 ft x 82.0 ft). The longerons fold between frames, and the shear members telescope. It is deployed by means of crank arms at one end and a motor-driven screw jack actuator. With a 10:1 compaction ratio, the entire support beam is expected to be compacted and transported in one orbiter flight.

The mechanical interface with the orbiter is a passive system mating with a shuttle-provided active system mounted in the cargo bay. Payloads and ROTV stages berth to identical active interface mechanisms. Umbilical panels are configured to supply propellant to the ROTV through the berthing systems at the ROTV refuel and launch station only.

The utility module is constructed of aluminum isogrid structure. The manipulator is a 20-in.-diameter x 100-ft-long graphite epoxy device incorporating 7 deg of freedom; it has a tip force of 37.5 lb.

The active mechanical berthing systems are a self-aligning hexagonal frame design with three capture guides and dual-motor actuators.

Cryogenic propellant resupply tanks are berthed to the support beam with two active longeron retention devices and one active keel retention actuator developed for the orbiter.

- Operations. Following deployment of the utility module and support beam, the empty LO_2/LH_2 depot tanks are delivered and positioned, using the 100-ft-long manipulator. Propellant is delivered by the orbiter in a cryogenic tanker module. The tanker module is removed from the orbiter and berthed to the platform, using the orbiter RMS and/or the station manipulator.

This procedure minimizes scarring associated with cryogenic lines in the orbiter cargo bay.

Following separation of the orbiter, the platform reaction control system supplies the necessary impulse to permit cryogenics to be transferred into the depot storage tanks, and from the depot tanks into the ROTV.

The onboard manipulator stacks the ROTV stages and mates the payload. Propellant is pressure transferred from the depot into the ROTV, which is then mechanically separated from the platform.

The first stage of the ROTV returns with an automatic rendezvous to the platform, where it is captured by the onboard manipulator and berthed. The procedure is repeated for the second stage.

4.4.2 ROTV/Multimission Platform

This section discusses the second, low-cost, intermittently manned space platform, which is either an alternative or a growth version of the ROTV support platform previously discussed. The additional functions included in this platform relate to satellite servicing, commercial, and science and applications missions that are suitable for a low-cost platform system in a

28.5-deg-inclination orbit. These additional missions have a beneficial effect in that they provide additional orbit traffic to the platform, and thus offer the potential for payload topping propellant that may be available at a reduced transportation cost into LEO.

The principal design differences between the ROTV multimission platform and the previously discussed ROTV support platform are (1) substitution of a large utility module for the 2.5-kW module, (2) additional support beams and berthing ports along the Y-axis, and (3) addition of TMS.

4.4.2.1 Satellite Servicing Mission Model/Operations Scenario. As the quality and value of our space assets grow, the need for logistics support and orbital maintenance and repair services will increase. At present, several high-value satellites are inoperable or malfunctioning and are candidates for such service. Still others are planned that will require periodic servicing and support as part of normal operations.

On-orbit servicing from a space facility (station or platform) is a candidate for the first operations mission. Thirteen satellites have been identified as candidates for servicing in the years 1992 to 2000 (see Figure 4-6). These satellites are of high value, are accessible to a facility in the indicated orbit, and most were designed for on-orbit servicing.

Seven of the satellites will be in a 28.5-deg orbit. Six of these satellites have been designated for orbital service missions in the mission model for the space station systems. The average interval between scheduled maintenance activities is about 2.5 yr. When all satellites are on orbit simultaneously, there are over two service missions per year. Each requires a dedicated launch if serviced from the space shuttle. Repair of failed equipment adds to the number of service missions and required shuttle launches. Figure 4-7 illustrates a typical satellite (space telescope) that can be serviced by the ROTV multimission platform.

Dedicated launches are not required for service performed from a space station or space platform because replacement parts, supplies, and equipment can be taken to the facility in advance of the service mission when space is

FIGURE 4-6.

VGB560

SATELLITE-SERVICING MISSIONS

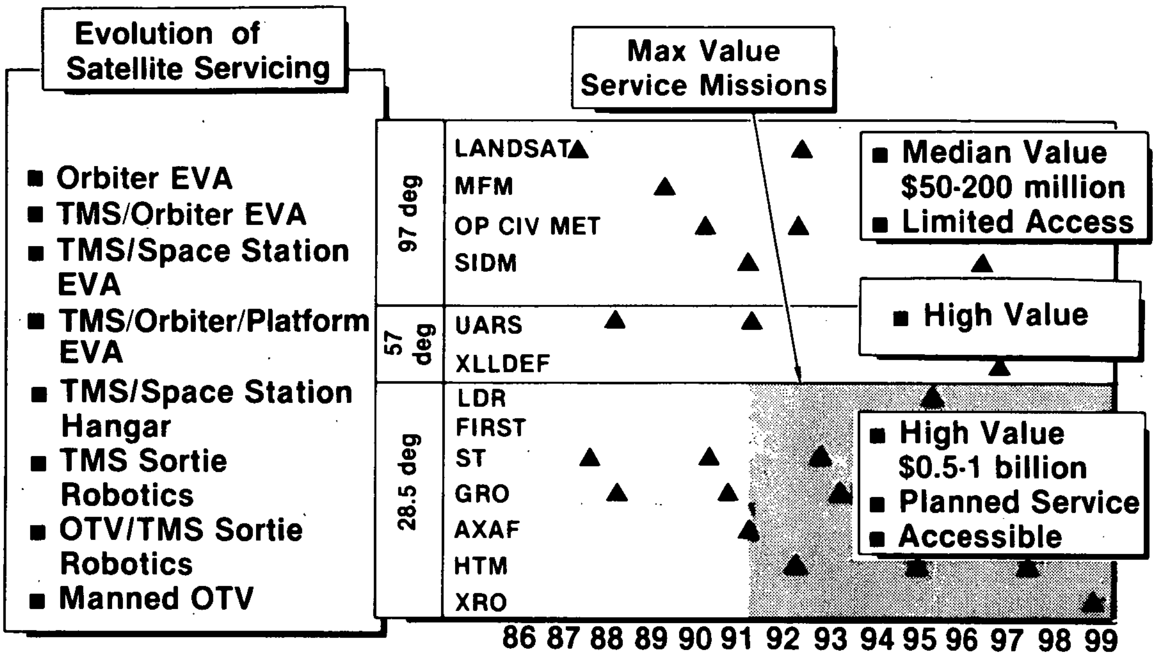
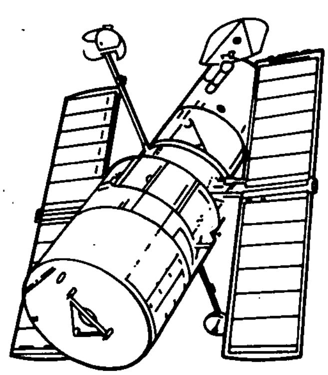


FIGURE 4-7.

VGD938

SAS009 SPACE TELESCOPE (ST)



CHARACTERISTICS

Space Station Service Mission
Astronomical Observatory, Near-IR Through UV 2.4 m Optics

CONSIDERATIONS

Inertial View
Maintenance Every 2-1/2 Year
Refurbishment Every 5 Years
On-Orbit Servicing Desired

MISSION DATA

Status:	Fabrication
Earliest Availability:	1985
Mass:	24,200 lb
Preferred Orbit:	600 km, 28 deg
Power:	2.1 kW
Data Rate:	
Accommodation:	Station – U Platform – U Satellite – R
Crew Hours/ Operations Per Year:	Scientist/Observer – 0 Operator/Engineer – 0 Technician – 31/0.4
Launch Volume:	4 Pallets (40 Ft)
Peak Rate Duty Cycle:	0.8
Priority Rating:	1
Study Disposition:	1985 IOC, Dedicated Satellite (28.5 deg) Service from Space Station

available on the shuttle. In addition, repairs can be performed in a timely manner without perturbing the shuttle launch schedule. The net savings in shuttle launches is estimated at two to three per year.

