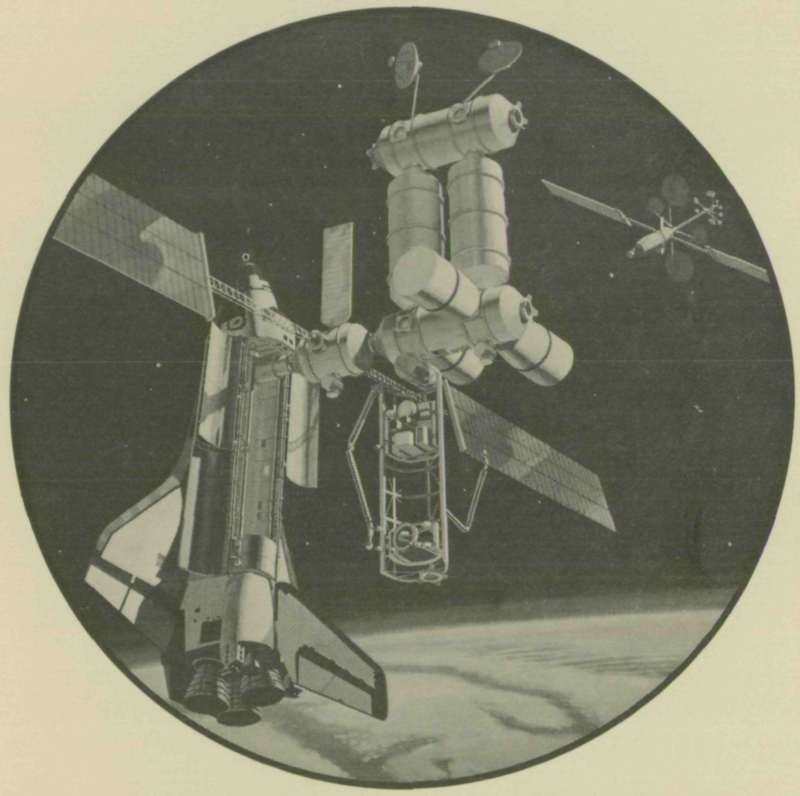
SSD 83-0032-2

SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY

Volume II



PROGRAM OPTIONS, ARCHITECTURE, AND TECHNOLOGY

APRIL 22, 1983

CONTRACT NASW 3683

Rockwell International

Shuttle Integration &
Satellite Systems Division
Rockwell International Corporation
12214 Lakewood Boulevard
Downey, California 90241

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FOREWORD

The Space Station Needs, Attributes, and Architectural Options Study contract (NASW 3683) was conducted by the Rockwell Shuttle Integration and Satellite Systems Division for NASA.

The final report summarizes the results of this study in five volumes, which are:

- Final Executive Summary Report
- Missions and Requirements
- Program Options, Architecture, and Technology
- Cost and Benefits
- DOD Task

Any questions regarding this final report should be directed to G.M. Hanley, study manager, at (213) 922-0215.

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TABLES

1. PROGRAM OPTIONS

PROGRAM OPTIONS TASK SUMMARY

In this task, six program options were identified and defined, as indicated in Figure 1-1. The Mission Scenario 4 mission model defined the payloads, the payload missions, and their operational schedule. Elements to support the operation of the payloads on-orbit were defined as were elements needed to transport the various payloads to their operational destinations.

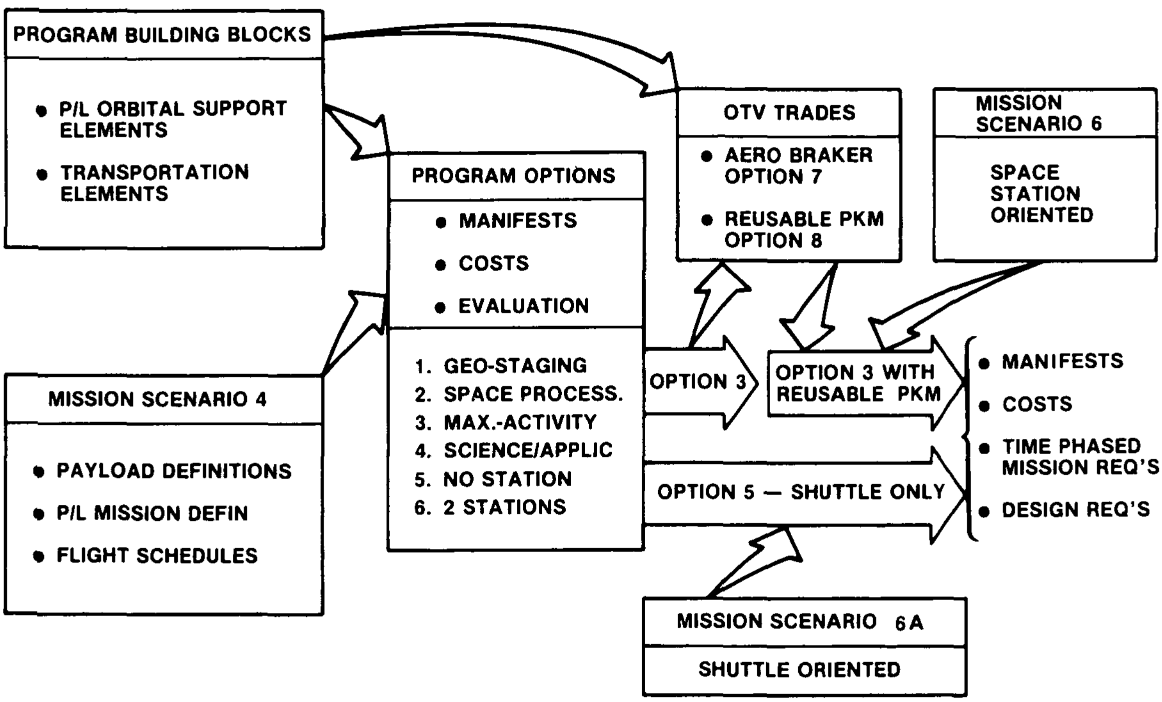


Figure 1-1. Study Summary--Program Options

Five of the options featured a Space Station as the primary support element for orbital operations. Option 5 was defined to form a basis for comparison. It was determined that almost all the payload missions in Mission Scenario 4 could, in fact, be accomplished by operations with the Shuttle. The major exception was the long-duration life sciences missions. Some of the orbiter operations represented relatively inefficient approaches to accomplishing some of the payload missions, but the capability to accomplish all the Mission Scenario 4 missions provided a simple evaluation criterion: lowest total cost to accomplish all the payload missions. For the five Space Station options, the payload missions captured by the station were costed. The costs for accomplishing the rest of the missions with the Shuttle were costed and the two costs added to get the total.

Option 3, which provided the maximum activity feasible at a 28.5-degree inclination station, was found to have the lowest total cost and was selected for further study along with the no-station option, which forms the basis for comparisons.

The Option 3 selected used a large single-stage reusable OTV to perform all phases of the high energy missions. Two alternative OTV designs were evaluated. Provisions for aerobraking were added to the large single stage. This variation was designated as Option 7. Option 8 substituted a smaller OTV that was sized to perform the perigee burn and return to the station. Circularization at apogee was accomplished by the most appropriate one of several standard storable propellant apogee stages, which would be integrated with the spacecraft. Option 8, which used the smaller reusable PKM OTV, offered some advantages and was selected for the final Space Station program definition. This definition was based on the Mission Scenario 6 mission model, which assumed that a Space Station would be available. Mission Model 6A was developed to reflect the scenario judged most likely if no Space Station should exist to form the basis for definition of the Shuttle-only program.

Airborne support equipment needed for each of the payloads was estimated and cargo manifests developed using computer programs developed at Rockwell during the past year. These program definitions formed the basis for program cost estimates as well as the development of time-phased mission requirements and Space Station design requirements.

Table 1-1 summarizes the Mission Scenario 4 mission model, which defined the payload program for the six program options. The upper portion of the

Table 1-1. Mission Scenario 4 Mission Model Summary (1990-2000)

MISSION AREA	NO. OF PAYLOADS	MISSION LOCATION						PAYLOAD WEIGHT (KIPS)	CREW HOURS REQUIRED
		GEO NODE		MED INCL		HIGH INCL			
		LEO	HIGH	LEO	HIGH	LEO	HIGH		
SPACE SCIENCES/APPLICATIONS & TECHNOLOGY	117	52	16	25	—	24	—	905.4	27,290
COMMERCIAL COMMUNICATIONS	120	—	120	—	—	—	—	587.4	31,020
SPACE PROCESSING	229	231	—	—	—	—	—	634.4	56,329
DOD	271	43	61	15	80	72	—	2739.2	46,744
FUTURE TECHNOLOGY DEVELOPMENT	TBD	—	—	—	—	—	—	—	—
TOTAL	737	326	197	40	80	96		4866.4	161,383

PAYLOAD SERVICES	NO. OF PAYLOADS	PAYLOAD WEIGHT (KIPS)	CREW HOURS REQUIRED
LEO PLACEMENT & RETRIEVAL	261	2859.9	22,205
GEO PLACEMENT & PLANETARY	183	1026.4	75,326
SERVICING — LEO & HIGH ENERGY	165	586.9	13,379
ATTACHED/INTEGRAL	126	347.4	49,063
STORAGE	TBD	—	—
ASSEMBLY/CONSTRUCTION	2	45.8	1,410
TOTAL	737	4866.4	161,383

table segregated the payloads into the major user categories. The lower portion of the table segregates the payloads by the type of payload service involved. This mission model was frozen in early October to form the basis for the program options evaluation presented at the mid-term briefing in November. Based on insights gained from user contacts, significant revisions were made to the commercial communications, DOD, and space processing areas of Rockwell Mission Scenario 3. Some revisions were made to Mission Scenario 3 in the laboratories and pallets portion of the science, applications, and technology area. These revisions were based on insights gained from user contacts.

Table 1-2 summarizes the major characteristics of the six program options evaluated. Options 1 and 2 performed only the functions shown. Option 4 gave first priority to science, applications, and technology payloads, but as a second priority, also performed the space processing missions. Options 2 and 4 performed all the high energy missions in the Shuttle-only mode, since neither included a reusable OTV. The Mission Scenario 4 mission model included some payloads stated to consider either 28.5-degree or 57-degree inclinations as acceptable destinations. Both Options 3 and 4 included these payloads. Option 6 located these payloads at 57 degrees. Option 1 was capable of deploying some of the payloads to their medium inclination destinations from a 28.5-degree station. These payloads were included in Option 3 as well as Option 1. Options 1, 3, and 6 use propellant scavenging from the orbiter and from the external tank as shown. Capability of the standard orbiter to the appropriate location is used as the reference for 100 percent load factor, which by this definition permits load factors greater than one to occur in Options 1, 3, and 6. Option 6 conducted space processing research and process development activities at the 57-degree station since their logistics requirements are low and they prefer the quieter environment. Space processing factories are located at the 28.5-degree station to accommodate the heavier logistics requirements of these free-flyers.

Table 1-2. Program Options Definition

SPACE STATION				OTHER ELEMENTS			
			LOCATION	STS PERFORMANCE			
OPTION	FUNCTIONS	SIZE	ALT/INCL	STD (LB)	SCAVENGE	OTV	TMS
1	HIGH-ENERGY MISSION STAGING	4-MAN	200 NMI 28.5°	61,000	8,000	SPACE-BASED REUSABLE SINGLE-STAGE CRYOGENIC	GROUND & SPACE BASED REUSABLE BI-PROPELLANT
2	SPACE PROCESSING MISSION SUPPORT	4-MAN	200 NMI 28.5°	61,000	—	PAM A&D IUS IUS FIRST STAGE CENTAUR F&G	GROUND & SPACE BASED REUSABLE BI-PROPELLANT
3	MULTIPLE MISSION SUPPORT	4-MAN 8-MAN	200 NMI 28.5°	61,000	8,000	SAME AS OPTION 1	SAME AS OPTION 2
4	SPACE PROCESSING & SCIENCE & APPLICATIONS MISSION SUPPORT	4-MAN	200 57°	47,500	—	SAME AS OPTION 2	SAME AS OPTION 2
5	NO SPACE STATION		160 NMI 28.5° 57° 98°	70,000 49,000 25,000	— — —	PAM A&D IUS IUS FIRST STAGE CENTAUR F&G	GROUND-BASED REUSABLE BI-PROPELLANT
6	TWO SMALL MULTIFUNCTIONAL STATIONS	4-MAN 4-MAN	200 NMI 28.5° 57°	61,000 47,500	8,000 8,000	SAME AS OPTION 1	SAME AS OPTION 2

Figure 1-2 shows the arrangement of the basic elements used in the Space Station program options. All five use the four-man station, which is shown at the right side. The first station is initiated in 1990 for all options. The IOC for the OTV is 1992 for Options 1, 3, and 6. Option 3 grows to the eight-man size in 1993.

The same core Space Station concepts are used for the Option 3 program, which is defined in the latter part of the study for the Mission Scenario 6 mission model. For that program, the four-man station is initiated in 1991. It grows to eight men in 1993. IOC for the OTV is 1994.

Figure 1-3 shows the dimensions and weights of the core Space Station elements and their capabilities to accommodate experiment hardware. The module dimensions shown were used in all the cargo manifests developed during the study. The weights shown in the figure are the most current values used in manifesting Option 3 to accommodate Mission Scenario 6. Options 1, 2, 3, 4, and 6 used weights that could be found in the mid-term briefing brochure for the manifests to accommodate Mission Scenario 4. In general, the earlier weight estimates were heavier than the current values presented here.

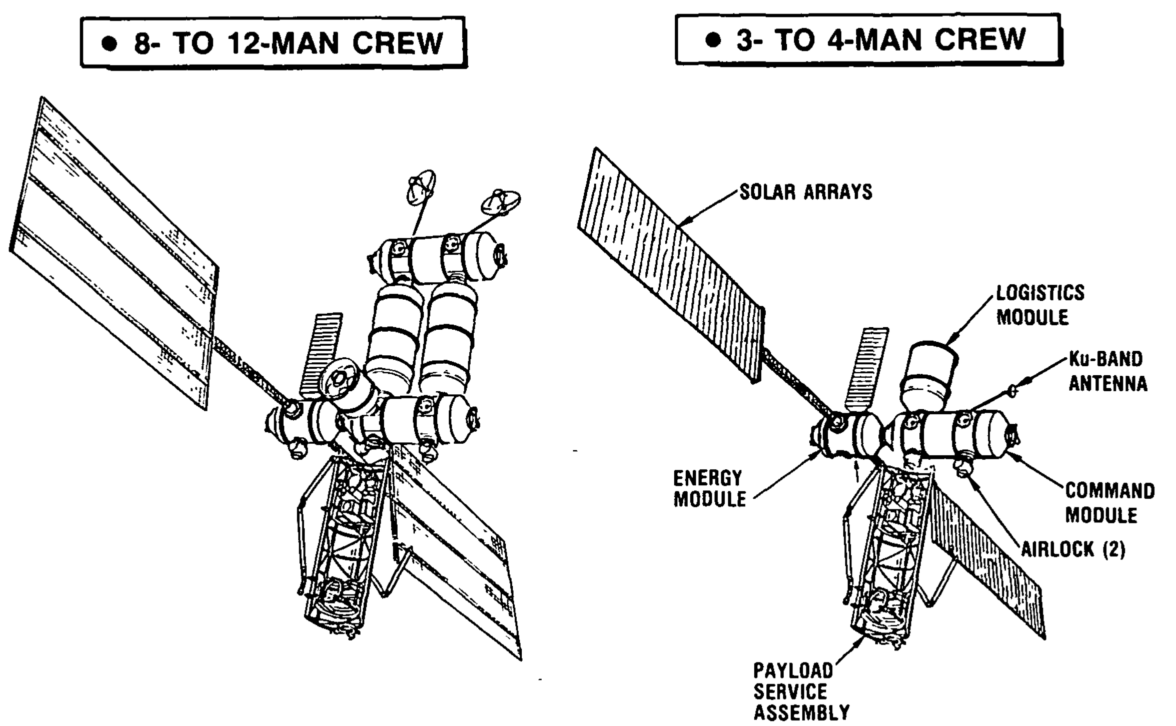


Figure 1-2. Core Space Station Concept

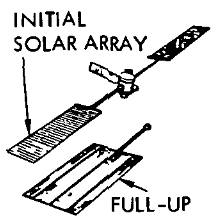
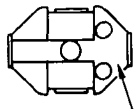
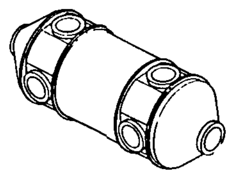
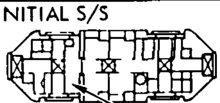
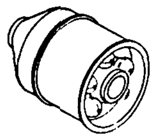
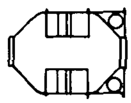
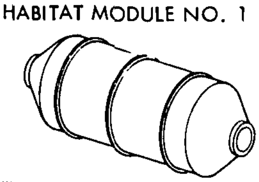
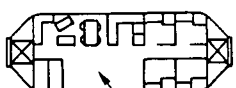
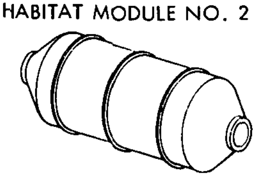
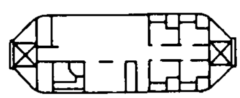
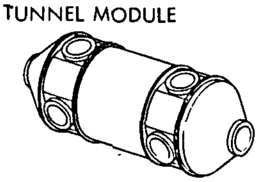
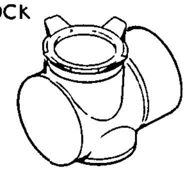
ELEMENT		LENGTH	WEIGHT (lbs)		VOLUME FOR EXPTS	COST CATEGORY
			GROSS	EXPT		
ENERGY MODULE 		20 ft 53 ft PACKAGE	31,382	1,980	330 ft^3	CORE SPACE STATION
COMMAND MODULE 	INITIAL S/S  FULL-UP 	40 ft	30,271 29,627	456 4,714	76 ft^3 786 ft^3	CORE SPACE STATION
LOGISTICS MODULE 		20 ft	15,784	- 3,480	- 125	CORE SPACE STATION
HABITAT MODULE NO. 1 		40 ft	22,864	2,929	488 ft^3	CORE SPACE STATION
HABITAT MODULE NO. 2 		40 ft	22,864	-	-	CORE SPACE STATION
TUNNEL MODULE 		40 ft	18,421	11,721	1953 ft^3	CORE SPACE STATION
AIRLOCK 		7 ft	1,983	-	-	CORE SPACE STATION

Figure 1-3. Core Space Station Building Blocks

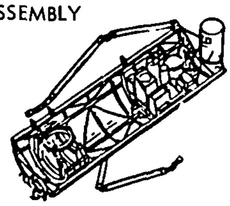
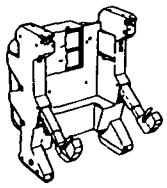
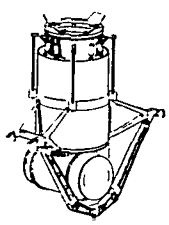
ELEMENT		LENGTH	WEIGHT (lbs)		VOLUME FOR EXPTS FT^3	COST CATEGORY
			GROSS	EXPTS		
PAYLOAD SERVICE ASSEMBLY 		53	17,206	-	8,129	CORE SPACE STA
MANNED MANEUVERING UNIT 		-	225	-	-	STS MOD
DOCKING MODULE 		7	4,500	-	-	STS MOD

Figure 1-3. Core Space Station Building Blocks (Cont)

The Space Station elements and all the payload elements defined in the various levels of Mission Scenario 6 were manifested to form the basis for cost estimates, the development of time-phased mission requirements, and Space Station requirements.

For any equivalent level of mission accomplishment, the Space Station program option showed a significant advantage in number of required Shuttle launches and in total program cost.

MISSION SCENARIO 4

OPTION 1: GEO STAGING

In Option 1, the function of staging high-energy missions from a Space Station located at 28.5 degrees inclination was examined in depth. To enable this function, the building blocks defined in Figure 1-4 were utilized. The teleoperator maneuvering subsystem (TMS) used primarily to transport payloads to nearby locations, is also used as the means for remote servicing of high-energy payloads. In this function, it is transported to the proper orbit by the orbiter transfer vehicle (OTV) in a loaded condition and returned empty. Its load consists of propellant for maneuvering to each payload plus servicing packs. (In later Scenario 6 studies, this operation was changed.)

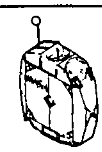
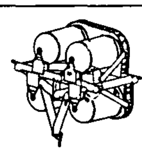
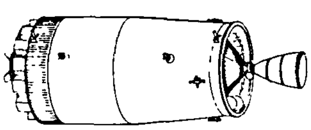
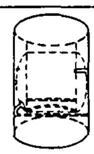
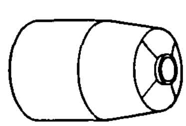
ELEMENT	LENGTH (ft)	WEIGHT GROSS (lbs)	WEIGHT OF PROPELLANT (lbs)	COST CATEGORY
TELEOPERATOR MANEUVERING SYSTEM 	3.1	8,245 (2,545)	- 5,700	UPPER STAGES
STORABLE PROPELLANT TANKS 	9	31,153 (7,153)	- 24,000	STS MODIFICATIONS
ORBIT TRANSFER VEHICLE 	30.2	53,020 (5,020)	- 48,000	UPPER STAGES
SCAVENGE/TOP-OFF TANK 	9	26,550 (2,550)	- 24,000	STS MODIFICATIONS
PROPELLANT STORAGE MODULE 	27	59,700 (5,700)	- 54,000	STS MODIFICATIONS

Figure 1-4. Option 1 Building Blocks

The storable propellant tanks are brought to the station full and used for bulk storage, from which TMS propellant is supplied. The propellant storage module has a similar function for servicing the OTV, but is brought up empty to the station and then filled by transfer from the scavenge/top-off tanks carried in the orbiter cargo bay. The OTV was sized to a nominal delivery capability of 12,000 pounds to geosynchronous orbit (GEO). In this respect, it is similar to ground-based cryogenic OTV's with a gross weight near the orbiter lift capacity; however, it is significantly lighter since it is space-(station) based and is only subjected to the high launch inertial loads when empty. Conceptual design studies established that a propellant fraction of 0.906 was achievable using an engine thrust/initial weight ratio of near 0.1.

Option 1: STS Launch Summary

The results of analysis of the Option 1 payload traffic are illustrated in Figure 1-5. Payloads that did not go to the station involved 65 Shuttle polar flights and 270 that were deployed by the Shuttle. They do not use the station since, by definition, Option 1 relegates the station to high-energy payload staging only. These high-energy payloads require 166 Shuttle launches. The cryo propellant needed for the OTV to carry these payloads is also included in the 166 launches.

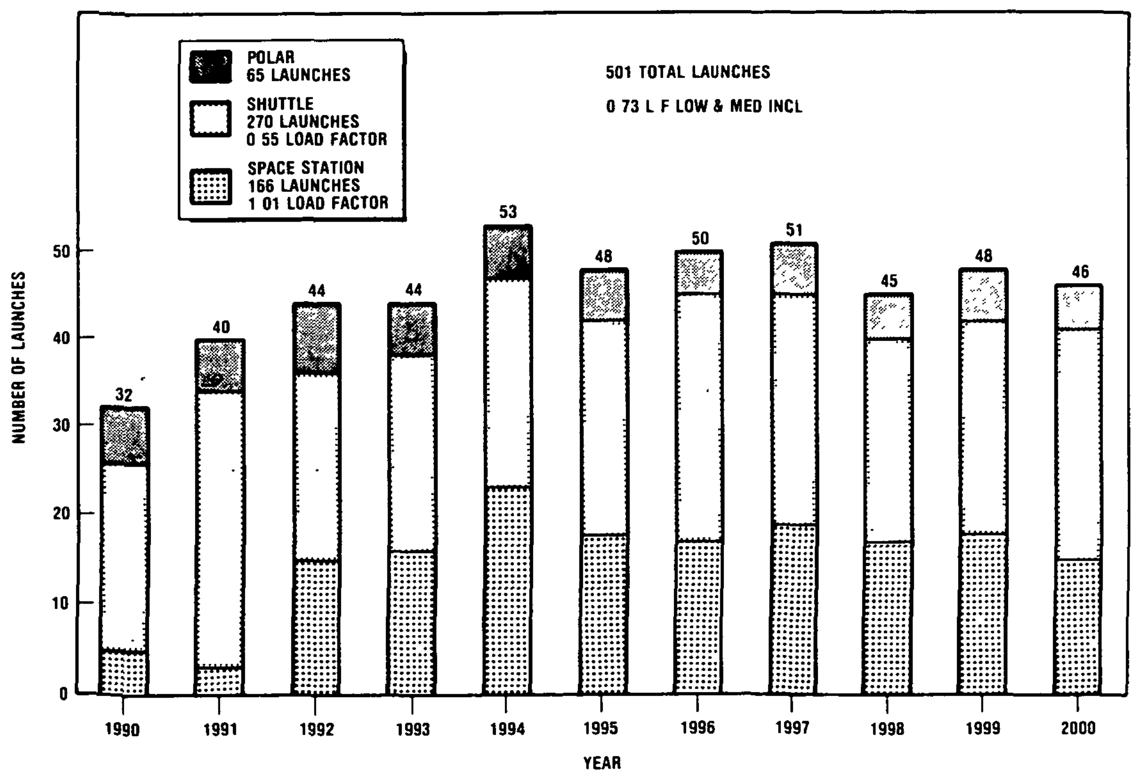


Figure 1-5. Option 1 Launch Summary, 28.5-Degree Space Station

Option 1: OTV Flight/Operations Summary

Figures 1-6 through 1-8 illustrate the results of computer analysis of the high-energy payloads manifested on the OTV. Low-inclination payloads, principally to GEO, totaled 164. Medium-inclination payloads (up to 65 degrees inclination) that were within the OTV capability totaled 67. The number of individual payloads decreased in the end years of Scenario 4, reflecting a trend to larger payloads. In Figure 1-7, the OTV flight summary, the number of OTV flights and their destination class are shown for each year. Also listed is the number of OTV's required to be manufactured, their disposition, and the number of Shuttle deployments for required OTV's. Although not shown on the figure, the code established data by year to enable Shuttle manifesting, and used ground rules of ten flights between overhauls with one overhaul per vehicle. (This was increased to 20 flights for Scenario 6.) The results of computer-code manifesting of the OTV are shown in Table 1-3. Two OTV's were on station at all times, and the flight history of each serial unit was tracked to establish its disposition regarding overhaul. For each flight, the best unit and a compatible payload set were selected. Ground rules for manifesting used required compatible destinations (not more than two DOD payloads or more than three commercial communication payloads per flight), and a compatibility matrix that restricted payload companions, e.g., DOD payloads traveled only with other DOD payloads.

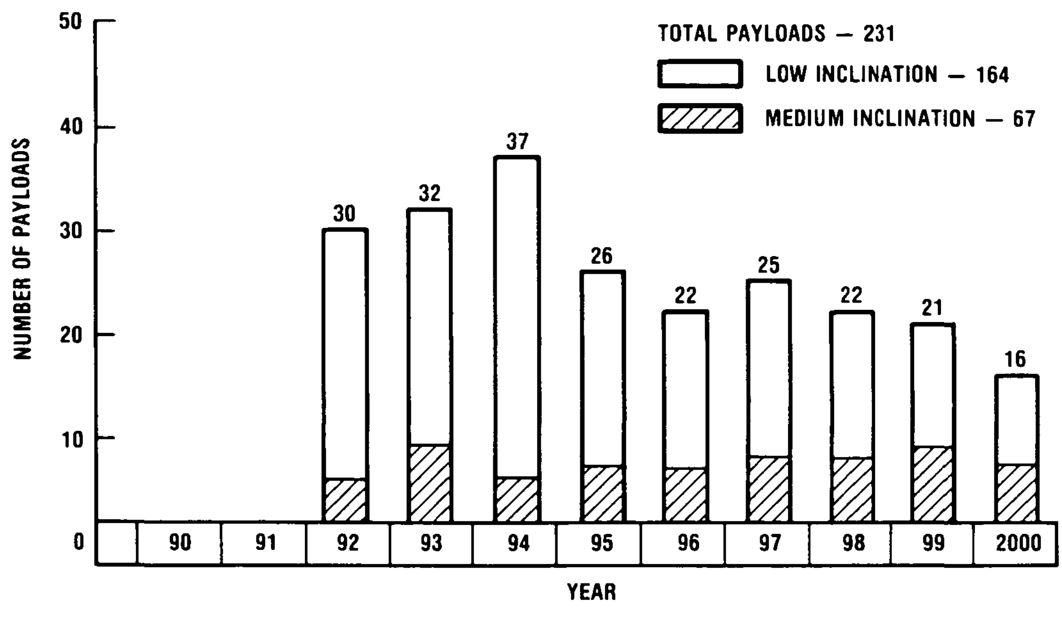


Figure 1-6. High Energy Payloads

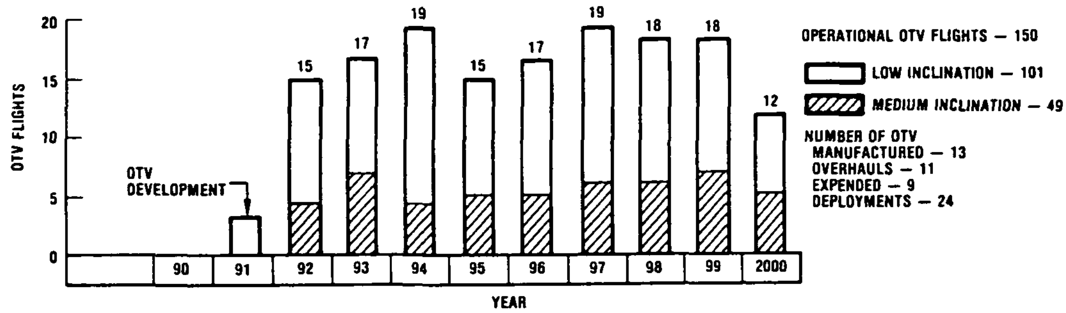


Figure 1-7. OTV Flight Summary

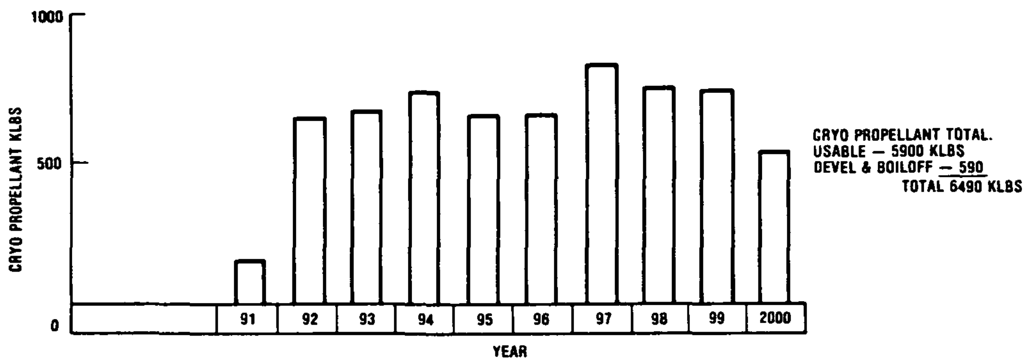


Figure 1-8. OTV Propellant Requirement

Table 1-3. OTV Manifest

Flight No.	Payloads			Cryo Weight	Load Factor	Year	OTV Serial No.
42	RCA DBS F/O	4.5 KLB CLASS	4.5 KLB CLASS	46550	961	94	3
43	4 KLB CLASS	4.5 KLB CLASS	4.5 KLB CLASS	48303	997	94	3
44	4.5 KLB CLASS	4.5 KLB CLASS	NASA growth GEO's	46017	950	94	3
45	4.5 KLB CLASS	4.5 KLB CLASS		41445	856	94	3
46	DOD 9G	DOD 9G		37990	784	94	3
47	DOD 9G	DOD 9G		37990	784	94	3
48	DOD 21			33602	694	94	4
49	DOD 21			33602	694	94	4
50	Mars geochem orbit			12653	261	94	1
51	Uranus/Neptune probe			39012	806	94	4
52	DOD 1G	DOD 7G		45255	935	95	6
53	DOD 19G			45256	935	95	5
54	DOD 23 SERVICE-2			36587	755	95	6

Table 1-3. OTV Manifest (Cont)

Flight No.	Payloads			Cryo Weight	Load Factor	Year	OTV Serial No.
55	Westar F/O	ODSRS	Telstar Z F/O	48150	944	95	5
56	Satcom KF/O	Intelsat VII P		44493	919	95	6
57	RCA DBS F/O	L-SAT F/O		43167	891	95	5
58	4 KLB CLASS	4.5 KLB CLASS	4.5 KLB CLASS	48303	997	95	6
59	4 KLB CLASS	4.5 KLB CLASS	4 KLB CLASS	47541	982	95	5
60	4 KLB CLASS			33064	683	95	6
61	ACTS 2 or P-#			45256	935	95	5
62	DOD 9G	DOD 9G		37990	784	95	6
63	DOD 9G	DOD 9G		37990	784	95	5
64	DOD 21			33602	694	95	6
65	DOD 21			33602	694	95	5
66	DOD 22			19061	393	95	6
67	DOD 1G			33064	683	96	5
68	DOD 3 SERVICE-2			51303	1059	96	6
69	DOD 5G SERVICE-2			54351	1122	96	5
70	DOD 19G			45256	935	96	6
71	DOD 23 SERVICE-2			36587	755	96	5
72	4.5 KLB CLASS	Intelsat VII P		48303	997	96	6
73	4.5 KLB CLASS	4.5 KLB CLASS	NASA growth GEO's	46017	950	96	5
74	ACTS 2 or P-#			45256	935	96	6
75	ACTS 2 or P-#			45256	935	96	5
76	DOD 9G	DOD 9G		37990	784	96	6
77	DOD 9G	DOD 9G		37990	784	96	5
78	DOD 20			33122	684	96	6
79	DOD 21			33602	694	96	5
80	DOD 21			33602	694	96	6
81	Mars NETWORK ORBIT			8853	182	96	6

OPTION 2: SPACE PROCESSING

Option 2 consisted of one Space Station, orbiting the earth in a circular orbit, inclined 28.5 degrees with respect to the equator, and 200 nautical miles above the surface. All activity at the Space Station was related to either space processing or station operations. All other activity accomplished by Mission Scenario 4 (e.g., GEO staging) was accomplished using the existing space transportation system, i.e., these other activities were accomplished independent of the existence of a Space Station. The station acquires IOC in 1990, with an initial crew size of two. The crew size grows to three in 1992 and to four in 1998. It remains at four through the year 2000.

The space processing model of Mission Scenario 4 consisted of three phases. Phase I accomplished all space processing research. All such research activity was accomplished on the Space Station. Phase II accomplished all space processing related prototype hardware demonstration. Prototype hardware could be demonstrated either on the Space Station attached to a research pallet (if the demonstration could stand the station environment), or on the prototype hardware demonstration satellite, which is a separate co-orbital satellite serviced by the station. Phase III accomplished all space processing factory (SPF) production. All such production occurred on a fleet of SPF's. The factories were all separate co-orbital satellites, serviced by Space Station.

The space processing model of Mission Scenario 4 required the following Option 2 building blocks: one energy module, one command module, one payload service assembly (PSA), one growth Spacelab, two space processing laboratory modules, one research pallet, one prototype hardware demonstration satellite (PHDS), three TMS's, one set of station-attached TMS propellant storage tanks, two generic types of SPF's, and continuous station resupply via logistics modules. The energy, command, and logistics modules, the PSA, and the TMS were described in the previous section. The new (space processing related) building blocks are described in Figure 1-9. A summary of when the new building blocks are required and how long they remain operational is presented in Figure 1-10.

The various payloads required to accomplish the space processing model of Mission Scenario 4 and Space Station operations were grouped, by calendar year, into files called payload data lists. The payload data lists were then manifested into STS missions using the SOSMAN computer program. The Shuttle payload cargo bay was loaded using a maximum payload weight of 61,000 pounds or a length of 55.5 feet (4.5 feet must be reserved on all Space Station destined missions for the docking module). The number of such STS missions per year, required to support Option 2, is presented in Figure 1-11.

Close inspection of Figure 1-11 will reveal two basic facts. First, the number of STS missions per year necessary to support the space processing model of Mission Scenario 4 is very low (too low, in fact, for timely return of the high value finished products). Second, the total Option 2 STS load factor for Space Station destined missions is very low. This is because the number

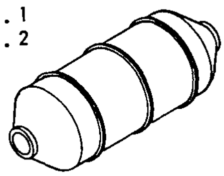
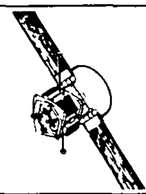
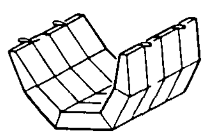
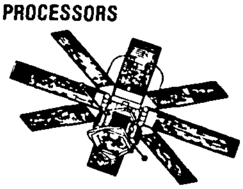
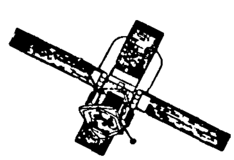
ELEMENT	LENGTH (ft)	WEIGHT (lbs)		VOLUME FOR EXPTS (ft^3)	COST CATEGORY
		GROSS	EXPT		
GROWTH SPACE LAB 	14	13,300	4,700	783	PAYLOAD SUPPORT ELEMENTS
LAB MODULE NO. 1 LAB MODULE NO. 2 	40 40	27,100 23,400	12,100 8,400	2,017 1,400	PAYLOAD SUPPORT ELEMENTS
PROTOTYPE HARDWARE DEMONSTRATION SATELLITE (PHDS) 	6.5	6,300	4,000	667	PAYLOAD SUPPORT ELEMENTS
RESEARCH PALLET 	10	5,650 (1,650)	4,000	667	PAYLOAD SUPPORT ELEMENTS
TELEOPERATOR MANEUVERING SYSTEM 	3.1	8,245 (2,545)		5,700 LB PROPELLANT	UPPER STAGES
SPACE PROCESSING FACTORY • BIOLOGICAL PROCESSORS 	22.5	25,100	11,000	1,700	USER ELEMENTS
SPACE PROCESSING FACTORY • CRYSTAL GROWER 	10.0	12,500	5,000	700	USER ELEMENTS

Figure 1-9. Option 2 Building Blocks

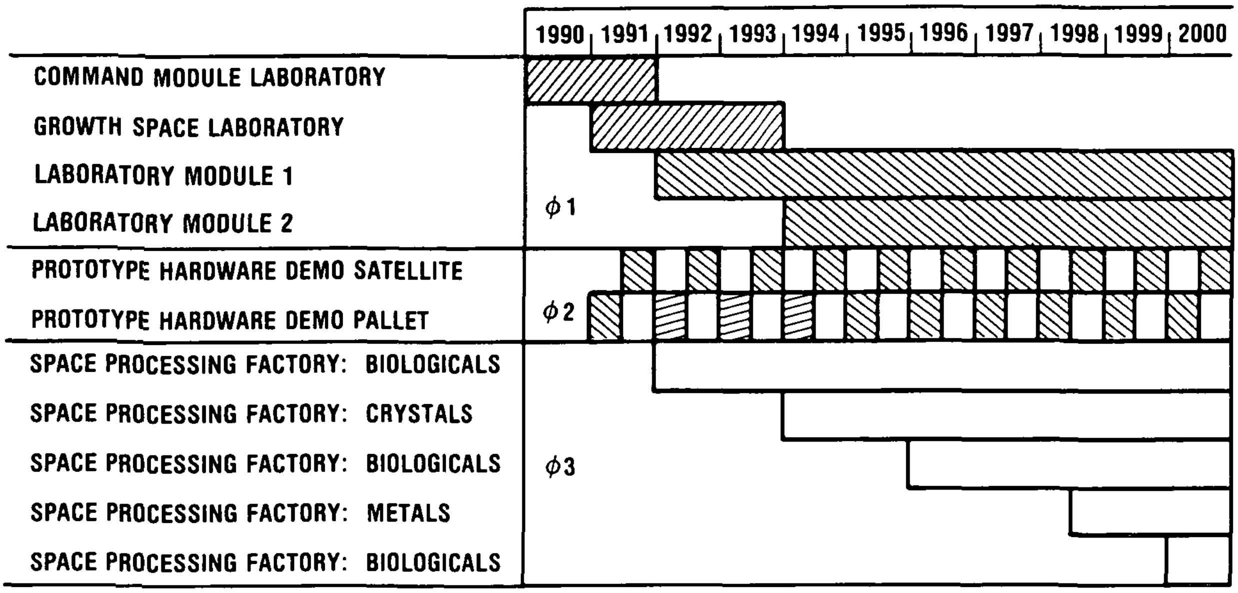


Figure 1-10. ESTS Option 2 Operations Summary

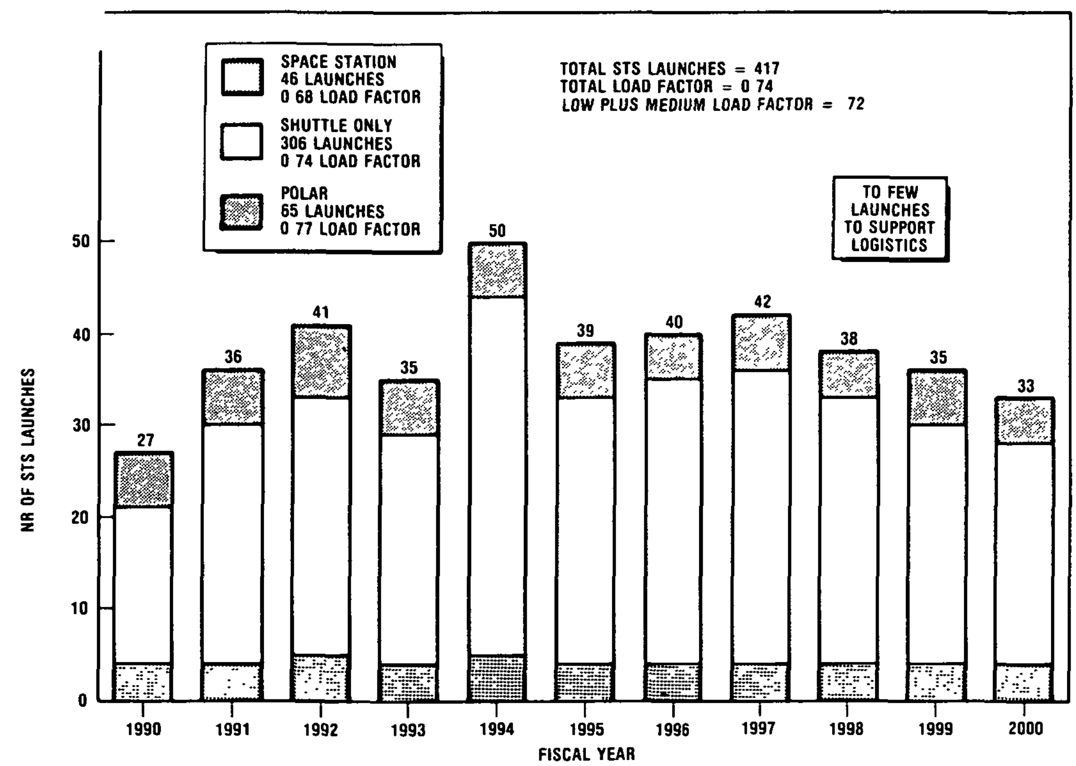


Figure 1-11. Option 2 STS Launch Summary

of payloads per year necessary to support space processing is very low, and because very little propellant is required at the Space Station. (The only propellant required on orbit is that needed by the TMS, to service the various SPF's and PHDS.) The propellant is very dense relative to the average density of most spaceborne payloads, and is able to be manifested almost wherever extra cargo bay length and load-carrying capability exist on a given STS mission. The net result of the inclusion of much propellant in a set of STS manifests is a high load factor. Option 2 cannot take advantage of this situation; hence, the low total load factor.

The net result of this entire analysis is that because space processing, as defined in Mission Scenario 4, requires infrequent and inefficient utilization of the STS, which results in a higher cost per value received; a Space Station dedicated to only space processing is not a viable option. Space processing is, by nature, a low mass flow to orbit, high labor intensive, large volume operation, as is activity in the life science and physical science mission categories. Low-mass flow to orbit, high labor intensive, large volume operations must be integrated with high-mass flow to orbit, low labor intensive, low volume operations (e.g., GEO staging), and with high-mass flow to orbit, high labor intensive, high volume operations (e.g., space construction) in order to achieve the most efficient utilization of the STS and Space Station, thus achieving the maximum value per monetary unit spent.

OPTION 4: SCIENCE AND APPLICATIONS

Option 4 placed the Space Station at an inclination of 57 degrees. Missions for space processing for Option 2, when the Space Station was at 28.5 degrees, were relocated to the new Space Station inclination of 57 degrees because of the independence of space processing to inclination. All of the science/applications/technology (S&A) payloads at 57 degrees were run through the station. Of the S&A payloads at 28.5 degrees, 49 payloads had optional locations and were moved to the station location of 57 degrees. All DOD flights at 57 degrees were included, which then total 399 payloads through the station. The building blocks for space processing were described under Option 2 and include the growth Spacelab, the two lab modules, the prototype hardware demonstration satellite and pallet, and the factories. The building blocks for S&A include servicing of the free-flyers such as space telescope, S&A pallets, and experimental modules (Figure 1-12).

Launch Summary

The launch manifest was run with the computer SOSMAN. The Shuttle launches are shown for each year in Figure 1-13. The Shuttle payload bay was loaded using a maximum payload weight of 47,500 pounds or a length of 53 feet, whichever value controls for the mix of payloads. The number of launches and the respective load factors are summarized as follows.

Item	Launches	Load Factor
Space Station	99	0.64
Shuttle only	247	0.75
Polar	65	0.77
Total	411	

The weighted average load factor for the Space Station and the Shuttle-only flights was 0.71. The load factor for the polar flights was not included in the average value because a Space Station was not considered as an option at a polar orbit and its value should not influence the comparison of Space Station options. The maximum number of flights was 49 per year; the minimum number of flights was 27, with an average number of 37.4 per year.

Service missions are conducted from the Space Station to the free-flyer space processing factories that are orbiting in the Space Station orbit. Service missions are also conducted for the S&A free-flyer satellites in a 470 nautical mile orbit, as shown in Figure 1-14. These missions were conducted with a storable bipropellant TMS by visiting and servicing the free flyers

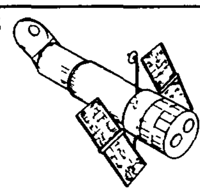
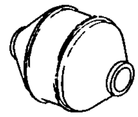
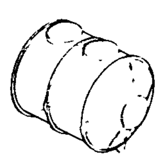
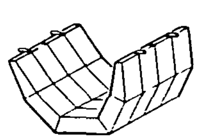
ELEMENT	LENGTH (ft)	WEIGHT (lbs)		VOLUME FOR EXPTS (ft^3)	COST CATEGORY
		GROSS	EXPT		
SERVICED FREE FLYERS • SPACE TELESCOPE 	42	24,200	-	-	PAYLOAD SUPPORT ELEMENTS
SCIENCE/APPLICATIONS/TECHNOLOGY LAB 	20	14,300	6,300	1,050	PAYLOAD SUPPORT ELEMENTS
SPACE LAB 	22	27,000	14,000	2,333	PAYLOAD SUPPORT ELEMENTS
SCIENCE/APPLICATIONS/TECHNOLOGY PALLET 	10	8,450 (1,650)	6,800	1,133	PAYLOAD SUPPORT ELEMENTS

Figure 1-12. Option 4 Building Blocks

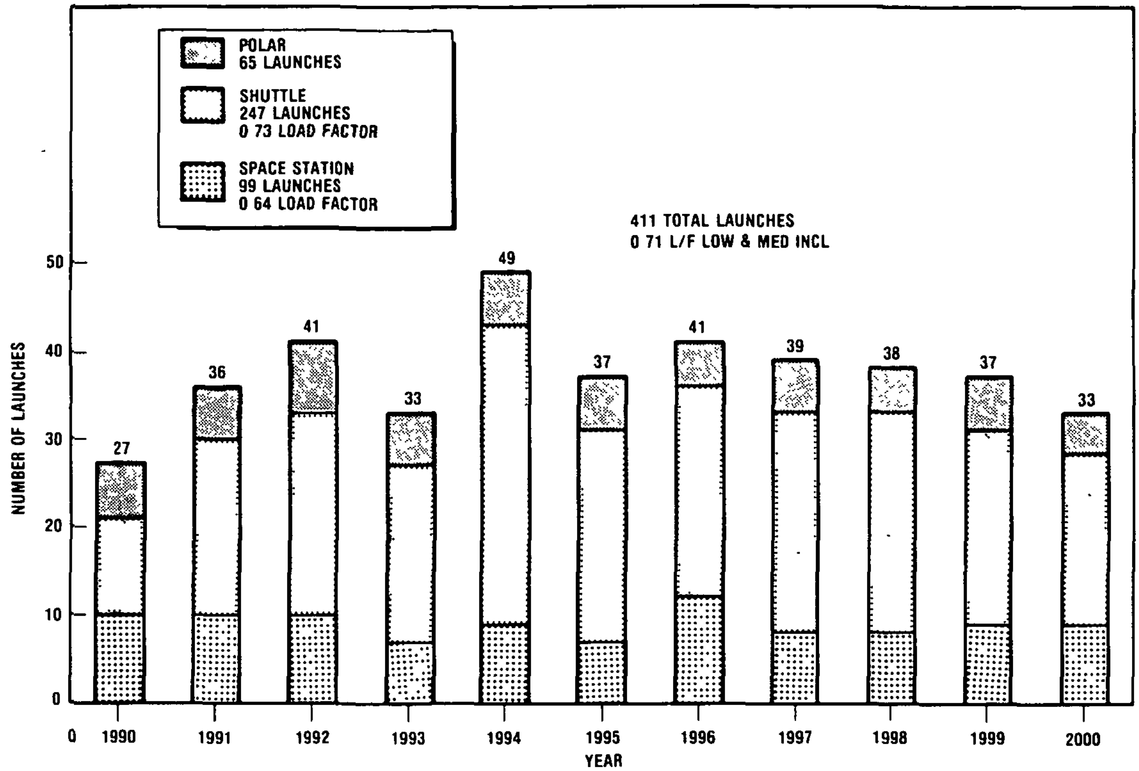


Figure 1-13. Option 4 Launch Summary, 57-Degree Space Station

in orbit. The SPAS-01, the space telescope, and the LDEF were returned to the Space Station for servicing and returned to their orbits. The TMS propellant required for the space processing was 45.7 kips and for the S&A free flyers was 91.1 kips for a total of 136.8 kips. The storable propellant tank assembly described in Option 1 and used in Option 2 contained the four OMS tank version with a capacity of 37 kips. Using this tank, the Shuttle delivered a total of 145 kips in five years.

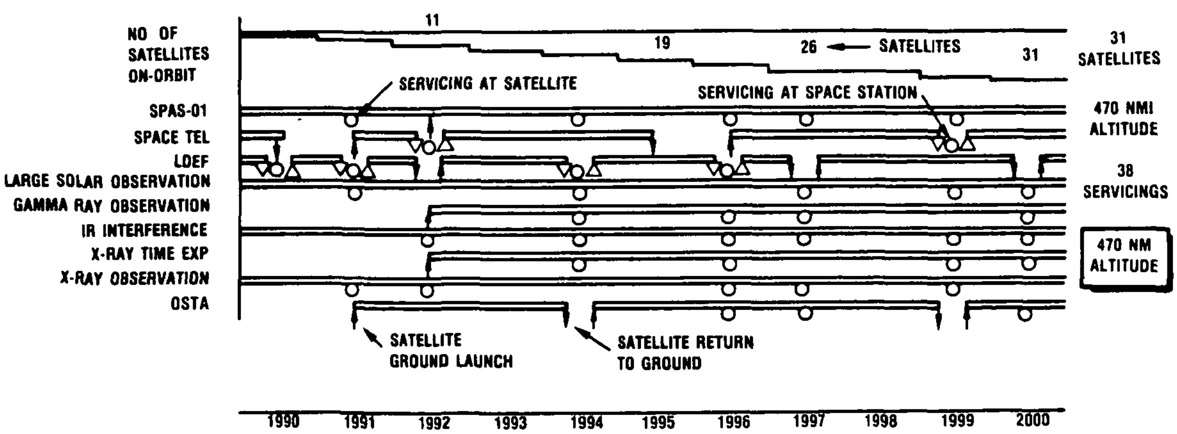


Figure 1-14. Option 4 Free-Flyer Operations (57-Degree, 47.5 kips Shuttle) Service Missions

Labs and Pallets

The labs and pallets scheduled for Space Station are shown in Figure 1-15. Each pallet used for Experiments 1 through 10 has a capacity of 6,800 pounds. Because of the phasing, not all pallet experiments are attached to the Space Station at one time, and only three or four pallets will be required to assemble and check out the experiments. Each pallet remains on the Space Station for two to three years.

The initial three experimental modules used an upgraded short and long Spacelab module with experiments weighing 6,300 pounds and 14,000 pounds, respectively. The last three experimental modules used improved experiments based on early results using standard Space Station construction components.

OPTION 3: MAXIMUM ACTIVITY AT 28.5 DEGREES

Option 3 provided the Space Station at an inclination of 28.5 degrees. The mission payloads include the space processing, S&A, DOD payloads, and commercial communications. An addition to this includes some of the medium-inclination DOD flights that are launched from the Space Station with a high-energy upper stage to make a plane change from 28.5 to 57 degrees, as in Option 1. The Space Station evolution is shown in Figure 1-16 to accommodate the payload traffic. Early Space Station elements of energy module, command module, PSA, and storable propellant tank with a four-man crew support the servicing flights with the TMS and low-energy free-flyer deliveries. As the traffic through the Space Station increases, the station is increased by adding two habitat modules, a tunnel module, and an eight-man crew.

Launch Summary

The major activities for 1990 consists of activating the four-man Space Station, servicing the space processing labs, and servicing the low-energy free-flyer missions. In 1991, the development of cryo propellant handling is started with transfer to propellant storage tanks and loading the OTV. In 1992, the high-energy OTV flights begin.

The launch summary is shown in Figure 1-16. The number of launches for each year is also shown to the Space Station for Shuttle only, and the polar flights. The total summary is:

Item	Launches	Load Factor
Space Station	233	0.98
Shuttle only	49	0.57
Polar	65	0.77
Total	347	

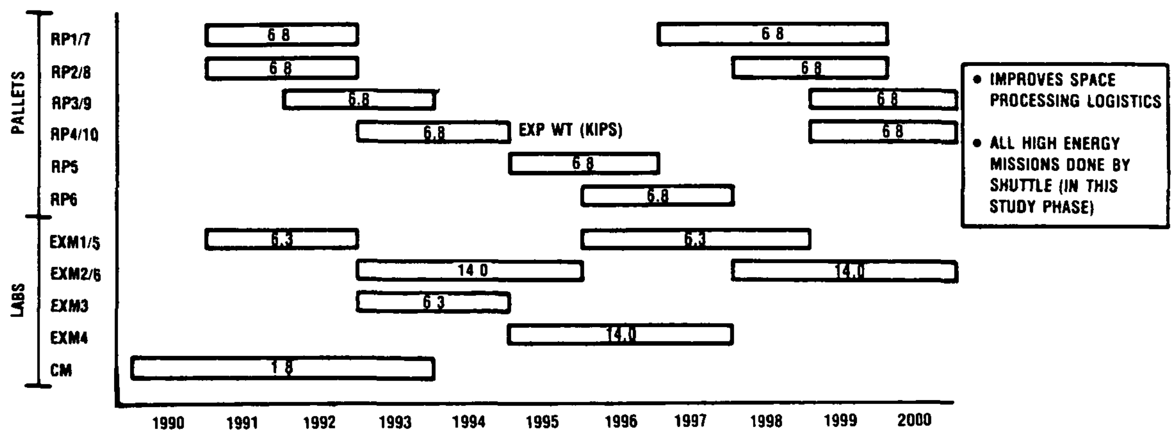


Figure 1-15. Option 4 Free-Flyer Operations (57-Degree, 47.5 kips Shuttle) - Labs and Pallets

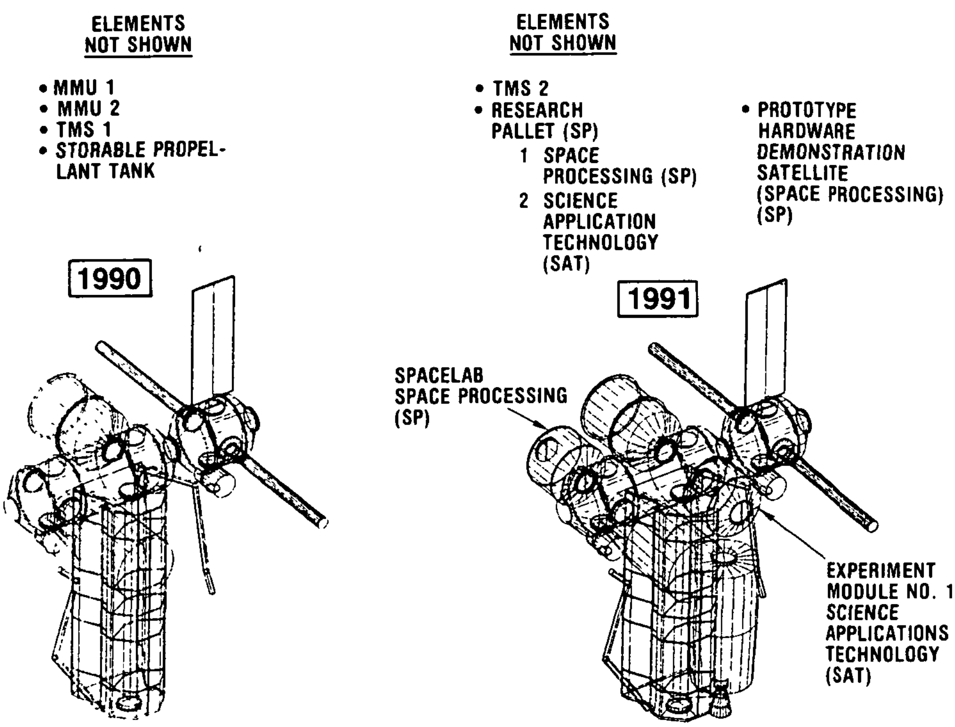


Figure 1-16. ESTS Option 3--Evolution

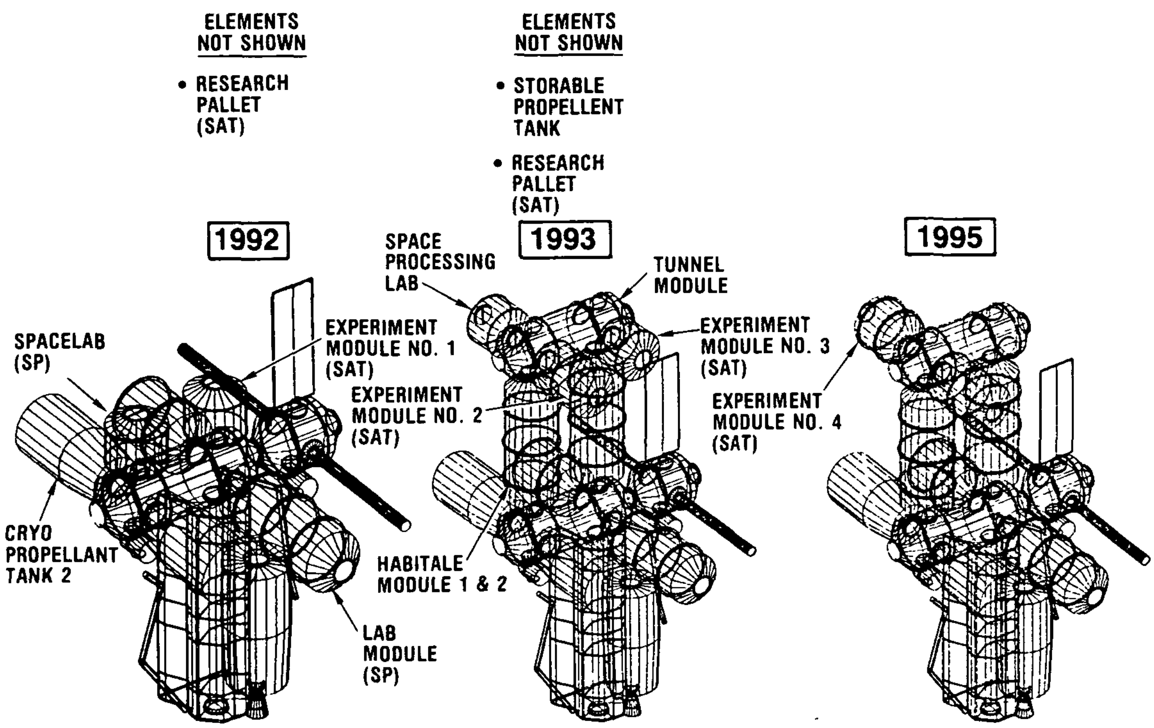


Figure 1-16. ESTS Option 3--Evolution (Cont)

The weighted average for the Space Station and Shuttle-only flights was a 0.92 load factor. As in Option 4, the polar flights load factor was not included in the average value, because the Space Station was not an option in a polar orbit. Figure 1-17 shows the number of launches to reach a maximum of 35 per year, a minimum of 26 per year, and an average value of 31 per year.

Option 3 is different from Option 4 in that it has the addition of the high-energy flights to geosynchronous orbit from Option 1. Additional high-altitude payloads delivered to 57 degrees were launched in the Shuttle to the Space Station at 28.5 degrees. The OTV then launches them from the Space Station through an orbit plane change to 57 degrees. These flights required the orbiter to carry propellant tanks for the liquid oxygen and liquid hydrogen. These flights required 6,485 kips of propellant, and the flights provided 6,590 kips as manifested. The yearly propellant balance is shown in Figure 1-18. The cryo propellant stored at the Space Station includes the two storage tanks for 108 kips and the two OTV's for 96 kips, with a total of 204 kips.

The TMS storable propellant for the space processing servicing was 45.7 kips and for the S&A free-flyer servicing, was 75.2 kips for a total of 120.9 kips. A total weight of 130 kips of propellant was delivered in five Shuttle flights. In retrospect, a smaller storable propellant tank than the 37-kip tank could have been used for the transfer tank in the Shuttle to permit at least one delivery in each year instead of five deliveries in 11 years.

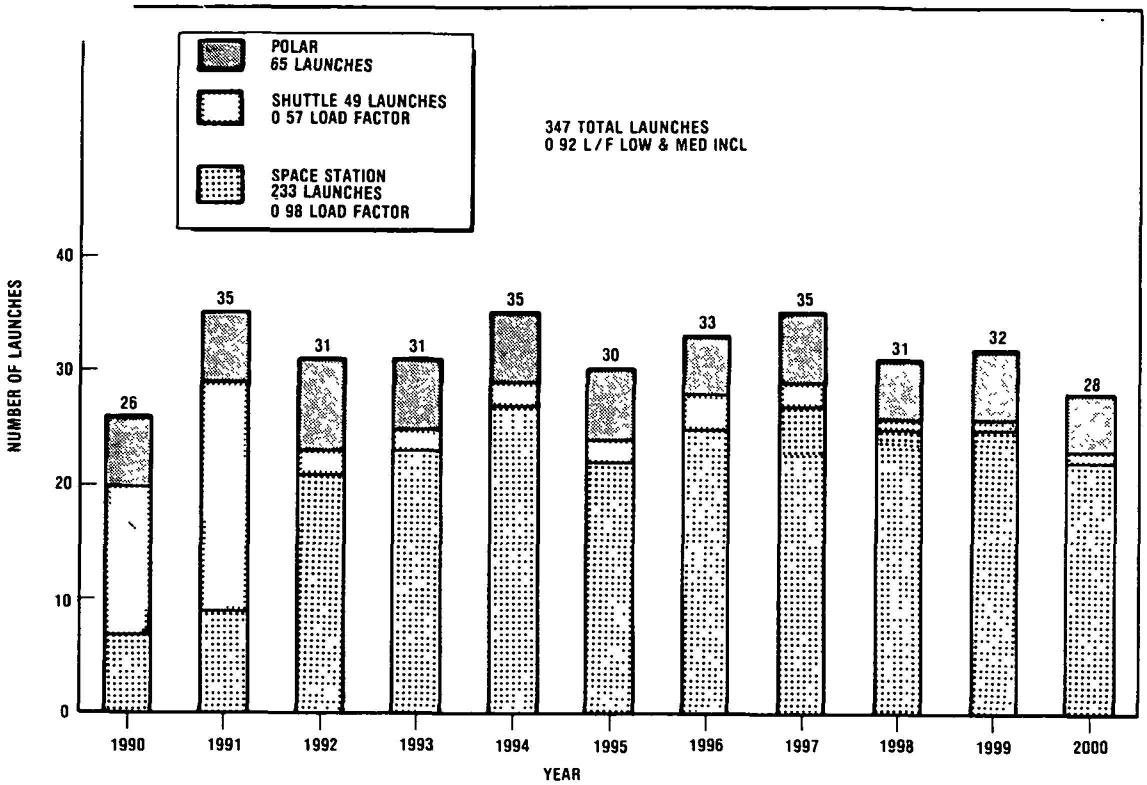


Figure 1-17. Option 3 Launch Summary (28.5-Degree Space Station)

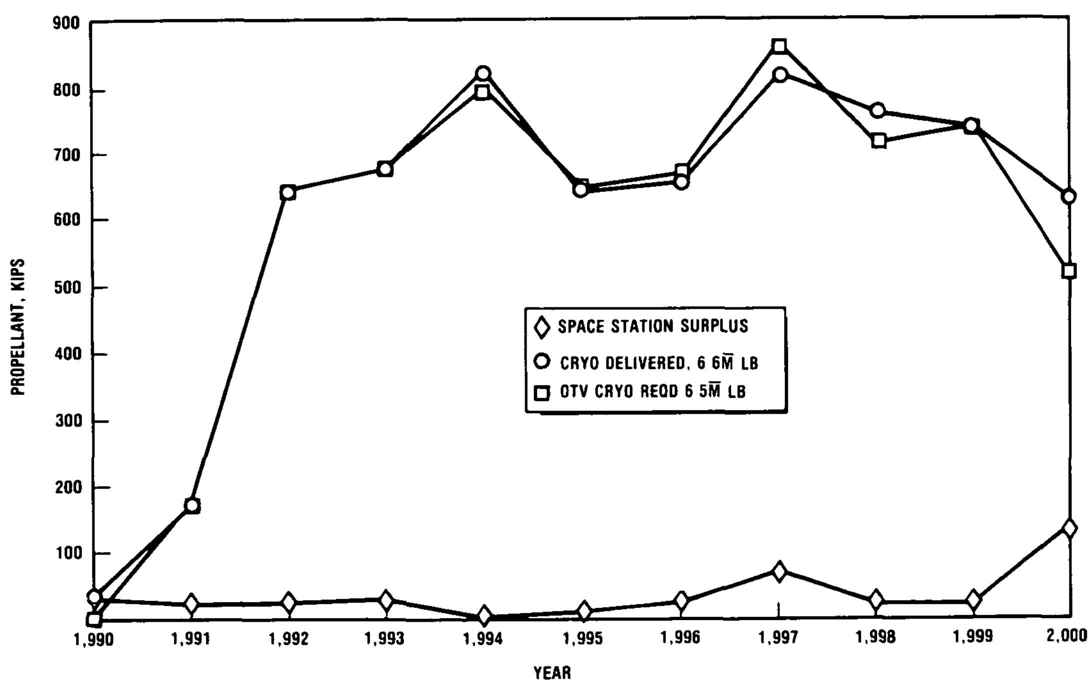


Figure 1-18. Option 3 Cryo Propellant Space Station Status

Manifest

Table 1-4 is a typical example of the manifest for each Shuttle payload. The Shuttle is loaded to a maximum of 61 kips, or a maximum of 53 feet, whichever value controls. The scavenging or cryo propellant tanks are added to carry the cryogenic propellant to the two Space Station propellant tanks and two OTV's. The payload bay is loaded with all the payloads, including the docking module, for a maximum of weight or length. The use of the scavenging and top-off tanks permit the Shuttle to be loaded to a higher load factor of 0.98, as compared to Option 4, which had a 0.64 load factor.

Table 1-4. Manifest for Each Shuttle Payload (Typical Example)

ID. No.	Payload Name	OTV Type	Payload Mass (kips)	Payload Length (feet)	Mass To LEO (kips)	Unused Mass (kips)	Load Factor
1	Docking module		4.5	7.0	69.0	0.0	1.13
	DOD 3S	USA-P	45.0	35.0			
	DOD 23	USA-M	6.9	6.5			
	Scavenge tank		2.5	9.0			
	Scavenge fuel		8.0	0.0			
	Topoff fuel		2.1	0.0			
2	Docking module		4.5	7.0	69.0	0.0	1.13
	DOD 3S	USA-P	45.0	35.0			
	DOD 1G	USA-M	4.6	6.5			
	Scavenge tank		2.5	9.0			
	Scavenge fuel		8.0	0.0			
	Topoff fuel		4.4	0.0			
3	Docking module		4.5	7.0	69.0	0.0	1.13
	Propellant tank (2)	None	26.6	9.5			
	Lab resupply:mod	None	.8	2.0			
	Scavenge tank		2.5	9.0			
	Scavenge fuel		8.0	0.0			
4	Docking module		4.5	7.0	67.3	0.0	1.10
	Lab module start	None	24.3	40.0			
	SPF resupply:B10	None	8.0	2.0			
	PHD start:module	None	4.0	2.0			
	Scavenge tank		2.5	9.0			
	Scavenge fuel		8.0	0.0			
	Topoff fuel		16.0	0.0			
5	Docking module		4.5	7.0	69.0	0.0	1.13
	DOD 21 (M)	USA-M	23.0	18.5			
	DOD 6A	USA-I	20.0	18.0			
	DOD 6A service (1)	USA-P	1.0	3.5			
	Scavenge tank		2.5	9.0			
	Scavenge fuel		8.0	0.0			
	Topoff fuel		10.0	0.0			

Table 1-4. Manifest for Each Shuttle Payload (Typical Example) (Cont)

ID. No.	Payload Name	OTV Type	Payload Mass (kips)	Payload Length (feet)	Mass To LEO (kips)	Unused Mass (kips)	Load Factor
6	Docking module		4.5	7.0	65.5	0.0	1.07
	DOD 21 (M)	USA-M	23.0	18.5			
	DOD 5G	USA-M	11.5	22.5			
	Scavenge tank		2.5	9.0			
	Scavenge fuel		8.0	0.0			
	Topoff fuel		16.0	0.0			
7	Docking module		4.5	7.0	69.0	0.0	1.13
	SPF start:CRS	None	22.0	11.0			
	Logistics mod	None	20.6	20.5			
	IR Intrferomtr ser	USA-P	9.9	10.5			
	SPF resupply:CRS	None	1.5	2.0			
	Scavenge tank		2.5	9.0			
	Scavenge fuel		8.0	0.0			

OPTION 6: TWO STATIONS

Option 6 was concepted with two, small, four-man Space Stations with one at 28.5 degrees inclination and the other at 57 degrees. Payloads were assigned to each station as follows.

28.5-Degree Station	57-Degree Station
• All geosynchronous payloads	• All S&A technology experiment modules and research pallets
• All planetary spacecraft	• All space processing research pallets
• All low inclination (25 to 32 degrees) mandatory spacecraft (those stated to be optional at 28 degrees or 57 degrees will be located at 57 degrees)	• All space processing process development and demonstration payloads (pallet and free-flyer) • All medium inclination (54 to 60 degrees low altitude [<1200 nmi] spacecraft)
• All five space processing factories (SPF)	• All medium inclination, high-altitude spacecraft OTV • Any high-inclination (90 to 98 degrees) high-altitude spacecraft feasible with single-stage reusable OTV

Option 3 contained some payloads that were launched from the Station at 28.5 degrees using an OTV to be delivered through a plane change to a medium inclination. A second station at 57 degrees would provide a launch platform location that would reduce the OTV cryo propellant requirement. Option 3 required 6,485 kips of propellant. Option 6, with two stations, required 4,588 kips of propellant at 28.5 degrees, and 1,060 kips of propellant at 57 degrees for a total of 5,648 kips. The propellant savings for Option 6 was 837 kips over Option 3. An offsetting factor in the OTV propellant savings is the reduction in Shuttle payload capability from 61 kips at 28.5 degrees to 47.5 kips at 57 degrees. Option 6 launch summary is shown in Figure 1-19. The maximum number of launches was 44 with a minimum of 29 and an average of 33.1. The total number of launches was 364 compared to 347 for Option 3.

The propellant savings can be equated to a single-launch cost of $77 X 10^6$ for $1,262/pound at 28.5 degrees inclination, and $1,621/pound at 57 degrees inclination. Using these costs and assuming a 1.0 load factor, gives a total mission propellant cost of $8.184 X 10^9$ for Option 3. For Option 6, the propellant costs $7.508 X 10^9$ for a cost savings of $676 X 10^6$. The load factors for flights to the Space Station were 0.98 for Option 3, and 0.97 at 28.5 degrees and 0.87 for 57 degrees for Option 6. If these load factors are used to correct the cost of propellant, the propellant costs for Option 3 are $8.35 X 10^9, and for Option 6 are $7.944 X 10^9, for a cost savings of $407 X 10^6. Comparing the two options to the number of launches gives a greater cost of $131 X 10^6 of Option 6 over Option 3.

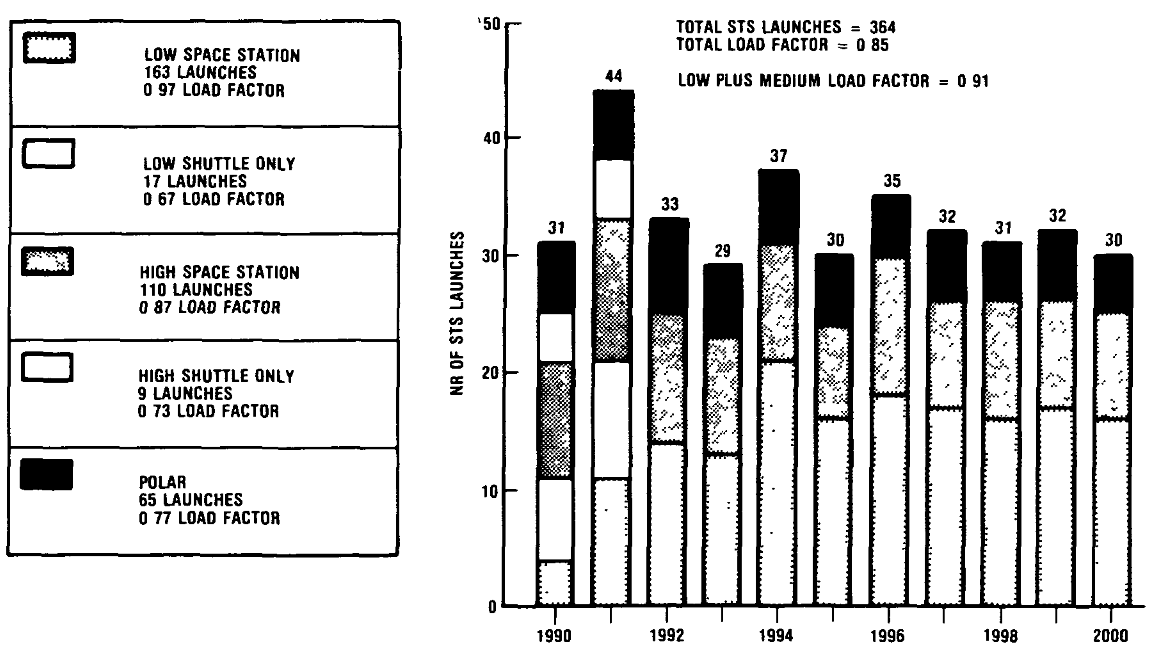


Figure 1-19. Option 6, STS Launch Summary

OPTION 5: NO STATION

The building blocks for Option 5 are illustrated in Figure 1-20. Option 5 assumes that Mission Scenario 4 is executed without a Space Station. All detached payloads are deployed to their final or transfer orbit by the Shuttle. Accordingly, missions with final orbital inclinations greater than 28.5 degrees are assumed deployed by the Shuttle at or near their final orbital plane.

GEO missions and other high-energy missions use expendable upper stages. These are shown in Figure 1-19. Each upper stage is dedicated to one payload. Servicing is performed either directly from the orbiter (EVA, RMS) or with a TMS. The TMS is ground-based and carried to LEO with each servicing mission. On high-energy (e.g., GEO) servicing missions, the TMS is mounted on an upper stage and launched to the high-energy orbit. The TMS is normally retrieved after servicing missions. For servicing missions to high-energy orbits, however, it is expended.

Manned on-orbit research and development (R&D) is needed for commercial space processing and for NASA science and applications. This work is performed with the Spacelab module, sometimes including a pallet. The number of Spacelab missions was selected to give a number of R&D hours on orbit equivalent to that of the Space Station. For Space Processing, this is achieved with 129 dedicated Spacelab missions from the year 1990 through 2000. For S&A, 33 such missions are needed.

Launch Summary

The launch manifest was created with the SOSMAN program. Figure 1-21 shows the Shuttle launches by year. The Shuttle was assumed to have the following lift capacity:

1. 70,000 pounds to 160 nmi/28.5 degrees
2. 49,000 pounds to 160 nmi/57 degrees
3. 25,000 pounds to 160 nmi/98 degrees

Since no fuel scavenging or docking equipment was carried, all 60 feet of the payload bay length were available.

A major part of the launch total is the Spacelab flight scenario. Spacelab flights are summarized as follows:

Inclination (Degrees)	User Area	Number of Flights
28.5	Space Processing R&D	129
57.0	NASA science and applications	33

Spacelab flights are assumed to be dedicated and to lift 35,000 pounds into LEO. This gives each low-inclination Spacelab flight a load factor of 0.5. The large number of such flights reduces the average load factors for launches to each orbital inclination are shown in Figure 1-20. Low-inclination launches have the lowest average load factor. This is because of the large number of Spacelab flights at that inclination.

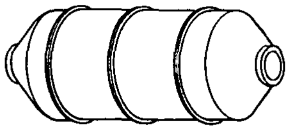
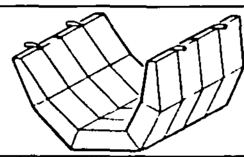
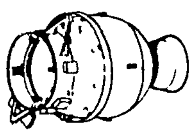
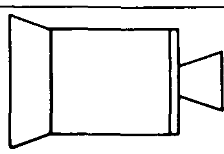
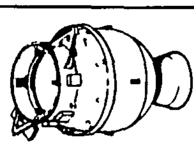
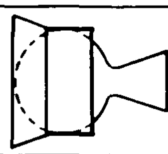
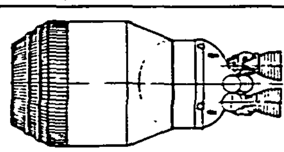
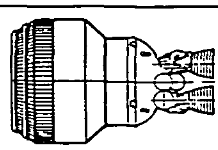
ELEMENT		LENGTH (ft)	WEIGHT (lbs) GROSS	WEIGHT (lbs) EXPT	VOLUME FOR EXPTS (ft³)	COST CATEGORY
SPACE LAB MODULE		40	29,350	18,000	3,000	PAYLOAD SUPPORT ELEMENT
SPACE LAB PALLET		10	5,650 (1,650)	4,000	667	PAYLOAD SUPPORT ELEMENT
TELEOPERATOR MANEUVERING SYS		3.1	8,245 (2,545)	- -	- 5,700 lbs PROPELLANT	UPPER STAGES
PAM D		8	8,600	-	-	UPPER STAGES
PAM A		7.6	14,700	-	-	UPPER STAGES
PAM II		10.8	13,000	-	-	UPPER STAGES
IUS 1st STAGE (SRM-1)		10.4	36,200	-	-	UPPER STAGES
CENTAUR - F		29.5	52,000	-	-	UPPER STAGES
CENTAUR - G		20	40,000	-	-	UPPER STAGES

Figure 1-20. Option 5 Building Blocks

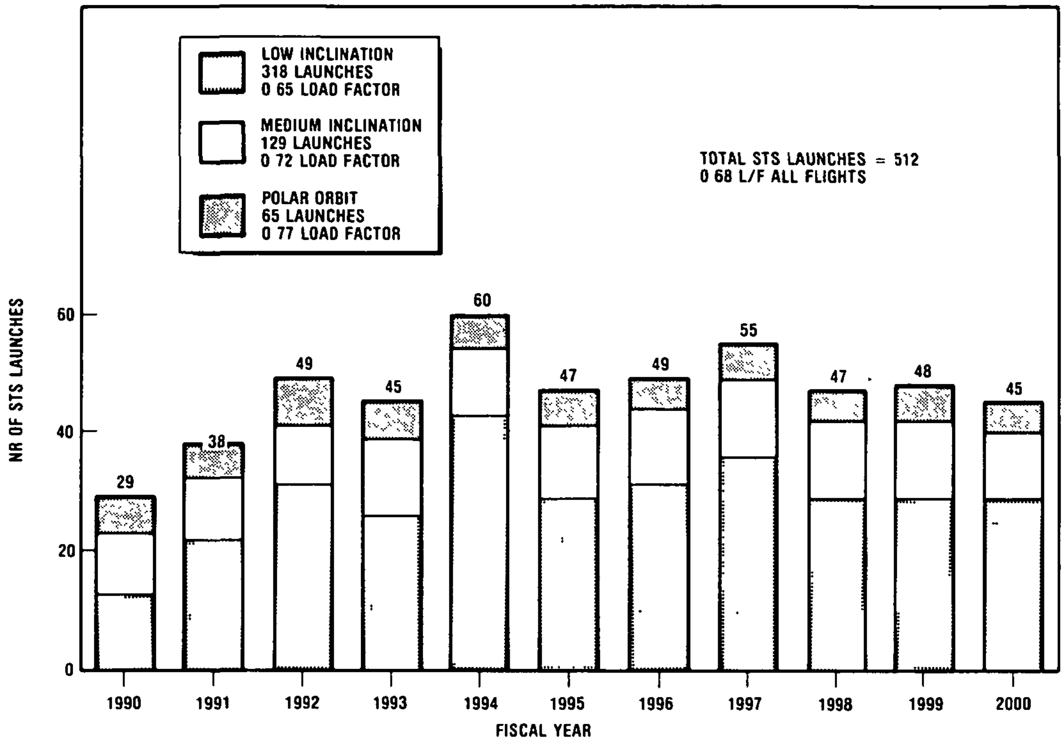


Figure 1-21. Option 5 STS Launch Summary

Key Comparisons

The most significant differences between Options 5 and the Space Station options are shown in Table 1-5. These fall into two areas: upper stages and Spacelab flights.

Options 1 and 3 involve the Space Station in loading, servicing, and launching reusable OTV's. These vehicles boost the high-energy payloads. In Option 5, the OTV does not appear. The same payloads must be boosted with expendable upper stages. As shown in Table 1-5, Option 5 requires 248 expendable upper stages of various types to boost the Mission Scenario 4 high-energy traffic. The same thing can be done in Option 3 with 13 OTV's, serviced and launched at the Space Station. These OTV's consume 6.5 million pounds of propellant.

In the Space Station options, commercial and NASA R&D are performed in experiment modules and in the command module. There is no permanent manned orbiting facility in Option 5; therefore, the equivalent research must be done on ten-day Spacelab missions. As shown in Table 1-5, it takes 162 Spacelab missions to do the R&D planned for the Space Station.

PROGRAM OPTIONS EVALUATION

It was determined that essentially all of the payload missions defined in the Mission Scenario 4 mission model could, in fact, be accomplished by

Table 1-5. Option 5 Key Comparisons

	OPTION 5 NO. STATION						SPACE STATION OPTIONS
	GEO NODE		57°		TOTAL		
UPPER STAGES	TOTAL	193	TOTAL:	72	248	VS	13 OTV'S & 6.5 MLB PROPELLANT OPTIONS 1 & 3
	PAM-D:	2	PAM-D:	10			
	PAM-II:	14	PAM-A:	2			
	PAM-A:	17	IUS 1ST STG:	17			
	IUS 1ST STG:	76					
	CENTAUR-F:	35	CENTAUR-F:	1			
	CENTAUR-G:	39	CENTAUR-G:	25			
	EXPENDED TMS:	10					
SPACE LAB FLIGHTS							
• SPACE PROCESSING	129				129	VS	3 EXPERIMENTAL MODULES & CM LAB — OPTIONS 2 & 4
• NASA R&D	33				33	VS	6 EXPERIMENTAL MODULES & CM LAB — OPTION 4

the Shuttle even though some were not accomplished very efficiently. This capability provided a straightforward quantitative criterion to evaluate the relative merits of the program options, which is the total cost to accomplish the entire Mission Scenario 4 mission model. For each Space Station option, the payload missions captured by the station are identified. The costs of conducting the mission and the costs of the station and the other supporting elements are estimated. The costs for conducting the rest of the payload missions in Mission Scenario 4 with the Shuttle-only mode were then estimated and added to the costs for the Space Station missions. Total costs to accomplish all the Mission Scenario 4 payload missions by each of the program options were derived in this manner and compared.

Figure 1-22 shows the total number of Shuttle launches required to perform all the Mission Scenario 4 payload missions by each of the six program options. The lower segment of each bar (except for Option 5) indicates the number of launches associated with the Space Station operations. The upper segment of each bar indicates the number of Shuttle launches to polar orbit that are required by Mission Scenario 4. This segment is the same for each option. The middle segment of each bar indicates the number of Shuttle launches required by Mission Scenario 4 to inclinations other than polar. The figures to the right of the bars indicate the average load factors for the adjacent segments. For example, in Option 3, the average load factor for Space Station logistics flights is 0.98. The average load factor for Shuttle flights to inclinations other than polar is 0.57 and the weighted average load factor for all flights to inclinations other than polar is 0.92.

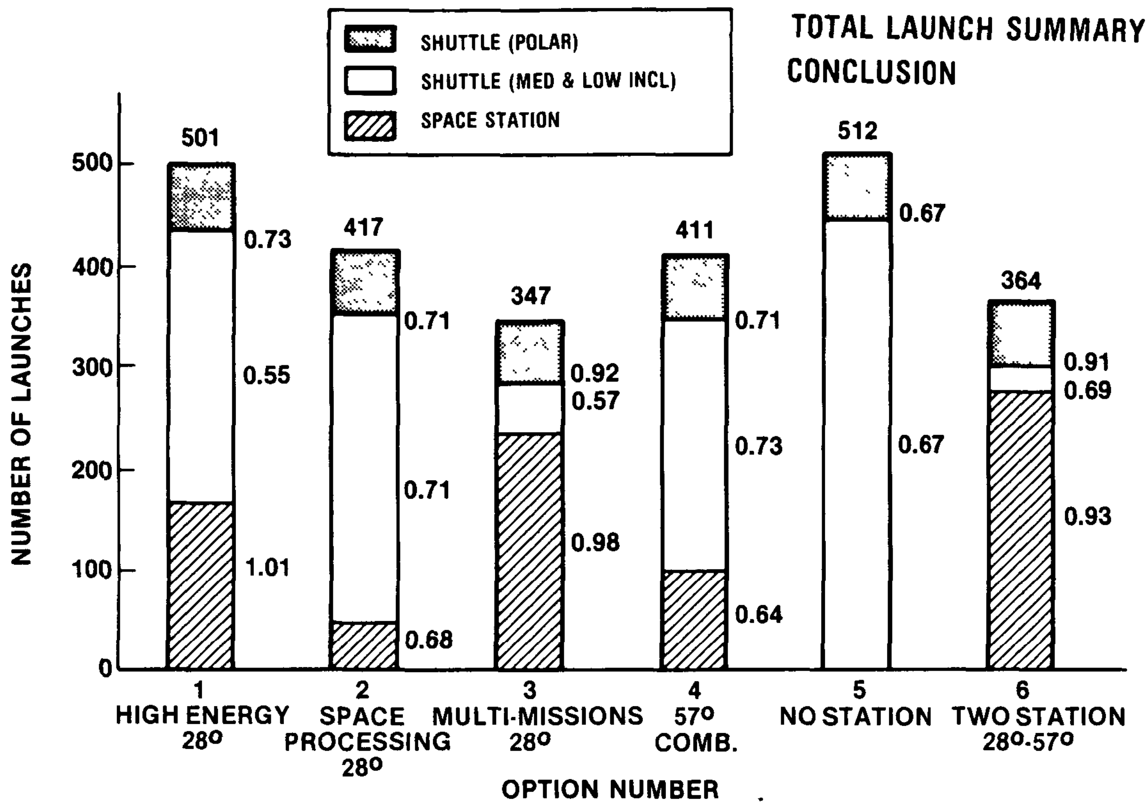


Figure 1-22. Total Launch Summary (1990-2000)

It can be seen that the two stations of Option 6 capture the highest proportion of the total number of flights. Option 3 results in the lowest number of launches, and the no station (Shuttle only) Option 5 requires more launches than any of the Space Station options.

Figure 1-23 compares the total costs of each program option to accomplish all the Mission Scenario 4 payload missions. In the left-hand side of the figure, the lower segments identify the development and production costs for each of the Space Station options. The upper segment, which is identical for all options, indicates the costs of Shuttle operations in polar orbit. In the right-hand side of the figure, the lower segments indicate the costs associated with Space Stations and the middle segments indicate costs associated with Shuttle operations at inclinations other than polar.

It can be seen that the costs follow the same pattern as the launch summary. The two stations of Option 6 require the highest proportion of total cost, but the evolutionary growth station of Option 3 (maximum activity at 28.5 degrees) requires a somewhat lower total cost. Option 3 was therefore selected as the most desirable option for further study.