4.4.2.2 Functions and Requirements. Table 4-4 lists candidate satellite servicing functions and requirements, which involve extensive investment in servicing and support equipment, as well as considerable training and specialized gear for each specific mission.

The kinds of functions listed in Table 4-4 are only feasible at present with manned participation. For specific cases, remotely controlled operations may prove feasible, but the ability to respond to any mission need and to

Table 4-4. ROTV/Multimission Platform Requirements (Satellite Servicing)

Function	Requirements
Satellite retrieval and deployment; disposal	6 missions/year (12 TMS flights); to 324 nmi max
TMS refueling depot size	8,360 lb N_2O_4; 5,060 lb MMH; 54 lb GHe
TMS/payload attachment/berthing	Manipulator; berthing space and ports/ attachments
TMS/satellite checkout and launch control	Manned supervision; instrumentation and control
TMS recovery	Automatic/unsupervised
Equipment removal and replacement	Manipulator, crew support, EVA access, special tools and lighting
Refueling (TMS/satellite)	Fluid/propellant and gas supplies, lines and displays/controls
Thermal control	Sun shields
Electrical power	Lights, satellite checkout and tools/equipment
Parts and equipment storage	External and internal racks (pressurizable module)
Equipment cleaning	Cleaning provisions; EVA

resolve real-time problem situations with efficiency will require manual operations in orbit.

Table 4-5 summarizes a typical set of missions that are compatible with a low-cost ROTV/multimission platform (orbiter-tended) at 28.5-deg inclination. The table presents the experiments alphabetically by code and also gives the experiment name. Table 4-6 presents a sort by typical experiment IOC date. Table 4-7 is a summary of cumulative space platform resource requirements as functions of year, based on the mission IOC dates and durations from Tables 4-5 and 4-6. For example, the peak power requirement is 34.66 kW, which occurs in 1993, and the peak logistic requirement 164,496 kg (362,714 lb) occurs in 1996 and 1997. The need for 4404 man-hours (1996 to 1997) may be high for an orbiter-tended program, and further work is needed to adjust resource estimates and mission selection and scheduling of the system resource requirements. MDAC Report H0533 presents a more detailed explanation of the various entries in the mission computer printouts.

4.4.2.3 Description and Operations

The multimission platform makes maximum use of hardware common to other space station facilities.

- Configuration. The multimission platform, shown in Figure 4-8 with a typical complement of mission equipment, incorporates the basic telefold core structure, the LO_2/LH_2 propellant storage tanks, and the ROTV launch services of the ROTV support platform. The small 2.5-kW utility module is replaced with a 35-kW module to support the additional non-ROTV missions. Two telefold support beams are added to the $\pm$Y-axis; they incorporate berthing ports and integrated subsystems to support satellite servicing, repair, and deployment. The space telescope and SIRTF are depicted in Figure 4-8 as representative satellites on the platform for servicing. A TMS support facility with TMS berthing, retrieval, and propellant resupply systems is berthed to the core element.

EVA associated with satellites, ROTV payloads, and platform servicing exceeds the orbiter's support capabilities; therefore, a pressurizable platform service center is added to support EVA operations and other platform activities. The service center is a standard 14.5-ft-diameter x 27.0-ft-long module incorporating an airlock, tool storage, data equipment, and ROTV launch

Table 4-5. Space Station Data Base

MCDONNELL DOUGLAS ASTRONAUTICS HUNTINGTON BEACH
Apr.15, 1983

STATUS
O=operational
P=planned
C=candidate
I=opportunity

ACCOMMODATION
R=required S=supply
D=desired L=launch
A=acceptable M=maint/repair
B=assemb/build

VIEW
A=any M=multiple
E=earth S=solar
I=inertial V=velocity
Z=anti earth

LEGACY
S=spacelab
O=other legacy

CODE	NAME	SOURCE	DATE STAT	DUR	INC DEG	INC MAX	INC MIN	ALT DES	ALT MAX	ALT MIN	STAT	PLAT	SERV	MOD	RACK PAL	PORT	POWER	DATA	DUTY	POWER *DUTY	LMASS	EXPEND	G	CODE	VIEW	CREW SIZE	HRS DAY	DAYS YR	BEN	SAVE CONS	SAVE RISK	BEN* CONS	SAV* RISK	PRIORTY	LEGACY
CIR001	MATERIALS RES FAC	MH	I 93	5	A	97	28	400	700	370	R			SM	0	.0	1	25000	10000	.20	5000	7500	10	-3	CIR001	A	2	2.00	60	23	7 21	27	161	567	2.00	
CMP001	ELECTROPHORETIC PRO	MS	C 90	5	A	99	0	400	700	370	A	A	M	SM	0	.0	1	15000	1000	.80	12000	7500	6000	-3	CMP001	A	1	2.00	50	29	9 21	30	261	630	1.00	0
CMP012	GA AS FACILITY	B	I 95	5	A	97	28	370	700	370	R				2	.0	0	5000	1000	.20	1000	2500	0	-3	CMP012	A	2	4.00	50	20	6 22	23	120	506	4.00	
OSR001	SAT SERV OPS	MH	P 92	99	28	28	28	400	700	350	R		S	SS	0	.1	1	2000	700	.01	20	1000	0	0	OSR001	A	2	10.00	10	21	6 23	24	126	552	1.00	
OTR001	TMS OPS	MH	P 92	99	28	28	28	400	700	350	R		L		0	.3	1	2000	350	.02	40	1300	650	0	OTR001	A	2	10.00	30	20	6 24	24	120	576	1.00	
OTR004	OTV OPS (2STG)	MH	C 96	99	28	28	28	400	700	350	R		L		0	.3	1	3000	500	.07	210	1400	13000	0	OTR004	A	3	10.00	60	22	5 22	20	110	440	2.00	
SAS008	XRAY OBSER	MH	C 99	2	28	28	0	400	570	370	A	A	M		0	2.0	0	900	1000	.00	0	3550	0	0	SAS008	I	2	9.00	2	20	4 28	22	80	616	3.00	
SAS010	HIRES X&G-RAY SPEC	MH	C 90	2	28	45	0	400	500	350	D	A	M		0	.5	1	530	35	.80	424	1668	10	0	SAS010	I	2	7.00	1	20	3 28	21	60	588	4.00	S
SAS011	XRAY TIMING EXPL	MH	A 89	5	28	45	0	400	600	300	A	A	M		0	2.0	1	600	1000	.80	480	1000	0	0	SAS011	I	2	2.00	1	19	5 30	23	95	690	1.00	0
SAS014	LAMAR(HTM)	MH	C 92	10	28	28	0	400	435	200	A	A	S		0	4.0	1	3400	130	.80	2720	9516	18	0	SAS014	I	2	13.00	1	22	4 24	21	88	504	3.00	S
SLS002	PLANT BIO/LS FACIL	MH	P 92	10	A	97	28	400	700	350	R			SM	0	.0	1	4400	50	1.00	4400	1800	0	-5	SLS002	A	2	3.00	12	23	5 27	23	115	621	2.00	S
SMP002	MATERIALS EXP CARR	MH	C 90	10	A	99	0	ANY	999	300	A	D			0	2.0	1	10000	500	.80	8000	13600	30	0	SMP002	A	2	6.50	26	25	7 23	25	175	575	2.00	
SMP003	MATERIALS EXP AGS	MH	P 88	10	A	99	0	ANY	999	300	A	A			0	1.0	1	4000	6	.50	2000	2215	0	-5	SMP003	A	2	6.50	26	23	7 27	24	161	648	1.00	0
SMP004	WAKE SHIELD EXP	MH	I 90	1	A	97	0	400	700	350	R				0	1.0	1	500	10	.20	100	600	0	0	SMP004	V	2	5.00	10	16	3 33	24	48	792	4.00	
SMP005	ULTRAVACUUM FAC	MH	I 95	10	A	97	0	400	700	350	D	A			0	1.5	1	3000	10	.50	1500	1200	0	0	SMP005	V	3	5.00	26	18	3 31	24	54	744	4.00	
TGN004	TETHER DYNAMICS	MH	C 94	1	28	97	0	400	600	300	R				0	.5	1	1000	0	.01	10	250	0	0	TGN004	E	2	4.00	30	18	4 31	24	72	744	3.00	