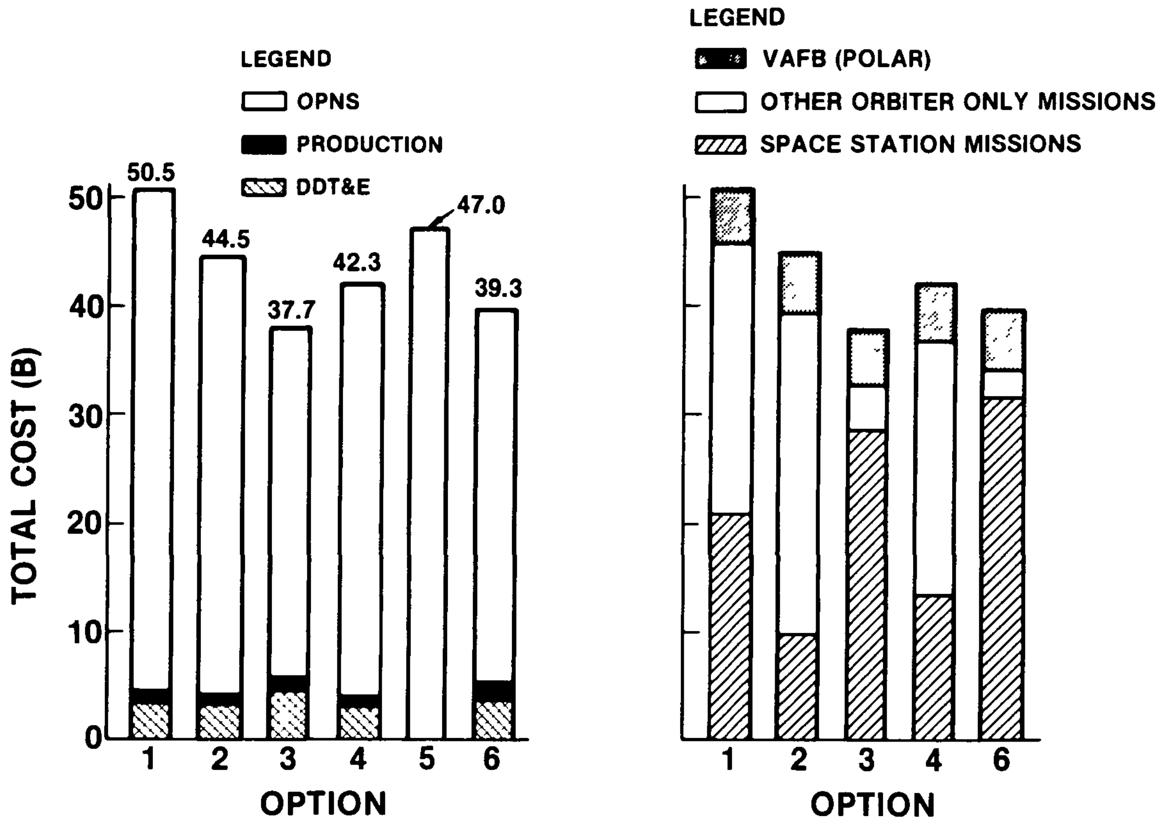


Figure 1-23. Options Cost Comparison (1986-2000)

OTV TRADES

Propulsion Candidate Definitions

Three types of orbit transfer vehicles were considered: a single-stage reusable OTV with a capability for delivery of 12,000 pounds to GEO and return of the stage, the same stage modified for aerobraking on return, and a small reusable OTV sized for the same GEO capability as the single stage when used in a two-stage mode, with the second stage being a storable liquid propulsion unit integrated with the payload. Characteristics assumed for these vehicles are shown in Table 1-6. The basis for the single stage was, as previously noted, a conceptual study. The smaller two-stage OTV was scaled from that concept. The second stages were treated as "rubber" at a constant propellant fraction of 0.9 and specific impulse of 325 seconds. (A subsequent conceptual study for Scenario 6 showed that both of these values are somewhat high for a pressure-fed storable propulsion unit. More representative values are 0.85 and 310 seconds.) The aerobraker characteristics were adapted from the NASA/JSC briefing, "OTV Candidates," August 16, 1982. Return propulsive velocity was reduced by 7,000 feet per second, but not reduced below 1,000 feet per second in order to allow for return to LEO and station rendezvous maneuvers.

Table 1-6. OTV Candidate Characteristics

STUDY OPTION	1 & 3 SINGLE STAGE	7 AEROBRAKER	8 TWO STAGE	
			1ST STAGE	2ND STAGE
PROPELLANTS (OX/FUEL)	LOX/LH_2 →	→	→	N204/MMH
SPECIFIC IMPULSE — (SEC)	470 →	→	→	325
MAX PROPELLANT CAPACITY — LBS	48400 →	→	22900	AS REQ'D
CUTOFF WEIGHT — LBS	5022	5982	2830	VARIABLE
PROPELLANT FRACTION	0.906	0.890	0.890	0.90
AEROBRAKING ΔV — (FPS)	NA	7000	NA	NA
MINIMUM RETURN ΔV — (FPS)	NA	1000	NA	NA

Propulsion Options Evaluation

A comparison of the candidates is shown in Figure 1-24, using data listed in Table 1-7. The aerobraker and the two-stage concepts (Options 7 and 8) are nearly equal in their improvement over the single stage in Shuttle lift mass, number of Shuttle launches, and number of OTV's used. Since the aerobraking concept is still in a technology development phase, it was not selected for further application in this study. It is considered a potential second-generation OTV. In comparing the single- and two-stage concepts (Options 3 and 8), it is clear at the outset that two stages always save mass over one stage in any application, but the added cost of doubling the number of propulsion units and their support operations is a counter factor to be considered. In this case, the saving in mass is best measured by the saving in Shuttle launches. The reduction of Shuttle launches by 25 at $77 million each will offset a $9.6 million average cost for second-stage production and launch support. Any second stage average cost less than this break-even point would be a system cost savings, e.g., a $5 million average second stage cost (a plausible assumption) would imply a $1 billion system saving over the nine-year operational OTV model of Scenario 4. On the basis of these positive implications, the two-stage concept was selected for further study effort.

The most significant uncertainty in this evaluation is the cost of the second-stage launch support. Current Shuttle operational practice indicates this cost can vary widely--up to $8 million; however, improvement can be anticipated since the 200 second stages could have substantial commonality and Shuttle operations are expected to follow a repetitive operation learning curve. A resolvable (in future studies) uncertainty is the best size for the OTV. A somewhat larger unit than selected here could add high-energy mission capability and flexibility with little penalty.

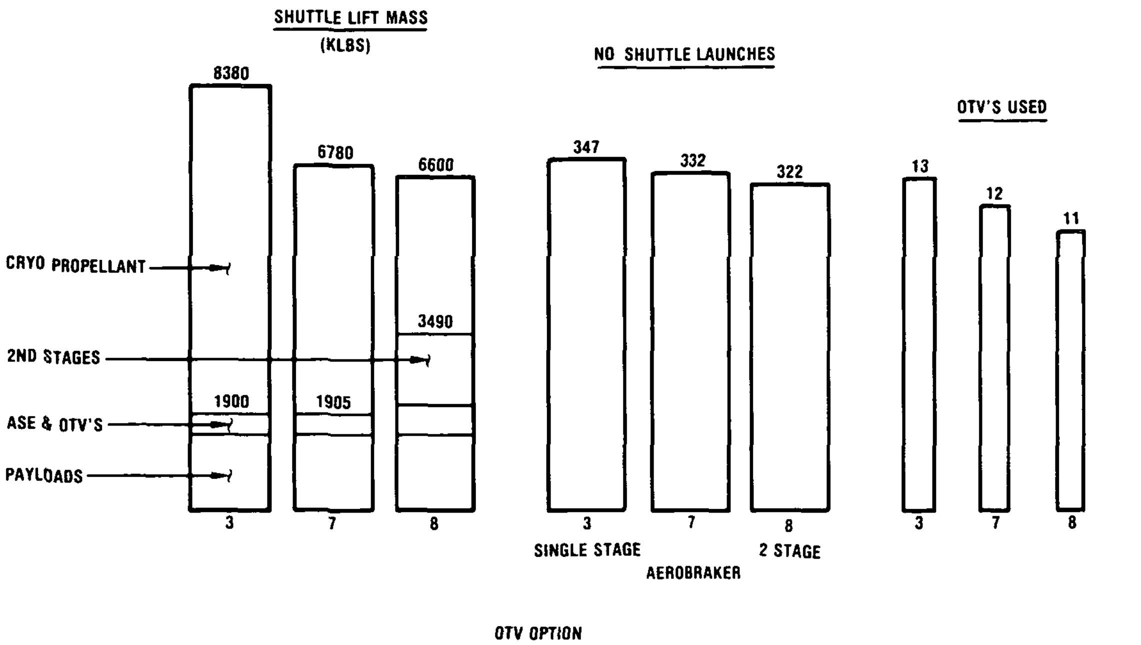


Figure 1-24. OTV Candidate Comparisons

Table 1-7. OTV Candidate Comparisons Data

OPTION	3 SINGLE STAGE	7 AEROBRAKER	8 TWO STAGE
NO. OF SHUTTLE LAUNCHES	347	332	322
NO. OF OTV'S MFG	13	12	11
NO. OF OTV DEPLOYMENTS	24	21	20
NO. OF OTV FLIGHTS	150	138	153
NO. OF APOGEE STAGES	0	0	200
SHUTTLE LIFT MASS — (KLBS)			
PAYLOADS	←	1549	→
APOGEE STAGES	0	0	1438
ASE	232	232	448
OTV'S — DRY	118	124	55
SUB TOTAL	1899	1905	3490
CRYO PROPELLANT	6485	4870	3109
TOTAL	8384	6775	6599
DELTA MASS	1785	176	0
DELTA SHUTTLE LAUNCHES	25	10	0

MISSION SCENARIO 6

MISSION SCENARIO 6: MEDIUM TRAFFIC MODEL

Table 1-8 summarizes the Mission Scenario 6, medium traffic mission model. The medium model is our best estimate of the expected levels of mission activity and the types of missions likely to fly through the year 2000. It reflects the existence of a manned Space Station and other complementary STS elements including a space-based OTV, a station-based TMS, and Shuttle/station-tended platforms.

All of the Scenario 6 models were developed in close coordination with the users. The model summarized in the table reflects the maximum practical use of the Space Station and station-based services. More detailed information on the mission models can be found in the Task 1 final report.

Table 1-9 compares Mission Scenario 6 with Mission Scenario 4, which was the model used for all the analysis of alternative program options described previously in this report. The first difference noted between the two mission models is a significantly larger number of payloads in Scenario 6 as compared with Scenario 4, although the total payload weight is slightly lower for the Scenario 6 model. These two differences indicate the more detailed definitions

Table 1-8. Mission Scenario 6, Medium Traffic Model

YEARLY TOTALS FOR ALL LOCATIONS

NUMBER OF PAYLOADS

TOTALS	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
	15	20	19	26	51	59	87	81	91	96	97	110	105	111	127	964

INCLINATION	X LOW		Y MED		Z HIGH		SUM		TOTAL
ALTITUDE	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	1991 2000
CATEGORIES									
1 COM COMMUNICATIONS	0	152	0	0	0	0	0	152	152
2 COM PROCESSING	395	0	0	0	0	0	395	0	395
3 COM RESOURCE OBS	0	1	0	0	10	0	10	1	11
4 DOD	41	39	40	50	57	0	138	89	227
5 GEO SERVICING	0	11	0	0	0	0	0	11	11
6 COV'T ENVIRONMTL	0	5	0	0	5	0	5	5	10
7 NASA SCI & APPL	108	5	8	0	17	0	133	5	138
8 NASA TECHNOLOGY	20	0	0	0	0	0	20	0	20
TOTALS	564	213	48	50	89	0	701	263	964

WEIGHT (KLB)

TOTALS	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
	335 4	376 2	382 7	457 4	426 9	506 4	523 1	512 5	477 1	445 3	4443

INCLINATION	X-LOW		Y MED		Z HIGH		SUM		TOTAL
ALTITUDE	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	1991 2000
CATEGORIES									
1 COM COMMUNICATIONS	0	522 3	0	0	0	0	0	522 3	522.3
2 COM PROCESSING	639 1	0	0	0	0	0	639.1	0	639 1
3 COM RESOURCE OBS	0	4	0	0	35	0	35	4	39
4 DOD	755 2	291	624	208.2	552 8	0	1932	499 2	2431 2
5 GEO SERVICING	0	118	0	0	0	0	0	118	118
6 GOV'T ENVIRONMTL	0	21	0	0	20	0	20	21	41
7 NASA SCI & APPL	404 7	17 2	58 8	0	86	0	549.5	17 2	566 7
8 NASA TECHNOLOGY	85 7	0	0	0	0	0	85.7	0	85 7
TOTALS	1884 7	973 5	682 8	208.2	693 8	0	3261 3	1181 7	4443

Table 1-9. Comparison of Mission Scenario 6 With Scenario 4 Space Station Oriented Models

MISSION AREA	NUMBER OF PAYLOADS		TOTAL PAYLOAD WEIGHT (KLB)		TOTAL CARGO WEIGHT (KLB)		EQUIV STS FLIGHTS	
	6	4	6	4	6	4	6	4
• COM. COMMUNICATIONS	153	120	522.3	587.4	2,848.6	3,314.9	45	63
• COM. PROCESSING	407	229	639.1	634.4	661 3	657.8	11	12
• COM. RESOURCE OBS.	11	—	39.0	—	138.3	—	7	—
• DOD	227	271	2,431.2	2,739.2	5,535.9	7,652.0	125	175
• GEO SERVICING	11	—	118.0	—	458.4	—	7	—
• GOV'T ENVIRONMENTAL	10	—	41.0	—	240.6	—	4	—
• NASA SCIENCE & APPL	143	117	566.7	905.4	1,127.4	1,248.4	31	41
• NASA TECHNOLOGY	19	—	85.7	—	126.7	—	4	—
• SPACE STATION ASSEMBLY, LOGISTICS & UPPER STAGE LOGISTICS	—	—	—	—	2,332.8	3,351.0	39	58
TOTAL	981	737	4,443 0	4,866.4	13,470.0	16,141.1	273	347

developed for Scenario 6, particularly in the commercial processing and the NASA science and applications areas. Mission Scenario 6 also defined payloads that were not identified in the four areas indicated (commercial resource observation, GEO servicing, government environmental, and NASA technology). The table also shows the total cargo weights, including propellants and airborne support equipment, and the equivalent STS flights associated with each of the payload categories.

Airborne Support Equipment (ASE)

Payloads and upper stages carried in the orbiter require ASE provisions to properly distribute launch loads into orbiter primary structure. These elements have a significant Shuttle lift mass impact ranging from 8 to 25 percent of the cargo load. Cradles for existing upper stages place in the upper penalty range, as do any for payloads or stages with diameters much less than the cargo bay's 15 feet. The bulk of the payloads and storable second stages used in Scenario 6 were modeled to represent the Shuttle STS era by being designs that match the cargo bay diameter and require only trunnions and keel fittings as opposed to cradles. In Figure 1-25, the ASE weights are defined for the range of cargoes considered. Combinations of pallets were used for small (less than 11.9 feet diameter) cargo longer than 30 feet in length or heavier than 12,000 pounds.

For the storable second stages, it was assumed that total integrated propulsion and payload length was the same as the payload model except in a few special cases. For example, all payload lengths for commercial communications

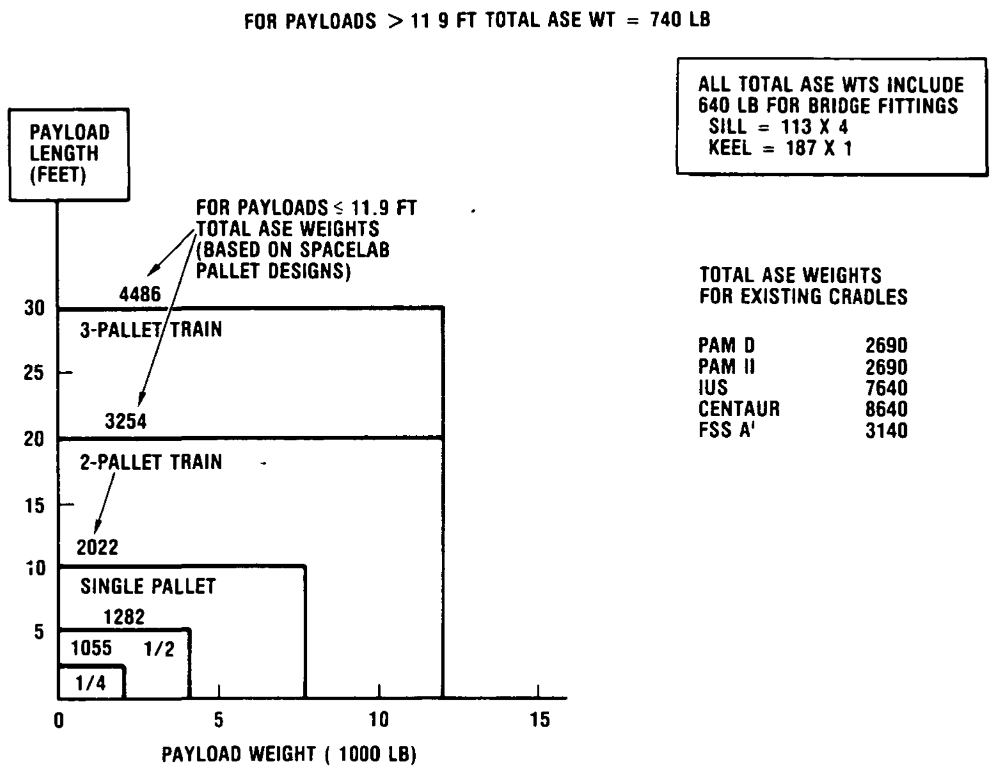


Figure 1-25. ASE Considerations

satellites were established by assuming integrated propulsion. At full cargo bay diameter, representative design layouts revealed that payload/propulsion overlap made this possible.

Mission Scenario 6, Medium Traffic Model, Option 3: Maximum Activity at 28.5 Degrees

Option 3 consisted of one Space Station, orbiting the earth in a circular orbit, inclined 28.5 degrees with respect to the equator, and 200 nmi above the surface. All activity contained within Mission Scenario 6 (as previously described) occurs at the Space Station, with the following three exceptions:

1. All high inclination missions (greater than 65 degrees) are Shuttle-launched out of the Western Test Range.

2. Those few medium-inclination payloads too heavy to be launched on the Space Station OTV are Shuttle-launched out of the Eastern Test Range.

3. All high-energy payloads launched in 1991, 1992, and 1993 are Shuttle-launched out of ETR or WTR. (The Space Station based OTV does not become operational until 1994.)

All three of these classes of activities are accomplished independent of the Space Station.

Mission Scenario 6 was fully described in a previous section. The various building blocks necessary to accomplish Mission Scenario 6 at the Space Station are: one energy module, one command module, one payload service assembly, two habitability modules, three LEO TMS's, two GEO TMS's, one GEO TMS service module, one set of station-attached TMS propellant tanks, seven OTV's, two sets of station-attached OTV propellant tanks, one (life sciences lab) tunnel module, one growth Spacelab (monkey module), one MPS module, two generic types of space processing factories, one astronomy platform, and continual supplies via the logistics module. All of these building blocks have been described in previous sections, with the exception of those new building blocks appearing in Figure 1-26. A summary of when all the Option 6 building blocks are required is presented in Table 1-10.

<u>Launch Summary</u>. The various payloads required to accomplish Mission Scenario 6 and Space Station operations were grouped by calendar year into files called payload data lists. The payload data lists were then manifested into STS missions using the SOSMAN computer program. The Shuttle payload cargo bay was loaded using a maximum payload weight of 61,000 pounds or a length of 53 feet for all payloads destined for the Space Station (7 feet must be reserved on all Space Station destined missions for the docking module). Payloads destined for medium inclination and launched there directly by the Shuttle,

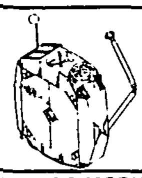
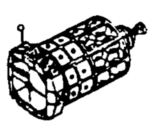
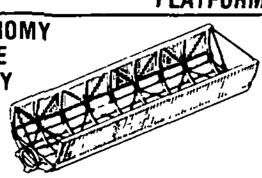
ELEMENT	LENGTH (FT)	WEIGHT (LB)		VOLUME FOR EXPTS (FT^3)	COST CATEGORY
		GROSS	EXPT		
GEO TMS 	3 FT X 14.5 FT DIA	3,785 B.O.			UPPER STAGE
GEO TMS SERVICE MODULE 	22 FT X 13.0 FT DIA	2,400			PAYLOAD SUPPORT ELEMENTS
 ASTRONOMY PLATFORM	52	96,000	61,600	9,200	PAYLOAD SUPPORT ELEMENTS
ASTRONOMY SERVICE FACILITY 	52	71,300	61,600	9,200	PAYLOAD SUPPORT ELEMENTS

Figure 1-26. Option 3 Building Blocks; Scenario 6

Table 1-10. Option 3 Building Block Phasing Summary

FISCAL YEAR	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
BASIC SPACE STATION BUILDING BLOCKS											
ENERGY MODULE		1									
AIR LOCK		2									
COMMAND MODULE		1									
LOGISTICS MODULE (4-MAN STATION)		1	4	2							
LOGISTICS MODULE (8-MAN STATION)				3	6	6	6	6	6	6	6
MANNED MANEUVERING UNIT		2									
PAYLOAD SERVICING ASSEMBLY (PSA)		1									
HABITABILITY MODULE				2							
TMS RELATED BUILDING BLOCKS											
LEO TMS		1	1				1				
GEO TMS				1		1					
GEO TMS SERVICE MODULE				1							
TMS PROPELLANT TANKS		1									
OTV RELATED BUILDING BLOCKS											
OTV				1	2		2		4		
OTV PROPELLANT TANKS				1	1						
SCIENCE AND APPLICATIONS BUILDING BLOCKS											
PSA (ASTRONOMY PLATFORM)			1								
ENERGY MODULE (ASTRONOMY PLATFORM)					1						
TUNNEL (LIFE SCIENCES LAB) MODULE				1							
SPACELAB (MONKEY) MODULE									1		
SPACE PROCESSING BUILDING BLOCKS											
MPS MODULE		1									
BIOLOGICAL PROCESSORS	1	1	1		1	1		1	1	1	1
CRYSTAL GROWER					1	1					

were manifested to a maximum cargo bay capacity of 49,000 pounds or a length of 60.0 feet. Payloads destined for high inclination were manifested to a maximum cargo bay capacity of 25,000 pounds or a length of 60.0 feet. The number of such STS missions per year required to accomplish Mission Scenario 6 is presented in Figure 1-27. The comparison between Space Station's efficiency of handling Mission Scenario 6 and the space transportation system's efficiency of doing the same job will be discussed in a future section.

OTV Operations.

Propulsion Vehicle Definitions. For Scenario 6, the high-energy propulsion subsystem characteristics were refined. Apogee second stages were sized over the payload range of interest as shown in Table 1-11. Figure 1-28 illustrates the points used in the computer code algorithm to approximate a "rubber" second-stage model. For the smallest sizes, the second-stage propellant is assumed to be contained in enlarged payload attitude control system tanks. The resulting weight saving yields an increase in propellant fraction over a small unit with separate tanks for delta-V propellant. For GEO payloads, the second-stage velocity increment used was 6,000 feet per second. For medium-inclination payloads, the increment varied, but included at least the apogee burn, unless the resulting stage exceeded the maximum stage size of 12,000 pounds gross weight.

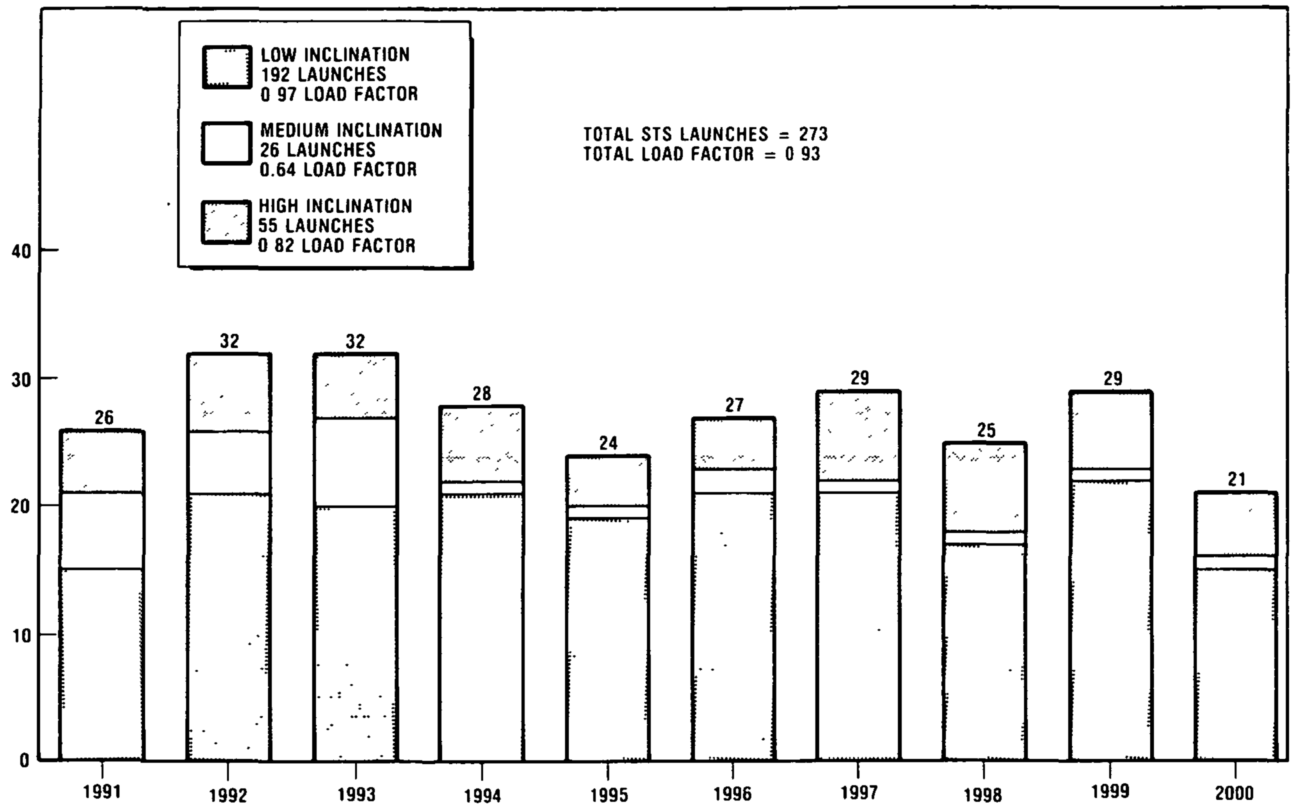


Figure 1-27. Option 3, STS Launch Summary, Mission Scenario 6, Medium Model

Table 1-11. Liquid Apogee Stages

PAYLOAD AT 6000 FPS	12000	9000	6000	3500	2500	1000
PROPELLANT FRACT	0.878	0.869	0.861	0.828	0.811	0.86 <= USE
SPECIFIC IMPULSE	310	<= =	<= =	310	<= =	<= =
USABLE PROP-MAX	11227	8508	5736	3478	2547	952
CUTOFF WEIGHT	1559	1278	929	723	592	155

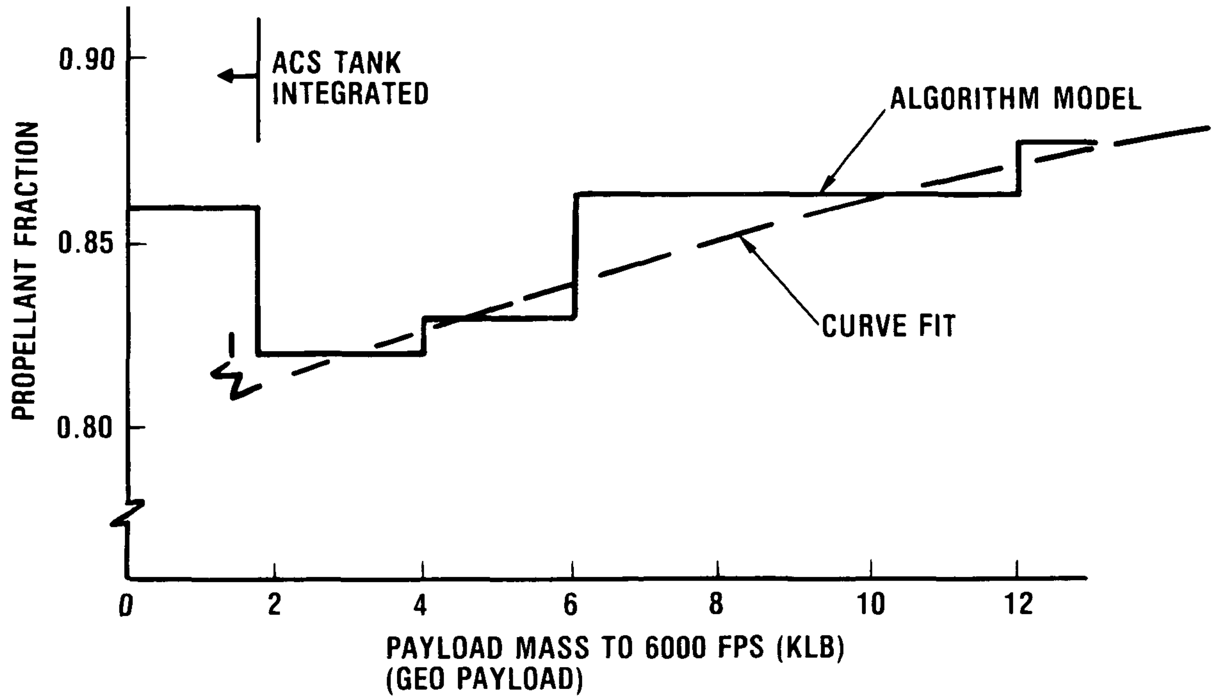


Figure 1-28. Apogee Stage Propellant Fraction Model

OTV concept characteristics were derived using the data shown in Table 1-12. A study of perigee stage velocity requirements resulted in selecting 100 and 200 feet per second allowances over impulsive requirements for outbound and return legs (respectively) to provide for outbound gravity losses and return phasing and station rendezvous. The low outbound allowance at the selected engine thrust (10,000 pounds) implies multiple perigee burns.

Recent reusable OTV engine concepts (e.g., Rocketdyne's RS44 advanced expander cycle) are rated at ten-hour service life. At 10,000 pounds thrust, this equates to 31 flights. For Scenario 6, the model ground rule used 20 flights to overhaul and one overhaul. For the 130 flights required in the medium traffic model, the resulting OTV usage history is shown in Table 1-13. Two units on station at any time were assumed. The average utilization of units expended on planetary missions was 23 flights.

High-Energy Mission Model Results. Summary data on OTV operations with medium traffic are listed in Table 1-14. The number of OTV units deployed by the Shuttle (11) and the number manufactured (7) are less than the numbers required in Scenario 4 because the service life to overhaul was increased from 10 to 20 flights. Other data listed (payloads, apogee stage, and ASE weight) represent the results of computation methods and models that were refined over Scenario 4, Option 8, however, no significant differences resulted other than that attributable to the payload traffic changes. Apogee stages are only slightly heavier and ASE represents about the same proportional weight contribution. OTV operation trends, as shown in Figure 1-29, show a relatively flat number of flights per year, indicating that multiple payload manifesting helps

Table 1-12. Reusable OTV Concept Data

STAGE TYPE	PERIGEE	SINGLE
BASING MODE	SPACE	SPACE
PROPELLANT FRACT	0.869	0.906
SPECIFIC IMPULSE	470	470
USABLE PROP-MAX	23500	48400
CUTOFF WEIGHT	3554	5022
LENGTHS: (FT)		
NOZZLE EXTENSION	2.5 (RETRACTED)	
STAGE (INCL NOZ)	25.0	

Table 1-13. OTV Usage History, Scenario 6, Medium Traffic

	OTV UNIT SERIAL NO							
	1	2	3	4	5	6	7	TOTAL/NO.
YEAR DEPLOYED	93	94	94	97	97	99	99	7
YEAR OVERHAULED	–	96	96	99	99	–	–	4
YEAR EXPENDED	–	–	97	99	99	–	–	3
YEAR LIFE LIMIT REACHED	93	97	–	–	–	–	–	2
NUMBER OF FLIGHTS	–	40	22	26	22	10	10	130
FINAL STATUS	DEVELOPMENT	RETIRED	EXPENDED	EXPENDED	EXPENDED	ON STATION	ON STATION	–

Table 1-14. OTV Operations Summary

CASE NO. 1 PERIGEE OTV AND RUBBER APOGEE STAGES CATEGORY 1 TOTAL MANIFEST											
YEAR	91	92	93	94	95	96	97	98	99	2000	TOTAL
NO. OF PAYLOADS	0	0	0	25	30	34	35	25	24	26	199
PAYLD GROSS WT-KLBS	0	0	0	153	172	183	195	169	190	159	1221
APSTAGE GROSS-KLBS	0	0	0	122	151	160	162	139	137	135	1006
ASE WEIGHT-KLBS	0	0	0	29	32	28	32	18	24	21	184
PAY + APSTG + ASE-KLBS	0	0	0	304	355	371	389	326	351	315	2411
PAY + APSTG + ASE-FEET	0	0	0	349	374	417	423	349	358	322	2592
USABLE PROPELLANT	0	0	82	324	387	396	414	342	377	329	2651
C/D, RESID & B/O PROP	0	0	8	32	38	39	41	34	37	32	261
CRYO PROPELLANT-KLBS	0	0	90	356	425	435	455	376	214	361	2912
NO. OF FLIGHTS	0	0	0	16	21	20	21	18	18	16	130
AVE LOAD FACTOR-OTV	0	0	0	826	752	808	804	775	854	839	806
NO. OF OTVS MFG	0	0	1	2	0	0	2	0	2	0	7
RETURNED FOR OVHAUL	0	0	0	0	0	2	0	0	2	0	4
EXPENDED	0	0	0	0	0	0	1	0	2	0	3
RET'D AT LIFE LIMIT	0	0	1	0	0	0	1	0	0	0	2
OTV DEPLOYMENTS	0	0	1	2	0	2	2	0	4	0	11
NO. APOGEE STGED PAYLDS	0	0	0	24	30	34	34	25	22	26	195

****STATION PAYLOAD PROPULSION MANIFEST****
STAPPMAN
— SCENARIO 6 OPTION 3 MEDIUM TRAFFIC

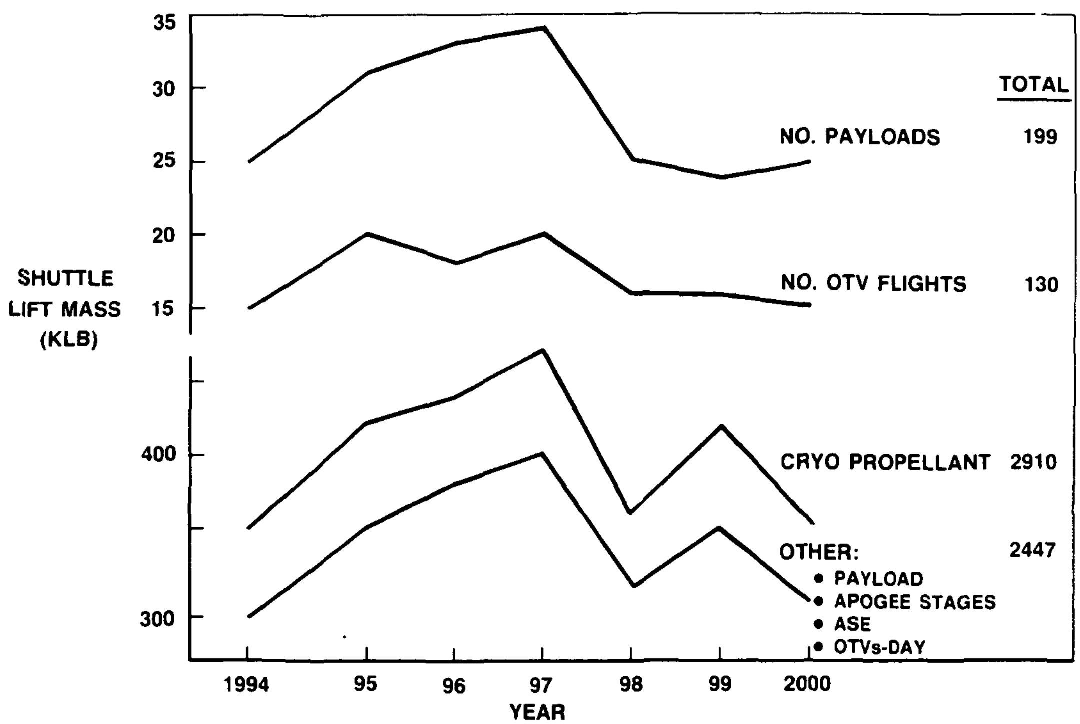


Figure 1-29. Option 3, OTV Operations Trends, Scenario 6, Medium Traffic

smooth out operations. The peak year for all parameters shown is 1997. The immediate drop the following year is primarily because of an absence of planetary payloads in 1998.

Mission Scenario 6, Medium Traffic Model, Option 5: No Station

The building blocks for Option 5 are the same as those previously described, with additions described in the following. As in Scenario 4, most of the high energy payloads are launched one to an upper stage; however, some DOD missions to medium inclination share upper stages. This does not introduce any new upper stages beyond those already listed. Thus, the total number of expendable upper stages does not correspond exactly to the number of high-energy payloads.

The new Scenario 6 elements are the GEO TMS and the GEO TMS service module. These are the same as in the Space Station option. They are depicted in Figure 1-26.

Launch Summary. The execution of Mission Scenario 6, medium traffic, requires 523 STS launches when no Space Station is used. The breakdown of these by year and inclination is shown in Figure 1-30. The same Shuttle capabilities used for Scenario 4 were assumed. The Spacelab sorties of Scenario 4 were retained. Mission Scenario 6 covers the years 1991 to 2000, rather than starting in 1990, like Scenario 4; therefore, the Spacelab flights are adjusted as follows:

Inclination (Degrees)	User Area	No. Flights
28.5	Space Processing R&D	233
57.0	NASA Science and Applications	30

As in Scenario 4, Spacelab flights are assumed to be dedicated. Payload weight is 35,000 pounds. The load factor of low-inclination Spacelab flights is thus 0.5. This lowers the average load factor for low-inclination missions. The average load factors and total number of flights for each type of orbit are given in Figure 1-30.

Key Comparisons. The Shuttle-only option, Option 5, and the Space Station Option 3 are compared in Figure 1-31. The two key comparisons are the use of upper stages and OTV, and the conduct of orbital manned R&D.

Option 5 does not include an OTV for high-energy orbital boost. Boost is done by various expendable upper stages. Figure 1-31 shows the number and type required from 1994 to 2000. This period is taken for comparison, since it corresponds to the operational period of the Option 3 OTV. A total of 163 expendable upper stages is needed under Option 5 during this period. By comparison, Option 3 uses seven OTV's and 2.9 million pounds of propellant. A few small satellites are expected to fly on expendable upper stages, even after the OTV is operational. These expendable stages are shown in the figure. The comparison thus becomes one between 163 expendable upper stages in Option 5, and seven OTV's complemented by 11 expendables in Option 3.

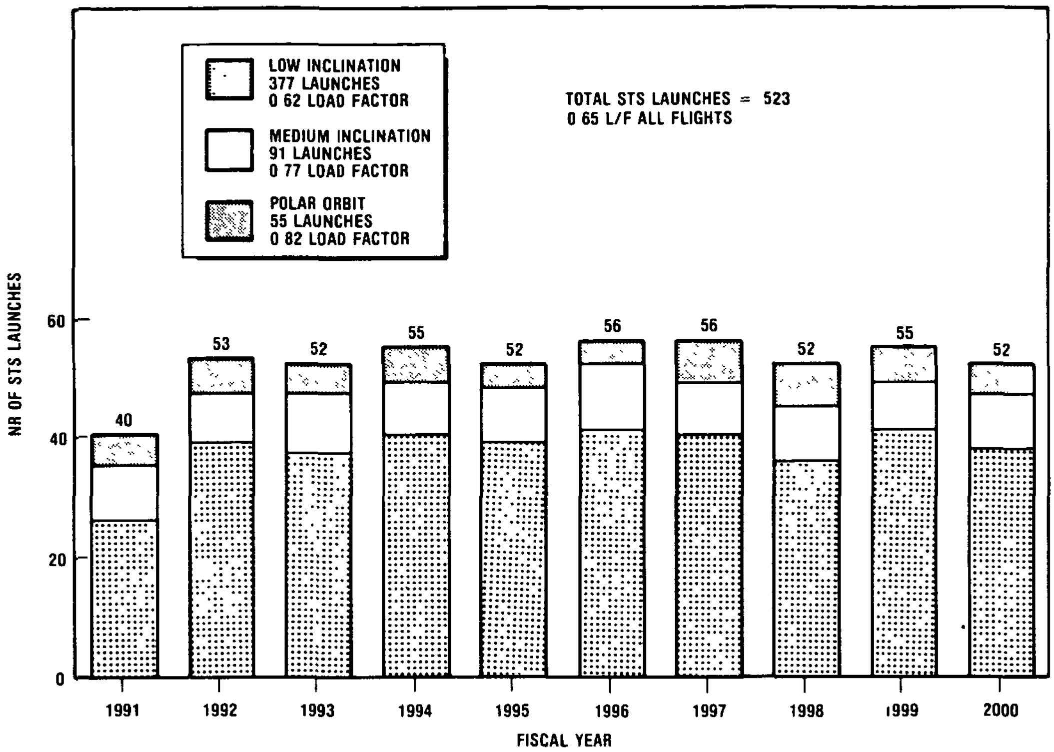


Figure 1-30. Option 5, STS Launch Summary, Mission Scenario 6, Medium Model

OPTION 5

UPPER STAGES, '94-00

	28.5	57°	TOTAL
PAM-D		1	1
PAM-D II	8		2
PAM-A	22		33
IUS 1ST STG	55	14	69
CENTAUR-G	43	14	57
CENTAUR-F	6		6
TOTAL	134	29	163

SPACELAB FLIGHTS, '91-00

SP PROC	NASA R&D	TOTAL
233	30	263

OPTION 3

UPPER STAGES & OTV, '94-00

EXPENDABLE.

PAM-D II	4
PAM-A	7
TOTAL	11

OTV

VEHICLES	7
PROPELLANT	2.9 MLB

STATION R&D FACILITIES

SP PROCESSING	NASA R&D
• MPS MODULE	• 7 PALLETS ON PSA • SPACELAB MODULE

Figure 1-31. Option 5 Key Comparisons, Mission Scenario 6, Medium Model

Orbital manned R&D in Option 3 is performed in station-attached modules and pallets. An equivalent amount of R&D for 1991-2000 under Option 5 would require 263 fifteen-day Spacelab missions. The comparison between the manned orbital R&D requirements and those of Option 3 is detailed in Figure 1-31.

MISSION SCENARIO 6A: SHUTTLE ORIENTED (MEDIUM TRAFFIC)

To aid in establishing Space Station benefits and for additional programmatic comparisons, a medium model was established for Mission Scenario 6A, the case without a Space Station. It reflects changes from the model in Scenario 6 resulting from different ways of doing some of the missions without a Space Station. Significant reductions are made in most user areas (except DOD). Constrained research and limited productivity are predicted for space processing. Life sciences would be reduced to sorties, LEO on-orbit servicing missions would be reduced in number, GEO servicing and space-based OTV's would be deleted, and technology development missions would be refocused to include station-related technologies that would likely occur to support a Space Station beyond the year 2000.

Table 1-15 compares this Shuttle-oriented mission model (6A) with the Scenario 6 medium model (6) discussed previously. The reduced number of payloads in space processing and NASA science and applications provide the best indication of the reduced accomplishment of objectives associated with Shuttle-only Model 6A when compared with the Space Station oriented model (6). The equivalent STS flight columns at the right side of the table also show that significantly more Shuttle launches are required to accomplish the reduced mission objectives when no Space Station is available.

Mission Scenario 6A, Option 5: Shuttle-Only

Option 5 Approach. Option 5 executes Mission 6A using the same building blocks as in Mission Scenarios 4 and 6. The Shuttle transports all payloads to LEO. High-energy payloads are boosted on expendable upper stages. Payloads deployed to lower orbits are either released into their final orbit from the orbiter, or boosted with a reusable TMS. The TMS is also used for some servicing missions. Other servicing missions, such as those to space processing free-flyers, are performed directly from the orbiter. As in the other scenarios, there is no space-based transfer vehicle. A significant aspect of Scenario 6A is the departure from Spacelab sortie space processing. The requirement for a large number of Spacelab missions thus disappears. Spacelab is still used for NASA R&D. This activity requires three flights per year.

Launch Summary. The execution of Mission Scenario 6A through Option 5 requires 297 launches. The breakdown of these by year and inclination is shown in Figure 1-32. The 297 launches include 30 Spacelab flights. These support NASA R&D programs.

The smaller number of Spacelab flights accounts for higher load factors than when Option 5 executes other scenarios. The average load factor and total number of flights for each type of orbit are given in Figure 1-32.

Table 1-15. Comparison of Mission Scenario 6A: Shuttle Oriented With Scenario 6--Space Station Oriented

MISSION AREA	NUMBER OF PAYLOADS		TOTAL PAYLOAD WEIGHT (KLB)		TOTAL CARGO WEIGHT (KLB)		EQUIV STS FLIGHTS	
	6	6A	6	6A	6	6A	6	6A
• COM. COMMUNICATIONS	153	159	522.3	505 0	2,848.6	3,065.1	45	60
• COM. PROCESSING	407	175	639.1	730.0	661.3	796.3	11	13
• COM. RESOURCE OBS.	11	11	39.0	39.0	138.3	111 3	7	7
• DOD	227	226	2,431 2	2,441.7	5,535 9	5,984.8	125	151
• GEO SERVICING	11	0	118.0	0	458.4	0	7	0
• GOV'T ENVIRONMENTAL	10	10	41.0	41.0	240.6	159.6	4	4
• NASA SCIENCE & APPL	143	69	566.7	483.4	1,127 4	1,969.0	31	60
• NASA TECHNOLOGY	19	21	85.7	90.3	126.7	46.4	4	2
• SPACE STATION ASSEM. LOGISTICS & UPPER STAGE LOGISTICS	—	—	—	—	2,332.8	0	39	0
TOTAL	981	671	4,443 0	4,330.4	13,470.0	12,132.5	273	297

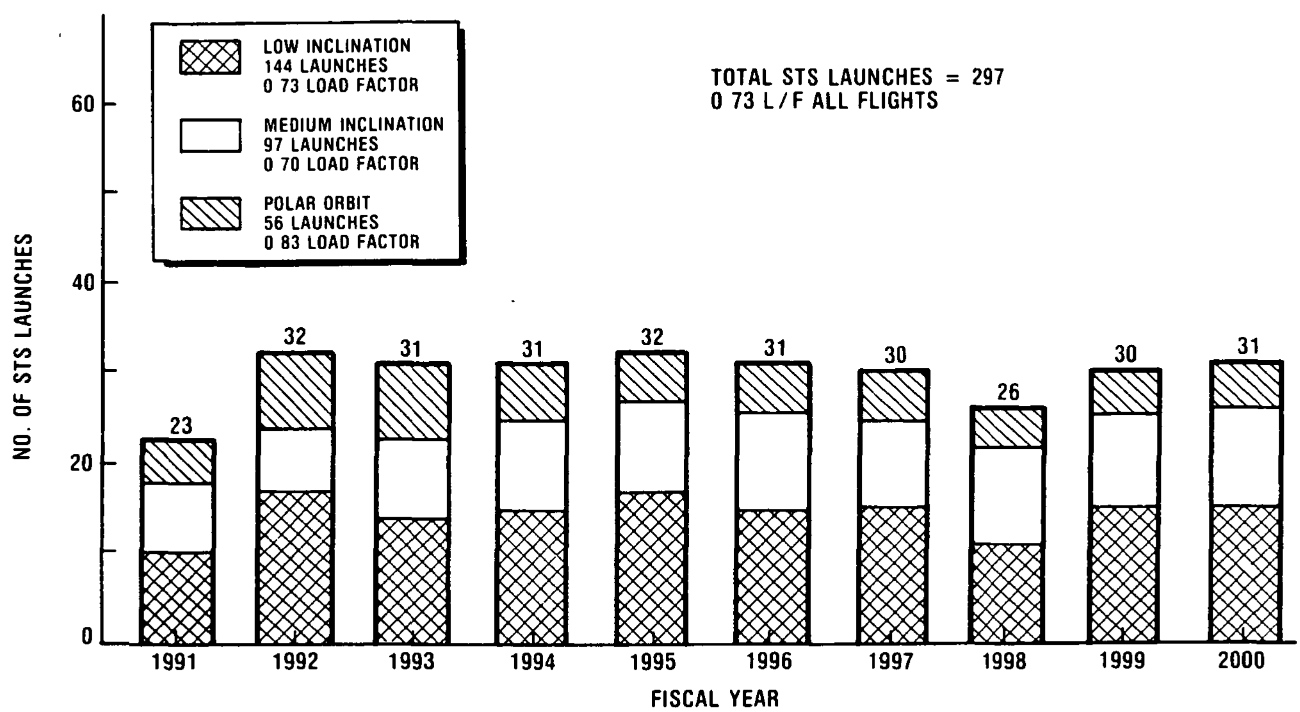


Figure 1-32. Option 5, STS Launch Summary, Mission Scenario 6A, Medium Model

MISSION SCENARIO 6: LOW TRAFFIC MODEL

The low model presumes lower funding is available for both government and private space endeavors because of pressures from other priority programs and continued sluggish patterns of world economic growth. It reflects budget constraints in government programs, pessimistic market forecasts for commercial activities, and continues the current DOD space functions with no new types of DOD missions introduced. It is unlikely that world events could produce a more severe downturn in space activity. Thus, the low model represents a very high probability of occurrence, almost certain to be achieved, not necessarily on a mission-by-mission basis, but as a representative total.

Table 1-16 compares the low model (6L) with the medium model (6M) discussed previously. The table indicates the degree of activities reduction for each of the mission areas shown.

Mission Scenario 6, Low Traffic Model, Option 3 Space Station

The low traffic model Option 3 had all the same basic ground rules as previously described in the medium traffic model Option 3 section.

The various building blocks necessary to accomplish the Mission Scenario 6 low traffic model at Space Station are as follows: one energy module, one command module, one payload service assembly, two LEO TMS's, one set of station-attached TMS propellant tanks, five OTV's, two sets of station-attached OTV propellant tanks, one life sciences laboratory module, one MPS module, two generic types of space processing factories, one astronomy platform, and continual resupply via the logistics module. All of these building blocks have been described in previous sections. A summary of when the Option 3, Mission Scenario 6 low traffic level model building blocks are required is presented in Table 1-17.

The station acquires initial operational capability in 1991, with an initial crew size of two. The crew size grows to three in 1993, and to four in 1994. It remains at four through the year 2000.

Launch Summary. The various payloads required to accomplish Mission Scenario 6 low traffic model and Space Station operations were manifested, using the SOSMAN program, as previously described. The Shuttle payload cargo bay was loaded using a maximum payload weight of 61,000 pounds or a length of 53 feet for all payloads destined for Space Station. Payloads destined for medium inclination and launched there directly by the Shuttle, were manifested to a maximum cargo bay capacity of 49,000 pounds or a length of 60.0 feet. Payloads destined for high inclination orbits were manifested to a maximum cargo bay capacity of 25,000 pounds or a length of 60.0 feet. The number of such STS missions per year required to accomplish Mission Scenario 6 low traffic model is presented in Figure 1-33.

OTV Operations. The reduced traffic in the low model resulted in OTV operations characteristics as listed in Table 1-18. Only about 13 OTV flights

Table 1-16. Comparison of Mission Scenario 6: Space Station Option Medium With Low Traffic Level

MISSION AREA	NUMBER OF PAYLOADS		TOTAL PAYLOAD WEIGHT (KLB)		TOTAL CARGO WEIGHT (KLB)		EQUIV STS FLIGHTS	
	6M	6L	6M	6L	6M	6L	6M	6L
• COM COMMUNICATIONS	153	106	522.3	349.0	2,848.6	2002.4	45	33
• COM PROCESSING	407	314	639.1	440.0	661.3	455.3	11	8
• COM RESOURCE OBS	11	6	39.0	28.0	138.3	72.2	7	4
• DOD	227	153	2,431.2	1,257.0	5,535.9	3,369.0	125	89
• GEO SERVICING	11	0	118.0	0	458.4	0	7	0
• GOVT ENVIRONMENTAL	10	10	41.0	41.0	240.6	240.6	4	4
• NASA SCIENCE & APPL	143	127	566.7	467.0	1,127.4	908.5	31	25
• NASA TECHNOLOGY	19	15	85.7	43.0	126.7	77.1	4	3
• SPACE STATION ASSEM LOGISTICS & UPPER STAGE LOGISTICS	—	—	—	—	2,332.8	2087.9	39	36
TOTAL	981	731	4,443.0	2,625.0	13,470 0	9,213.0	273	202

Table 1-17. Phasing Summary for ESTS Option 3, Executing Mission Model 6, Low Traffic Level

FISCAL YEAR	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
BASIC SPACE STATION ELEMENTS											
ENERGY MODULE		1									
AIRLOCK		2									
COMMAND MODULE		1									
LOGISTICS MODULE (4-MAN STATION)		1	4	4	4	4	4	4	4	4	4
MANNED MANEUVERING UNIT		2									
PAYLOAD SERVICE ASSEMBLY		1									
TMS-RELATED HARDWARE											
LEO TMS		1	1								
TMS COMMAND CENTER (CM)		1									
TMS PROPELLANT TANKS		1									
TMS STOR/MAINT/REPAIR FACILITY (PSA)		1									
OTV-RELATED HARDWARE											
OTV				1	2			3		1	
OTV COMMAND CENTER (CM)				1							
OTV PROPELLANT TANKS				1	1						
OTV STOR/MAINT/REPAIR FACILITY (PSA)				1							
SCIENCE & APPLICATIONS HARDWARE											
PSA (ASTRONOMY PLATFORM)			1								
LIFE SCIENCES LAB MODULE				1							
ENERGY MODULE (ASTRONOMY PLATFORM)					1						
SPACE PROCESSING LABORATORIES											
MPS MODULE		1									
SPACE PROCESSING FACTORY HARDWARE											
MDAC BIOLOGICAL PROCESSORS		1	1				1	1			
CRYSTAL GROWER							1				
SPF COMMAND CENTER (CM)		1									
SPF STOR/MAINT/REPAIR FACILITY (PSA)		1									
SPF MATERIAL STORAGE (PSA)		1									

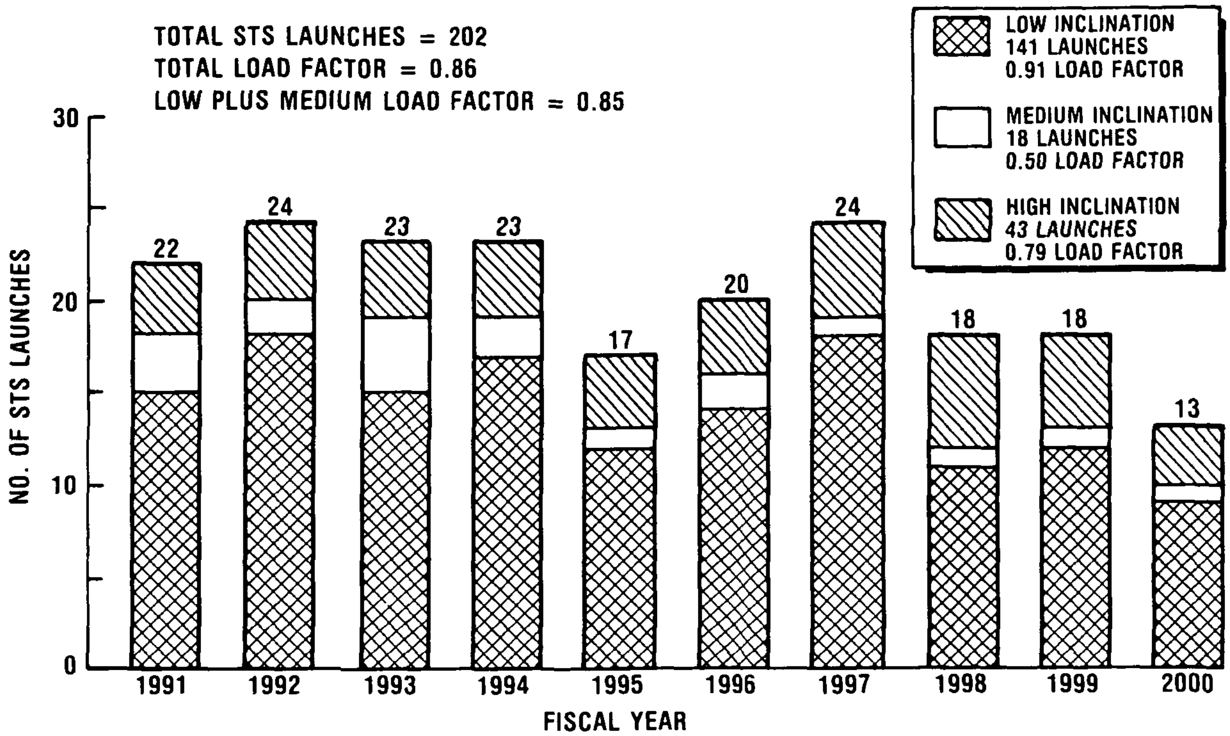


Figure 1-33. Option 3, STS Launch Summary, Mission Scenario 6, Low Model

Table 1-18. OTV Operations Summary--Low Traffic

YEAR	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
NO. OF PAYLOADS	0	0	0	25	24	26	26	17	19	19	156
PAYLOAD GROSS WT-KLB	0	0	0	96	93	112	118	64	71	67	621
APSTAGE GROSS-KLB	0	0	0	99	101	122	118	69	71	77	657
ASE WEIGHT-KLB	0	0	0	35	29	23	32	18	24	22	183
PAY + AP STG + ASE-KLB	0	0	0	230	223	257	268	151	166	166	1461
PAY + AP STG + ASE-FEET	0	0	0	346	279	388	363	225	261	211	2098
USABLE PROPELLANT	0	0	82	277	272	304	309	187	121	197	1840
C/O, RESID & B/O PROP	0	0	8	27	27	30	30	18	21	19	180
CRYO PROPELLANT-KLB	0	0	90	304	299	334	339	205	233	216	2020
NO. OF FLIGHTS	0	0	0	14	15	16	16	10	11	10	92
AVG LOAD FACTOR-OTV	0	0	0	807	740	775	788	763	786	804	780
NO OF OTVS MFG	0	0	1	2	0	0	1	0	1	0	5
RETURNED FOR OVHAUL	0	0	0	0	0	0	2	0	1	0	3
EXPENDED	0	0	0	0	0	0	1	0	1	0	2
RETD AT LIFE LIMIT	0	0	1	0	0	0	0	0	0	0	1
OTV DEPLOYMENTS	0	0	1	2	0	2	1	0	2	0	8
NO. APOGEE STAGED PAYLOADS	0	0	0	24	24	26	25	17	18	19	153

CASE 1 PERIGEE OTV & RUBBER APOGEE STAGES
CATEGORY 1 TOTAL MANIFEST

per year are necessary to accommodate this traffic. All but 3 of the 156 payloads require storable apogee stages. The average OTV load factor is a low 78 percent of capability which reflects a lack of compatible payloads each year for full manifesting.

Mission Scenario 6, Low Traffic Model, Option 5; Shuttle Only

Launch Summary. The execution of the Mission Scenario 6 low traffic model, requires 382 launches when no Space Station is used. The breakdown of these by year and orbital inclination is shown in Figure 1-34. The same Shuttle capabilities as those assumed for the medium model and for Scenario 4 were used. The Spacelab space processing sortie mission level was selected to be equivalent to the reduced Space Station activity in this area. This results in an approximately 25 percent reduction in sortie flights over the medium model. NASA science and applications Spacelab flights are kept the same as in the medium model. This is because the low model for science and applications is the same as the medium model in the research areas appropriate to Spacelab. The Spacelab flight summary is:

Inclination (Degrees)	Item	No. Flights
28.5	Space processing R&D	173
57	NASA science and applications	30

Spacelab flights account for 45 percent of the low model. The load factor of low inclination Spacelab flights is 0.5. The large number of such flights lowers the overall load factor. The overall load factors and total number of flights for each type of orbit are given in Figure 1-34.

Key Comparisons. The Shuttle-only option, (Option 5) and Space Station Option 3 are compared in Figure 1-35. The operative comparisons here, as in the medium model, are the use of upper stages and OTV and the conduct of orbital manned R&D.

Option 5 does not include an OTV for high-energy orbital boost. Boost is done by various expendable upper stages. Figure 1-35 shows the number and type required from 1994 to 2000. This period is taken for comparison, since it corresponds to the operational period of the Option 3 OTV. A total of 131 expendable upper stages are needed under Option 5 during this period. By comparison, Option 3 uses five OTV and 2.02 million pounds of propellant. Even after the OTV is operational, a few small satellites are expected to fly on expendable upper stages which are shown in the figure. The comparison thus becomes one between 131 expendable upper stages and five OTV complemented by 45 expendables in Option 3. Orbital-manned R&D in Option 3 is performed in station-attached modules and pallets. An equivalent amount of R&D for 1991 to 2000 under Option 5 would require 203 10-day Spacelab missions. The comparison between the Option 5 manned orbital R&D requirements and those of Option 3 is detailed in Figure 1-35.

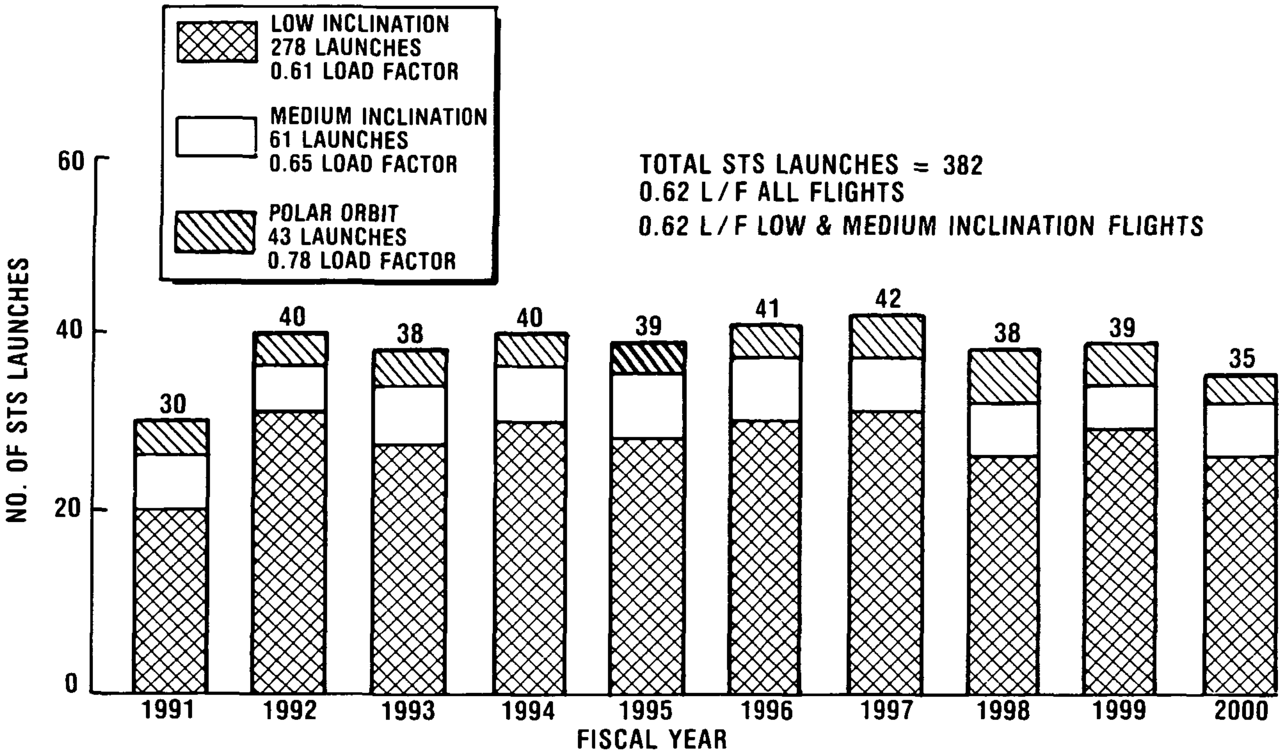


Figure 1-34. Option 5, STS Launch Summary, Mission Scenario 6 Low Traffic Level

OPTION 5

UPPER STAGES, 1994-2000

	28.5°	57°	TOTAL
PAM-D	0	30	30
PAM-DII	7	0	7
PAM-A	25	0	25
IUS 1ST STG	44	0	44
CENTAUR-G	25	0	25
CENTAUR-F	0	0	0
TOTAL	101	37	131

SPACELAB FLIGHTS 1991-2000

SP PROCESSING	NASA R&D	TOTAL
173	30	203

OPTION 3

UPPER STAGES & OTV, 1994-2000

EXPENDABLE

PAM:	28
PAM-A:	11
IUS 1ST STG:	1
CENTAUR-G:	2
TOTAL	42

OTV

VEHICLES:	5
PROPELLANT:	2.02 MLB

STATION R&D FACILITIES

SP PROCESSING	NASA R&D
• MPS MODULES	• 7 PALLETS ON PSA • LIFE SCIENCES MODULE

Figure 1-35. Option 5, Key Comparisons, Mission Scenario 6, Low Model

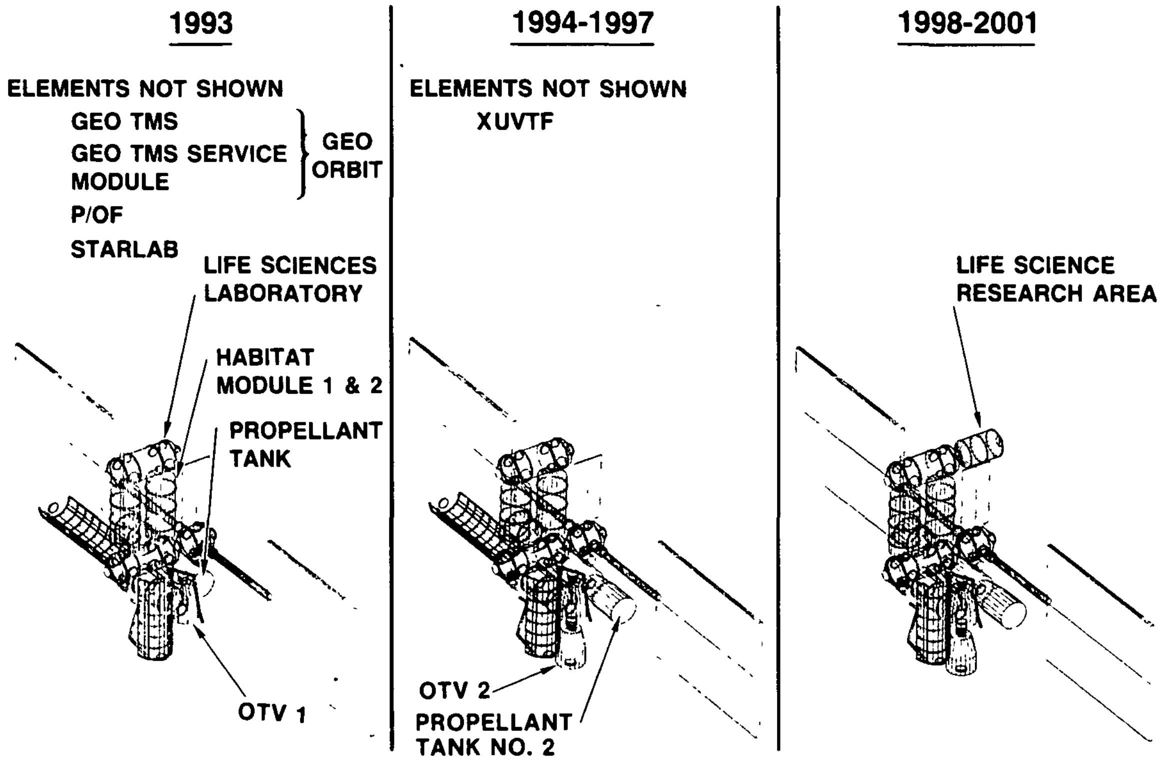


Figure 2-18. Space Station Growth

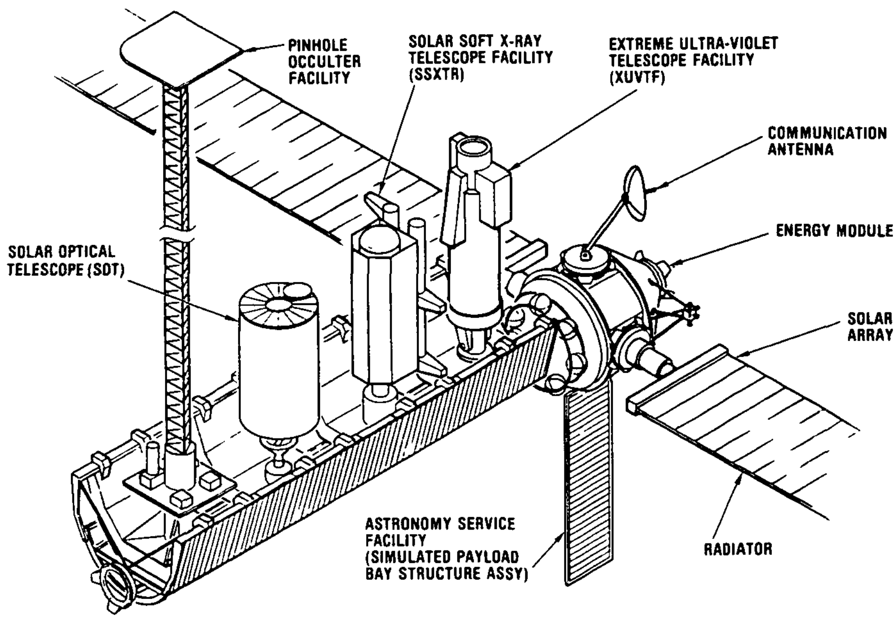


Figure 2-19. Solar Physics Platform

addition of the life sciences research area module in the year 1998. Figure 2-18 defines the build-up sequence and module locations for the years 1993, 1994 through 1997, and 1998 through 2001. In 1995, a modified energy module is mated to the astronomy service facility. This facility will then be separated from the station and will operate as a free-flying astronomy platform tended from the station. This configuration concept is illustrated in Figure 2-19.

Because both stellar and solar observation instruments are identified for the astronomy services activity, separation of these disciplines onto individual platforms may be desirable. Figure 2-20 illustrates two platform configuration concepts that will accommodate this separation. As stated earlier, the astronomy service facility is similar in construction to the PSA service bay. The energy module is identical in construction to the Space Station energy module, but only the subsystems required for platform operations are provided.

System Z Platform

An earth observation group of instruments, System Z, has been identified as a potential scientific mission of the Space Station program. These instruments want to operate in a sun-synchronous polar orbit at 500 km altitude. A concept for placing these instruments on a free-flying platform is shown in Figure 2-20.

The System Z platform consists of two major elements that share a commonality with the Space Station. The first is the payload bay instrument rack, which is constructed similar to the PSA without the manipulator arms. This rack contains the standard pallet attaching interfaces as provided both in the Shuttle payload bay and the PSA. Thus, attachments of the instrument pallets to the payload bay instrument rack replicate the orbiter payload bay attachments.

The second element to share a commonality with the Space Station is the System Z energy module. This module is identical in construction to the Space Station energy module. The subsystems supplied are those required for platform operation only. An example is the 35-kW solar array assembly and electrical power subsystem required by System Z.

SPACE STATION EVOLUTION OPTIONS

The previous discussion has been concerned with the multidiscipline Space Station development and its capability and facilities arrangements that accommodate the mission requirements. It became apparent that the varied activities being performed simultaneously on this station may have some incompatibility (i.e., vibration levels, contamination, etc.). Consequently, a station concept that essentially replicates the initial station but separates the various mission disciplines into more compatible groups was investigated. Figure 2-21 shows the station development options of either performing the mission activities via a single multidiscipline station or via two four-man stations.

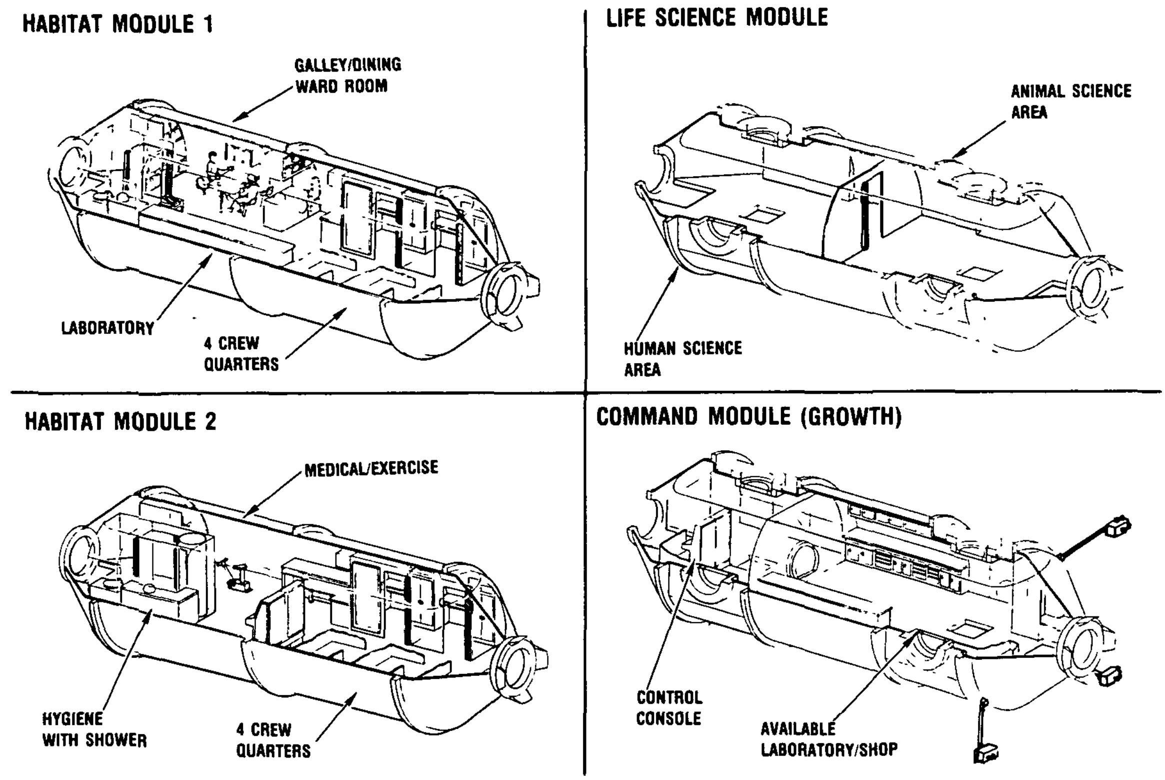


Figure 2-17. Growth Station Modules

Command Module. The command module will have all of the crew habitability provisions, such as crew staterooms, hygiene facilities, galleys, and dining/ward room removed after the build-up has been completed. Also removed will be the medical/exercise facility and the back-up station operations console. All of these facilities are now contained in Habitat Modules 1 and 2. The scar wiring and plumbing lines will remain. The subsystem components in the equipment bay are retained to maintain the redundancy and safety requirements. The space now available in the living/working volume can be utilized for laboratories and workshops, which have yet to be defined.

Growth Build-Up Sequence

The growth core Space Station, to accommodate a crew of eight, is completed within the year 1993 with the addition of two habitat modules and a life sciences module. During this build-up, the 70-inch-diameter Ku-band antenna is removed from the command module. A 13-foot Ku-band antenna and a 5.1-foot-diameter S-band antenna, dedicated for Department of Defense use, are added to the top of the life sciences module. The initial station solar array assemblies are replaced with larger array assemblies capable of providing the required 50 kW of bus power. An OTV propellant storage tank is also mated to the command module. A second OTV propellant storage tank is mated to the end of the first tank in the year 1994. With this configuration, six berthing ports on the life sciences module are available for the addition of other modules or pallets. Of these, the forward berthing port is dedicated for the

Table 2-5. Baseline Subsystem Hardware Matrix--Growth Space Station

SUBSYSTEMS	ENERGY MODULE	COMMAND MODULE	HABITABILITY	
			MODULE 1	MODULE 2
• ELECTRICAL POWER (EPS)	CONCENTRATOR SOLAR ARRAYS, FUEL CELLS, ELECTROLYSIS	FUEL CELLS, ELECTROLYSIS, POWER CONDITIONING	LIGHTING	LIGHTING
• THERMAL CONTROL	RADIATOR, WATER/FREON PUMPS, HEAT EXCHANGER	SAME AS ENERGY MODULE (EM)	SAME AS EM	SAME AS EM
• LIFE SUPPORT	—	—	GALLEY, WASTE MANAGEMENT, CLOTHES WASH, EMU	WASTE MANAGEMENT, SHOWER, BACKUP GALLEY, EMU
• ENVIRONMENTAL CONTROL	CABIN VENTILATION & PRESSURIZATION	AIR REVITALIZATION, VENTILATION & PRESSURIZATION	AIR REVITALIZATION, VENTILATION, & PRESSURIZATION	
• PROPULSION	LO_2/LH_2 PROPELLANT TANKS (SMALL), ACCUMULATOR, VALVE ASSEMBLY, & FOUR THRUSTER QUADS	FOUR THRUSTER QUADS, VALVE ASSEMBLY	—	—
• GN&C	CMG's (3), LASER RENDEZVOUS SENSOR	CMG's (2), LASER RENDEZVOUS SENSOR	—	—
• COMMUNICATIONS	INTERCOM	INTERCOM	INTERCOM	INTERCOM
• DATA MANAGEMENT*	—	SPACE OPERATIONS CONTROL CENTER	—	STATION OPERATIONS CONTROL CENTER

*INFORMATION MANAGEMENT SYSTEM CONSISTS OF DISTRIBUTED LOCAL MICROPROCESSORS IMBEDDED IN VARIOUS SUBSYSTEMS THROUGHOUT THE STATION, AND AT LEAST ONE LEVEL OF SUPERVISORY PROCESSORS. DATA BUS SERVICES TO ALL STATION MODULES

SUBSYSTEMS	PAYLOAD SERVICE ASSEMBLY (PSA)	LOGISTICS MODULE	TUNNEL MODULE	AIRLOCK	PROPELLANT STORAGE MODULE
• ELECTRICAL POWER (EPS)	PAYLOAD INTERFACES	LIGHTING	LIGHTING	LIGHTING	—
• THERMAL CONTROL	PAYLOAD INTERFACES	SAME AS EM	—	SAME AS EM	REFRIGERATION SYSTEM
• LIFE SUPPORT	—	FREEZER	TBD	—	—
• ENVIRONMENTAL CONTROL	VENTILATION & PRESSURIZATION	VENTILATION & PRESSURIZATION	VENTILATION & PRESSURIZATION	DEPRESSURIZATION, REPRESSURIZATION	—
PROPULSION	TWO THRUSTER MODULES	—	—	—	LO_2/LH_2 PROPULSION TANKS, ACCUMULATORS, VALVES, PROPULSION TRANSFER EQUIPMENT
• GN&C	LASER RENDEZVOUS SENSOR	—	STAR SENSORS, IRU, GPS NAVIGATION, SET, DIGITAL SUN SENSORS	—	—
• COMMUNICATIONS	INTERCOM	INTERCOM	13 FT DIA Ku-BAND ANTENNA 5 1 DIA. S-BAND ANTENNA, INTERCOM	INTERCOM	—
• DATA MANAGEMENT*	—	—	—	—	—

*INFORMATION MANAGEMENT SYSTEM CONSISTS OF DISTRIBUTED LOCAL MICROPROCESSORS IMBEDDED IN VARIOUS SUBSYSTEMS THROUGHOUT THE STATION, & AT LEAST ONE LEVEL OF SUPERVISORY PROCESSORS. DATA BUS SERVICE TO ALL STATION MODULES

The subsystem hardware definition and their locations within the individual modules are identified in Table 2-5.

Growth Station Configuration

The standard modular construction elements described earlier are used for the 40-foot-long habitat modules. The interior floor location, aisle widths, false ceiling, and integrated environmental protection subsystem are also incorporated. The structural arrangement of the life sciences module is identical to the command module except that the pressure bulkhead separating Volume I and Volume II is not required.

The internal arrangements and features of each module are described in this section. The build-up sequence from the initial station architecture to the growth station arrangement is also described.

Habitat Module 1. Located in the living/working area of this module are four crew staterooms, the galley, a dining/ward room/quiet recreation facility, a hygiene facility without a shower, and a larger volume, 490 cubic feet, identified as a workshop/laboratories facility. The requirements for this facility have not been fully defined. Each stateroom, nominally accommodating one crew member, has the capability to accommodate two during overlap or emergency. The required components of the subsystem, as defined in Table 2-5, are located in the equipment bay below the floor. The end cones provide storage for infrequently needed items and access to the interface connectors. This arrangement is illustrated in Figure 2-17.

Habitat Module 2. Located in the living/working volume of this module are four crew staterooms of the same configuration and capability as those located in Habitat Module 1, a back-up galley with 21-day food storage capability, a medical/exercise facility, a full hygiene facility including a shower, and a control center, containing the station operations console. The subsystem equipment identified in Table 2-5 is located in the equipment bay. Similar to Habitat Module 1, the end cones provide storage for infrequently needed items and access to the interface connectors. Figure 2-17 illustrates the arrangement.

Life Science Module. This module is divided into two volumes by partitions above and below the floor. The resulting areas are utilized for life science research (animals) and medical research (humans). A slight pressure differential between the volumes will contain any animal odors. The research facilities are located in the working volume above deck. Only the air circulation equipment has been identified, to date, to support this facility. Consequently, the equipment volume below the floor is available for the installation of special equipment or storage. The end cones provide storage for four emergency escape subsystems and other infrequently required items as well as access to any interface connectors. This arrangement is illustrated in Figure 2-17. In 1998, this module will be reconfigured to a full medical research facility equivalent to a two-bed hospital and the life science research area (LSRA), shown mated to the forward end of this module, will provide the animal research facility. At this time, some reconfiguration of the medical/exercise facility in Habitat Module 2 may be desirable.

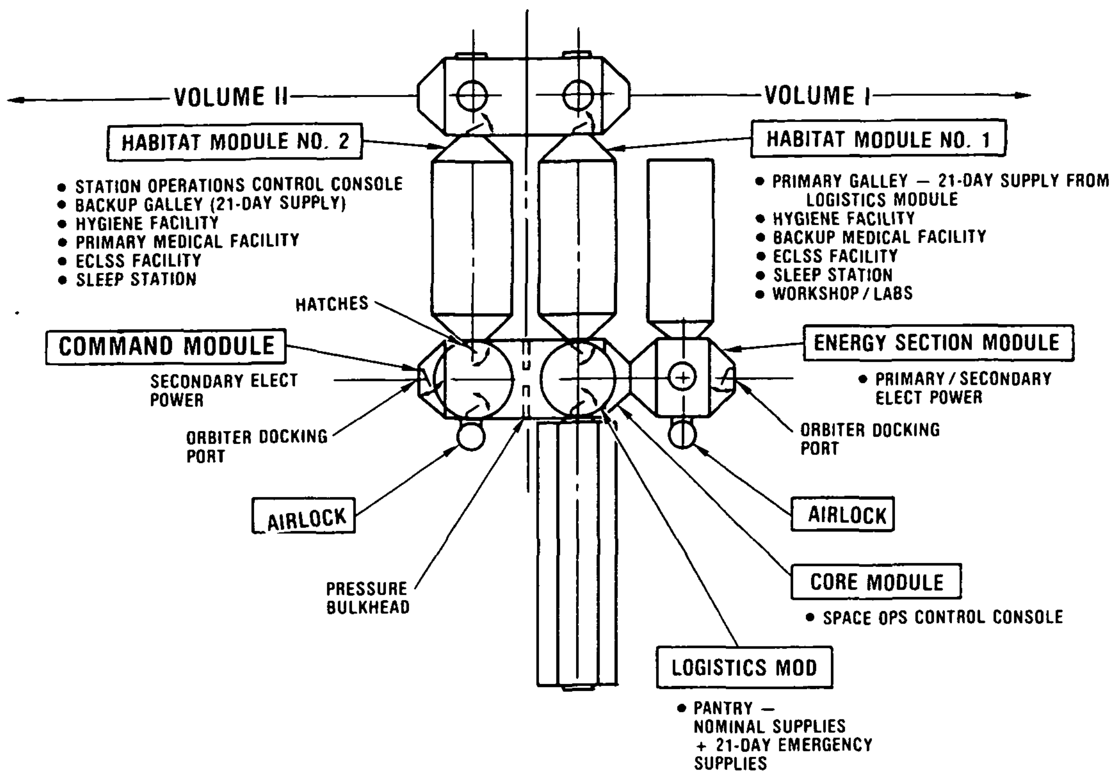
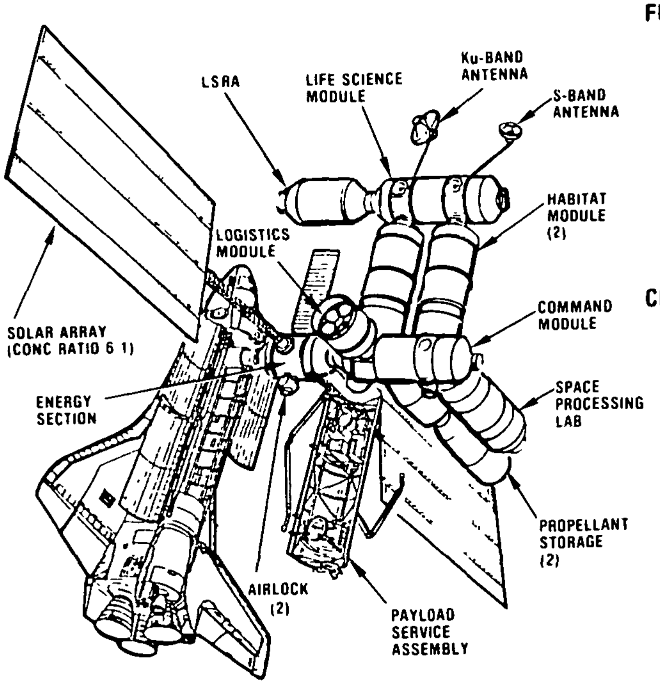


Figure 2-15. Baseline Space Station Concept Arrangement for Crew Safety



FUNCTION:

- ACCOMMODATE SPACE OPERATIONS
  - LEO SERVICING OF SATELLITES
  - SCIENCE EXPERIMENT MODULES / PALLETS
  - R&D DEVELOPMENT
  - SPACE PROCESSING
- PROVIDE ELECT POWER, COMMUNICATIONS, CREW ACCOMMODATIONS

CHARACTERISTICS:

- 7 MATING PORTS TO ACCEPT EXPT MODULES
- PALLET MATING ACCOMMODATIONS ON PSA
- OTV / SPACECRAFT SERVICING ACCOMMODATIONS ON PSA
- CRYO STORAGE
- 50 kW POWER AT BUS
- ACCOMMODATIONS FOR 8 CREW
- REPLACEABLE SOLAR ARRAYS & RADIATOR
- DUAL VOLUMES FOR CREW SAFETY
- EVA ACCOMMODATIONS

Figure 2-16. Growth Eight-Man Space Station Architecture

Build-Up Sequence

All of the basic station elements are launched and assembled in 1991 with the ASF being added in 1992. Figure 2-14 presents a detailed build-up sequence for the year 1991. When the logistics module is delivered, on the third launch, the initial station is then capable of being occupied. Figure 2-14 also illustrates the configuration of the initial station in 1992.

The station's operations elements, such as the MMU's and the first TMS, are not shown within the PSA as was indicated in Figure 2-13. The placement of the astronomy sensors within the ASF is also not shown on the figure; however, the installation of these sensors is shown within the free flying astronomy platform illustrated in Figure 2-9.

GROWTH STATION ARCHITECTURE

The growth Space Station, designed to provide a habitable and working environment for a crew of eight, is assembled by building on to the initial Space Station. The core station modules added are: Habitat Module 1, Habitat Module 2, and a life sciences module that interconnects the two habitat modules. These modules are arranged, as shown in Figure 2-15, to provide two exits out of each occupied area and to provide dual independent volumes for emergency safe havens. The baseline configuration is defined in Figure 2-16, which also lists the principal functions and characteristics of the growth station.