TOTALS ARE=		80330	16291	56599
NUMBER OF MISSIONS=	16			

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Table 4-6. Space Station Mission Analysis

FILE ID: GMCK.HNN
Apr.15, 1983

CODE	DATE	DUR	INC DEG	INC MAX	INC MIN	POWER W	DAYS YEAR	HRS DAY	CREW SIZE	STAT PLAT SER	MOD	RACK	PAL	DATA KBPS	DUTY
SMP003	88	10	A	99	0	4000	26	6.50	2	A A		0	1.0	6	.50
SAS011	89	5	28	45	0	600	1	2.00	2	A A M		0	2.0	1000	.80
CMP001	90	5	A	99	0	15000	50	2.00	1	A A M	SM	0	.0	1000	.80
SAS010	90	2	28	45	0	530	1	7.00	2	D A M		0	.5	35	.80
SMP002	90	10	A	99	0	10000	26	6.50	2	A D		0	2.0	500	.80
SMP004	90	1	A	97	0	500	10	5.00	2	R		0	1.0	10	.20
OSR001	92	99	28	28	28	2000	10	10.00	2	R S	SS	0	.1	700	.01
OTR001	92	99	28	28	28	2000	30	10.00	2	R L		0	.3	350	.02
SAS014	92	10	28	28	0	3400	1	13.00	2	A A S		0	4.0	130	.80
SLS002	92	10	A	97	28	4400	12	3.00	2	R	SM	0	.0	50	1.00
CIR001	93	5	A	97	28	25000	60	2.00	2	R	SM	0	.0	10000	.20
TGN004	94	1	28	97	0	1000	30	4.00	2	R		0	.5	0	.01
CMP012	95	5	A	97	28	5000	50	4.00	2	R		2	.0	1000	.20
SMP005	95	10	A	97	0	3000	26	5.00	3	D A		0	1.5	10	.50
OTR004	96	99	28	28	28	3000	60	10.00	3	R L		0	.3	500	.07
SAS008	99	2	28	28	0	900	2	9.00	2	A A M		0	2.0	1000	.00

TOTALS ARE= 2 15.2
NUMBER OF MISSION= 16

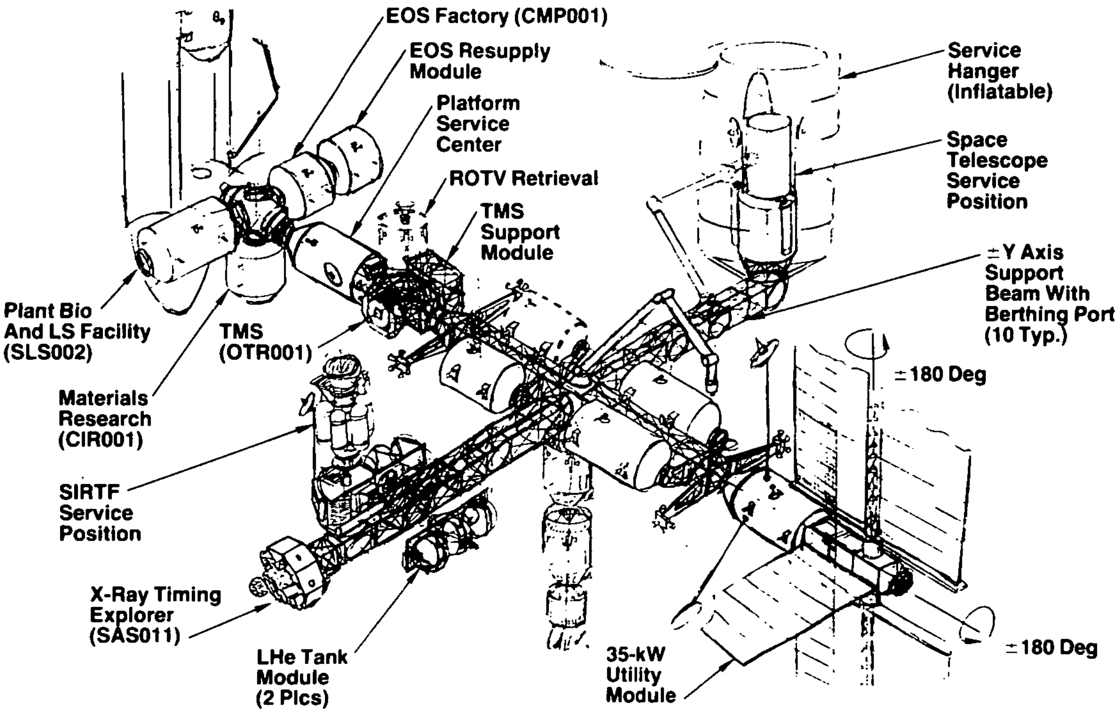
Table 4-7. Yearly Breakdown of Major Resources

YEARLY BREAKDOWN OF MAJOR RESOURCES
For 20-year period beginning 1988
(Cond: FRITZ=99)

	POWER WATTS	MASS KG	MANHOURS	DATA KBPS	PAL	MOD	RACK	NEW MASS KG	EXP	PORT
YEAR 1988	2000	2215	338	3	1.0	0	0	2215	0	1
YEAR 1989	2480	3215	342	803	3.0	0	0	1000	0	2
YEAR 1990	23004	26583	894	2033	6.5	1	0	23368	72480	6
YEAR 1991	22904	25983	794	2031	5.5	1	0	0	72480	5
YEAR 1992	29660	37931	1678	2171	9.4	2	0	13616	80376	8
YEAR 1993	34660	45431	1918	4171	9.4	3	0	7500	80496	9
YEAR 1994	34190	44681	2154	3371	7.9	3	0	250	80496	9
YEAR 1995	24680	40631	2604	2776	8.9	2	2	3700	8496	8
YEAR 1996	24890	42031	4404	2811	9.2	2	2	1400	164496	9
YEAR 1997	24890	42031	4404	2811	9.2	2	2	0	164496	9
YEAR 1998	17890	32316	3826	808	8.2	1	2	0	164376	7
YEAR 1999	17890	35866	3862	808	10.2	1	2	3550	164376	7
YEAR 2000	8890	19766	3124	208	8.2	1	0	0	164016	6
YEAR 2001	8890	16216	3088	208	6.2	1	0	0	164016	6
YEAR 2002	1770	4900	2990	54	2.2	0	0	0	163800	4
YEAR 2003	1770	4900	2990	54	2.2	0	0	0	163800	4
YEAR 2004	1770	4900	2990	54	2.2	0	0	0	163800	4
YEAR 2005	270	3700	2600	49	.7	0	0	0	163800	3
YEAR 2006	270	3700	2600	49	.7	0	0	0	163800	3
YEAR 2007	270	3700	2600	49	.7	0	0	0	163800	3

FIGURE 4-8.
ROTV/MULTIMISSION PLATFORM

VGD937



control. Commercial and science and application missions are included by adding a docking module interfacing with the service center and the orbiter. The mission elements are clustered about the docking module, making IVA access to any given module possible with minimum interference. The modules are standard 14.5-ft-diameter with length based on one or more standard building block sections. The docking module is 10.0 ft in diameter x 27.0 ft long, with four active radial ports and two end ports (one active and one passive). Crew support and living provisions are supplied by the orbiter.

The basic platform structural and mechanical elements are as defined in Section 4.4.1.3. The additional ±Y-axis support beams are of the same graphite epoxy telefold design as the core, but configured to accommodate multimission objectives. Orbiter interface mechanisms are configured compatible with the pressurized orbiter docking module so that they can be used in either the manned or unmanned mode. The berthing mechanism is a self-aligning hexagonal frame design with three capture guides and dual-motor actuator. Each mechanism is configured to accept a 1.0-m (3.28 ft)-diameter opening with an orbiter-type hatch. For applications requiring a shirtsleeve egress, a pressure seal is incorporated in the interface.

The pressurized modules are integrally machined isogrid panel with external waffles and bolted end domes, machined from 1.0-in.-thick 2219-T851 aluminum plate. The shell is protected with 50 layers of multilayer insulation (MLI) and a 0.16-in.-thick 7075-T6 aluminum meteoroid shield.

- Characteristics. The characteristics of the ROTV multimission platform are summarized in Table 4-8, along with related remarks and rationale.
- Operations. In addition to the ROTV support described in Section 4.4.1.3, the initial growth platform becomes a facility to service and repair

Table 4-8. ROTV/Multimission Platform Characteristics

Function/Item	Selected Approach	Remarks/Rationale
Satellite retrieval, deployment and disposal	TMS	Two flights per mission; six missions per year; three flights per fuel load
TMS depot size	Two fuel loads	Orbiter manifest/platform flexibility
PLayload attachment/ berthing/equipment	100 ft manipulator (on tracks)(	Size and tracks permit platform flexibility and evolutionary growth
TMS recovery	Automatic; laser range/attitude	Same as ROTV system
Mission power	35 kW	Standard utility module (solar array/regenerative fuel cells)
Crew support	Orbiter-tended	Early, low cost; pressurizable module or EVA
Resupply mass,	365 thousand lb/hr	Typical, maximum year
Payload ports	30	Extra for flexibility/growth
Data rate	4 mbps	
Orientation/stability	Gravity gradient	Simple, low cost; payload gimbal as required.

free-flying satellites. Candidate satellites are retrieved by the TMS, brought to the station, and berthed to a preselected location by the TMS or with assistance from the onboard manipulator. This operation is controlled from the ground and/or from the platform service center. Incorporation of the TMS may improve ROTV retrieval. EVA operations are conducted during orbiter visits with support provided in the platform service center and with manipulator assistance. Satellites requiring cryogenic replenishing, such as SIRTF, are serviced by a cryogenic tank module delivered by the orbiter and installed on the support beam. Integrated systems transfer the cryogenics, as required. Multiple berthing provisions are provided for the orbiter to facilitate positioning of station and/or playload elements.

Commercial activity and science experiments are conducted in specially configured modules attached to the platform via the docking module. Operations are accomplished in a controlled environment equal to the orbiter environment, permitting freedom of interchange between elements. Crew members eat and sleep in the orbiter. After orbiter separation, the station operates in an automatic mode with ground control.

Section 5
ARCHITECTURAL VARIATIONS

Several analyses were performed to examine sensitivities of architectures that were variations of those presented in Sections 3 and 4. Data from these studies provide insight into which architectural variables have a significant impact on the program and which alternate concept variations show promise for increasing the effectiveness of the architectures.

5.1 IMPACT OF INCLINATION

The cost of implementing a facility may be greater at higher inclination because the amount of weight the orbiter can lift decreases as orbital inclination increases. At lower inclinations, orbiter launch lifting capacity is expected to always be adequate. After accounting for the orbiter docking module weight, an orbiter in the 1992 era is expected to be able to launch about 61,000 lb for 28-deg inclination. Based on 53 ft of available orbiter bay length, the launch weight limit would be limiting for payloads having an overall density greater than 8.5 lb/cu ft (see Figure 5-1). Typical densities are estimated at 3 to 4 lb/cu ft for facility launches and 6 to 7 lb/cu ft for logistics launches; therefore, all the 28-deg-inclination launches are expected to be volume limited.

For a 57-deg inclination, facility launches are expected to be volume limited, but logistics launches may be weight limited. At higher inclinations, all launches are most probably weight limited. This can be seen from Figure 5-1, where a payload density below the orbiter capability line is volume limited, and a payload density lying above the orbiter capability line is weight limited.

Figure 5-2 shows a more detailed example, i.e., results for the four-man initial-capability space station launched to various inclinations. Facility launches are volume limited for 28- and 57-deg inclinations, but they are weight limited at higher inclinations; therefore two additional launches are required at higher inclinations. This represents two effects caused by higher

FIGURE 5-1.