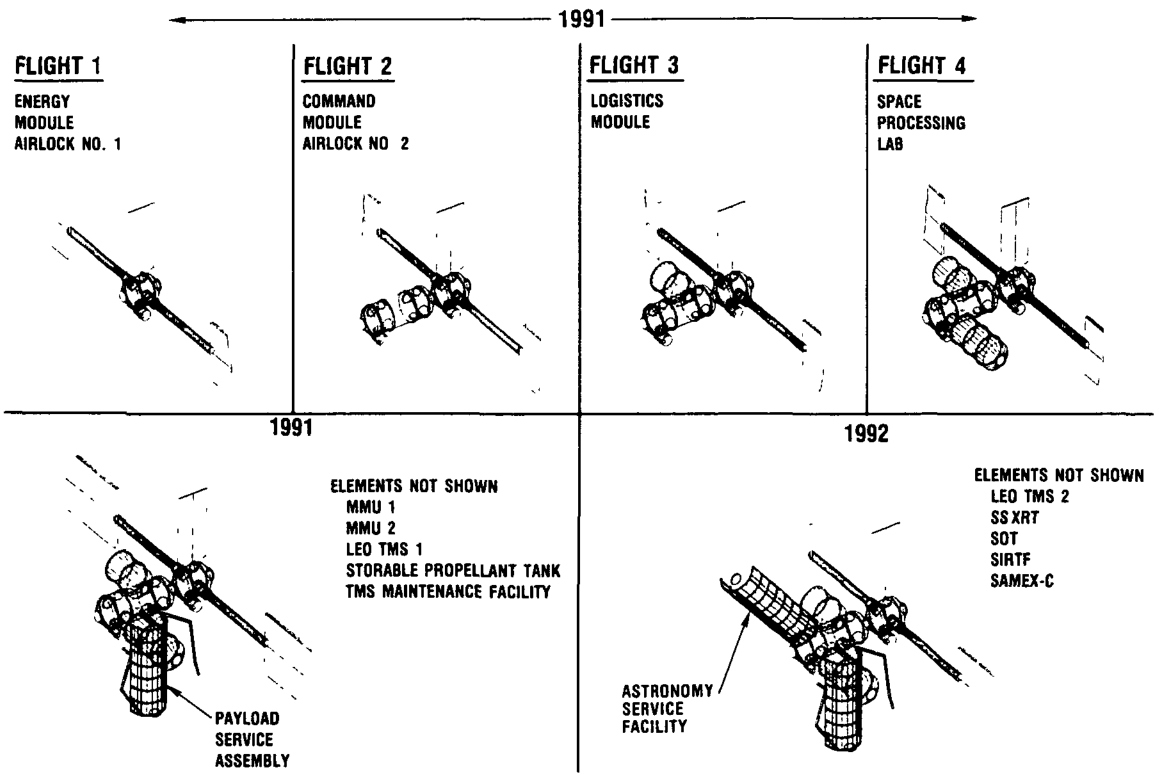


Figure 2-14. Initial Station Buildup

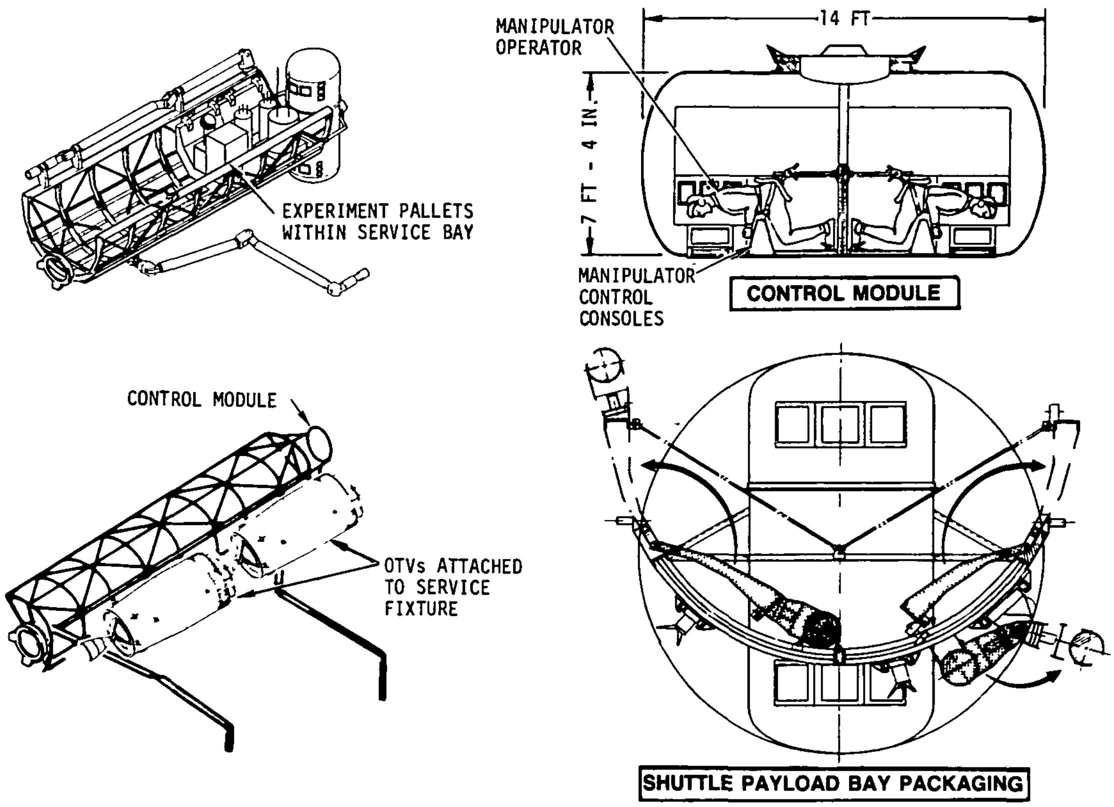


Figure 2-12. Payload Service Assembly Concept

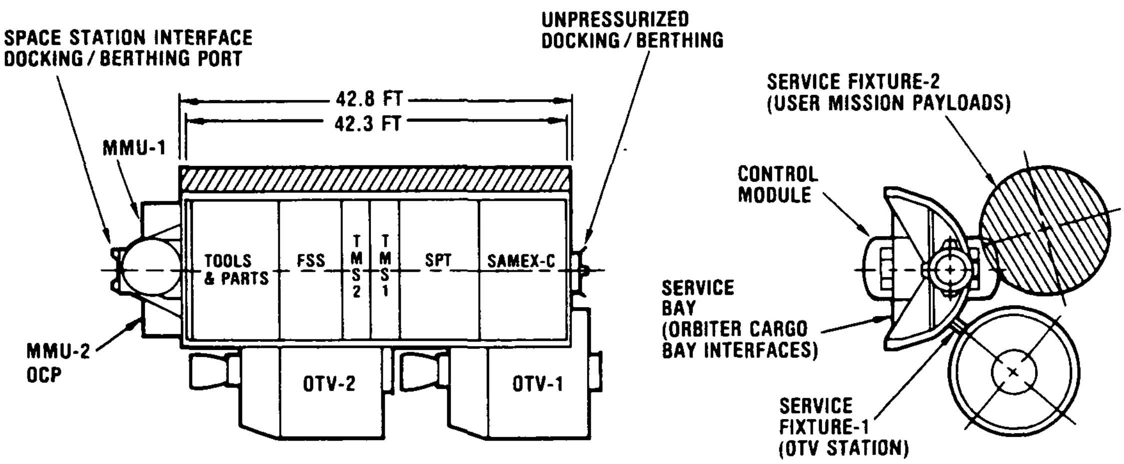


Figure 2-13. Payload Service Assembly Space Allocation

An important aspect of the PSA design is its payload accommodation flexibility. Within the service bay, the arrangements of payloads are only limited by their aggregate length, which cannot exceed 42.3 feet. Similar flexibility is provided on the service fixture. For example, one set of payload retention devices can be utilized to retain two OTV's in line, as seen in Figure 2-13, and the other set can accommodate the storage of free-flying spacecraft or other payloads. A payload arrangement concept within the PSA service bay that provides for the storage of two TMS vehicles and its servicing facilities is shown. The flight support subsystem for servicing satellites and the earth observation instrument SAMEX-C are also accommodated within the service bay.

Astronomy Service Facility (ASF)

The concept of an astronomy service facility (ASF) was developed to accommodate the three astronomy observation sensors: soft solar X-ray telescope (SSXRT), solar optical telescope (SOT), and solar infrared telescope facility (SIRTF), which need to be supported by the initial Space Station. The ASF is a structure similar to the PSA, Figure 2-8, without manipulators or a control module. The ASF is mated to a command module side port where its viewing path to stellar space is clear (Figure 2-9). The ASF will eventually be detached from the Space Station and become a free flyer as discussed in subsequent sections of this report.

Logistics Module

The logistics module assumes the same basic exterior configuration as the other pressurized elements. This includes standard end cones, frames, cylindrical body section, and interface ports. A mating port is attached to one end cone while a pressure plate seals the second end cone. On the periphery of the second end cone, a structural skirt is attached to protect external tank installation provisions, as seen in Figure 2-8. The total length of the logistics module is 23 feet.

Inside the logistics module are two structural bulkheads that coincide with the external frames. In the center of each bulkhead is a 40-inch diameter opening. On both sides of each bulkhead, pie-shaped, 20-inch-deep storage compartments with hinged doors are mounted to provide the majority of storage space. Storage compartments are also provided on the end cones. On the near end cone, 10-inch deep by 50-inch wide compartments are mounted around the periphery. On the far end cone, a 48-inch-diameter by 24-inch-deep freezer is provided. Around the freezer, additional storage compartments are mounted. The internal arrangement features 36-inch-wide aisles between storage compartments and between each storage compartment and the end cone. This width is sufficient for opening storage compartment doors and for crewmen, carrying supplies, to easily maneuver. Of the total logistics module internal volume of 2,565 cubic feet, 1,014 cubic feet are available for storage, which satisfies the average requirements for a 60-day resupply period for an eight-member crew.

capable of supporting both volumes. Redundant station control consoles are located in each volume. The main staterooms are in Volume II with back-up sleep stations in Volume I. Other features, their locations, and volume requirements are noted in Figure 2-11.

Payload Service Assembly (PSA). An important feature of the Space Station is its ability to provide servicing operations in low earth orbit. The servicing operations cover a spectrum of in-space support activities such as refueling, repairing, and maintaining free flyers and co-orbiting satellites. In addition, the Space Station is to support major assembly and deployment of large spacecraft and their eventual launch to operational orbit. The PSA is the principal element of the Space Station on which most of these servicing activities will take place. Consequently, its architecture is an important factor in simplifying the servicing operations and, in turn, the viability of the Space Station as a cost-effective member of the national space program.

Present and future STS missions and operations performed from the orbiter payload bay prior to Space Station IOC can be considered as forerunners to PSA operations. The PSA architecture tapped this legacy by simulating the orbiter payload bay in many of its features. The most important of these are a service bay and a manipulator arm similar to the orbiter payload bay and its remote manipulator subsystem (RMS), as can be seen in Figure 2-8. Payload latching mechanisms, subsystem interfaces, manipulator design, and controls will also be similar to the orbiter's payload bay interfaces.

The major architectural features of the PSA are shown in Figures 2-8 and 2-12. The service bay will be utilized in a similar capacity as the orbiter payload bay (i.e., for servicing free flyers, housing research experiments on pallets, storing spares, etc.). The back side of the service bay is the service fixture where a mobile manipulator arm and two sets of payload retention devices on carriage assemblies are featured. The service fixture will be utilized for servicing OTV's. The two retention devices will allow simultaneous servicing of two OTV's. In that event, the service fixture manipulator arm is complemented by the service bay manipulator arm in servicing the OTV's. Both manipulators are operated by crewmen within the control module, which is permanently attached to the service bay structure. The control module incorporates a standard mating port for interfacing with the Space Station. Internally, it accommodates two control stations, one for each manipulator. The control stations simulate the Shuttle aft deck from where the RMS is controlled and operated. Observation windows similar to those of the Shuttle are also provided. The other end of the PSA features a mating port where incoming OTV's dock for subsequent transfer to the service fixture for servicing. The service fixture manipulator arm is used for OTV transfer to the service fixture.

The PSA will be packaged within the orbiter payload bay for launch to LEO. The packaging concept is illustrated in Figure 2-12. The side structures of the service bay are designed to fold so the entire PSA fits within the 15-foot-diameter payload envelope of the orbiter.

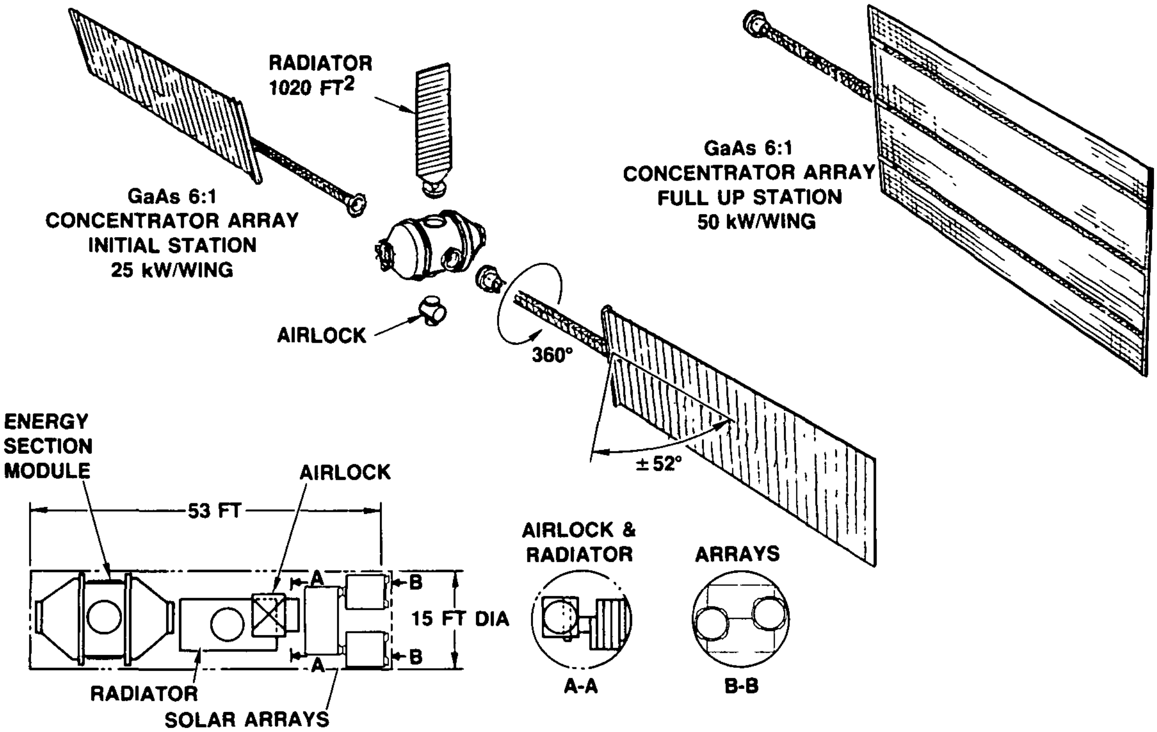


Figure 2-10. Energy Section Concept

VOLUME 1				PRESSURE BULKHEAD	VOLUME 2	
ENERGY MODULE		COMMAND MODULE			COMMAND MODULE	
NO DECK—EQUIP MOUNTING BLKHDS (FT^3)		ABOVE-DECK VOLUME (FT^3)				
• EMERGENCY SLEEP STATIONS	150	• CONTROL CENTER	126 00		• STATEROOMS, 4 @ 185 2 EA	740 76
• DEDICATED AISLE	273	• CENTER & SIDE AISLES	366 90		• CENTER & SIDE AISLES	540 01
• EQUIPMENT & ACCESS	1170	• HYGIENE FACILITY	73 33		• GALLEY	87 00
• EXPERIMENT LABS		• BACKUP GALLEY	42 00		• WARDROOM/QUIET REC	139 33
		• CLOTHES WASHER & DRYER + SUPPLIES STORAGE	26 00		• HYGIENE FAC /SHOWER	231 46
		• MEDICAL/EXERCISE/LABS	146 67		• STATION OPERATIONS CONSOLE	21 93
		• END INTERDECK ACCESS	50 00		• END INTERDECK ACCESS	50.00
		• END CONE STORAGE/EQUIP /UTILITIES & DOCKING PORT UTIL FEEDTHROUGHS	321 37		• END CONE STORAGE/EQUIP /UTILITIES & DOCKING PORT UTIL FEEDTHROUGHS	396.57
		SUBTOTAL	1152 27	76 54	SUBTOTAL	2207 06
		• MID-DECK FLOOR STRUCTURE 6-INCH-THICK VOLUME	73 15	5 56	• MID-DECK FLOOR STRUCTURE 6-INCH-THICK VOLUME	150 93
		EQUIPMENT BAY VOLUME (FT^3)				
		• END INTERDECK ACCESS	26 67		• END INTERDECK ACCESS	26 67
		• CONE STOR /UTIL FEEDTHROUGHS	62.47		• CONE STOR /UTIL FEEDTHROUGHS	62 47
		• CENTER AISLE	101 73		• CENTER AISLE	242.70
		• EQUIPMENT SPACE	61 11		• EQUIPMENT SPACE	498 97
		SUBTOTAL	251 98	40 15	SUBTOTAL	830 81
		TOTAL	1477 4	122 3	TOTAL	3188.8
TOTAL VOLUME (FT^3) = 1923		TOTAL VOLUME (FT^3) = 4788.45				

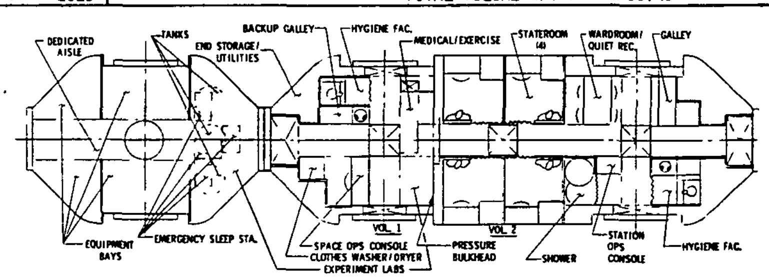


Figure 2-11. Energy Module and Command Module Initial Station Baseline

Energy Module. The energy module, shown in Figure 2-8, provides the main source of electrical power for the Space Station. It is constructed in accordance with the standardized concept having cone ends and a cylindrical center location that contains four mating ports. Mating ports are also provided at each end of the energy module. The overall length of the module is 20 feet; the maximum inside diameter of the center section is 164 inches (13 feet 8 inches). Peripheral rings between the 90-inch-long center section and each cone end are 178 inches in diameter. The module is of welded aluminum with external meteoroid bumper and insulation as shown in Figure 2-4.

The internal structure consists of two bulkheads for equipment mounting, one at each end of the center section. Equipment mounted within the module includes fuel cells, electrolysis units and electrical power conversion, and distribution components. The control moment gyros and their associated computer and inertial measurement units are also mounted in the energy module. Docking radar and communication equipment is mounted in one end of the module.

Four reaction control engine modules are mounted on one cone end with provision for shirtsleeve servicing from inside the energy module. Figure 2-8 illustrates this concept.

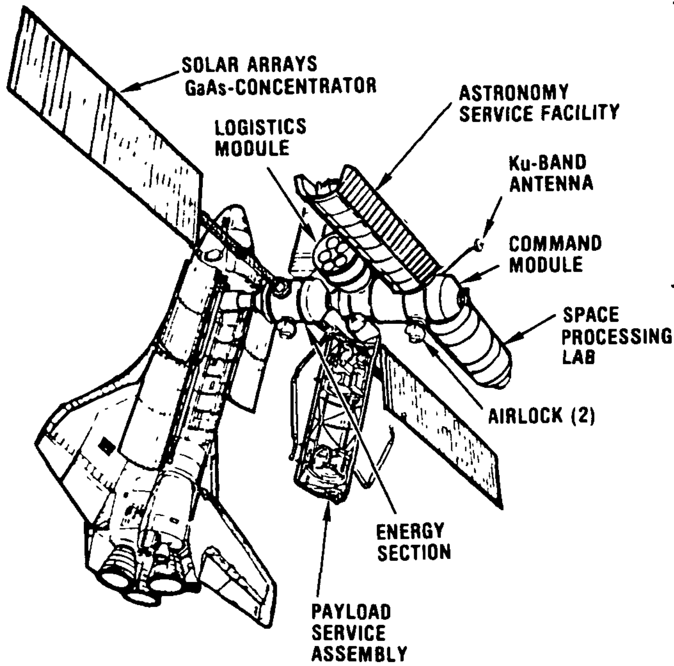
The reaction control subsystem propellant storage and accumulator tanks are mounted outside the energy module around the cone ends. All internally mounted equipment is accessible from a 40-inch-wide aisle for service or removal and replacement. Electrical, fluid, air, and gas lines to other modules, externally mounted equipment, and to a docked orbiter are provided through the interface connections at the mating ports. Air circulation is provided through the interface with the command module, assisted by fans internal to the energy module.

Station access to the orbiter in its normal docked location is through the energy module.

The four berthing ports on the center section are interfaces for two solar arrays, a deployable radiator and an airlock, all detachable and packageable within one orbiter cargo bay, as indicated in Figure 2-10. The initial solar arrays, which provide a total of 50 kW of power, are replaced for the growth configuration by arrays that provide 100 kW of power.

Command Module. The command module, Figure 2-8, is of a similar construction as the energy module except its longer center section contains two segments of four berthing ports each and a cylindrical section. Its total length is 40 feet. The volume above deck houses staterooms, hygiene facilities, galleys, dining/ward room, and medical/exercise facility. All of these provisions are removable for the growth phase. A station operations console also located within this volume remains throughout the life of the station. The volume below deck is used primarily for subsystem equipment.

A combined internal arrangement of both the energy and command modules is illustrated in Figure 2-11, noting the two independent pressure volumes. Each volume has an independent environmental control and life support subsystem



FUNCTIONS:

- ACCOMMODATE SPACE OPERATIONS
  - SCIENCE EXPERIMENT MODULES/PALLETS & INTERNAL VOLUME
  - SERVICE OTV'S, TMS & SPACECRAFT
  - R&D
  - SPACE CONSTRUCTION AN ASSEMBLY
  - SPACE PROCESSING RESEARCH & FACTORY
- PROVIDE ELECT. POWER, COMMUNICATIONS, CREW ACCOMMODATIONS

CHARACTERISTICS:

- 4 MATING PORTS TO ACCEPT EXPT MODULES
- PALLET MOUNTING ACCOMMODATIONS ON PSA
- 23.5 kW POWER AT BUS
- ACCOMMODATIONS FOR 4 CREW
- REPLACEABLE SOLAR ARRAYS & RADIATOR
- DUAL VOLUMES FOR CREW SAFETY
- EVA ACCOMMODATIONS

Figure 2-9. Initial Space Station Architecture

Table 2-4. Baseline System Hardware Matrix--Initial Space Station

SUBSYSTEMS	ENERGY MODULE	COMMAND MODULE	LOGISTICS MODULE	PAYLOAD SERVICE ASSEMBLY (PSA)
• ELECTRICAL POWER	CONCENTRATOR SOLAR ARRAY, FUEL CELLS, ELECTROLYSIS	FUEL CELLS, ELECTROLYSIS, POWER CONDITIONING	LIGHTNING	PAYLOAD INTERFACES
• THERMAL CONTROL	RADIATOR, WATER/FREON PUMPS, HEAT EXCHANGERS	RADIATOR, WATER/FREON PUMPS, HEAT EXCHANGERS	RADIATOR, WATER/ FREON PUMPS, HEAT EXCHANGERS	PAYLOAD INTERFACES
• LIFE SUPPORT	EMU'S	GALLEY, WASTE MANAGEMENT, CLOTHES WASH, SHOWER & HANDWASH, REFRIGER-ATION, FREEZER, DISHWASHER, & EMU'S	FREEZER	—
• ENVIRONMENTAL CONTROL	CABIN VENTS & PRESSURIZATION	AIR REVITALIZATION, VENTILATION & PRESSURIZATION, WATER MANAGEMENT	CABIN VENTILATION & PRESSURIZATION	VENTILATION & PRESSURIZATION
• PROPULSION	LO_2/LH_2 PROPELLANT TANKS (SMALL), ACCUMULATOR, VALVE ASSEMBLY, THRUSTER QUADS (4)	FOUR THRUSTER QUADS, VALVE ASSEMBLY	—	TWO THRUSTER QUADS
• GUIDANCE, NAVIGATION, & CONTROL (GN&C)	CMG'S, STAR SENSORS, IRU'S, DIGITAL SUN SENSORS, GPS NAVIGATION SET, LASER RENDEZVOUS SENSORS	CMG'S LASER RENDEZVOUS SENSORS	—	LASER RENDEZVOUS SENSOR
• COMMUNICA-TIONS	S- & UHF-BAND ANTENNAS, INTERCOM	Ku-BAND DISH (70 IN DIAMETER), S- & UHF-BAND ANTENNAS, INTERCOM	INTERCOM	INTERCOM
• DATA MANAGEMENT*	—	CONTROL CENTER	—	—

*SYSTEM CONSISTS OF DISTRIBUTED MICROPROCESSORS IMBEDDED LOCALLY IN SUBSYSTEMS THROUGHOUT STATION, & ONE LEVEL OF SUPERVISORY PROCESSORS DATA BUS SERVICES PROVIDED THROUGHOUT

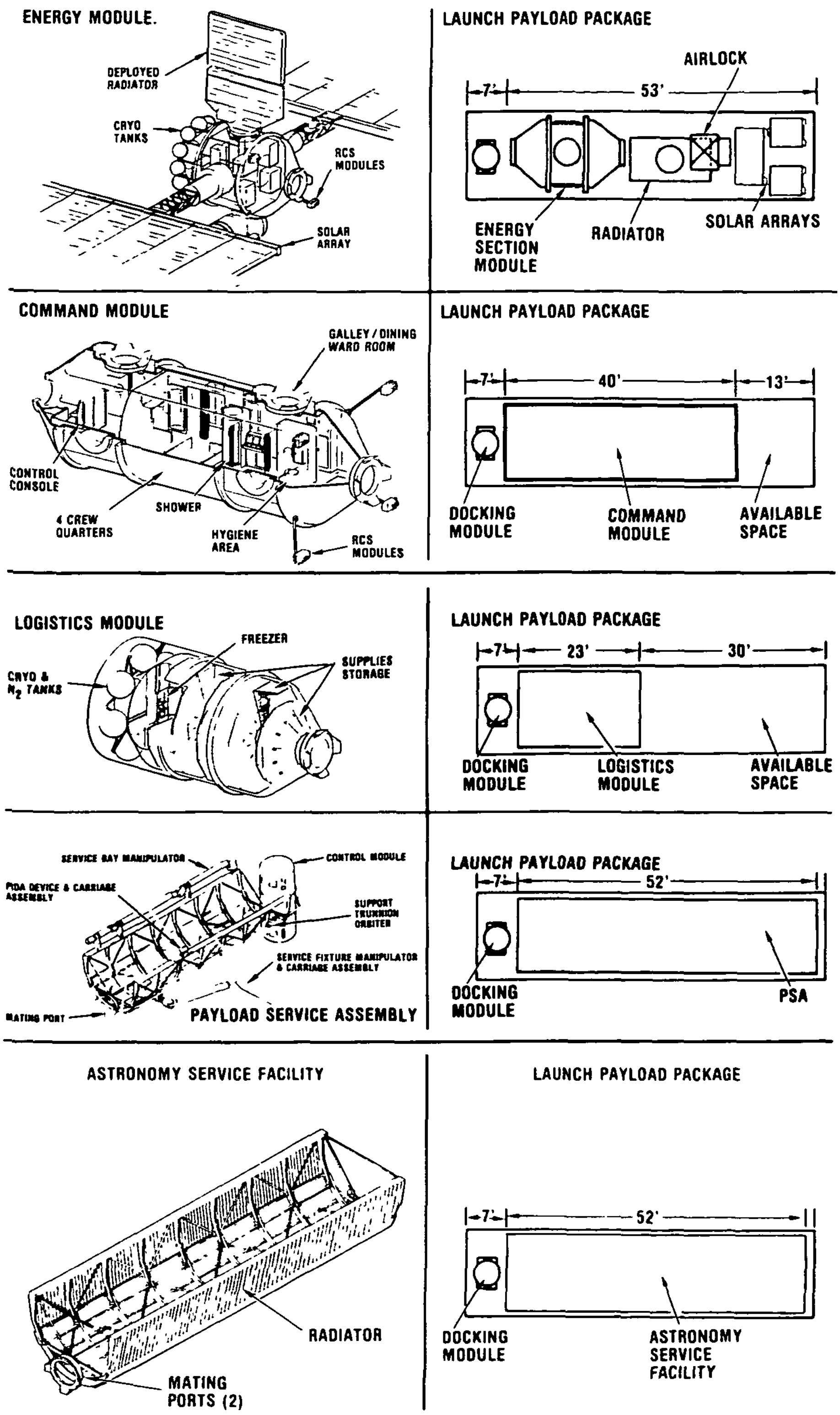


Figure 2-8. Initial Station Modules

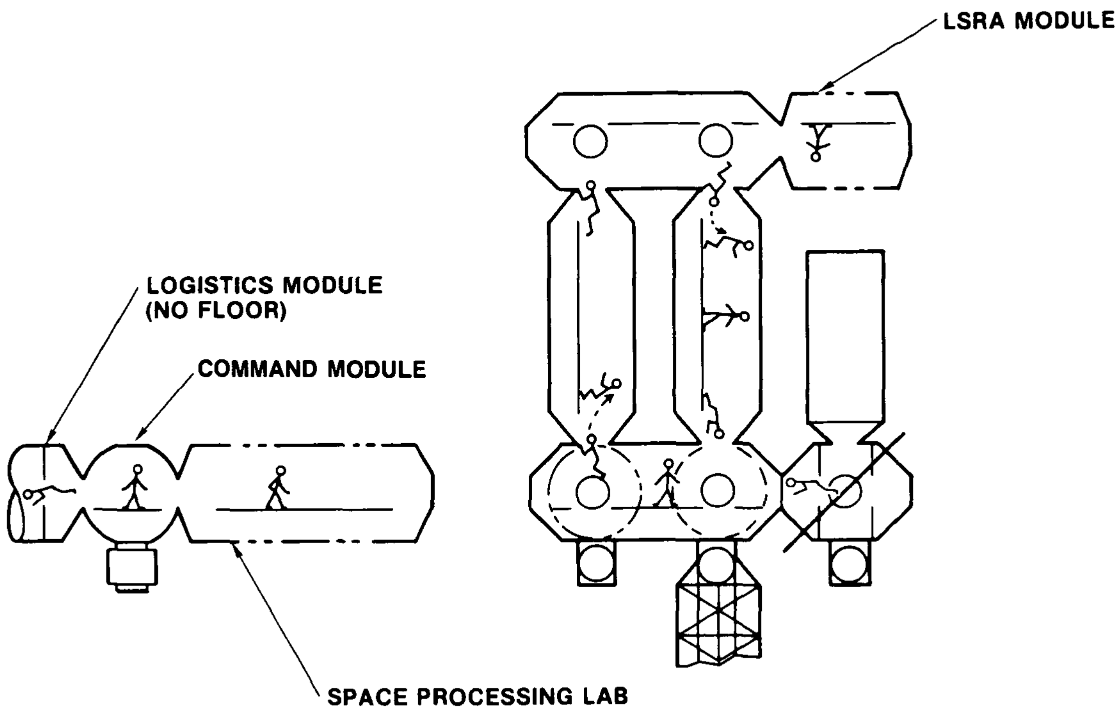


Figure 2-6. Growth Station Floor Arrangement

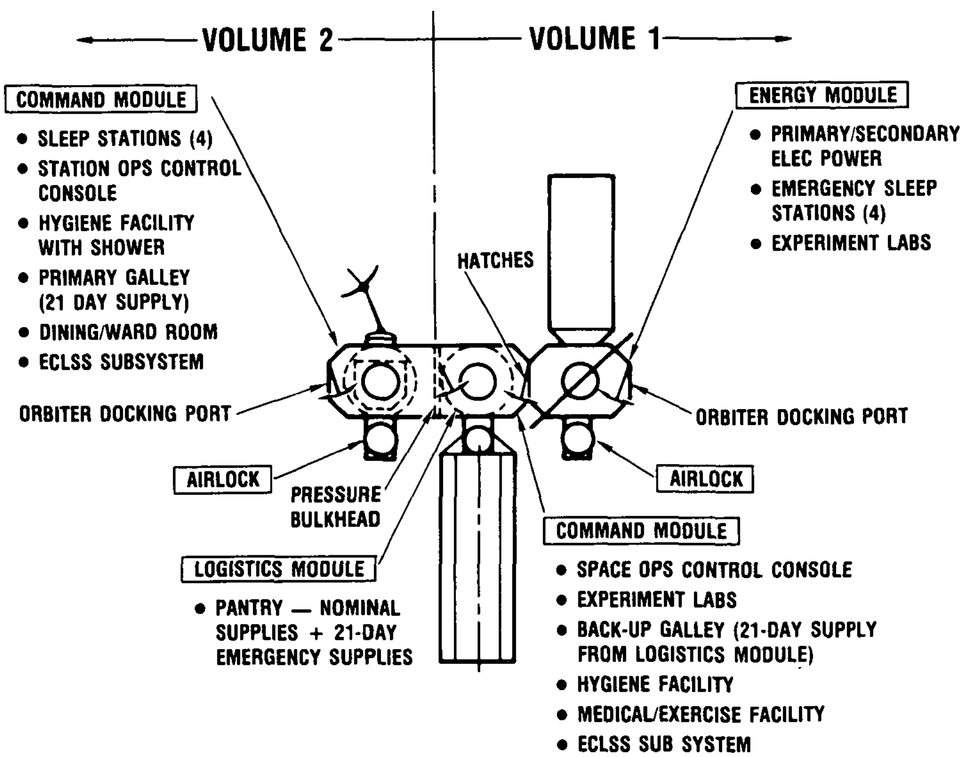


Figure 2-7. Initial Baseline Space Station Arrangement for Crew Safety

floor, the aisle is 40-inches wide, which provides for a pressure-suited crewman to perform maintenance operations. Both aisle widths are compatible with the equipment envelope sizes identified in Figure 2-3.

A false ceiling is provided in each module, which contains the lighting fixtures and air supply registers. The space behind the false ceiling is for wiring and air recirculation subsystem (ARS) ducts.

An integrated environmental protection subsystem consisting of meteoroid protection, thermal control radiators and insulation, and radiation protection is provided on each module.

An implication of the standardized floor location is the orientation of the floor within each pressurized element of the Space Station relative to each other. It is important to minimize the need for reorientation whenever a crewman moves from one element to another. The result of a specific analysis that addressed this aspect of Space Station architecture is shown in Figure 2-6 where the floor orientations are shown.

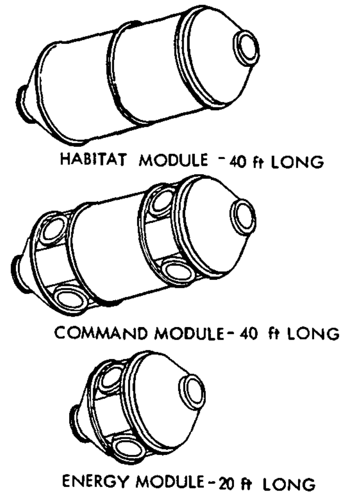
The standard docking/berthing interface accommodates module mating, orbiter-to-station mating, and user module/pallet mating to the station. It features standard mechanical alignment and latching provisions and a standard utilities interface arrangement. A 30-inch by 40-inch clear opening provides for passage of equipment and pressure-suited crewmen. All the utility interfaces are remotely activated after completing and verifying the mechanical mating. In addition, all connections feature manual override provisions permitting servicing or maintenance to be performed by either a shirtsleeve or a pressure-suited crewman.

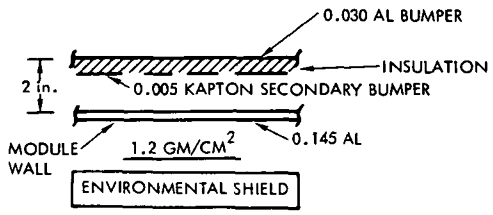
The crew safety requirements are fulfilled by dividing the Space Station into two independent pressure volumes, each capable of serving as an emergency safe haven for the entire crew. Safety features and characteristics of both pressure volumes are summarized in Figure 2-7. A pressure bulkhead within the command module separates the two volumes. Volume I contains the energy module, the forward end of the command module and the logistics module. The aft end of the command module is in Volume II.

Initial Station Configuration

The elements that make up the initial Space Station are the energy module, the command module, two airlocks, the logistics module, and the payload service assembly. One airlock is mounted on the energy module and the other on the crew module, thus providing EVA egress from either pressure volume. The individual modules are illustrated in Figure 2-8 along with the packaging arrangement of the module within the orbiter's payload bay. The arrangement of these elements into a baseline configuration is shown in Figure 2-9. The generic functions and characteristics of the initial Space Station are also shown in Figure 2-9. Eight major subsystems were considered in developing the initial Space Station architecture. The subsystems and the allocation of their components among the modules of the initial Space Station are listed in Table 2-4.

• MONOCOQUE CONSTRUCTION	0.145 in. PRESSURE SHELL 5052 AL ALLOY 13 ft 8 in. I.D.
• EXTERIOR FRAMES (ADHESIVE BONDED)	SHUTTLE SUPPORT MANIPULATOR PICKUP ELIMINATES PEEL-TYPE LOADING CLEAR INTERIOR
• CONE/KNUCKLE ENDS	LEAST WEIGHT -- NO KICK REACTION
• WELDED CONSTR	MINIMUM LEAK RATES
• ENVIRON SHIELD • METEOROID PROTECTION • THERMAL CONT • RADIATION PROTECTION	14 ft O.D. 0.030 AL -- PRIMARY BUMPER 0.005 KAPTON -- SECONDARY BUMPER 1 in. SUPER INSULATION 0.145 in. PRESSURE SHELL 0.030 in. METEOROID BUMPER





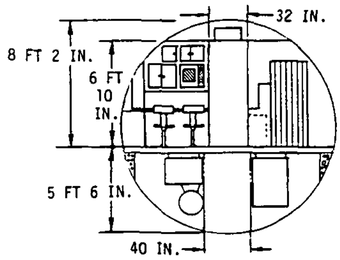
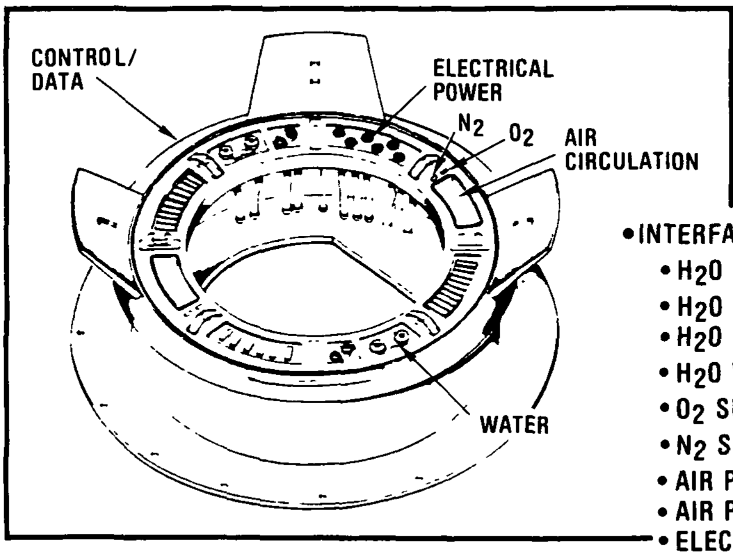


Figure 2-4. Standardized Module Concept



- INTERFACE
  - H_2O COOLANT SUPPLY (PRI & SEC)
  - H_2O COOLANT RETURN (PRI & SEC)
  - H_2O POTABLE SUPPLY
  - H_2O WASTE RETURN
  - O_2 SUPPLY
  - N_2 SUPPLY
  - AIR PRESSURE
  - AIR PROCESSING DUCTS
  - ELEC POWER-PRIMARY
  - ELEC POWER-SECONDARY
  - DATA / CONTROL
  - G / N-RCS
  - ECLSS
  - IMS
  - COMM.-AUDIO / VISUAL

Figure 2-5. Standard Mating Port

Temporary storage facilities for multiple communication and/or DOD satellites have been identified. A volume has been allocated to provide this capability.

A construction and assembly operations volume has been identified as was indicated in Figure 2-1. No particular facility requirements have been identified at this time for construction and assembly of large space elements; however, past studies, such as the Space Construction Systems Analysis that was performed by Rockwell under a NASA JSC contract, have indicated that the volume identified in Figure 2-1 is compatible with future planned platforms and large satellites.

SPACE STATION ARCHITECTURE

The initial Space Station architecture and growth concept are described in this section. The modular elements that make up each of the station concepts are also described as are the standardized module construction concepts. The station build-up sequence for each station arrangement is also included in the description.

INITIAL SPACE STATION ARCHITECTURE

Architectural development of the initial Space Station considers two categories: external architecture and internal arrangements of the basic station elements. The external architecture is concerned with overall station configuration and standardization of the construction of the modular elements. Internal arrangements were developed that fulfill the habitable needs of the initial four-man crew and, at the same time, minimize the scars that may result when the initial station progresses to the full-up architecture.

Configuration of the pressurized basic station elements evolved from a standardized module concept that opted for common diameters, bulkheads, environmental protection, floor locations, and docking/berthing interfaces (Figures 2-4 and 2-5). The pressurized modules are of monocoque aluminum, welded for minimum leakage. Each module is two standardized end cones and a center cylindrical section. A standard segment that contains four standard interfaces is also available. The standard interfaces are also incorporated in the end cones. The cylindrical sections feature standard structural rings 7 inches deep, which allow handling the modules during manufacturing and transportation and are of sufficient depth to allow installation of the environmental shield within a 14-foot outside diameter envelope. A standard floor location was also incorporated into the internal arrangements.

In the habitable volume above deck, a 32-inch wide by 82-inch high aisle is provided, which will allow the simultaneous passage of two pressure-suited crew members in an emergency condition. In the equipment section below the

Table 2-3. Time-Phased Support Systems Requirements

		INITIAL STATION		GROWTH STATION →						
FISCAL YEAR	1990	91	92	93	94	95	96	97	98	99
• **FACILITY**										
• **BASIC SPACE STATION ELEMENTS**										
ENERGY MODULE		X				X				
AIRLOCK (2)		X								
COMMAND MODULE		X								
LOGISTICS MODULE (4 MAN STA)		X	X	X						
LOGISTICS MODULE (8 MAN STA)				X	X	X	X	X	X	X
MANNED MANEUVERING UNIT (2)		X								
PAYLOAD SERVICE ASSY		X								
ASTRONOMY OBSERVATION PLATFORM			X							
HABITAT MODULE 1				X						
HABITAT MODULE 2				X						
• **TMS RELATED HARDWARE**										
LEO TMS		X	X				X			
GEO TMS				X		X				
GEO TMS SERVICE MODULE				X						
TMS PROPELLANT TANKS		X								
SPARES & TOOL STORAGE PALLET		X								
FLIGHT SUPPORT SYSTEM		X								
• **OTV RELATED HARDWARE**										
OTV				X	X		X	X		X
OTV PROPELLENT TANKS				X	X					
• **EXPERIMENTS/MISSIONS**										
• **LIFE SCIENCES HARDWARE**										
LIFE SCIENCE MODULE				X						
LSRA									X	
• **SPACE PROCESSING LAB**										
MAT'L PROCESSING SPACE MODULE		X								
• **SPACE PROCESSING SPACECRAFT**										
MDAC BIOLOGICAL PROCESSORS	X	X	X		X	X		X	X	X
CRYSTAL GROWER					X	X				
• **SPACE SCIENCE**										
SSXRT			X			X				
SOT			X			X				
SIRTF			X			X				
SAMEX-C			X							
P/OF				X		X				
STARLAB				X		X				
XUVTF					X	X				
• **SYSTEM "Z"**				X						
• **COMMUNICATIONS/DOD**										

(Bracket beside the 95 entries for SSXRT through XUVTF: } ASTRONOMY OBSERVATION PLATFORM)

ALLOCATE APPROXIMATELY 7000 FT^3 FOR TEMPORARY STORAGE OF SATELLITES
ALLOCATE VOLUME FOR ASSEMBLY AND CONSTRUCTION

Table 2-1. Subsystem Requirements

SUBSYSTEM	INITIAL STATION	GROWTH STATION
ELECTRICAL POWER (AT BUS)		
STATION	14.3 kW	35 kW
PAYLOAD	9 kW	15 kW
TOTAL	23.3 kW	50 kW
ENVIRONMENTAL CONTROL & LIFE SUPPORT		
CREW SIZE	4	8
THERMAL CONTROL		
HEAT REJECTION		
STATION	19.3 kW	42 kW
PAYLOAD	9.6 kW	15 kW
TOTAL	28.9 kW	57 kW
REACTION CONTROL		
ORBIT MAKEUP IMPULSE ATTITUDE CONTROL IMPULSE	0.8×10^6 LB-SEC/YR	1.8×10^6 LB-SEC/YR
GUIDANCE, NAVIGATION & CONTROL		
MOMENTUM STORAGE CAPACITY	13,000 FT-LB-SEC	22,000 FT-LB-SEC
ATTITUDE DETERMINATION ACCURACY	0.1 DEG	0.1 DEG
ATTITUDE CONTROL ACCURACY	0.3 DEG	0.3 DEG
ATTITUDE STABILITY	0.008 DEG/SEC	0.005 DEG/SEC
COMMUNICATION		
DOWN LINK DATA RATE	150 MBPS/ORBIT	287 MBPS/ORBIT
UP LINK DATA RATE	10 MBPS/ORBIT	12 MBPS/ORBIT
POINT TO POINT DATA RATE	16 KBPS TO	300 MBPS
BIT ERROR RATE	1×10^{-5}	1×10^{-5}
INFORMATION MANAGEMENT		
STATION OPERATIONS	10^9 BITS/DAY	10^{11} BITS/DAY
PAYLOADS	1×10^{13} BITS/DAY	2×10^{13} BITS/DAY

Table 2-2. Logistics Resupply Requirements

ITEM		WT (LBS)		VOL (FT^3)	
• STATION OPERATIONS SUPPLIES		INITIAL*	GROWTH**	INITIAL	GROWTH
— CONSUMABLES					
• FOOD		936.0	1248.0	121.0	148.0
• FOOD PACKAGING		360.0	480.0	81.0	108.0
• SPARES		55.0	322.3	4.0	23.6
	SUBTOTAL	1351.0	2050.3	206.0	279 6
— SUPPLIES					
• PERSONAL EQUIPMENT		68 4	91.2	3.6	4.8
• HOUSEKEEPING/HYGIENE		612.0	816.0	59.1	78.7
• SHIP STORES		25 5	34.0	3.2	4.3
• MAINTENANCE EQUIPMENT		25 5	34.0	2.9	3.8
• EVA SUPPLIES		684.0	912.0	52.6	70.1
• STORAGE PACKAGING		961.2	1281.6	46.8	62.4
• N_2		177.8	237.0	25 7	34.2
	SUBTOTAL	2554.4	3405.8	725 6 193.9	258 3
• CRYO CONSUMABLES					
— LOX		821 0		11.4	
— LH_2		114.0		25.9	
	SUBTOTAL	935.0		37.3	
• EXPERIMENT SUPPLIES					
— SCIENCE/APPLICATIONS/ SPACE PROCESSING	SUBTOTAL		3480.0		124.0

* 90-DAY SUPPLY FOR A CREW OF 8
** 60-DAY SUPPLY FOR A CREW OF 4

5. Minimize orientation change between modules

6. Consider both shirtsleeve and pressure-suited equipment repair and replacement capability

7. Dining capability for maximum of four at one sitting for the initial station and eight for the growth station

The significant subsystem requirements and characteristics that influence the station architecture concerning the external arrangements, sizing of the modules, and the interior space allocation are listed in Table 2-1. The solar array concept particularly influences the replaceable solar array panel goal identified earlier.