IMPACT OF INCLINATION ON ORBITER CAPABILITY

VGD936

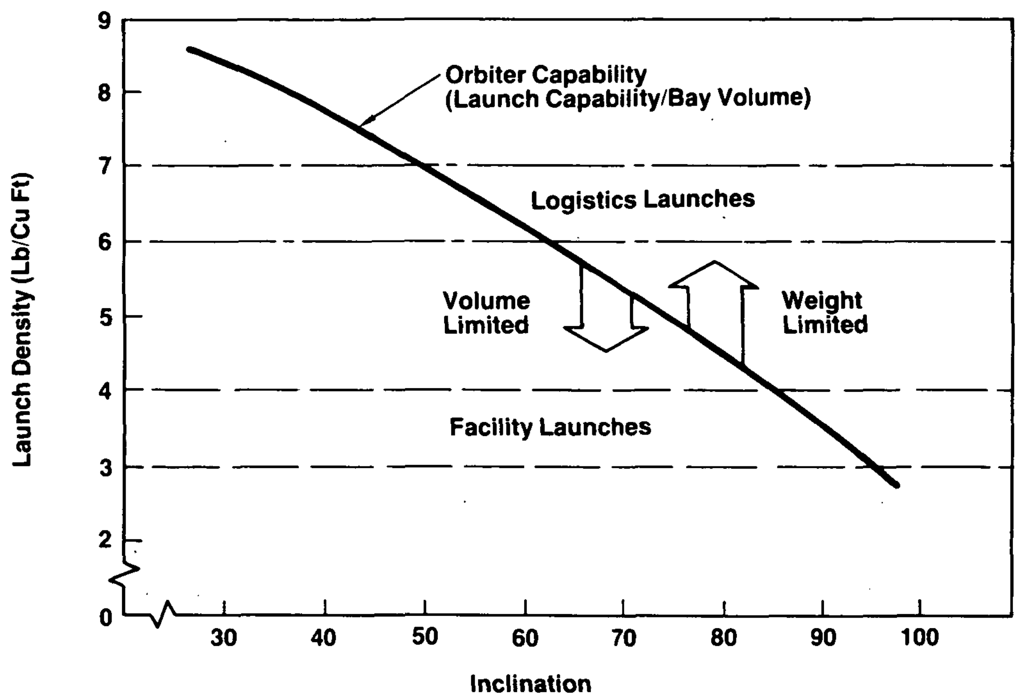
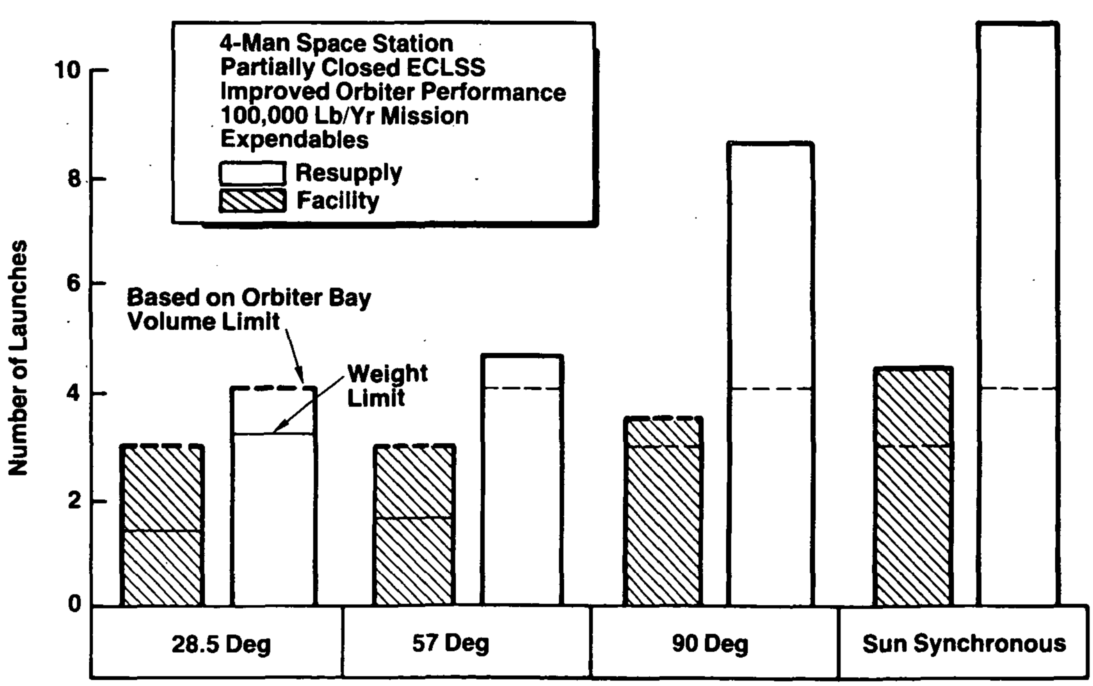


FIGURE 5-2.

IMPACT OF INCLINATION ON SPACE STATION LAUNCHES

VGD935



inclinations. First, more launches are required because of orbiter launch capability, and secondly, as the facility is designed for smaller but lighter weight modules, an additional penalty is incurred. This second penalty is related to the weight equipment required for each module regardless of length; end cones are an example of such equipment.

Logistics modules are predicted to be of higher density and weight limited above 28-deg inclinations; therefore, the number required at higher inclinations increases nearly in proportion to orbiter launch capability.

5.2 TECHNOLOGY VARIATION

The base for technology forecasts used in the study consists of NASA technology plans and recent studies, with emphasis given to those currently receiving significant funding from government agencies. Additional information is added from subcontractors, specifically Hamilton Standard (for ECLS) and Bendix (for attitude control). Additional contacts are made with industry and NASA in specialized areas. These technology candidates are grouped into three basic categories: existing hardware, current technology, and advanced technology.

The minimum level of technology considered is that required to meet mission and facility requirements. More advanced technology options are considered when significant program cost savings can be expected.

An example of technology to reduce program costs is ECLSS loop closure, where applying more advanced technology reduces resupply (orbiter launch) costs. Characteristics for varying degrees of loop closure are shown in Figure 5-3 for a four-man space station. The lowest level of technology shown, called existing hardware, consists of a solid amine CO_2 control concept and condensate water recovery by multifiltration. This technology level is relatively simple, and only a limited amount of development would be necessary. This concept has high ECLSS-related resupply, amounting to about 22,000 lb/yr. This does not account for logistics module structure, which amounts to an additional 15,400 lb/yr.

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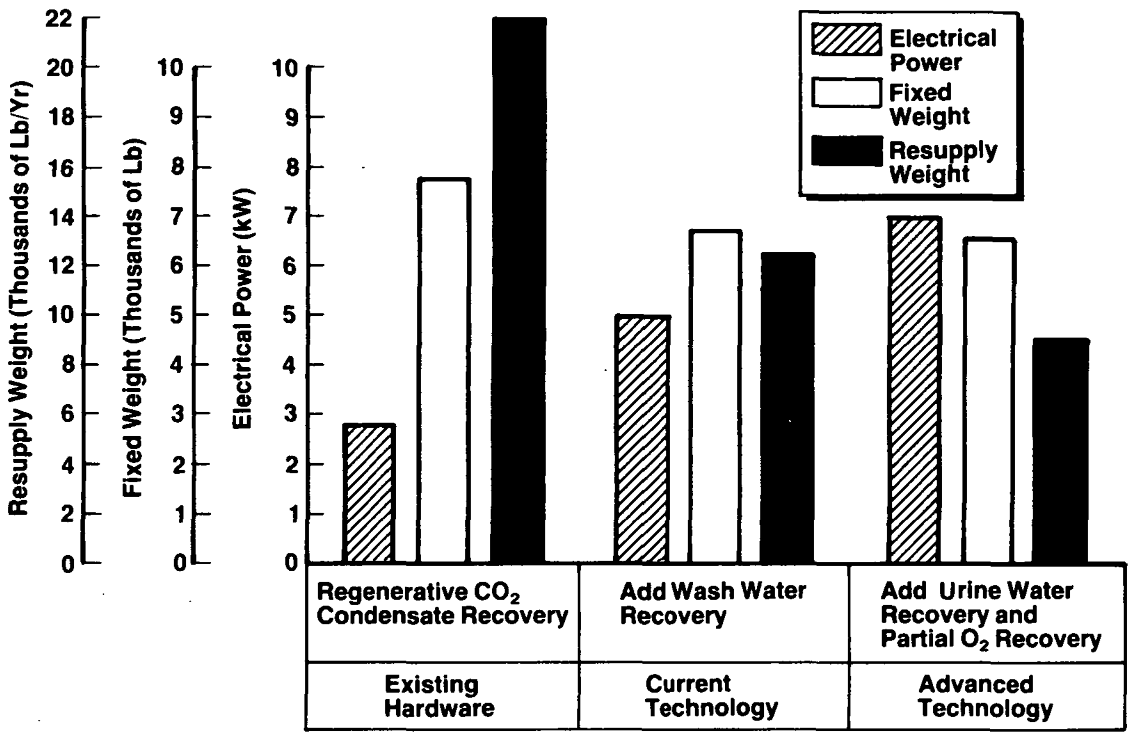
FIGURE 5-3.
IMPACT OF ECLSS TECHNOLOGY VARIATIONS

VGD934



Electrical power for the existing hardware level is low -- 2.8 kW. The required power increases as ECLSS closure increases, rising to 5 kW for current technology and to 7.0 kW for advanced technology. Resupply decreases to about 12,500 lb/hr for current technology and 9100 lb/yr for advanced technology. Fixed weight decreases slightly as technology level increases; this is primarily due to a decrease in onboard contingency supplies. Other space station definition variables are affected also in a secondary manner, as can be seen from Tables 5-1 to 5-3.

This ECLSS technology tradeoff essentially trades increased hardware cost and increased power in order to reduce resupply requirements. The increased technology level also increases program risk and design complexity. The reduction in expendable resupply amounts to about $34 million/yr in orbiter launch costs ($80 million/launch). The difference in hardware costs corresponding to this savings is about $60 million; therefore, the advanced technology concept trades favorably after 2 to 3 years.

Table 5-1. Four-Man Space Station Definition - Existing ECLSS Hardware

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	16646.	98.	91.	2842.	218.	504.
DATA	3.6	0.3	1034.9	22.4	2993.	75.	0.	721.	18.	730.
ECLS	2.8	0.0	0.0	0.0	7888.	487.	0.	22030.	1256.	297.
CREW	1.2	0.0	0.0	0.0	3863.	2026.	0.	748.	150.	0.
THERM	1.2	0.0	0.0	0.0	4446.	18.	93.	44.	2.	73.
STRUC	0.0	0.0	0.0	0.0	27966.	400.	75.	280.	11.	0.
A C S	2.1	0.0	0.0	0.0	6711.	16.	424.	2008.	88.	200.
PROP	0.3	0.0	0.0	0.0	2472.	0.	104.	8034.	316.	200.
COMM	2.3	0.0	0.0	0.0	2855.	64.	21.	688.	21.	365.
WIRE	0.0	0.0	0.0	0.0	1422.	201.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	96176.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	8584.	1616.	0.	0.	0.
MISS	24.5	300.0	0.0	0.0	150000.	8200.	300.	100000.	0.	9000.
TOTAL	38.1	300.3	1034.9	22.4	227261.	20168.	2723.	233570.	2079.	11369.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	25753.83	5290.52	42.11	14.00	3	50.88	4.00

P PORTS	DEP RAD Q	ARRAY PWR
4	0.00	100.08

-> SHOW LAUNCH FOR 1990

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1990	2.84	1.65	3.47	7.96	0.04

Table 5-2. Four-Man Space Station Definition - Current ECLSS Technology

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	17629.	104.	97.	3006.	219.	518.
DATA	3.6	0.3	1036.7	22.4	2993.	75.	0.	721.	18.	730.
ECLS	5.0	0.0	0.0	0.0	6714.	555.	0.	12502.	935.	200.
CREW	1.2	0.0	0.0	0.0	3913.	2026.	0.	748.	150.	0.
THERM	1.3	0.0	0.0	0.0	4690.	19.	97.	47.	2.	73.
STRUC	0.0	0.0	0.0	0.0	28948.	400.	75.	289.	12.	0.
A C S	2.1	0.0	0.0	0.0	6738.	16.	425.	2017.	89.	200.
PROP	0.3	0.0	0.0	0.0	2566.	0.	109.	8321.	331.	200.
COMM	2.3	0.0	0.0	0.0	2855.	64.	21.	688.	21.	365.
WIRE	0.0	0.0	0.0	0.0	1503.	208.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	89837.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	9254.	1649.	0.	0.	0.
MISS	24.5	300.0	0.0	0.0	150000.	8200.	300.	100000.	0.	9000.
TOTAL	40.4	300.3	1036.7	22.4	228547.	20921.	2773.	218175.	1776.	11287.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	26182.45	5617.68	44.23	14.00	3	53.84	4.00

P PORTS	DEP RAD Q	ARRAY PWR
4	0.00	105.97

-> SHOW LAUNCH FOR 1990

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1990	2.95	1.65	3.24	7.85	0.15

Table 5-3. Four-Man Space Station Definition - Advanced ECLSS Technology

SUBSYS	POWER K W	DATA TRANS MBPS	DATA COMP KOPS	DATA STORAGE 1000MB	FIXED W T LBS	INT VOL FT3	EXT. VOL FT3	RESUP W T LB/YR	RESUP VOL FT3/YR	CREW TIME MH/YR
POWER	0.0	0.0	0.0	0.0	18467.	109.	101.	3105.	221.	531.
DATA	3.6	0.3	1038.3	22.5	2993.	75.	0.	721.	18.	730.
ECLS	7.0	0.0	0.0	0.0	6622.	539.	0.	9116.	609.	166.
CREW	1.2	0.0	0.0	0.0	3907.	2026.	0.	748.	150.	0.
THERM	1.4	0.0	0.0	0.0	4894.	20.	101.	49.	2.	73.
STRUC	0.0	0.0	0.0	0.0	29056.	400.	75.	291.	12.	0.
A C S	2.1	0.0	0.0	0.0	6763.	16.	427.	2024.	89.	200.
PROP	0.3	0.0	0.0	0.0	2651.	0.	113.	8578.	344.	200.
COMM	2.3	0.0	0.0	0.0	2855.	64.	21.	688.	21.	365.
WIRE	0.0	0.0	0.0	0.0	1527.	207.	0.	0.	0.	0.
LOG M	0.0	0.0	0.0	0.0	0.	0.	0.	87724.	0.	0.
PACK	0.0	0.0	0.0	0.0	0.	9169.	1679.	0.	0.	0.
MISS	24.5	300.0	0.0	0.0	150000.	8200.	300.	100000.	0.	9000.
TOTAL	42.4	300.3	1038.3	22.5	229734.	20825.	2818.	213043.	1466.	11265.