The logistics supply requirements that dictate the size and volume of the logistics module are listed in Table 2-2. These logistics supply requirements are separated into the station operation supplies: those supplies that are needed to support the crew and maintain the station systems; experiment supplies; those consumable supplies identified to perform science experiments and the life science disciplines; and the cryo supplies required during initial station operations only. The LO_2 and LH_2 are required for initial station RCS and ECLSS operation. When the cryo storage tank is introduced for the support of the OTV, the RCS and ECLSS cryo need is supplied from this central storage facility, thus eliminating this requirement from the logistics module.

The time-phased mission requirements that affect the Space Station buildup and, consequently, the station arrangement are shown in Table 2-3. These requirements are separated into those that influence the station facilities and those that are identified for the implementation of the experiments and missions activities. The facility capabilities that need to be provided for the operation of the TMS are also indicated, such as the storage capabilities for tools and spares items.

Various facilities and capabilities that the station must provide to implement the experiment and mission tasks are identified. Specific modules are indicated for the life science activities and the space processing development activities. Even though the space processing factories are free flyers in the vicinity of the station, the servicing of these elements either at the station or remotely via a TMS indicates that supporting elements are needed at the station, such as the FSS, which was identified as a facility requirement.

The space science astronomy observation instruments are planned as Space Shuttle sortie elements, which are to be accommodated later by the Space Station. To minimize changes to these instrument packages that are mounted on Shuttle pallets, the facility to accommodate the Shuttle pallets at the Space Station introduced the astronomy observation platform as a station facility element. This platform is attached to the station until the station activities become so intense that they interfere with the proper functioning of these instruments. At this time, a modified energy module will be attached to the platform and it will then become a free flyer tended from the station.

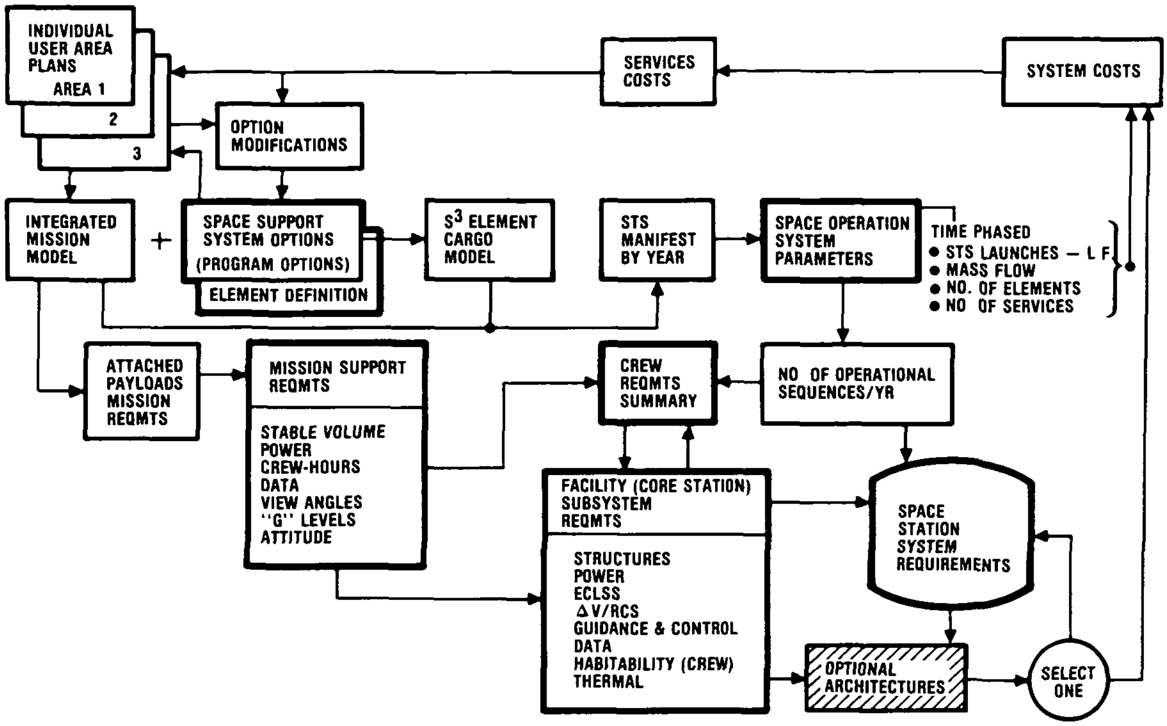


Figure 2-2. Rockwell System Analysis Approach

- STANDARD HATCH OPENING (36" X 40" DIA)
- MINIMUM AISLE WIDTH, 32"
- ALLOWANCE FOR CARGO HANDLING DEVICE
- CARGO PKG SIZES:
  - 26" X 6" X 50"
  - 28" DIA X 50"
  - 20" X 30" X 50"
- LOCAL PROTUBERANCES ALLOWED WITH DESIGN GROUP APPROVAL

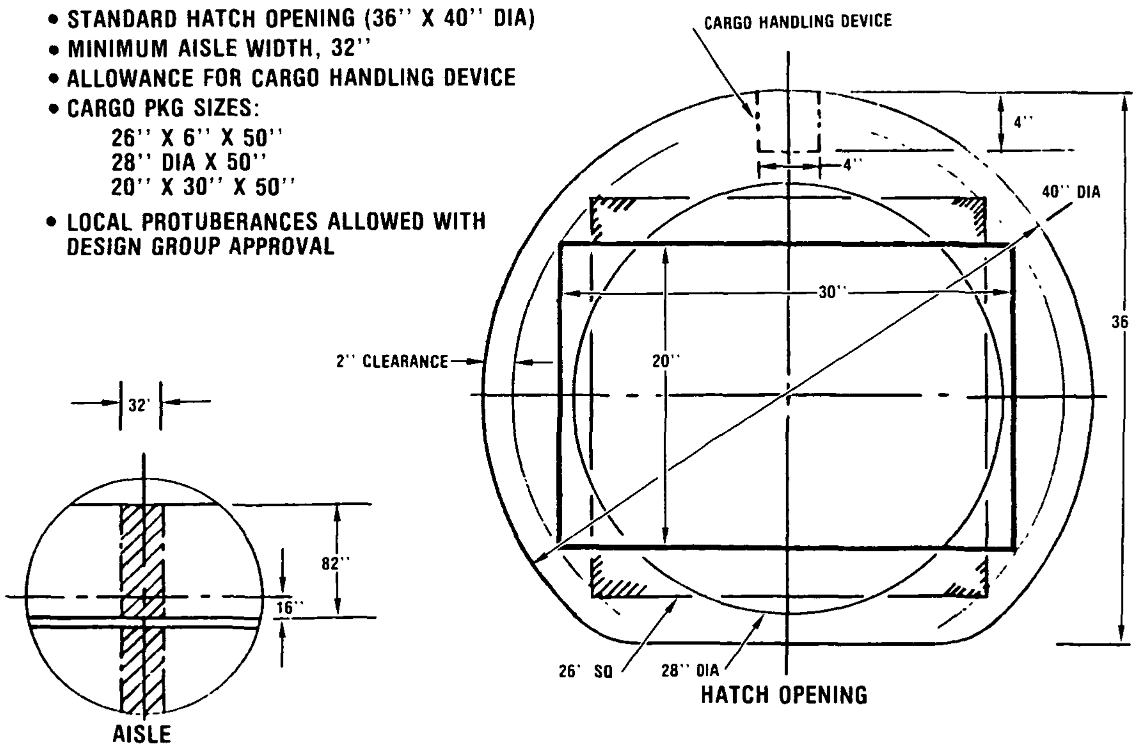


Figure 2-3. Equipment Clearance Envelope

The general ground rules and goals are:

1. Ground rules
   - Two pressure volumes
   - Two ways out of each module
   - Emergency operational and living accommodations in each pressure volume
   - EVA egress from each pressure volume
   - One orbiter docking position on each pressure volume
   - All equipment sized for passage through 40 in. by 36 in. opening
2. Goals
   - Replaceable solar array panels
   - Access to three sides of all equipment--utility interfaces accessible for manual connection
   - Smooth interior walls--exterior frames
   - Interior surface of pressure vessel visible and accessible
   - Integrate micrometeoroid, thermal insulation, radiation protection, and module structure
   - Standardize module construction

The first five ground rules are directly associated with providing a safe habitat for the crew by principally providing dual exits from all occupied areas and dual independent volumes that provide safe havens of pressurization. Rescue operation capabilities are also identified.

Figure 2-3 shows three equipment envelopes that must be adhered to in order to provide passage through the standard hatch openings of the modules. This requirement in particular influences the subsystem component specifications. It also places constraints on items that may be involved in the evolutionary growth plans considered for interior rearrangements.

Those items listed as goals are principally concerned with maximizing maintenance efficiency and standardizing module construction to minimize costs of fabrication.

The crew accommodation requirements that significantly influence the interior arrangement of the individual habitable modules are:

1. Habitable volume per man--240 ft^3
2. Provide private quarters per crewman--gross volume 150 ft^3
3. Crew overlap or emergency sleep provisions in each stateroom
4. Locate staterooms as remote as possible from noisy equipment

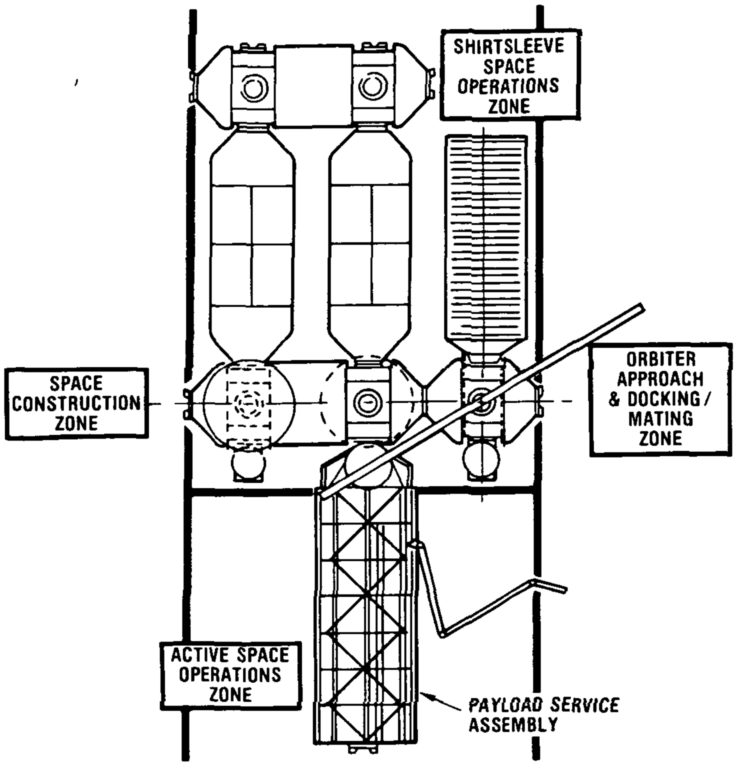


Figure 2-1. Space Station Architecture Zones-of-Operations Allocation

ARCHITECTURE REQUIREMENTS

A number of Space Station program analysis areas generate requirements that must be integrated in order to determine a viable station architecture that can implement all of the requirements. Figure 2-2 shows the system analysis approach flow diagram. Significant requirements to be implemented in the Space Station are mission system support requirements, space support system options, space operations system parameters, crew requirements, facility subsystem requirements, and Space Station system requirements. All of these requirements are integrated within the optional architectures development task.

These requirements have been categorized into five groups, which also include certain goals that are desirable and some basic ground rules associated with crew safety. The five requirement areas are:

1. General ground rules and goals
2. General accommodation
3. Subsystems
4. Logistics supplies
5. Time-phased mission requirements

Storage of satellites that comprise multiple payloads on a single transport vehicle are provided. This capability is utilized for the placement of multiple small-sized communications and/or DOD-type satellites by a single OTV.

Construction operations are provided for deployment and assembly of satellites. Space is allocated for future large construction missions as indicated in the following:

1. Crew living accommodations
   - Living space for crew--four to eight or ?
   - Environmental control
   - Environmental protection
2. Logistics resupply
   - Station operations
   - Spares
3. Station operations
   - Electrical power
   - RCS
   - GN&C
   - Data management/communications

Attached or integral missions that require the pressurized atmosphere such as dedicated modules for process development are accommodated via the standard interface ports that provide not only the physical attachment but also the utility services. Integral laboratory requirements within the core station are also provided.

Figure 2-1 illustrates the allocation of zones-of-operation that provide the accommodation of the mission operations. The active-type operations are principally allocated to the area around the payload servicing assembly (PSA). This area is utilized for the accommodation and servicing of OTV's, TMS's, the deployment and mating of satellites to transport vehicles, and the servicing of LEO satellites, if desired. The functions requiring pressurized, shirt-sleeve accommodations are within the zone occupied by the core station modules. Large construction missions are allocated to the area at the opposite end of the station from that reserved for the mating of the orbiter.

The remainder of this section will identify the significant functional and mission requirements that drove the station architecture. A description of the implementation of these requirements for both the initial station and growth station follows.

2. SPACE STATION ARCHITECTURE

The objective of the Space Station architecture task is to develop initial and full-up station arrangements that will support selected programs and determine the build-up sequence for the evolution of the initial station to a growth station.

The primary function of the Space Station is to accommodate the missions and provide the services required to sustain the mission activities. The principal areas of mission support and services and the facility services that need to be provided are listed in the following:

1. Space operations
   - LEO placement of satellites (goes through station)
   - GEO transfer (decouples payloads, OTV, propellant)
   - Servicing--OTV's, TMS's, satellites
   - Storage--mission-oriented requirements, time phased
   - Construction--deployment and assembly of satellites
     --large assemblies
2. Shirtsleeve operations
   - Attached/integral missions

Two principal divisions are made of the mission support and services functions: those functions that principally occur around the exterior of the station that may be considered as active operations, and those operations that principally require a pressurized, shirtsleeve atmosphere.

Satellites that will be operating within the vicinity of the station and those going to GEO are delivered to the station via the Shuttle. At the station, these satellites are deployed into their operating configuration, systems verified, mated to an OTV for transport to GEO, or for the LEO satellites, mated to a TMS for placement.

The LEO satellites that need frequent service, such as the space processing factories, can be serviced at the station. This service may be the extraction of completed materials and the installation of raw materials for processing as well as refueling the satellites. A routine inspection and verification of readiness may also be accomplished. If remote servicing via the TMS is utilized, the servicing functions performed on the TMS to maintain its usefulness are provided. Servicing the reusable OTV's and maintaining their usefulness are also performed at the station.

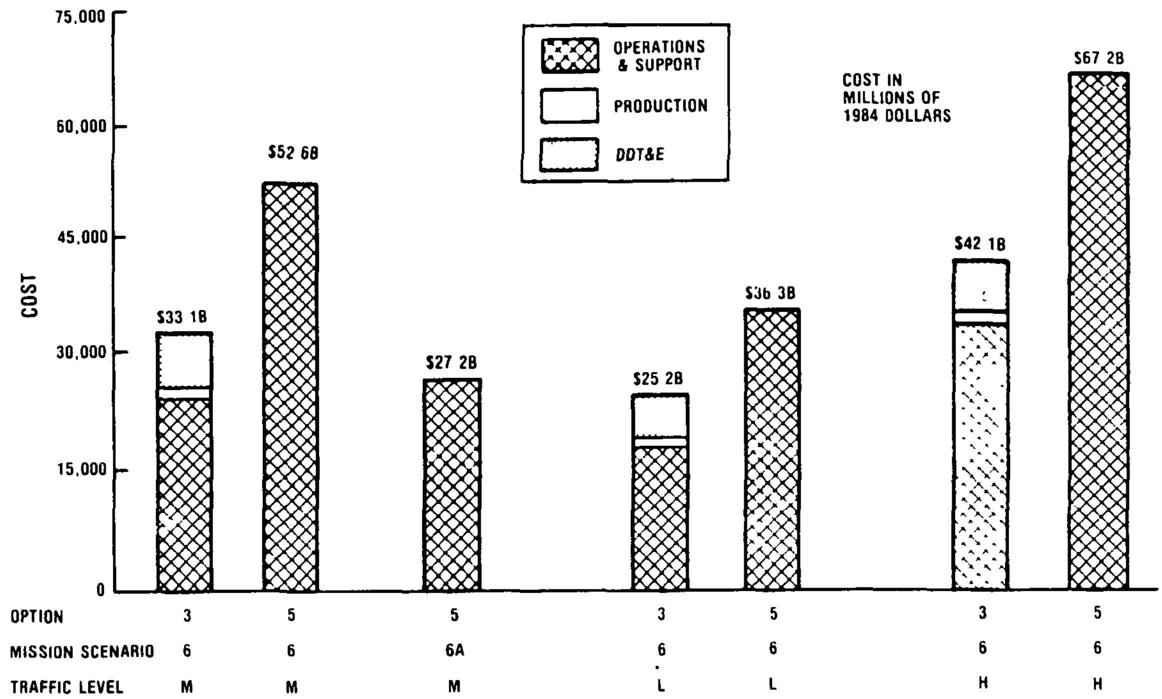


Figure 1-41. Option Cost Comparison

For any of the comparisons where Space Station Option 3 and the Shuttle-only Option 5 perform the same missions, it can be seen that significant cost savings result from the availability of a Space Station. It seems significant that a cost advantage results for the Space Station even with the most pessimistic forecast of the level of space activity. This comparison of the two options in performing the low traffic level model is shown at the center of the chart. The comparison of the two options in performing the high traffic level model is shown on the right side of the chart.

The significant advantage of the Space Station option for any equivalent level of mission accomplishment is determined from two factors:

1. A Space Station enables the operation and maintenance of reusable OTV's. This, in turn, allows high energy payloads to be launched from earth in the Shuttle without heavy and bulky upper stages. More payloads can be accommodated in each Shuttle launch, for a decrease of overall launch costs. The use of propellant scavenging and top-off adds to Shuttle efficiency by taking full advantage of the weight-life capacity on each flight.

2. A Space Station enables a high level of in-orbit manned R&D. This R&D fulfills both commercial and scientific objectives. Especially in the commercial area such work will foster the development of a space processing industry. In theory, the same R&D could be done with Spacelab sortie missions; however, the number of sortie missions needed to meet the same objectives is so large as to make the costs of such a program prohibitive. For all practical purposes, a Space Station is essential to a high level of on-orbit manned R&D.

The most significant comparison is between Options 3 and 5 at the left in performing Mission Scenario 6, which is the best estimate of the expected level of mission activity. The Space Station Option 3 shows a large advantage over Option 5 (no station) in number of launches required. A significant part of this advantage is derived from the better load factors developed by the Space Station option.

Mission Scenario 6 describes the best estimate of space activity based on the assumption that a Space Station exists. Some of the missions defined could not be accomplished very efficiently without a Space Station. Space processing research or production of material in a laboratory is the primary example of a mission that could be efficiently accomplished on a station, but would require a relatively large number of Shuttle sortie flights if no Space Station were available.

Mission Scenario 6A was constructed to represent the most likely space activities with the assumption that no Space Station would exist. The total number of launches required for this scenario approaches the number required by the Space Station option, but it should be recognized that nowhere near the same mission objectives are accomplished. More launches are required to achieve the reduced mission objectives.

Space Station Option 3 shows a large advantage over Option 5 (no station) in number of launches required for the Scenario 6 low model shown in the center, and for the Scenario 6 high model shown at the right side of the figure.

Program Option Cost Comparison

Figure 1-41 compares the costs of the seven mission model/program option combinations developed in the study.

The most significant comparison is that between Option 5 and Option 3 in performing Mission Scenario 6, medium mission model, which is regarded as the most likely level of space activity.

The lower cost for Option 5 in performing Mission Scenario 6A (shown at the right) must be recognized to be derived primarily from the reduced mission objectives achieved by the Scenario 6A mission model. The relative merits of Mission Scenario 6 versus Mission Scenario 6A are discussed in the Benefits volume. The operations cost of Option 3 to achieve the more beneficial mission objectives of Scenario 6 are lower than the operations costs of Option 5 to achieve the reduced objectives of Scenario 6A. The margin of cost advantage is sufficient to balance the production cost of the Space Station but not quite enough to pay the development costs during the operational period studied (1991 to 2000). It should be noted that the Space Station is estimated to have a 20-year life as compared with the 10-year operational period studied. The more beneficial mission achievements of Scenario 6 will be obtained for much less cost than the reduced achievements of Scenario 6A before the life cycle of the Space Station is completed.

With respect to a medium versus high traffic model comparison, the differences are seen to be slight. The high model payload average mass drops only 10 percent and the OTV load factor increases less than 1 percent. In fact, all of the OTV operational parameters are roughly equal in the two models, indicating that a saturation effect is reached at the medium traffic level.

These operational characteristics have a significant influence on any OTV and apogee concept design and programmatic conclusions. The wide disparity evidenced here indicates that many such conclusions are tenuous without traffic model projections from which statistical inferences can be drawn.

STS Launch Summary Comparisons

Figure 1-40 compares all seven combinations of the two program options (Options 3 and 5) in performing the several Scenario 6 mission models developed in the study.

The numbers at the top of the bars are the total number of launches; the numbers inside the bars and to the right of the bars are the cargo load factors associated with the sector of traffic described. For example, in Program Option 3, Mission Scenario 6, medium traffic level, there are 273 launches to all inclinations; the load factor associated with low-inclination operations (Space Station) is 0.97; the load factor for medium-inclination (Shuttle) missions is 0.64; and load factor for high inclination operations is 0.82.

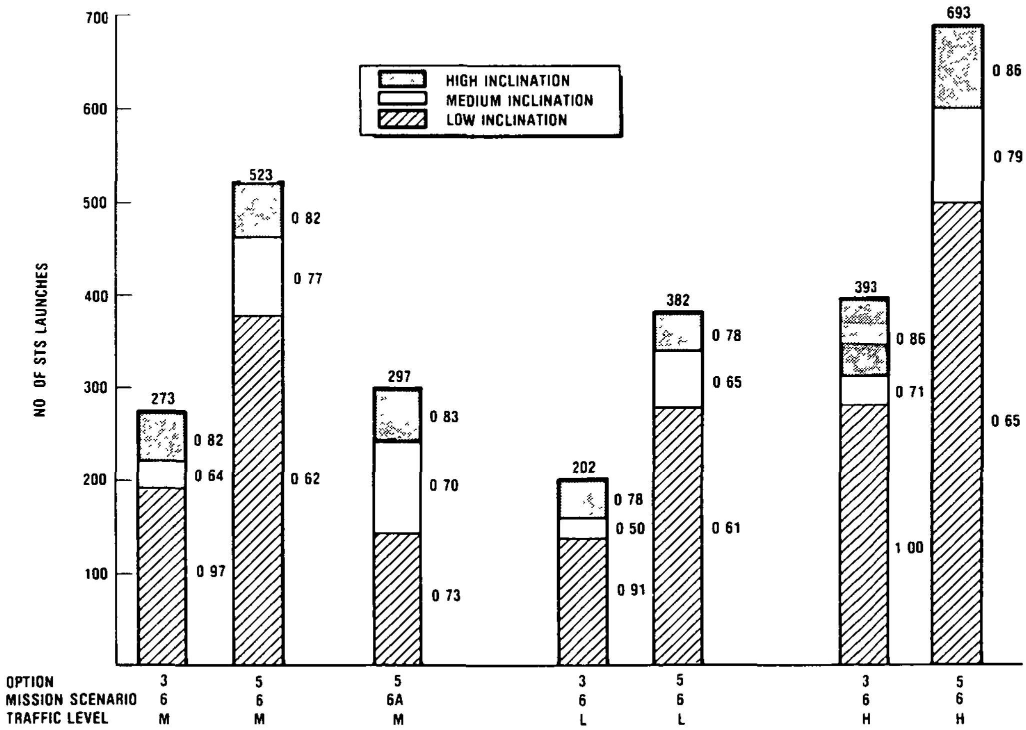


Figure 1-40. STS Launch Summary for all Program Options

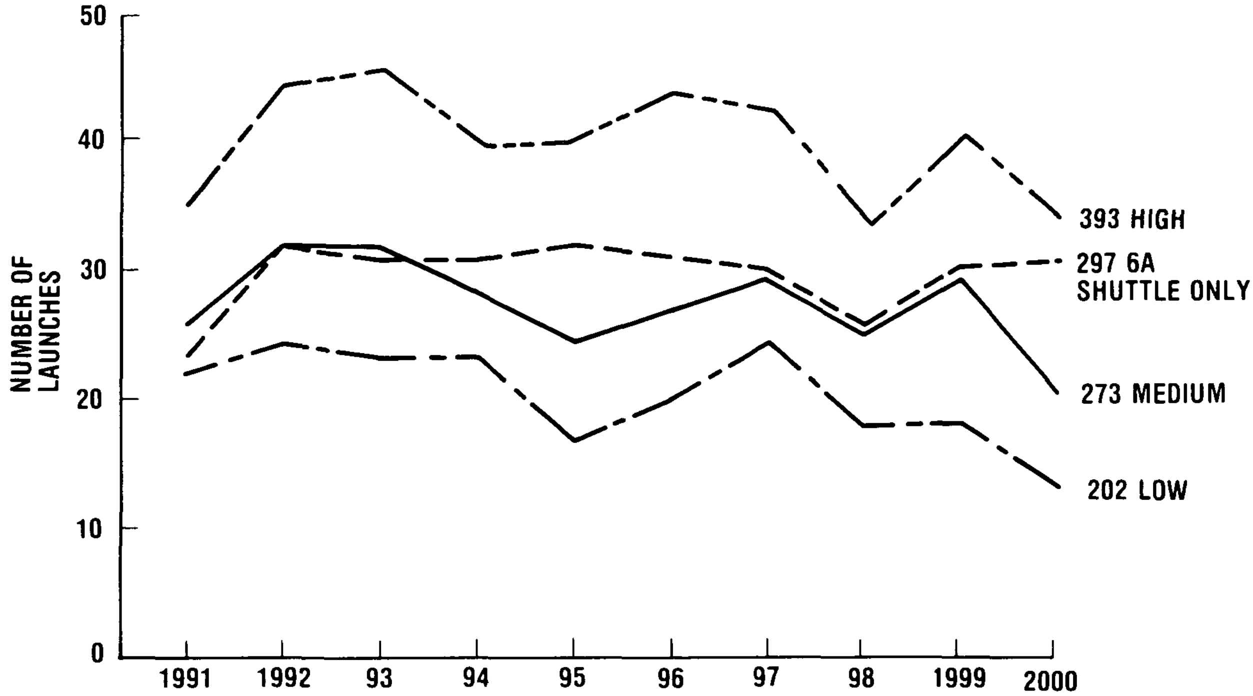


Figure 1-39. Time-Phased Launch Summary

Table 1-22. OTV Operations, Comparison of Traffic Models

	MEDIUM TRAFFIC	LOW TRAFFIC	HIGH TRAFFIC
• NO. OF PAYLOADS	199	156	285
• PAYLOAD WEIGHT	1221	621	1566
• CRYO PROPELLANT — KLB	2912	2020	3868
• OTHER SHUTTLE LIFT MASS — KLB	2455	1493	3225
• NO. OTV FLIGHTS	130	92	173
• OTV LOAD FACTOR	.81	.78	.81
• PAYLOAD AVG MASS — KLB	6.1	4.0	5.5
• CRYO PROPELLANT TO PAYLOAD RATIO	2.4	3.3	2.5
• OTHER LIFT TO PAYLOAD RATIO	2.0	2.4	2.1
• PAYLOAD MASS PER FLIGHT — KLB	9.4	6.8	9.1

OPTION 5

UPPER STAGES, 1994-2000

	28.5°	57°	TOTAL
PAM-D	0	0	0
PAM-DII	15	0	15
PAM-A	29	3	32
IUS 1ST STG	106	10	116
CENTAUR-G	50	24	74
CENTAUR-F	14	0	14
TOTAL	214	37	251

OPTION 3

UPPER STAGES & OTV, 1994-2000

EXPENDABLE

PAM:	0
PAM-A:	4
IUS 1ST STG:	3
CENTAUR-G:	10
TOTAL	17

OTV

VEHICLES:	8
PROPELLANT:	3.86 MLB

SPACELAB FLIGHTS 1991-2000

SP PROCESSING	NASA R&D	TOTAL
293	30	323

STATION R&D FACILITIES

SP PROCESSING	NASA R&D
• 2 MPS MODULES	• 7 PALLETS ON PSA • LIFE SCIENCES MODULE

Figure 1-38. Option 5, Key Comparisons, Mission Scenario 6, High Model

MISSION SCENARIO 6 COMPARISONS

This section provides a summary comparison of the data developed for the two program options (Options 3 and 5) in performing Mission Scenario 6 medium traffic level and for the Shuttle-only program option (Option 5) in performing the Mission Scenario 6A medium traffic level (Shuttle-oriented). Comparisons are also provided of the two program options in performing the low traffic level and the high traffic level models.

Figure 1-39 summarizes the launch data presented previously for the four program options of primary interest. The launch requirements associated with Space Station Option 3 in performing the medium, low, and high level models are shown as are the launch requirements associated with performing the Shuttle-oriented medium mission model without a Space Station.

OTV Operations Comparisons

In comparing the medium and low traffic models with respect to OTV operations, it is clear that substantial differences exist between the two. As shown in Table 1-22, the most notable difference is in the average payload mass, which drops 34 percent from medium to low. This effect would be expected to make full OTV manifesting predominate but, as noted previously, the reduced traffic caused a decline in the OTV load factors from 81 to 78 percent. Other parameters of the table follow these two drivers. For example, cryo propellant to payload ratio increases 38 percent from medium to low models.

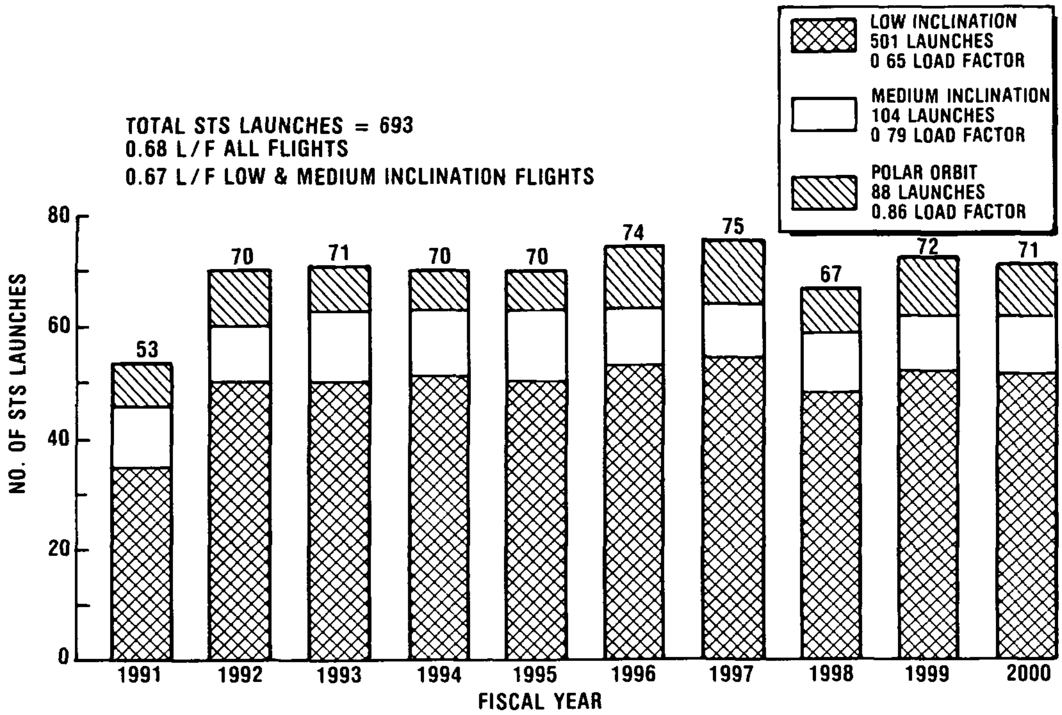


Figure 1-37. Option 5, STS Launch Summary, Mission Scenario 6, High Traffic Level

the medium model. The Spacelab flight summary that results is shown in Figure 1-38. Spacelab flights account for 47 percent of the high model. The load factor of low inclination Spacelab flights is 0.5. The large number of such flights lowers the overall load factor. The average load factor and total number of flights for each type of orbit are given in Figure 1-37.

Key Comparisons. The Shuttle-only option, Option 5, and the Space Station Option 3 are compared in Figure 1-38. The operative comparisons here are the use of upper stages and OTV, and the conduct of orbital manned R&D. Option 5 does not include an OTV for high energy orbital boost. Boost is performed by various expendable upper stages. Figure 1-38 shows the number and type required from 1994 to 2000. This period is taken for comparison, since it corresponds to the operational period of the Option 3 OTV. A total of 251 expendable upper stages would be needed under Option 5, during this period. By comparison, Option 3 uses eight OTV and 3.86 million pounds of propellant. A few satellites are expected to fly on expendable upper stages, even after the OTV is operational. These are shown in Figure 1-38. The comparison thus becomes one between 251 expendable upper stages in Option 5, and eight OTV complemented by expendable upper stages in Option 3. Orbital manned R&D in Option 3 is performed in station-attached modules and pallets. An equivalent amount of R&D for 1991 to 2000 under Option 5 would require 323 10-day Spacelab missions. The comparison between the Option 5 manned orbital R&D requirements and those of Option 3 is detailed in Figure 1-38.

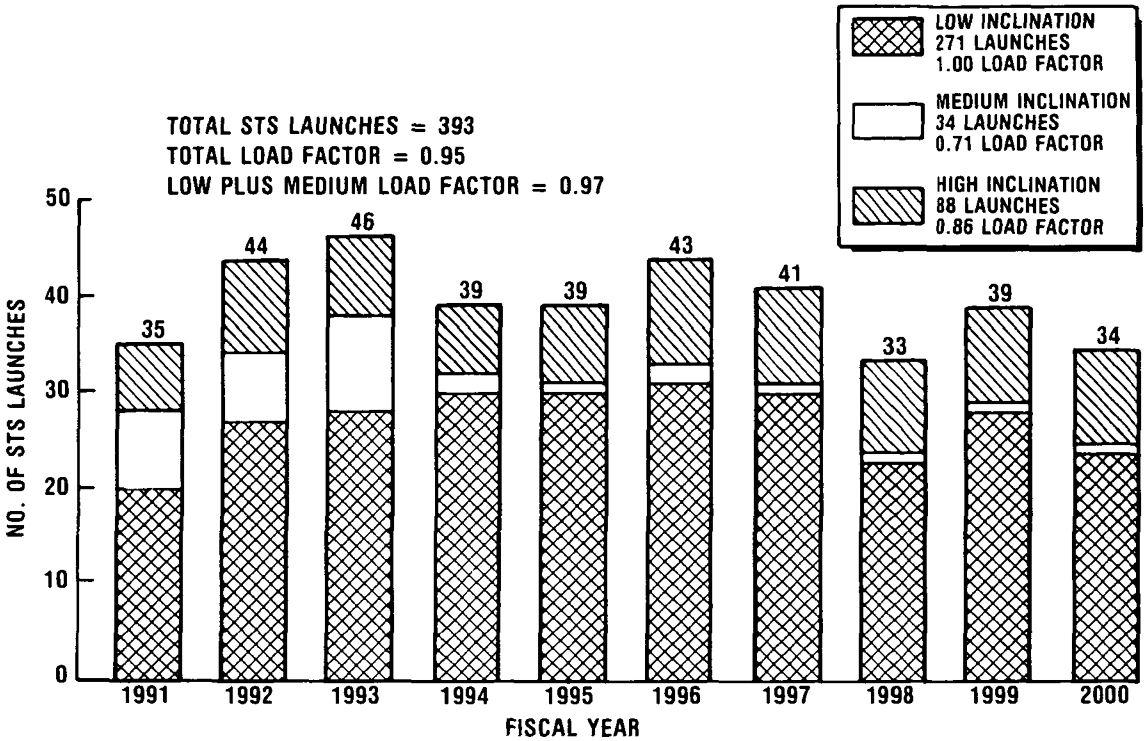


Figure 1-36. Option 3, STS Launch Summary, Mission Scenario 6, High Traffic Level

Table 1-21. OTV Operations Summary, High Traffic

CASE NO. 1 PERIGEE OTV & RUBBER APOGEE STAGES

CATEGORY 1 TOTAL MANIFEST

YEAR	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
NO. OF PAYLOADS	0	0	0	45	44	43	48	33	34	38	285
NO. OF APOGEE STAGED PAYLOADS	0	0	0	44	44	43	46	32	31	37	277
PAYLOAD GROSS WT-KLB	0	0	0	232	237	194	257	201	232	213	1566
APOGEE STAGE GROSS-KLB	0	0	0	195	206	176	228	180	185	194	1364
ASE WEIGHT-KLB	0	0	0	44	43	35	41	24	31	29	247
ORBITER LIFT WITHOUT CRYO-KLB	0	0	4	479	494	409	534	409	460	436	3225
ORBITER LIFT WITHOUT CRYO-FT	0	0	25	560	540	480	642	432	535	451	3665
UABLE PROPELLANT	0	0	82	487	509	440	589	438	500	475	3520
C/O, RESID & B/O PROPELLANT	0	0	8	48	50	44	58	43	50	47	348
CRYO PROPELLANT-KLB	0	0	90	535	559	484	647	481	550	522	3868
NO. OF OTV FLIGHTS	0	0	0	24	27	23	30	22	24	23	173
OTV AVG LOAD FACTOR	0	0	0	828	769	780	801	812	850	842	811
NO. OF OTVs MANUFACTURED	0	0	1	2	0	1	1	0	3	0	8
RETURNED FOR OVERHAUL	0	0	0	0	2	0	1	1	0	0	4
EXPENDED	0	0	0	0	0	0	1	0	2	0	3
RETURNED AT LIFE LIMIT	0	0	1	0	0	1	0	0	1	0	3
OTV DEPLOYMENTS	0	0	1	2	2	1	2	1	3	0	12

Table 1-20. Phasing Summary for ESTS Option 3 Executing Mission Model 6, High Traffic Level

Fiscal Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Basic Space Station Elements												
Energy module		1										
Air lock		2										
Command module		1										
Logistics module (4-man station)		1	4	2								
Logistics module (8-man station)				3	6	6	6	6	6	6	6	
Manned maneuvering unit		2										
Payload service assembly		1										
Habitability module				2								
TMS-Related Hardware												
LEO TMS		1	1				1	1				
GEO TMS				1		1						
GEO TMS service module				1								
TMS CM		1										
TMS propellant tanks		1										
TMS storage/maintenance/repair facilities (PSA)		1										
OTV-Related Hardware												
OTV				1	2	2	1	2	1	3		
OTV CM				1								
OTV Propellant Tanks				1	1							
OTV storage/maintenance/repair facilities (PSA)				1								
Science and Applications Hardware												
PSA (astronomy platform)			1									
Tunnel (life sciences lab) module				1								
Energy module (astronomy platform)					1							
Spacelab (monkey) module							1					
Space Processing Laboratories												
MPS module		1					1					
Space Processing Factory Hardware												
MDAC biological processors	1	1	1	1	1	1	1	1	1	1	1	
Crystal grower						1	1	1				
SPF CM		1										
SPF storage/maintenance/repair facilities (PSA)		1										
SPF material storage (PSA)		1										

Table 1-19. Comparison of Mission Scenario 6, Space Station Option, Medium With High Traffic Level

MISSION AREA	NUMBER OF PAYLOADS		TOTAL PAYLOAD WEIGHT (KLB)		TOTAL CARGO WEIGHT (KLB)		EQUIV STS FLIGHTS	
	6M	6H	6M	6H	6M	6H	6M	6H
• COM COMMUNICATIONS	153	233	522.3	802.0	2,848.6	4,682.4	45	48.8
• COM PROCESSING	407	524	639.1	864.0	661.3	942.0	11	10.6
• COM RESOURCE OBS	11	13	39.0	47.0	138.3	123.3	7	5.4
• DOD	227	324	2,431.2	4,803.0	5,535.9	9,018.7	125	175.3
• GEO SERVICING	11	15	118.0	165.0	458.4	717.0	7	5
• GOVT ENVIRONMENTAL	10	10	41.0	41.0	240.6	240.6	4	4
• NASA SCIENCE & APPL	143	144	566.7	580.0	1,127.4	1,155.6	31	26.6
NASA TECHNOLOGY	19	22	85.7	136.0	126.7	181.1	4	4.4
• SPACE STATION ASSEM LOGISTICS & UPPER STAGE LOGISTICS	—	—	—	—	2,332.8	2,500.3	39	47.7
TOTAL	981	1285	4,443.0	7,398.0	13,470.0	19,561	273	392

Mission Scenario 6, High Traffic Model, OTV Operations

The increased traffic in the high model resulted in the OTV operation characteristics listed in Table 1-21. Of the 285 payloads, all but 8 use an apogee stage. The level of activity results in a reasonable 0.811 average load factor for the OTV. OTV requirements increase to eight manufactured units and 12 Shuttle deployments to the station of new and overhauled units.

Mission Scenario 6, High Traffic Model, Option 5, Shuttle Only

Launch Summary. The execution of the Mission Scenario 6 high traffic model, would require 693 STS launches in the absence of a Space Station. The breakdown of these by year and orbital inclination is shown in Figure 1-37. The same Shuttle capabilities assumed for the medium model, and for Scenario 4, were used. The Spacelab space processing sortie mission level was selected to be equivalent to the increased Space Station activity in this area. This results in an increase of approximately 25 percent over the medium model. NASA Spacelab R&D activity is the same in the medium and the high models. Thus, the Science and Applications Spacelab sortie level is the same as in

MISSION SCENARIO 6: HIGH TRAFFIC MODEL

The high model presumes a vigorous space program driven by a return to a strong world economy, particularly in the high technology sector. It reflects modest increases in some of the NASA programs (planetary, life sciences, etc.), significant increases in commercial programs associated with optimistic market forecasts, and significant increases in DOD programs associated with the addition of survivability and strategic/tactical missions over those in the medium model.

Table 1-19 compares this more vigorous program (6H) with the medium model (6M) that is considered most likely and discussed previously. The pattern of increased activities is indicated in the table.

Mission Scenario 6, High Traffic Model, Option 3, Space Station

The high traffic level Option 3 had the same basic ground rules as those previously described in the medium and low traffic level Option 3 sections.

The various building blocks necessary to accomplish the Mission Scenario 6 high traffic model are as follows: one energy module, one command module, one payload service assembly, one tunnel module, four LEO TMS's, two GEO TMS's, one GEO TMS service module, 1 set of station-attached TMS propellant tanks, eight OTV's, two sets of station-attached OTV propellant tanks, two habitability modules, one life sciences Spacelab (Monkey) module, two MPS modules, two generic types of space processing factories, one astronomy platform, and continual resupply via the logistics module. All of these building blocks have been described in previous sections. A summary of when the Option 3 Mission Scenario 6 high traffic level model building blocks are required is presented in Table 1-20.

The Station acquires Initial Operational Capability in 1991, with an initial crew size of 2. The crew size grows to 3 in 1992, to 5 in 1993, and to 8 in 1994, to 9 in 1995, and to 10 in 1996. It alternates between 9 and 10 for the rest of the decade.

Launch Summary. The various payloads required to accomplish the Mission Scenario 6 high traffic model and Space Station operations were manifested using the SOSMAN computer program, as previously described. The Shuttle payload cargo bay was loaded using a maximum payload weight of 61,000 pounds or a length of 53 feet for all payloads destined for Space Station. Payloads destined for medium inclination and launched there directly by the Shuttle were manifested to a maximum cargo bay capacity of 49,000 pounds or a length of 60.0 feet. Payloads destined for high inclination were manifested to a maximum cargo bay capacity of 25,000 pounds or a length of 60.0 feet. The number of such STS missions per year required to accomplish Mission Scenario 6 high traffic level model is presented in Figure 1-36.