SWMAX	WT/MOD	VOL/MOD	LMOD	DMOD	NMOD	QSTC	CREW
67265.09	26577.93	5576.09	43.96	14.00	3	56.50	4.00

P PORTS	DEP RAD Q	ARRAY PWR
4	0.00	111.25

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->

->
SHOW LAUNCH FOR 1990
```

YEAR	STATION	MISSION	RESUPPLY	TOTAL	EMPTY
1990	2.95	1.65	3.17	7.76	0.24

Technology levels can also be increased in other subsystem areas in order to reduce program costs. Examples of these are subsystems that significantly reduce the attention required of the crew or substantially reduce resupply.

5.3 INCREMENTAL INCREASES IN CAPABILITY

This section identifies which resources provided for mission support have the greatest impact on the facility and program. The base for performing this analysis is the four-man space station located at 28 deg, (defined in detail in Section 3) to form the data base for making decisions for effective mission accommodation.

The major mission resources of electrical power, crew time, internal volume, and data rate are varied by small amounts. Impacts are calculated in terms of increased bus power, total facility weight, and total facility volume. The results are shown in Figure 5-4.

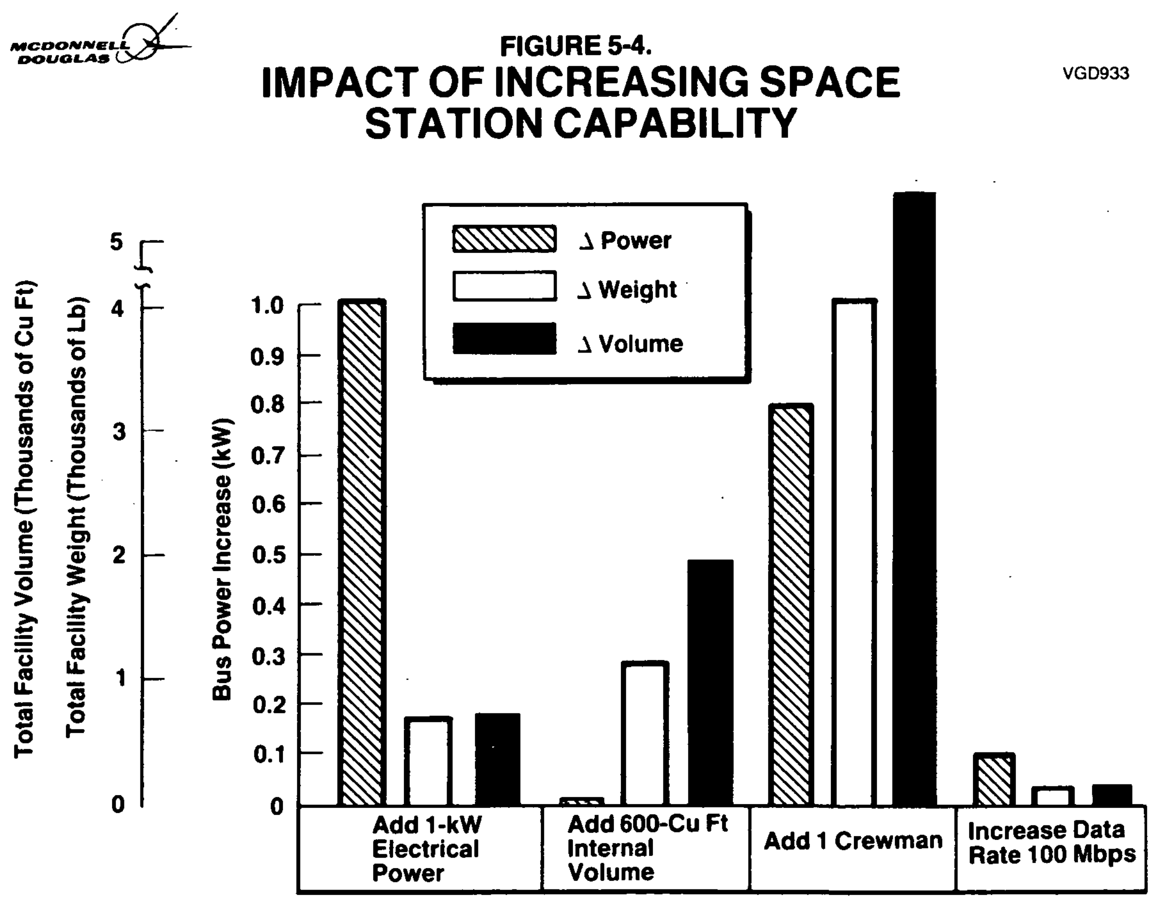


FIGURE 5-4.
IMPACT OF INCREASING SPACE STATION CAPABILITY

Addition of 1 kW of electrical power does not increase subsystem power appreciably, so the bus power only increases by the 1-kW added for missions. Weight increases by 700 lb and total volume increases by 730 cu ft for the 1-kW increase in mission power.

The addition of 600 cu ft of internal volume has negligible input on the power resources but increases weight by 1100 lb and volume by 2000 cu ft. This increase in volume is due to packaging factors.

An incremental increase of one crewman has a large impact, increasing power by 0.8 kW, weight by 4000 lb, and facility volume by 5500 cu ft. Increasing the data rate from 200 to 300 mbps has a very small impact on the facility definition.

5.4 SPACE STATION AS A DATA NODE

During the study, various concepts were considered for supporting a platform or free-flyer from a space station. Of these concepts, the use of space station as a data node could offer significant advantages.

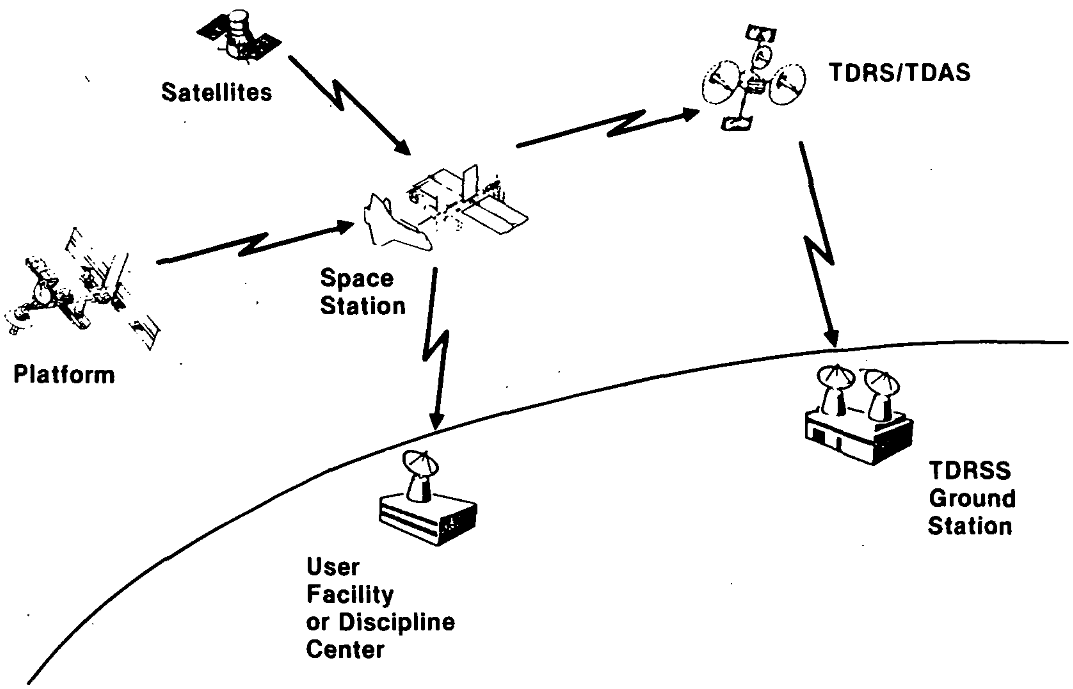
A manned space station in low Earth orbit can provide a valuable service in the end-to-end data network by acting as a data node for formation flyers (free-flying platforms or vehicles that are co-orbiting with the space station). As a data node, the space station acts as the interface with TDRSS or as a relay to dedicated user ground terminals. Advantages of this approach include (1) more efficient use of the limited TDRSS channels, (2) simplification of the free-flyer data and communications systems, (3) simplification of the direct user link option, and (4) opportunity for on-orbit manned interaction with the free-flyer mission, systems, and data. These operational modes are shown in Figure 5-5.

Some of these advantages are also available to free-flyers in orbits that are different from that of the space station. Because the line-of-sight time line is less than 100% for these cases, the free-flyer must be capable of operating independently of the space station for extended periods of time, and the benefits are thus not as great as in the co-orbiting case.

FIGURE 5-5.

SPACE STATION AS A DATA NODE FOR FORMATION FLYERS

VGB901



A space station acting as a data node is envisioned as providing three primary services to a co-orbiting free-flyer (see Figure 5-6). First, it acts as a TDRSS interface buffer, and as such collects data from the free-flyers in real-time, stores the data on a high-capacity, high-rate storage unit, and dumps the data through TDRSS at or near the 300-mbps channel limit. This minimizes the TDRSS channel time required. It also allows the free-flyers to acquire data without regard to the TDRSS time line, and reduces the RF (or optical) power required at the free-flyer to transmit the data.

A second service is to provide a central capability for direct data dump to a user's ground facility. This allows the user to have better access to his data and more immediate control of his mission equipment. NASA- data facilities (TDRSS, NASCOM, etc.) are unloaded, and the privacy of the user's data is enhanced.

FIGURE 5-6.

SPACE STATION DATA SERVICES TO FORMATION FLYERS

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Service	Benefit
■ TDRSS Interface Buffer	■ More Efficient Use of TDRSS ■ Less Data Storage and RF Power Required on Free-Flyer
■ Direct Link to Ground-Based User	■ Better User Access to Free-Flyer With Modest Free-Flyer Communications System
■ On-Orbit Manned Interaction	■ Improved Data Delivery Time ■ Enhanced Data Security ■ Real-Time Free-Flyer Monitor and Control ■ Fast Response to Targets of Opportunity and Contingencies ■ Opportunity to Evaluate/Edit Mission Data

The space station as a data node also allows on-orbit manned interaction with the free-flyer mission and its data. This provides a capability that can be used for manned response to targets of opportunity, response to contingencies, or preliminary evaluation or editing of mission data.

As an example, three independent free-flyers, each communicating with TDRSS at an assumed 10-mbps rate for 10 min per orbit, are compared to the same three free-flyers collecting the same data but transmitting it to the space station, where it is stored and dumped to TDRSS at 300 mbps. The advantages are shown in Figure 5-7 for two areas: (1) a 30:1 reduction in TDRSS channel time required and (2) a 40-db (approximate) reduction in free-flyer effective radiated power (ERP) required. These advantages lead to significant reductions in the weight, power, cost, and complexity of the free-flyer. However, to make this system feasible, a technology advancement is needed in mass data storage in space, especially in data playback and record rates, but also in data capacity. Current technology is based on magnetic tape recorders with capacities on the order of 10^{11} bits and record and reproduce rates on the order of 50 mbps. Optical disk memories, bubble memories, or advanced tape recorders are needed to provide the required in-orbit data buffering.

FIGURE 5-7.

COMPARISON OF INDEPENDENT FREE-FLYERS TO FREE-FLYERS USING SPACE STATION AS A TDRSS INTERFACE BUFFER