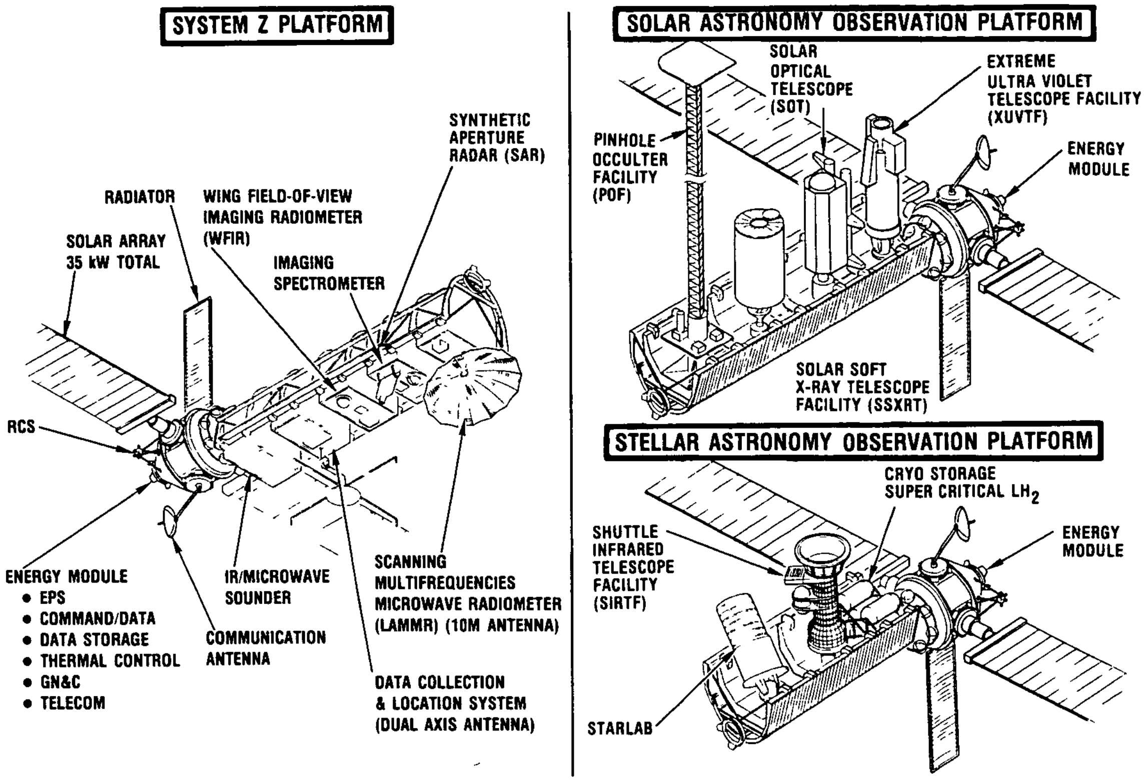


Figure 2-20. Space Science Platforms

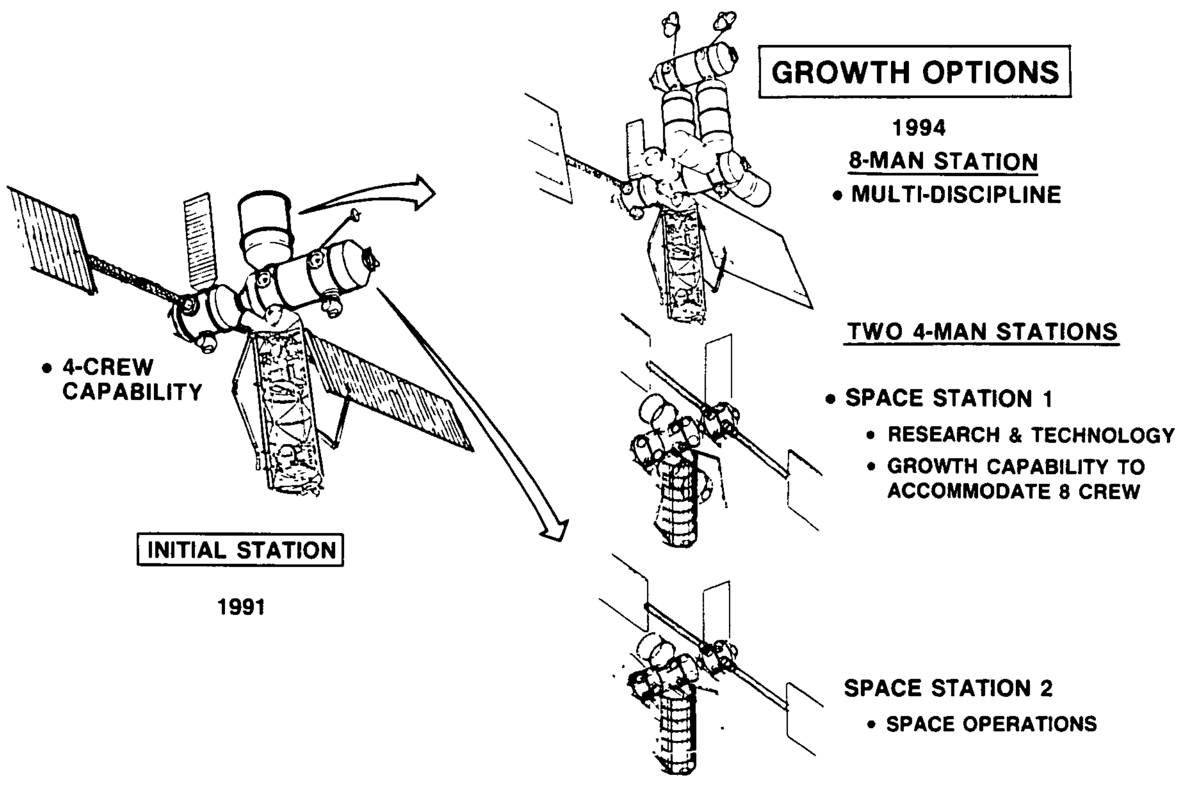


Figure 2-21. Alternate Space Station Architecture Options

The two four-man stations have divided the mission activities into science and technology and space operations activities. The science and technology station provides the capabilities to accommodate the space processing development activity, the life sciences experiments, the astronomy observation activity, and the earth resources activity. This combination permits the astronomy observation instruments to be retained on the station, thus eliminating the need for a dedicated station-tended platform. No space transportation vehicles (i.e., the TMS or OTV) are operating from this station arrangement.

Growth to accommodate more than a crew of four can be accommodated with the addition of two habitat modules. The life sciences laboratory module becomes the interconnecting tunnel module. A solar array sized to accommodate these science and technology disciplines with a four-crew complement may be provided at the outset without the need to grow unless crews greater than four are necessary. Figure 2-22 illustrates this science and technology station in a four crew member arrangement and a growth arrangement that will accommodate greater than four.

The space operations Space Station, Figure 2-22, provides the capabilities for the high-energy missions, utilizing an OTV, and the servicing of the space processing factories by the TMS. This station also provides the capability for temporary storage of satellites for a multiple satellite launch mission. Construction operations may be performed at this station utilizing the dedicated zone as indicated in Figure 2-1.

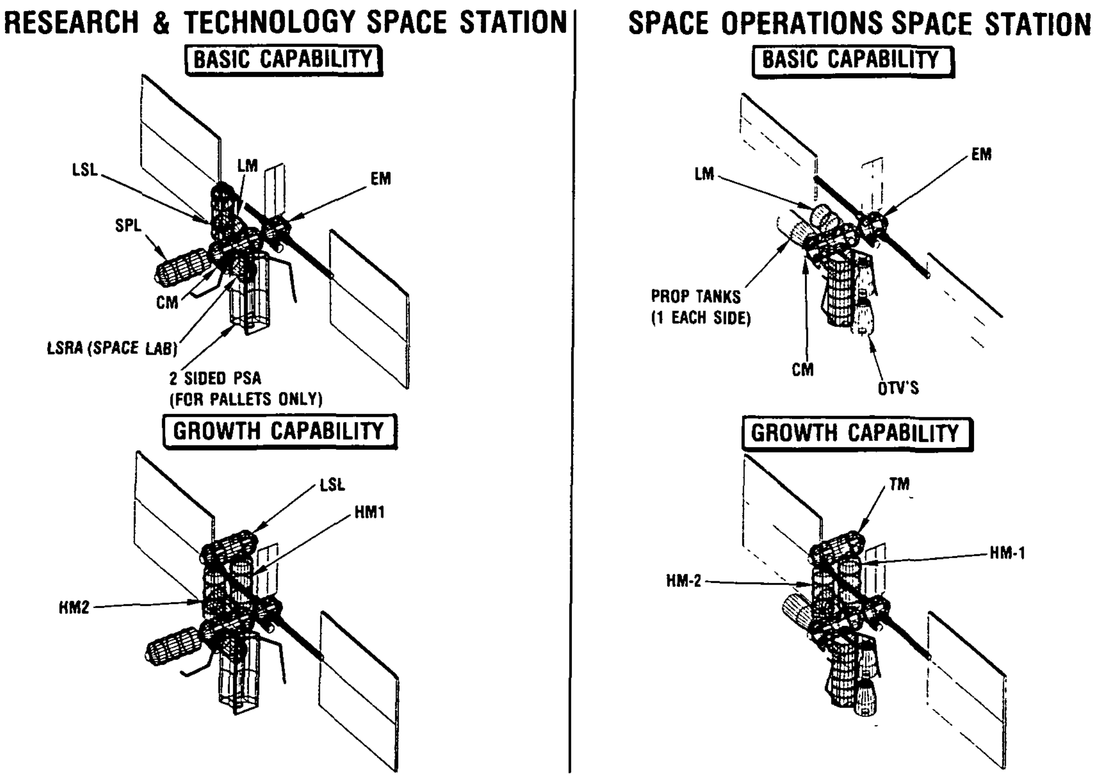


Figure 2-22. Space Station Options

The addition of two habitat modules and a tunnel module will provide the growth to accommodate crews greater than four.

Further study of these and other evolutionary options is desirable in order to fully explore and compare Space Station arrangement options that accommodate the user mission/experiment requirements.

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3. SPACE STATION SUBSYSTEM ARCHITECTURE

Space Station subsystem sizing requirements are shown in Table 3-1 for both the initial and all-up operational Space Station. These requirements represent the evolution of the Space Station from an initial configuration manned by a crew of four to a growth station manned by a crew of eight.

The architecture of each subsystem was derived to satisfy the requirements of Tables 3-1 and 3-2, top level requirements of NASA requirements document (yellow book), and detailed requirements generated by previous Rockwell studies and on-going Space Station study activities.

Trade studies were conducted that considered weight, power, volume, development status, reliability, and overall costs as evaluation criteria before arriving at subsystem concept selection. A major trade was conducted to evaluate an integrated subsystem approach for the electrical power subsystem (EPS), environmental control and life support subsystem (ECLSS), and reaction control subsystem (RCS) integrating a common usage of oxygen and hydrogen. Additional subsystem trades were conducted to define thermal control; guidance, navigation, and control (GN&C); information management subsystem (IMS); communication and tracking (C&T); and fluid subsystem architectures. The following sections describe these trade studies and a resulting subsystem architecture.

INTEGRATED EPS, ECLSS, AND RCS ARCHITECTURE

Trade studies of an integrated EPS, ECLSS, and RCS subsystem were conducted using the following selection criteria: life-cycling cost (DDT&E, recurring, spares resupply, consumables, crew maintenance, and transportation to LEO), reliability, weight factor, maximum ability to retain power, and minimum operation constraint. Based on these comparisons, the regenerative fuel cell energy storage subsystem was selected as the architecture for the Space Station program. Results showed cost savings over the life cycle of the station. Trade studies included open fuel cells, regenerative fuel cells, and Ni-H_2 battery concepts in an evolutionary process of going from an initial station to a growth, all-up operational station. Figure 3-1 shows cost comparisons for three of these concepts. A schematic of an integrated subsystem (EPS/ECLSS/RCS) is shown on Figure 3-2.

The selected integrated concept incorporates solar arrays, regenerative fuel cells for energy storage, and oxygen and hydrogen gas for reaction control jets. The solar array is the primary energy source to satisfy stationkeeping and payload electrical requirements, and provide electrical power to the electrolysis unit to meet the eclipse fuel cell energy and ECLSS ocygen supply requirements.

Table 3-1. Subsystem Requirements

SUBSYSTEM	INITIAL STATION	GROWTH STATION
ELECTRICAL POWER (AT BUS)		
STATION	14.3 kW	35 kW
PAYLOAD	9 kW	15 kW
TOTAL	23.3 kW	50 kW
ENVIRONMENTAL CONTROL & LIFE SUPPORT		
CREW SIZE	4	8
THERMAL CONTROL HEAT REJECTION		
STATION	19.3 kW	42 kW
PAYLOAD	9.6 kW	15 kW
TOTAL	28.9 kW	57 kW
REACTION CONTROL		
ORBIT MAKEUP IMPULSE ATTITUDE CONTROL IMPULSE	0.8×10^6 LB-SEC/YR	1.8×10^6 LB-SEC/YR
GUIDANCE, NAVIGATION & CONTROL		
MOMENTUM STORAGE CAPACITY	13,000 FT-LB-SEC	22,000 FT-LB-SEC
ATTITUDE DETERMINATION ACCURACY	0.1 DEG	0.1 DEG
ATTITUDE CONTROL ACCURACY	0.3 DEG	0.3 DEG
ATTITUDE STABILITY	0.008 DEG/SEC	0.005 DEG/SEC
COMMUNICATION		
DOWN LINK DATA RATE	150 MBPS/ORBIT	287 MBPS/ORBIT
UP LINK DATA RATE	10 MBPS/ORBIT	12 MBPS/ORBIT
POINT TO POINT DATA RATE	16 KBPS TO	300 MBPS
BIT ERROR RATE	1×10^{-5}.	1×10^{-5}
INFORMATION MANAGEMENT		
STATION OPERATIONS	10^9 BITS/DAY	10^{11} BITS/DAY
PAYLOADS	1×10^{13} BITS/DAY	2×10^{13} BITS/DAY

Table 3-2. Space Station Electrical Power Requirements

SUBSYSTEMS LOAD	INITIAL STATION (WATTS)	GROWTH STATION (WATTS)
• ECLSS	3,700	13,600
• COMM DATA MANAGEMENT	4,000	5,140
• PROPULSION	100	200
• THERMAL CONTROL	1,500	4,020
• ATTITUDE CONTROL	250	600
• LIGHTING	1,800	3,600
• CREW ACCOMMODATIONS	1,600	4,400
• SUBTOTAL	12,950	31,560
• CONTINGENCY 10%	1,550	3,440
TOTAL	14,500	35,000

MISSION SUPPORT	INITIAL STATION (WATTS)	GROWTH STATION (WATTS)
• COMMERCIAL PROCESSING	7,100	13,100
• SCIENCE & APPLICATIONS	350	350
• TECHNOLOGY DEVELOPMENT	1,480	1,480
• NATIONAL SECURITY	40	40
• COMMERCIAL COMMUNICATIONS	30	30
TOTAL	9,000	15,000
TOTAL SPACE STATION	23,500	50,000

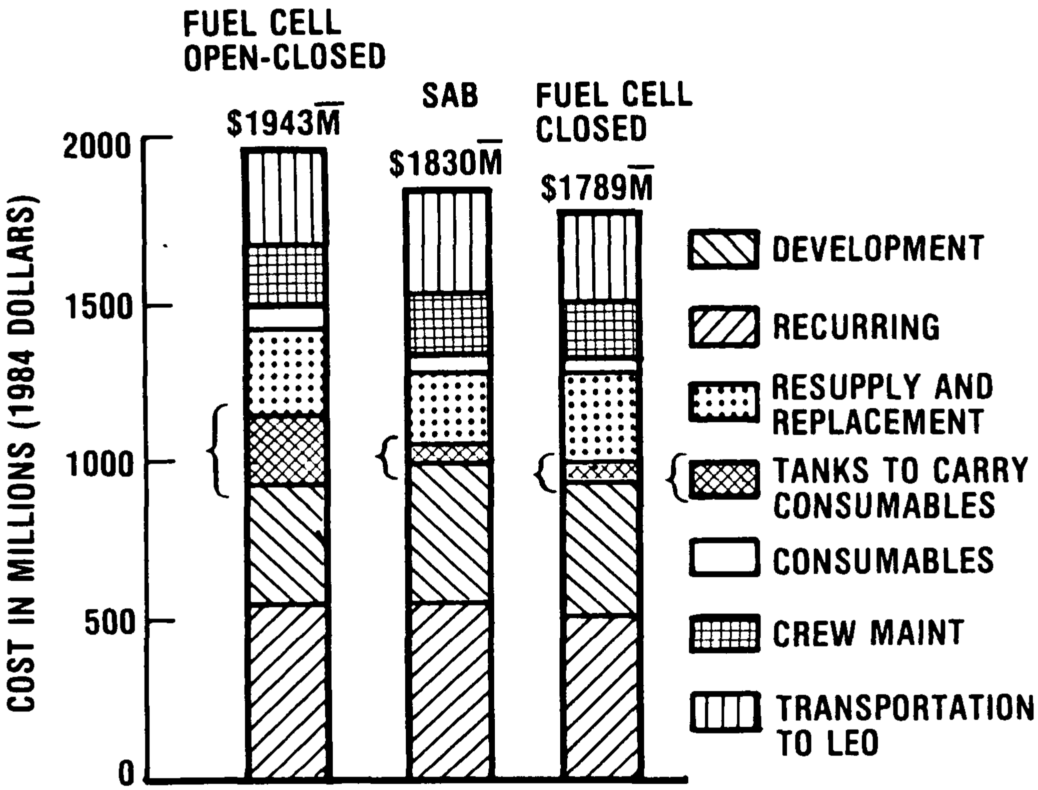


Figure 3-1. Cost Comparison of Open Versus Closed Subsystems

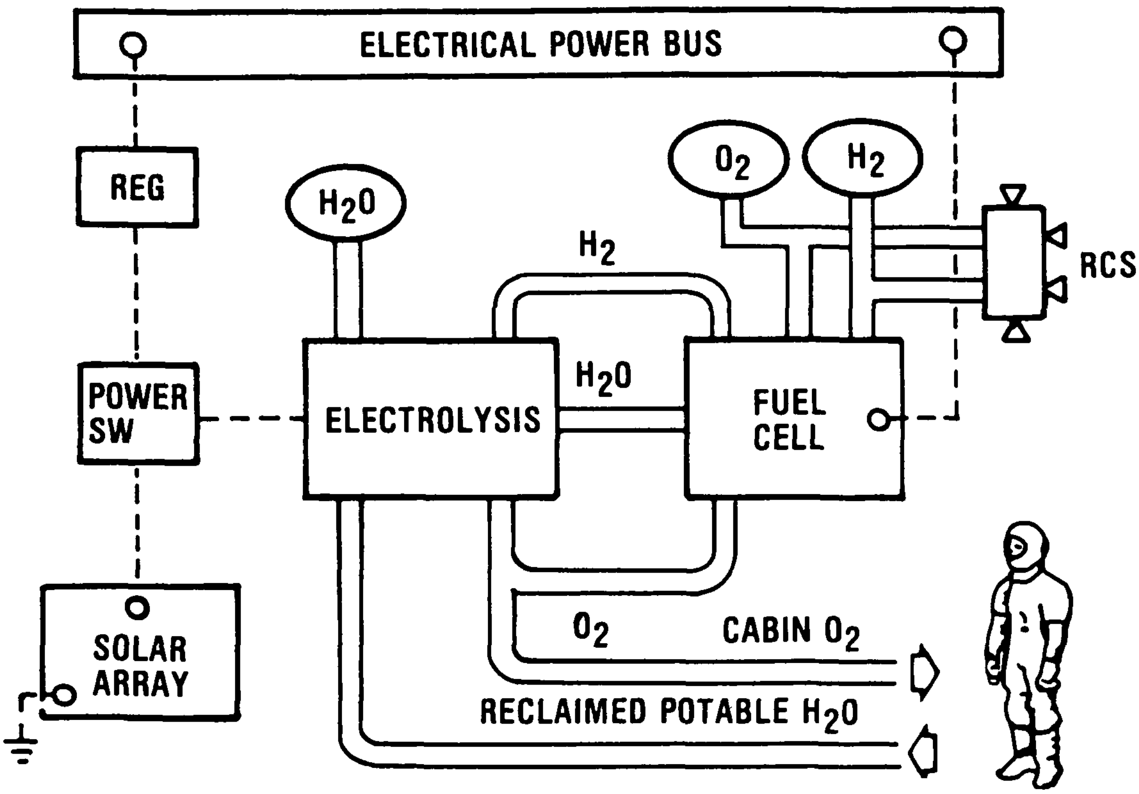


Figure 3-2. Integrated EPS/ECLSS/RCS Schematic

EPS ARCHITECTURE

The Space Station EPS has been divided into four assemblies: power generation, energy storage, power conditioning, and distribution. In the power generation area, Rockwell is completing an investigation of photovoltaic concentrator arrays for NASA/MSFC. Results show that designs incorporating low-concentration-ratio optical subsystems with simple planar reflectors yield the lowest solar array recurring cost (dollar per watt). The concentrator array design concept is based on multiple square panels, which are deployed and supported by lattice masts, and sized for optimum storage in the Shuttle, as illustrated in Figure 3-3. Several of the most common concerns of the concentrating arrays are its stowage, deployment, and pointing accuracy capabilities. These areas are presently under prototype concentrator verification. Preliminary analytical results indicate that the penalties for off-axis pointing and tilt orientation have a minor effect (see Figure 3-4). Optical ray trace analysis results also show that no catastrophic fall-off in optical efficiency is observed in angles of up to 10 or 15 degrees. The configuration of Space Station solar array wing design is shown in Figure 3-5. Table 3-3 shows the comparison of gallium arsenide (GaAs) versus silicon (Si) solar cells and illustrates the higher efficiency of the GaAs-type cells. The multi-100 kW low concentration ratio solar array technology offers the advantage of high design load, low life-cycle cost, and low-radiation degradation, and adapts to GaAs solar cell capability, as compared to the power extension package (PEP) type of planar array.

Regenerative fuel cells for the energy storage concept is the most favorable candidate based on life-cycle cost comparisons.

For power conditioning and distribution, a clearer definition of the nature of the loads and their magnitude (both of Space Station housekeeping and mission payload activities) is required. Preliminary EPS architecture includes two solar array wings, energy storage devices, and four independent electrical channels. Energy is supplied to the load through four separate busses. Cross-straps are available to link the busses if necessary or desirable. An EPS functional design block diagram with regenerative fuel cells for energy storage is shown in Figure 3-6. An ac subsystem is thought to be user friendly and it is of minimum weight, low cost, high reliability, and higher efficiency.

ECLSS ARCHITECTURE

Preliminary studies of Space Station subsystem loop closure show a significant cost advantage to integrate the EPS/ECLSS as a closed subsystem. Figure 3-1 showed the cost savings when comparing an open-loop subsystem to a completely closed regenerative type of subsystem.

The selected architecture for the ECLSS (Figure 3-7) is a closed regenerative air revitalization subsystem used for removing and reducing CO_2, and using the byproduct (water) from the CO_2 reduction process to provide usable oxygen and hydrogen. The oxygen would be used for breathing and cabin leakage, and the hydrogen would be used in the CO_2 reduction process.

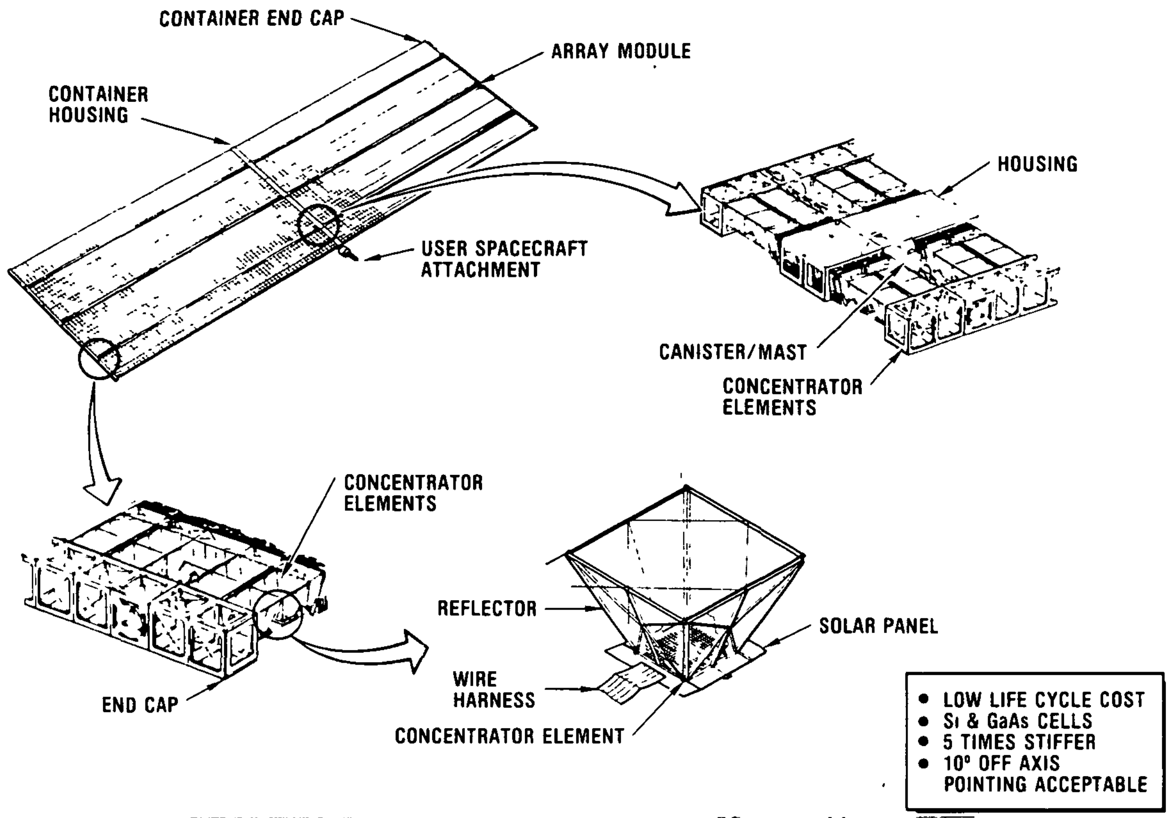


Figure 3-3. Low Concentration Solor Array Design

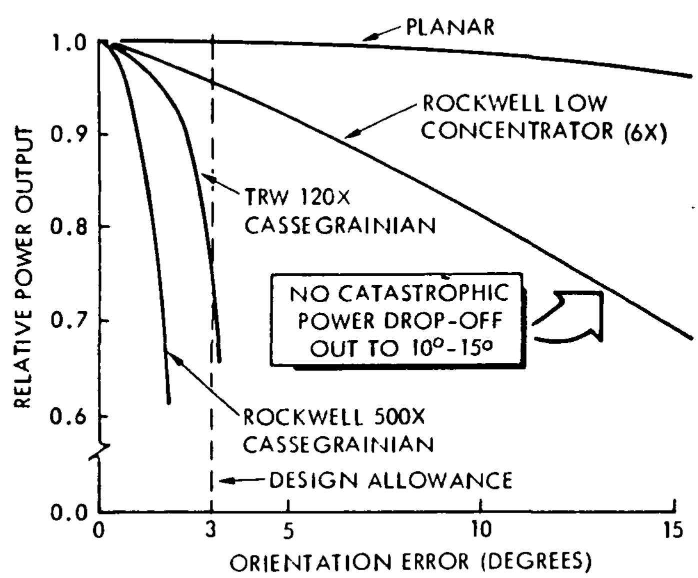


Figure 3-4. Why Low CR?

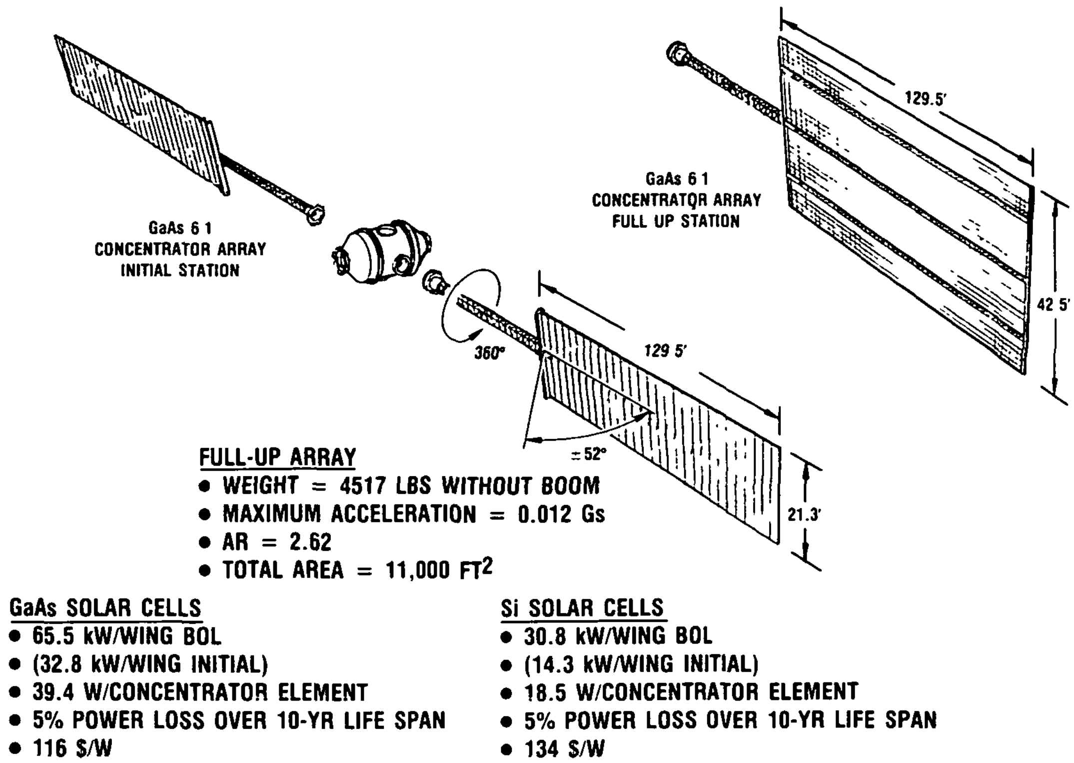
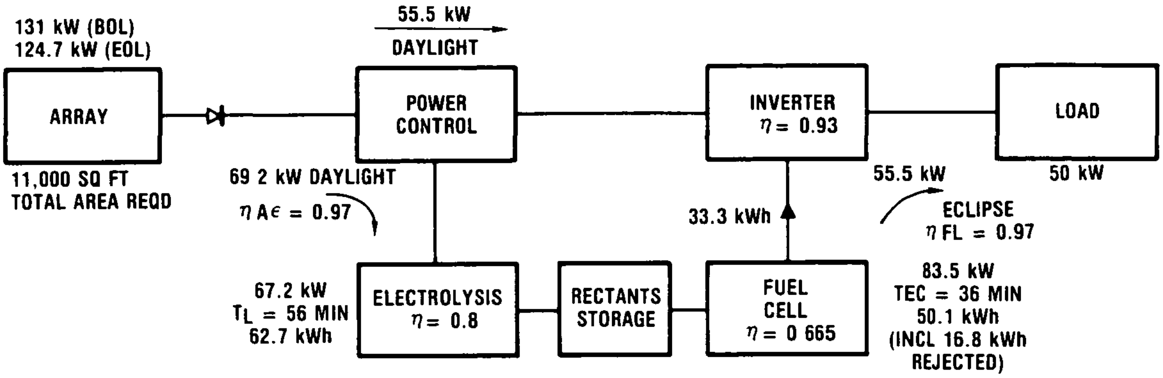


Figure 3-5. Low Concentrator Solor Array Concept

Table 3-3. Comparison of GaAs Versus Silicon Solar Cells

Low Concentrator Solar Array Concept		
	Solar Cells	
Description	GaAs	Silicon
Full-up array		
• Weight: 4517 pounds without boom	• 65.5 kW/wing (BOL) • 32.8 kW/wing initial	• 30.8 kW/wing (BOL) • 14.3 kW/wing initial
• Maximum acceleration: 0.012 g	• 39.4 W/concentrator element	• 18.5 W/concentrator element
• AR = 2.62	• 5% power loss over 10-year life span	• 5% power loss over 10-year life span
• Total area: 11,000 ft^2	• $116/watt	• $134/watt



η AL = TRANSMISSION EFFICIENCY FROM ARRAY TO LOAD

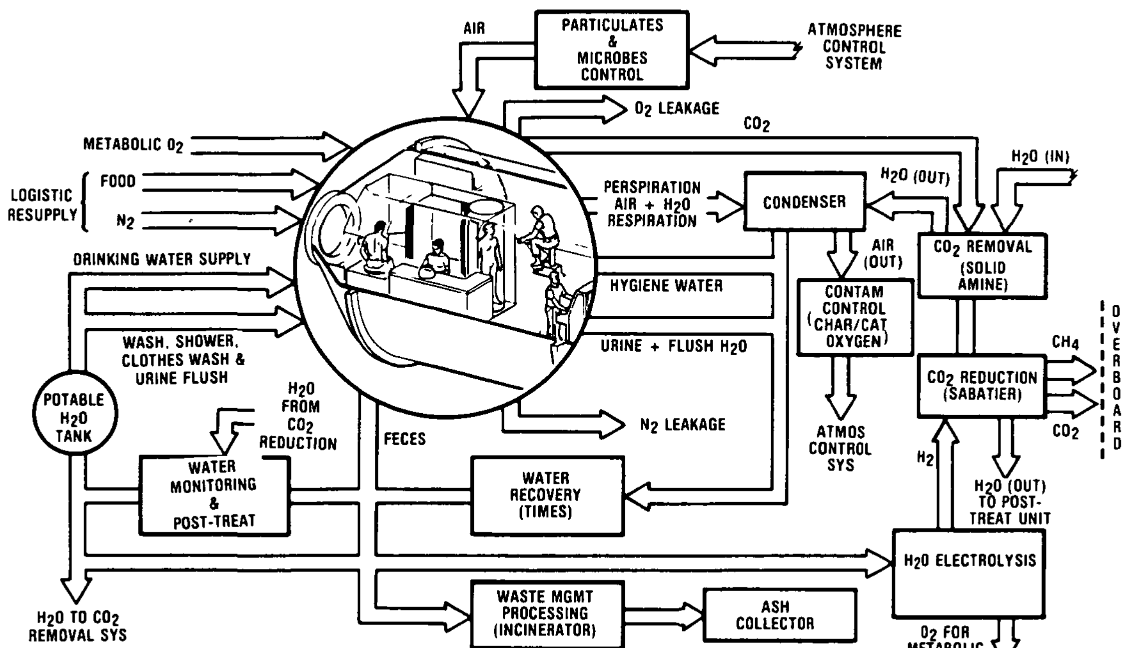
η Aε = TRANSMISSION EFFICIENCY FROM ARRAY TO ELECTROLYSIS

η FL = TRANSMISSION EFFICIENCY FROM FUEL CELLS TO LOAD

- REACTANT CONSUMPTION RATE = 0.77 LB/kWh
- ELECTROLYSIS REQUIREMENT = 2.75 kWh/1 LB O_2

CHARACTERISTICS
- LOW CONCENTRATION SOLAR ARRAY WITH GaAs SOLAR CELLS
- LONG LIFE > 200,000 kWh FUEL CELL
- HIGH EFFICIENCY > 90% AC INVERTER
- HIGH VOLTAGE DISTRIBUTION 416 VAC SYSTEM

Figure 3-6. Space Station Energy Balance (EPS Architecture Summary)



- CLOSED REGENERATIVE AIR & H_2O LOOPS
- WASTE PROCESSING
- REUSABLE CLOTHING
- MINIMUM LOGISTIC RESUPPLY
- CREW MAINTENANCE COST
- LOWER LIFE CYCLE COST

Figure 3-7. ECLSS Architecture

Cabin pressure levels are being traded off with the assistance of United Technology. The goal is to select a pressure level compatible with the orbiter and one that eliminates long prebreathing requirements for EVA operations. At this time, 10.2 psia is favored for the station and compatible with a suit pressure of 5.0 psia. The orbiter has a capability to manually reduce its 14.7 psia normal atmosphere to 10.2 psia in a docking mode operation. There has been considerable development of an 8 psia suit that would allow a 14.7 psia cabin pressure and no prebreathing. This is a technology issue that needs to be pursued for high EVA activities.

The command module and the two habitat modules are to be kept in a habitable condition at all times. All of these modules will be devoted to crew habitation, and this is where the majority of the ECLS equipment will be located. To provide for ease of moving from one module to another, all interfacing hatches will be kept open. The arrangement of the modules are located such that a failure or malfunction causing a module to be uninhabitable can be isolated from the active modules. Each habitable module will have its own ECLS subsystems necessary for survival.

The water subsystem will also be a fully-closed regenerative water recovery and management subsystem, thereby eliminating the need for potable water resupply from the ground. Figure 3-8 shows a mass balance schematic of the ECLSS closed-loop subsystem for a crew of four men. This is considered to be the basic subsystem for each habitat module and the command module for crew needs. Nitrogen, used for cabin atmosphere leakage, will be supplied from the ground. All processing equipment is redundant and distributed among the modules for safety. Cabin ventilation architecture will use forced convection to simulate free convection. This convective force is not present at zero-gravity, making necessary an artificially induced convective ventilation to simulate the free convection, which is lost. This phenomenon has been evaluated and lived with in all previous spacecraft, and a fan-induced average velocity of 25 feet/minute has evolved as the accepted ventilation design value for spacecraft. Health and hygiene equipment such as the clothes washer/dryer and dishwasher will interface with the water management subsystem for water processing.

High pressure oxygen for extra vehicular activity (EVA) operations will be by cryo oxygen storage tanks utilizing Shuttle technology.

RCS ARCHITECTURE

The basic functions of the RCS are to provide ΔV for orbit makeup stabilization and attitude control, and periodic control moment gyro (CMG) desaturation. The RCS was sized to satisfy the orbit makeup requirements because the other control requirements are relatively minor.

A general schematic of the LO_2/LH_2 bipropellant subsystem (selected on the basis of its higher specific impulse compared to hydrazine) is shown in Figure 3-9. The cryogenic oxygen and hydrogen propellants are stored in separate tanks and delivered to the conditioning unit to be converted to gas. From the conditioning units, some of the gaseous propellants are returned to the storage tanks to maintain the tank feed pressure and the remainder are

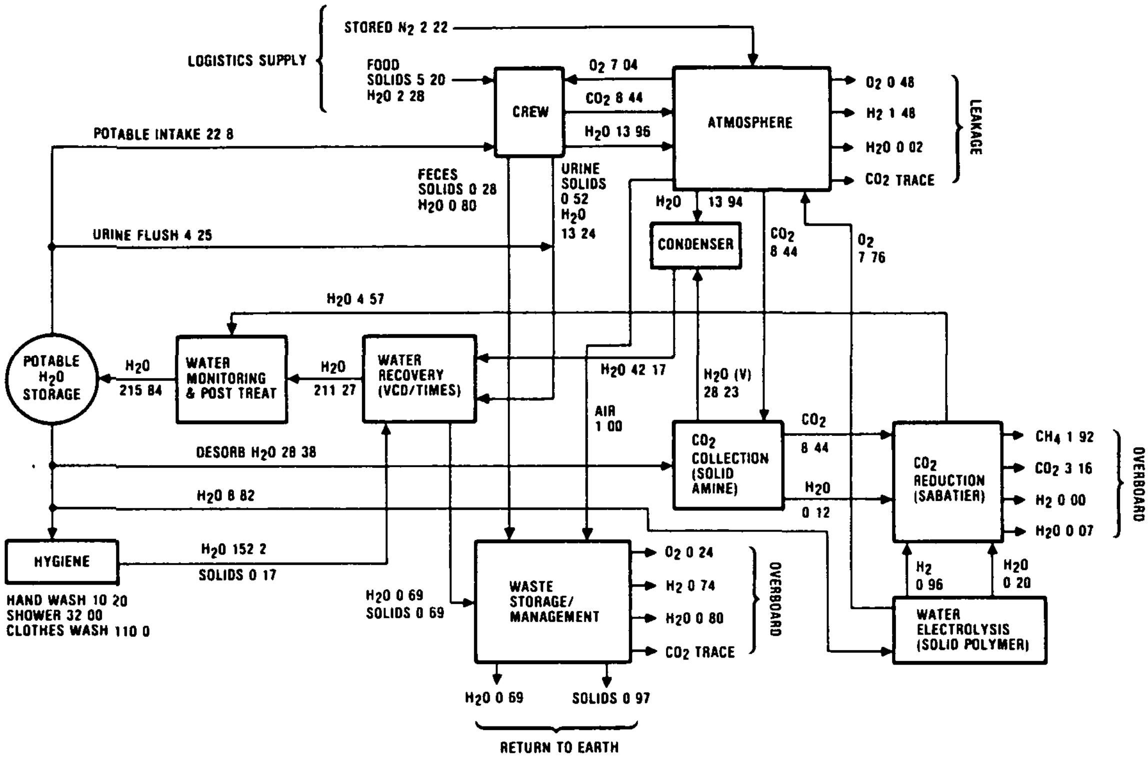


Figure 3-8. ECLSS--Closed Loop

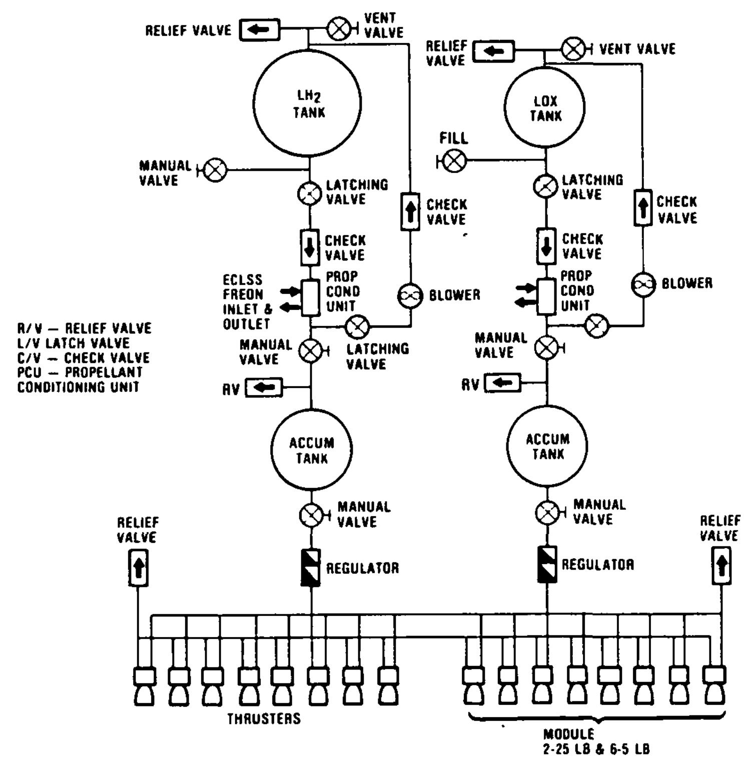


Figure 3-9. LO_2/LH RCS Schematic (Typical)

routed to the accumulator tanks. Propellants are then passed through the regulators and later to the thruster assembly when the thruster valve is actuated on. The majority of the components considered for this subsystem are either existing or modified versions of existing components. The major development items are the 5 lbf and 25 lbf thrusters and the PMD in the cryogen tanks.

The RCS propellants are stored as subcritical cryogenic fluids that are recovered from scavenge tanks in the orbiter cargo bay on the initial station and recharge from the propellant tank modules on the all-up operational station. The cryogens are vaporized using energy from the Freon heat transport loop and distributed to the thruster locations in gaseous form.

On the initial station, eight thruster modules are required: four modules of four 5-pound thrusters each on the energy module, two modules of four 5-pound and two 25-pound thrusters on the command module, and two modules with 5-pound thrusters on the PSA.

Preliminary analysis indicates that the initial station thruster location could satisfy all-up station requirements, as shown in Figure 3-10.

TCS ARCHITECTURE

The thermal control heat loads and associated heat rejection area requirements of the initial station configuration module are shown in Table 3-4. The rejection area requirements have been established on the basis of radiator coating degradation in α of 0.02 per year in space. A review of module heat loads and available rejection area indicates: the rejection capability of the available command module area is sufficiently close to meeting heat load requirements of 12.2 kW, the energy module with a relatively high heat load is limited in heat rejection area and requires significant supplemental area to meet heat load requirements, and the process laboratory module and logistic module rejection requirements are satisfied without utilizing the total area available.

The thermal control subsystem architecture for the initial station configuration is shown on Figure 3-11. The supplemental heat rejection area required by the energy module is obtained by a deployable heat pipe radiator. The potential extension of wraparound radiators to achieve the additional 239 ft^2 for the energy module (Table 3-4) was evaluated and found to be impractical because of docking requirements.

As indicated on Figure 3-11, each module contains an independent thermal control subsystem composed of a wraparound heat pipe radiator, dual water, and dual Freon loops, which interface through an interface heat exchanger. The water loops are utilized in the pressurized volumes, and the Freon loops and interface heat exchangers are installed outside of the pressurized volume to meet safety (toxic fluid) requirements.