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	3 Independent Free-Flyers	Using Space Station as an Interface
TDRSS SA Channel Time Required	10 min/Orbit Each Free Flyer (No Data Buffering)	1 min/Orbit Total (at 300 Mbps)
Effective Radiated Power on Each Free-Flyer	+ 40 dBW	≈ 0 dBW

Assumption: 3 Free-Flyers, Each Acquiring Data at 10 Mbps for 10 min/Orbit

Section 6
CONCLUSIONS AND RECOMMENDATIONS

In summary, this study has investigated various architectural options defined to accommodate the list of 88 most probable missions for the space station program. The results of these investigations are highlighted below.

- Of the identified mission list, 100% can be accommodated to a high degree with a four-facility architecture placing space stations at 28.5-deg and sun-synchronous orbits, plus platforms at 28.5- and 90-deg inclinations. Due to the relatively high cost of this architecture, the fullup capability would not be available until 1997, with a projected funding rate of $1.3 billion (1984 dollars). Additionally, this architecture reaches a point of diminishing return because facilities are provided that capture only a limited number of missions. The cost of capturing these last few missions is high on a dollars-per-mission-captured basis.

- Several single- and dual-facility architectures are defined that capture from 75 to 89% of the mission list and require less budget to implement than the 100% capture concept. These include a single-facility architecture consisting of a manned space station at a 28.5-deg inclination, and a dual-facility architecture consisting of a space station at 57-deg inclination and a platform at a 28.5-deg inclination. These architectures somewhat compromise the accommodation of missions, but the results show that a major portion of the identified mission list is accommodated in these budget-constrained programs.

- A budget-constrained architecture is defined that maximizes mission capture while staying within projected budget rates. This architecture can provide nearly all the resources in the orbit locations desired except for a small deficit in power and pressurized volume early in the program. Also, some commercial production missions are not accommodated during the 1994-to-1997 time frame because these missions are expected to be allocated to separately funded commercially dedicated facilities. This budget-constrained architecture initially consists of a four-man space station at 28.5 deg and a platform at sun-synchronous. In the 1994 time frame, the station expands to accommodate a crew of eight with TMS support. ROTV support is added in 1996, and a second platform is be added at 28.5-deg inclination in 1995.

- Based on the projections of the identified mission list, a likely evolutionary growth path adds manned capability to the platform at sun-synchronous orbit and another platform at a 57-deg inclination. This growth is projected for the 1998-to-2000 time period.

- Special-emphasis architectures are defined for three categories of missions, i.e., science and applications, operations and technology, and commercial. Requirements for these three architectures vary greatly, but a manned space station is required in all three. An additional platform is also required for science and applications and for commercial, but not for operations and technology. The architectures capture all missions in the categories of operations and technology and commercial, and capture 90% of the science and applications missions. Although the special-emphasis architectures differ considerably in performance capability, these architectures can evolve to capture missions of other categories as well.

- A low-cost ROTV (intermittently manned) concept is defined that can provide ROTV support early in a space station program. The concept can also be attractive in an architecture that places the space station facility at high inclination, while there is a requirement for ROTV support at low inclination. The concept is normally unmanned and provides storage, staging, and launch, and control functions for ROTVs. The concept can also be expanded to include support for missions of other categories.

Major recommendations of this effort are as follows:

- Continuing effort is recommended to refine the mission model. This is key to establishing firm design requirements for the selected architecture and to providing proper direction so that technology development can be focused on the limiting technologies.

- The study reported on herein defines the architectures only from a top-level system viewpoint. It is recommended that more detailed system-level studies be performed to consider the major system-level issues, such as degree of autonomy, role of the crew, data management approach, and mission management. Continued studies are needed now to develop the next level of requirements.

- Because the space station is not expected to be operational until the 1991 time period, on-orbit capability will be needed to bridge the gap between the relatively short-duration orbiter and the space station. We recommend that approaches be considered to bridge this gap, with particular attention being paid to obtainining incremental increases in on-orbit capability with technologies and elements that are applicable to the space station.

Conclusions of the study with regard to architectural options are as follows:

- A space station at 28.5-deg LEO should be provided early in the program because (1) it captures a very high percentage (64%) of the total mission list, (2) it is the only facility that can accommodate several high-priority missions (ROTV support), and (3) shuttle performance is best for this orbital location.
- A second facility should also be provided early in the program at high inclination to accommodate viewing missions that require full Earth coverage.
- Modular growth is essential for providing adequate on-orbit mission support in an affordable manner. The budget-constrained architecture is defined based on modular elements whose sizes are chosen to minimize cost while meeting the incremental performance needs at the various orbital locations.
- An evolutionary architecture is essential to providing capability in the early 1990s, with the flexibility to be expanded later on to meet increasing performance needs.

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