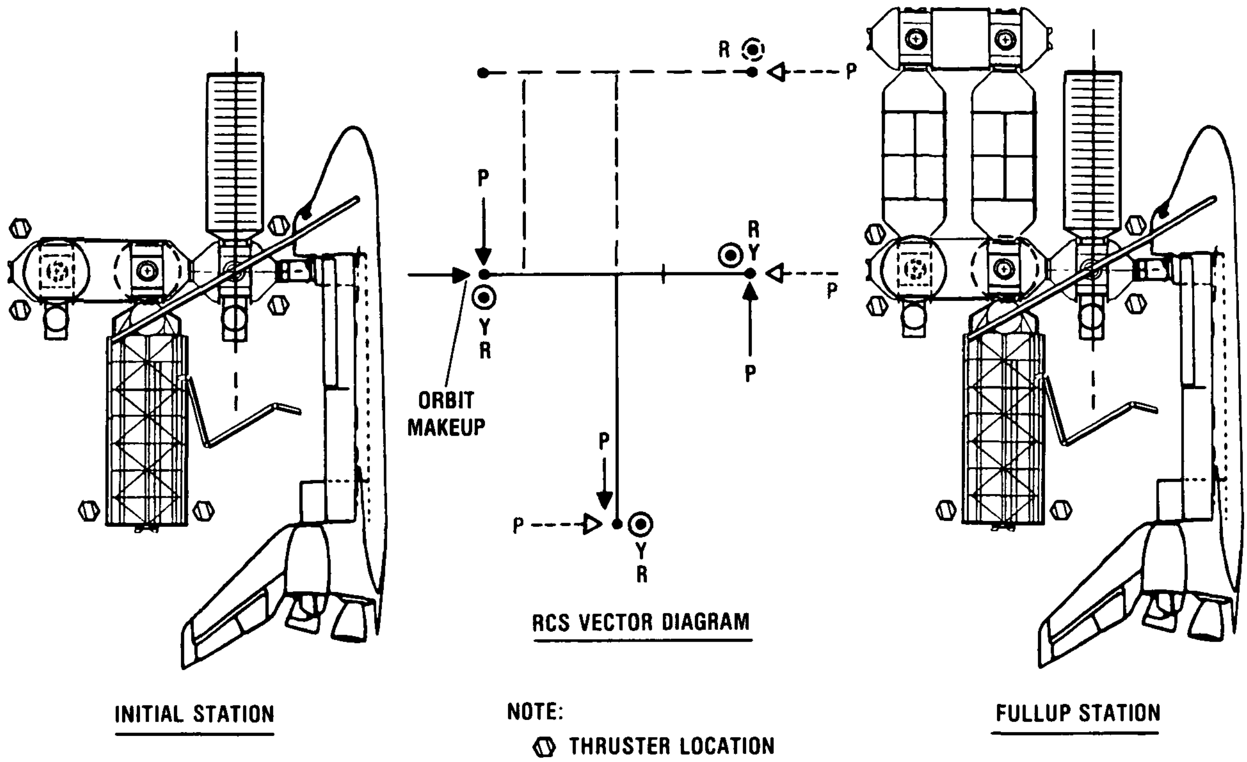


Figure 3-10. Recommended RCS Thruster Locations

Table 3-4. Initial Station Heat Rejection Requirements

SPACE STATION MODULES	ELECT. kW	PWR GENERATION WASTE HT ~ kW		METABOLIC kW	TOTAL HEAT LOAD kW		RADIATOR AREA FT²		
							REQD		AVAIL
		LIGHT	DARK		LIGHT	DARK	LIGHT	DARK	WRAPAROUND
• ENERGY MODULE	3.50	2.25	10.00	0	5.75	13.5	495	567	256
• COMMAND	8.8	2.25	10.00	1 172	12.20	19 97	1049	839	1000
• SPACE PROCESS LAB	7.0	0	0	0	7.0	7.0	602	385	1800
• PAYLOAD SERVICE ASSEMBLYS	2.57	0	0	0	2.57	2.57	221	141	1540
• LOGISTIC	1.33	0	0	0	1.33	1.33	114	73	570
• TOTAL	23.2	4.5	20.0	1.172	28.85	44 37	2481	2005	5166

TIME IN SPACE = 4 YEARS

α = .18, ϵ = .76

η = .80

TEMPERATURES	LS	DS
IN	90F	170F
OUT	36F	36F

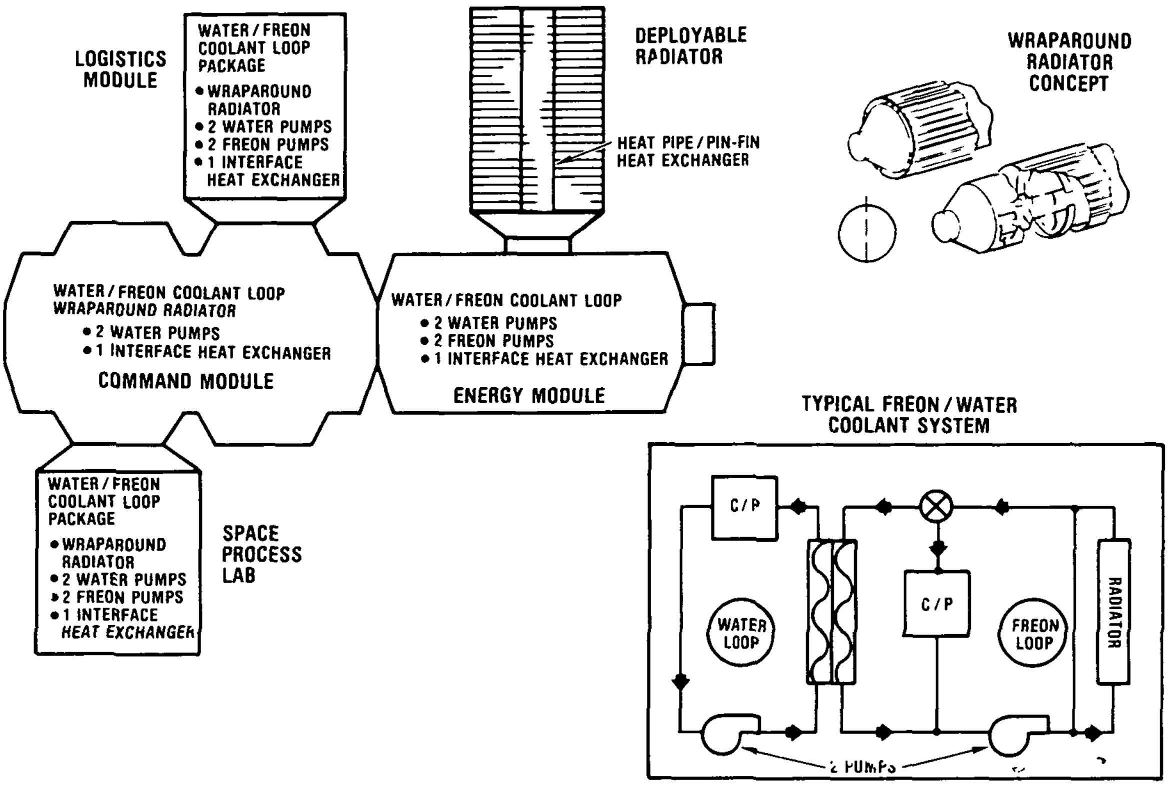


Figure 3-11. Space Station TCS Architecture (Initial Station)

The independent thermal control subsystem architecture has the technical advantages of eliminating the thermal control interface between modules; providing the simplicity of an autonomous unit throughout the design, development, and operation of that specific module; and, from the programmatic aspect of facility support requirements sizing (power, weight, and volume), presenting a maximum case to which improvements can be evaluated. On the other hand, the independent subsystem concept has the disadvantage of higher costs and maintenance activities associated with the larger number of dynamic components that might wear out.

Referring to Table 3-4, compares the heat load totals, a 28.85 kW heat load requires a rejection area of 2,481 ft^2 and has a capability of 60 kW if all of the module's exterior surface area of 5,166 ft^2 were utilized. This indicates that there is the potential for a space station central architecture, which would not require deployable radiators.

Table 3-4 also shows that only the energy module will require an additional 240 ft^2 of wraparound radiator area, or 267 ft^2 of deployable radiator area, however, the additional radiator could be eliminated for the initial station by reducing surface coating degradation, utilizing thermal capacitor, operating the radiator at slightly higher temperature on the sun side, and utilizing the capillary pump loop (CPL) concept. Preliminary analyses show that the CPL will reduce the area requirements by 33 percent.

The initial station evolves into a growth station with the addition of modules and has the heat rejection requirements shown in Table 3-5. Other than additional modules, the significant difference between the initial and growth station is that the growth station will be exposed to a space environment for a 20-year period and will have a significant degradation in radiator coating. In addition, as indicated on Table 3-5, the surface area on the energy module and command modules is greatly reduced in effectiveness. In the case of the energy module, as the evolution of the station takes place, the shadowing effect of added modules with the docked orbiter in place results in the heat rejection area becoming zero.

In generating the data shown on Table 3-4, it was assumed that the basic station modules would last the life of the station without cleaning or replacing radiator coatings. In the case of laboratory and experiment modules, coating degradation was based on the orbit stay time of individual modules.

A review of data presented on Table 3-5 indicates that the heat loads for the energy module and crew module are increased in conjunction with area reduction; therefore, supplemental radiator area for these modules is required. As was the case with the initial station, the extension of wraparound radiators is impractical and a larger deployable radiator is used with approximately 2,500 ft^2 radiating from both sides. Noting the large deployable area required (resulting from coating degradation) and the requirement for a deployable radiator change between the initial and growth station, the use of a plug-in deployable radiator is warranted. For example, if a plug-in radiator is used and is replaced at four year intervals, the area for the growth station can be reduced to approximately 1,000 ft^2 radiating from both sides.

Table 3-5. Growth Station Heat Rejection Requirements

SPACE STATION MODULES	ELECT kW	POWER GENERATION WASTE		METABOLIC kW	TOTAL HEAT LOAD kW		RADIATOR AREA FT^2		
							REQUIRED		AVAILABLE
		LIGHT	DARK		LIGHT	DARK	LIGHT	DARK	WRAPAROUND
• HABITAT ①	7.52	0	0	1.172	8.7	8.7	1696	479	1530
• HABITAT ②	6.22	0	0	1.172	7.4	7.4	1443	407	1530
• COMMAND MODULE	8.8	4.5	20.0	1.172	14.5	29.97	2827	1258	200
• ENERGY MODULE	3.5	4.5	20.0	0	8 0	23.5	1560	987	0
• LIFE SCIENCE MODULE	2.20	0	0	0	2.22	2.22	432	122	1000
• LOGISTICS	1 33	0	0	0	1.33	1.33	259	73	570
• LIFE SCIENCE RESEARCH AREA	2.5	0	0	0	2.5	2.5	487	138	570
• SPACE PROC LAB	9.0	0	0	0	9.0	9.0	1755	495	1800
• PAYLOAD SERVICE ASSEMBLY	2 5	0	0	0	2.5	2.5	487	137	1540
• TOTALS	43.6	9.0	40 0	3.5	56.2	87 1	10950	4096	8740

Table 3-5 presents a breakdown of the heat loads distribution, radiator area required, and available area on a module-to-module basis. For practical purposes, all modules provide adequate surface area to satisfy individual heat rejection loads requirements except the command and energy modules. These two modules will lose most of their effective surface area when the Space Station is fully operational. The total heat rejection requirement for the all-up station is about 56.0 kW and the corresponding radiator area required is about 11,000 ft^2. The required area exceeds the total available area of all modules combined by 2,210 ft^2; therefore, the deployed radiator is provided in the selected architecture.

The architecture of the thermal control subsystem is identical to the initial station with independent subsystems in each module, except the command and energy modules. For the growth station, each module has a dual water loop internal to the module and dual Freon loops, which transport the combined heat load of both modules to the deployable radiator.

The radiator panels for either wraparound or deployable radiators consist of heat pipe and a pin-fin heat exchanger where Freon is circulated. Early studies comparing heat pipe radiator panels with pumped liquid through parallel tubes demonstrated that heat pipe radiators are superior.

The present sizing of heat pipe radiator is based on an overall radiator efficiency of 0.80; however, the final sizing of radiator panels will be evaluated with aid of in-house heat pipe radiator optimization computer program.

Articulating radiators provide a tremendous advantage over the deployed radiator in terms of size. Preliminary data analysis shows that an articulating radiator subsystem will reduce radiator size by about a factor of 4.0.

GN&C SUBSYSTEM ARCHITECTURE

The principal GN&C subsystem requirement drivers arise from:

1. The large magnitude of the external disturbance torque environment (aerodynamics and gravity-gradient)
2. Subsystem architecture for evolutionary growth
3. Dynamic operations: the movement of large masses relative to the main body
4. Dynamic complexity: multibody control, structural flexibility, large sloshing masses, and manipulator controlled operation
5. Docking of unmanned spacecraft

The subsystem functional requirements are summarized in Table 3-6.

A functional block diagram of the GN&C subsystem is presented in Figure 3-12. The subsystem sensor devices are shown on the left and the control actuators are on the right. The heart of the subsystem is the control logic software (center of the figure), which is contained in the various distributed computer processors in the subsystem. The distributed processing architecture offers promise of reducing the high costs normally associated with software

Table 3-6. GN&C Functional Requirements

Function	Requirement
Attitude control	• Accommodate time varying configuration with and without orbiter attached
	• Accommodate dynamic operations, assembly/construction, moving modules, etc.
	• Stabilization of multiple controlled bodies, structural flexibility, and fluid slosh modes
	• Momentum management to minimize control sizing
	• Attitude reference determination
	• LVLH and inertial attitude hold
Navigation	• Space Station relative to earth
	• Relative motion navigation for co-orbital spacecraft, rendezvous vehicles, and other hazardous debris
Guidance	• Orbit makeup ΔV, and deorbit for Space Station
	• Rendezvous, docking, and stationkeeping commands for other vehicles in station proximity
System operation	• Autonomous and automatic control of all normal operations
	• Capable of unmanned operation
	• Capable of normal attitude hold operation without RCS firings for periods >90 days
	• Automatic fault detection, annunciation, and correction for flight critical functions
	• Accommodate evolutionary growth

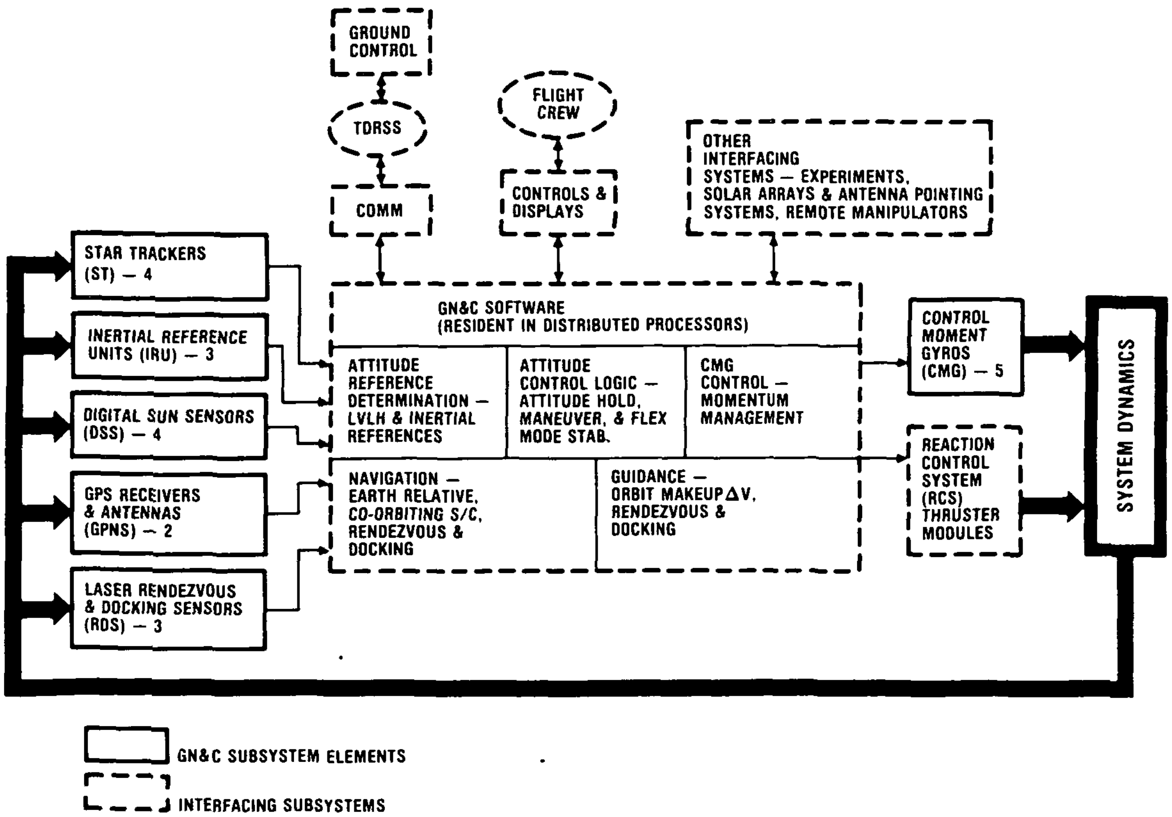


Figure 3-12. GN&C Subsystem Functional Diagram

development and software/hardware subsystem verification. Other potential advantages are: software development and testing at the lowest functional level, separation of dissimilar computations and alleviation of the constraints that they impose on each other, reduced data traffic (under normal operating conditions), and fewer complex interfaces, both in the subsystem and the people developing them.

In addition, improved control performance, safety, and crew time savings are possible as a result of larger available processing capacity, and the opportunity to utilize more automation, more sophisticated control algorithms, and failure detection algorithms.

CMG's provide the primary control torques for the attitude hold modes. These include local vertical-local horizontal (LVLH) orientation, as well as inertial orientation. The RCS thrusters provide the control torques to accommodate the infrequent high torque/high angular momentum control functions such as attitude maneuvering, docking transients, and high-torque nonstandard attitudes.

To minimize the CMG size requirements, torque equilibrium attitudes (TEAS) are employed. This is accomplished by approximately balancing the aerodynamic torque with gravity-gradient torque. A torque equilibrium adaptive momentum management subsystem (TEAMS) concept, which adaptively searches for the torque equilibrium attitude, is employed for this purpose. It accomplishes this by trimming the Space Station attitude (gravity-gradient torques) to control the momentum build-up in the CMG's. Five double-gimbaled CMG's with spin momentum of 4,500 ft/lb per second each are employed.

The attitude is determined with a stellar-aided inertial subsystem employing star trackers (ST), an inertial reference unit (IRU), and digital sun sensors.

The navigation function is accomplished by Navstar global positioning system (GPS) receivers and provides an accuracy better than 50 meters. The relative motion navigation for co-orbiting spacecraft and long-range rendezvous also utilizes the GPS receivers but contains an additional Space Station-to-spacecraft link. This feature improves the relative motion navigation accuracy down to better than 3 meters. TDRSS navigation is used as a backup.

The navigation sensing for short-range rendezvous, proximity operations, and docking is provided by a scanning laser radar. The subsystem provides for automatic docking of unmanned vehicles while retaining the safety of a Space Station crew-initiated abort. The automatic subsystem can enhance the manual control of Shuttle orbiter docking and berthing.

A variable altitude guidance strategy (VAGS) for controlling the orbit altitude and performing the drag-making ΔV maneuvers is employed. The strategy is based on flying on-orbital altitude, which satisfies one of the following two criteria:

1. Maximizes the useful payload delivered by the orbiter to the Space Station

2. Provides a safe orbit decoy time (typically $\lesssim$ 90 days) in presence of +3 sigma high atmospheric densities

The new Shuttle direct insertion technique offers promise of achieving higher orbital altitudes without the use of OMS kits; however, this technique does not significantly alter the altitude that maximizes the useful delivered payload.

The sizing of the momentum storage requirements for the CMG's is important since it can impact not only the CMG mass itself but also influence the mass of the momentum dumping elements and RCS propellant requirements. Figure 3-13 shows the momentum storage requirements and the related CMG mass necessary to accomplish a variety of attitude control functions. Based on these data, the CMG's have been sized to accommodate the functions that are highly repetitive and would otherwise require large RCS propellant quantities. This includes LVLH attitude hold (near the torque equilibrium attitude), inertial attitude hold, and dynamic payload operations. The other items that involve large momentum storage but are only required infrequently are accomplished with RCS control. These include attitude maneuvering, docking disturbance transient damping, and attitude hold in nonstandard attitudes. The subsystem is automated for normal operations and requires only minimal crew participation for special operations. It is capable of autonomous and unmanned operation.

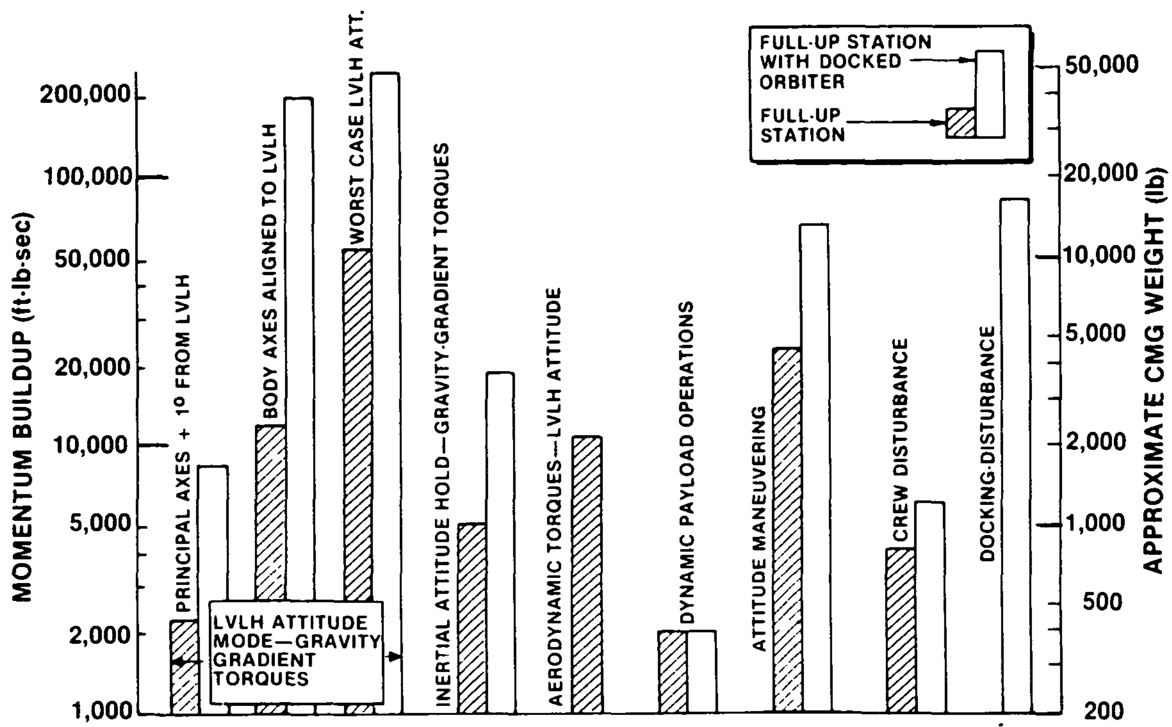


Figure 3-13. Momentum Build-Up From Various Sources

The number of components is also indicated in Figure 3-12. Ultimately, the redundancy levels should be based on an understanding of actual component reliabilities, the potential failure modes, and total subsystem reliability apportionments. As a preliminary basis for allocating redundancy requirements the following criteria was employed:

1. Flight critical failures: Fail-operational/fail-reduced-capacity/ fail safe (FO/FRC/FS)

2. Failures effecting mission success: FO/FS

3. Noncritical failures: FS

IMS ARCHITECTURE

The IMS architecture was based on requirements for a fault-tolerant, self-healing, technology-transparent, user-friendly, and autonomous subsystem control and data management subsystem.

The data rate requirements known at this time are summarized in Table 3-7. It is anticipated that these requirements are soft and will grow as the station concept matures. It is necessary for the IMS architecture to provide the flexibility to accommodate these changing requirements.

Table 3-7. Data Rate Requirements

DATA SOURCE	RAW DATA RATE (MBPS)	DATA RATE* (MBPS)	BITS/ORBIT (MB)	REMARKS
TECHNOLOGY DEMONSTRATIONS	10 69	0 20	1,171	26 PAYLOADS ALL ON-WORST CASE
SCIENCE & APPLICATIONS SENSORS	124.20	44.50	245,777	EARTH & COSMOS LOOKING
PERSONNEL COMMUNICATIONS	100.4	5.1	33,672	INCLUDES 1 FULL VIDEO, 2 SLOW SCAN VIDEO, 10 VOICE & 2 FACS
SUBSYSTEMS H&S	0.04	0 04	220	ALL SPACE STATION SUBSYSTEMS
MATERIALS PROCESSING	1 00	0.06	780	
MILITARY COMMUNICATIONS	1 00	1.00	5520	32 KBPS — 1 MBPS
TOTAL	237.40	51 90	286,693	

*EQUIVALENT CONTINUOUS DATA RATE
WITH DATA REDUCTION

UPLINK ~12 0 MBS
(BURST MODE)

While the IMS architecture design is of paramount importance, suitable devices must be available to mechanize the functions, i.e., the device must be sufficiently fast to provide the bandpass, small to permit packaging in low volume, and low-power consuming to ease the power generation and thermal loads of the Space Station. VHSIC technology appears to satisfy these requirements.

In order to quantify the power, weight, and volume of VHSIC, a comparison of the data processing equipment for the Shuttle (1972), Galileo (1982), and the Space Station (1992) was made. For example: power requirements in terms of processor operations/watt change from 570 in 1972 to 250,000 in 1992. The reduced power requirements translate into less fuel cells and solar panels, loads less heat dissipation (radiators), and the smaller size allows many functions to be packaged in the same volume. This reduction in power and weight can provide for greater user capability or reduced parasitic facility requirements, i.e., smaller panels; therefore, less drag that in turn reduces reboost requirements.

A modular subsystems approach was used to arrive at an IMS architecture. Two major IMS architectural features are:

1. Data network: the IMS data network provides a data communications media, an interconnect topology, an access scheme, and a communications protocol. A specific design requirement is that network operations and functional performance will be totally transparent to the system users whose operations are intersystem dependent.

The two attributes of the IMS network are:

- A dual data bus
- A standard BIU

The IMS data network is reconfigurable and adaptable to support Space Station build-up, operational growth, and technology infusion.

2. Fault-tolerant/self-healing control: the attributes of the data processing function are:

   - Fault detection and compensation
   - Hierarchical processor structure
   - High-order language (HOL)

BUS STRUCTURE

The bus structure was predicated upon the need for a high data rate user requirement and a lower data rate facility requirement. The initial approach is to include a dual bus, wire and fiber optic. The rationale for this approach is to address the weaknesses and strengths associated with each type as well as the combinations (synchronization, layout, and interfacing) of a dual bus structure. The wire bus provides reliability and sufficient capability during the initial build-up phase; the fiber optic bus provides the projected high data rate capability required for future user functions. The installation of two buses minimizes the impact of user requirements of the 1990's from the facility requirements of the 1980's. Figure 3-14, dual bus structure, presents a possible approach to solving the system problem generated by integrating facility and user functions. Separate functional busses minimize integration complexity and scheduling and allow the flexibility to incorporate soft future user requirements into an operational facility.

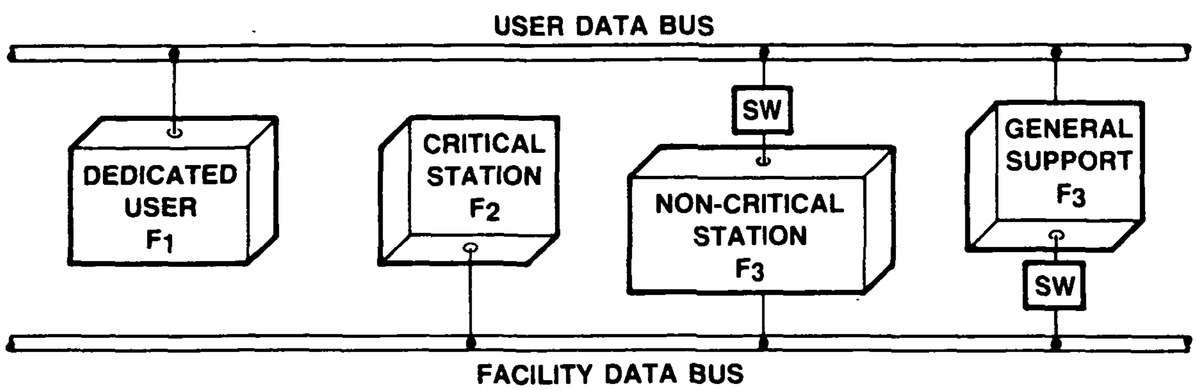


Figure 3-14. Dial Bus Structure

BIU

The BIU provides a standard interface between the subsystem or subassemblies and the IMS. Any device with a BIU can communicate over the data network with any other device containing a BIU. It interfaces the module level bus to the subassemblies, as depicted in Figure 3-15. The BIU is considered to be the building block of the IMS; it collects and distributes sensor and effector data. The subtlety of this approach cannot be overlooked; it forces subassembly design to be compatible with this standard interface. This approach permits the design, build-up, checkout, and verification of each subassembly to be the responsibility of the appropriate vendor while the interfacing requirements specification is the responsibility of the integrating contractor or agency. This methodology provides a clear distinction between local functions and regional functions. The former is accomplished by embedded microprocessors and is considered indistinguishable from the subassemblies. The latter, regional functions pertain to intersubassembly functions, module, and intermodule functions, and station functions. The data and control resources of this architecture are primarily based on the computational power of a regional processor as opposed to logical power (local control).

FAULT DETECTION AND COMPENSATION

Fault tolerance by reallocation of control functions, commonly termed dynamic dealing, allows separation of processors from the assigned functions and reassignment to other functions. In essence, to be flexible throughout

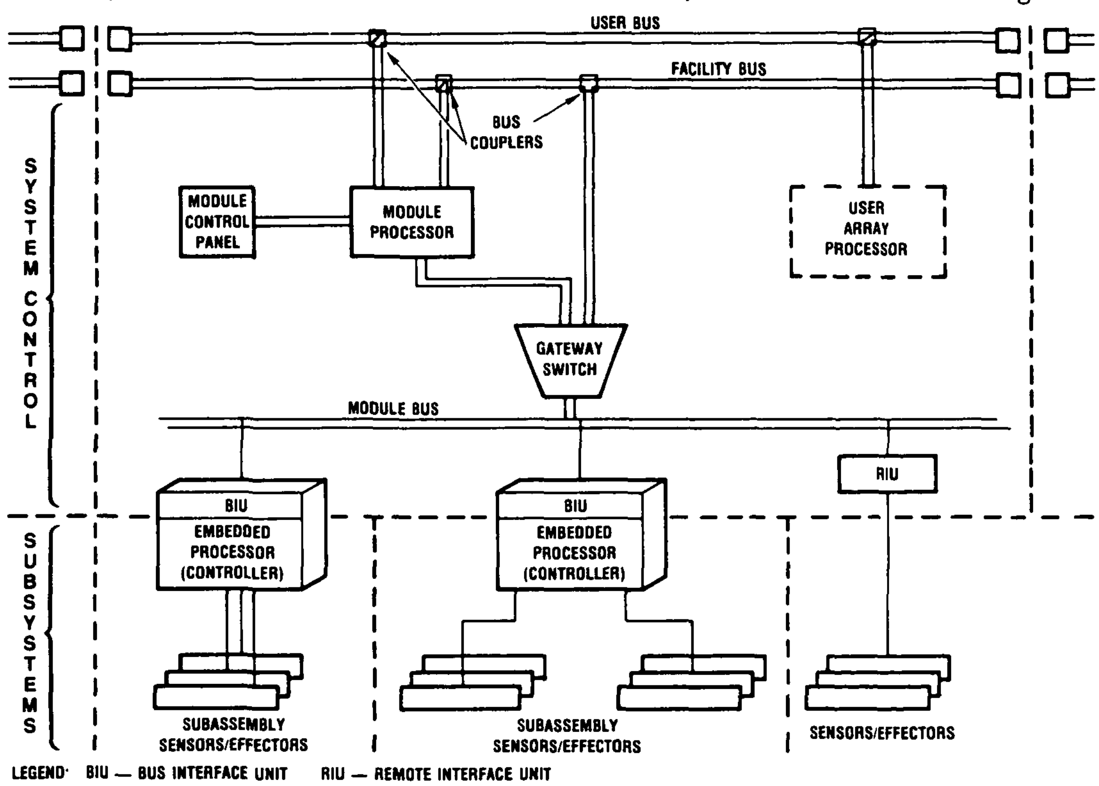
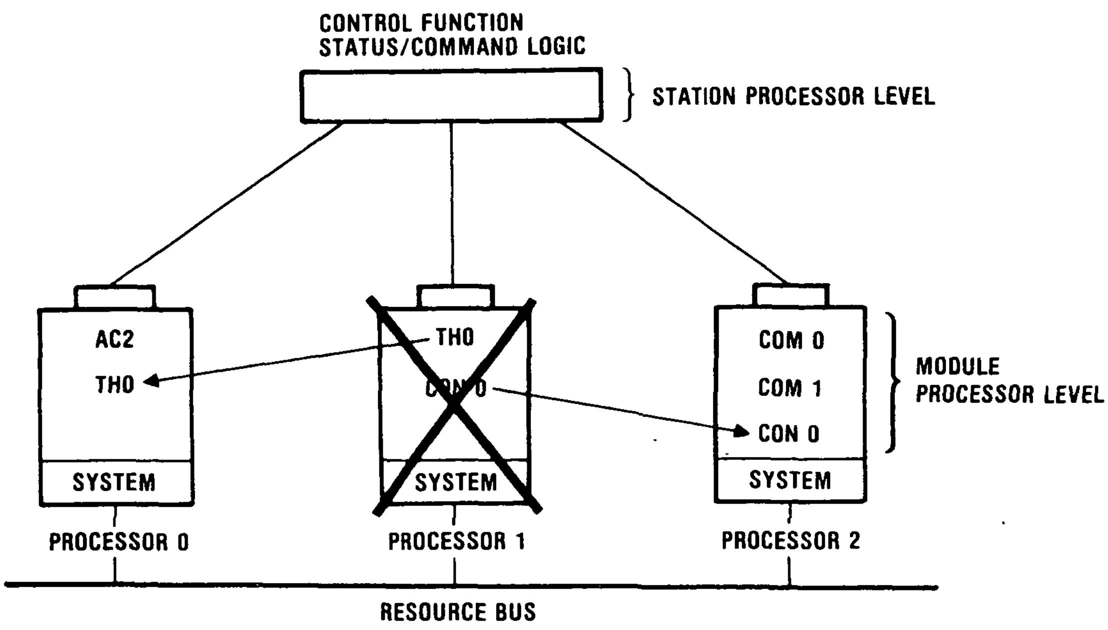


Figure 3-15. Hierarchal Structure

the build-up phase and to satisfy deactivation and reconfiguration requirements, a means has to be provided to allow a module processor to perform diverse functions. Figure 3-16 shows how functions from one processor can be reallocated to another processor. This allows for reconfiguration because of failures or maintenance while providing continuous monitoring and control capability at the local, regional, and station levels.

HIERARCHICAL STRUCTURE

The processor-hierarchical structure evolves from the requirement for station control while providing the capability of module autonomy. These requirements translate into a station-distributed processing structure and a centralized module processing subsystem. Figure 3-17 is indicative of the station distributed/mode centralized concept and the design goal of minimizing architectural hierarchical levels. The objectives are to force subsystems toward modularity and local control, isolate failures to subassemblies (minimize propagation of faults), provide a clear distinction between subassembly and integration activities, and incorporate in the design provisions for future technology advancements. This design approach incurs cost savings throughout the Space Station life cycle, from development through integration,



AC2 = ATTITUDE CONTROL FUNCTION 2
THO = THERMAL CONTROL FUNCTION 0
CON 0 = CONSOLE CONTROL FUNCTION 0
COM 0 = COMMUNICATIONS CONTROL FUNCTION 0
COM 1 = COMMUNICATIONS CONTROL FUNCTION 1

Figure 3-16. Reconfiguration Caused by Maintenance or Failure of Module Processor

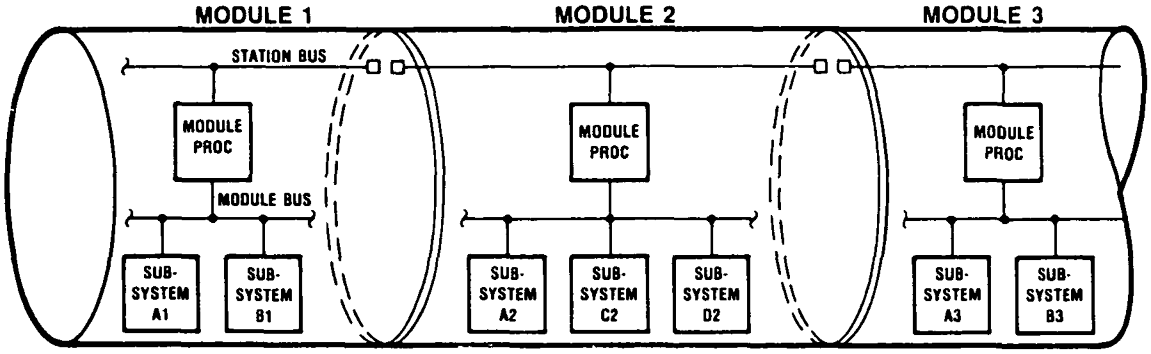


Figure 3-17. Distributed Processor Architecture

verification, operation, and maintenance. The development phase allows a parallel, piecewise building block approach; the integration phase can proceed along functional paths as opposed to specific hardware and software component checkout; the flight software and hardware can be verified at the module level; the operational phase provides for flexible modes as well as graceful degradation options; and the maintenance phase provides manual or automatic reconfiguration.

HIGH ORDER LANGUAGE (HOL)

The integrating contractor or agency will use a HOL that is adaptive to support the Space Station build-up, operational growth, maintenance, and contingency control. HOL attributes are:

1. User friendly subsystem
2. Consistent commands and options
3. Simple functions and commands

Use of the HOL and its support tools will result in reduced costs, shorter production time, and increased reliability and maintainability by providing a structured approach that supports modern software engineering practices.

The language is designed for embedded computer applications. HOL provides a means for converting statements into code. Thus, the subsystem (subassembly) suppliers are able to use embedded microprocessor and software, including previously developed off-the-shelf subsystems, to provide cost savings over installing a new microprocessor and developing the required subsystem software.

SOFTWARE SIZING

Facility requirements are driven by the station data and logical functions to be performed, e.g., input/output servicing (the number, type, and frequency of signals monitored and commanded), fault detection (error detection, isolation, reporting, and recovery), memory management, and network control. The range of user capabilities includes mode control, signal acquisition and data storage, data compression and reformatting, and active payload support. The latter requires the DMS to provide the resources necessary for filtering, thresholding, correlation, tracking, pointing, ranging, sequencing, staging, activation/deactivating, and repairing of known and currently unknown payloads.

In order to scope the software requirements the on-orbit phase of the Shuttle (375KOPS maximum) and a portion of the necessary ground support can be used as a reference point for the facility requirements. For the user requirements there appears to be two drivers: one assuming large storage and data manipulation, and the second assuming high speed throughput associated with imaging-type tasks.

C&T SUBSYSTEM ARCHITECTURE

The C&T subsystem architecture is driven from the overall mission and operational objectives, performance requirements of the Space Station and the C&T subsystem, and the unique characteristics (i.e., phased growth, blockage and coverage) of the Space Station and other interfacing subsystems (i.e., TDRSS, STS, etc.). The C&T subsystem receives health and status data from the TMS, EMU, various Space Station modules and subsystems, payloads, Space Station experiments, free flyers and platforms, and close proximity vehicles and the OTV/STS vehicles. Also, communications with the EMU, Space Station modules, and space vehicles (e.g., STS) must be provided. Docking navigation data from the OTV, STS, free flyers, EMU, and other close proximity vehicles may be part of the communications link or on a separate link. GPS data will be received by the Space Station for position and tracking. Sensor (i.e., mission) data must be received from the free flyers and close proximity vehicles, as well as on-board payloads, experiments, and laboratories. The received data are sent either to on-board processors or to the ground.

The C&T subsystem sends commands to the TMS, payloads and subsystems, free flyers and close proximity vehicles, and possibly the OTV. All communications with the Space Station are duplex; that is, the Space Station has voice video with the EMU, STS, and between the modules of the Space Station.

There are many data sources that must be handled by the C&T subsystem. Also, hardware characteristics and limitations during construction of the Space Station must be considered. A final consideration for the architecture analysis is the mutual impact of the C&T subsystem and other Space Station subsystems.

There are three primary functions of the C&T subsystem: communications and data transfer between the Space Station and the ground, internal communications between Space Station elements, and detection and tracking of vehicles interfacing with the Space Station.

As seen in Figure 3-18, the Space Station C&T RF subsystem architecture includes a number of different communications and tracking interfaces with various space objects. For the initial, full-up station, the primary method

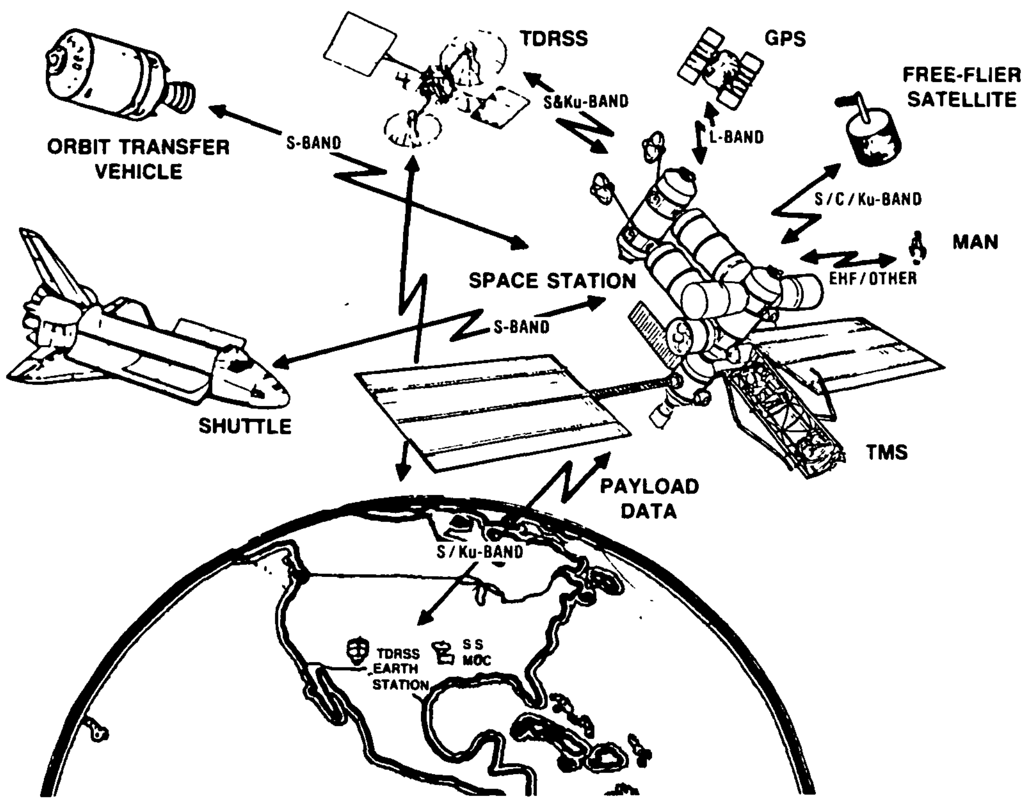


Figure 3-18. Space Station Potential Communications Links and Tracking Objects

of data communication will be via the TDRSS. This system is designed to handle high data rate intersatellite communications to low-altitude orbiting satellites on a time-sharing basis with nearly 100 percent orbital coverage.

The RF and other subsystem characteristics of the TDRSS will dictate many of the C&T subsytem requirements. During C&T subsystem architecture analysis, alternatives to using TDRSS were evaluated and the conclusions were that, at this time, there is not a clear economic or performance characteristic to warrant the use of another dedicated or laser relay subsystem. The primary area of concern regarding the use of the TDRSS is the time-sharing feature of the high data rate relay links. Other concerns are whether continuous, full-time data relay to the ground of high data rate (> 50 Kbps) information is required, and the requirement to process and store data for a period of time in order to burst these data via the Ku-band single access (KSA) link, with its limited 300 Mbps data rate capabilities, which may cause increased risk or degradation for some users.

It is anticipated that the evolution from TDRSS to TDAS usage by Space Station will alleviate many of the limitations of the space-to-ground links early in the Space Station operation.

Use of the TDRSS KSA link for both forward and return links of full-up Space Station operation is baselined. In order to minimize the length of time required to transfer data to the ground, the maximum KSA data rate of 300 Mbps is used. A lower data rate increases burst time duration and usage cost without significantly decreasing other costs. It has been estimated that the relay will last about 20 minutes each orbit. The forward link has also been analyzed, and a 25 Mbps data rate requirement has been estimated to monitor, command, control, and communication to the payloads, subsystems, and personnel on-board.

Real-time communications of subsystem health and status, some critical mission data, and limited personnel communications will be transmitted via a full-time, dedicated TDRSS multiple access (MA) link; likewise, critical real-time command and control will also be available via the S-band MA link.

As a back-up subsystem, a lesser capability direct space-to-ground station link will also be available in the event either the Space Station or TDRSS relay equipment fails.

The RF links to the various other spaceborne elements of the Space Station, such as free-flying platforms and satellite payloads, the STS, OTV, EVA, and GPS, will require multiple-access systems at L, S, C, Ku, and possibly higher frequency bands. Since some of these interfacing systems have similar or identical characteristics (i.e., STS and OTV), there will be reduced hardware requirements for the C&T subsystem.

The C&T subsystem, as shown in Figures 3-19 and 3-20, interfaces with the IMS processors and data bus to receive, transmit, and display data on the Space Station. The health and status of all subsystems and payload, as well as the crew communications (voice and video) are transmitted via a data bus and IMS processor to either a storage device or directly to the C&T transmitter for real-time transmission. Some of the H&S data will be displayed on a control panel.

The attached payloads and sensors (those that can be hardwired to the high-rate IMS data bus) will also be processed and either stored or sent directly to the ground. Since there will be too much data generated to transmit down for any reasonable burst period via TDRSS KSA (at 300 Mbps), there will have to be reduction and compression processing by the IMS or payload.

All nonattached data sources (such as free-flyers), as well as EVA data/communications and operational interface data (STS and OTV) will communicate via a compatible antenna and RF subsystem.

The tracking, ranging, and docking information for the many objects expected to be in the Space Station environment will require two different subsystems. One subsystem will utilize the GPNDS satellite system for active space objects. The navigation data from each vehicle/object will be transmitted to the Space Station via the communications link and relative ranging/

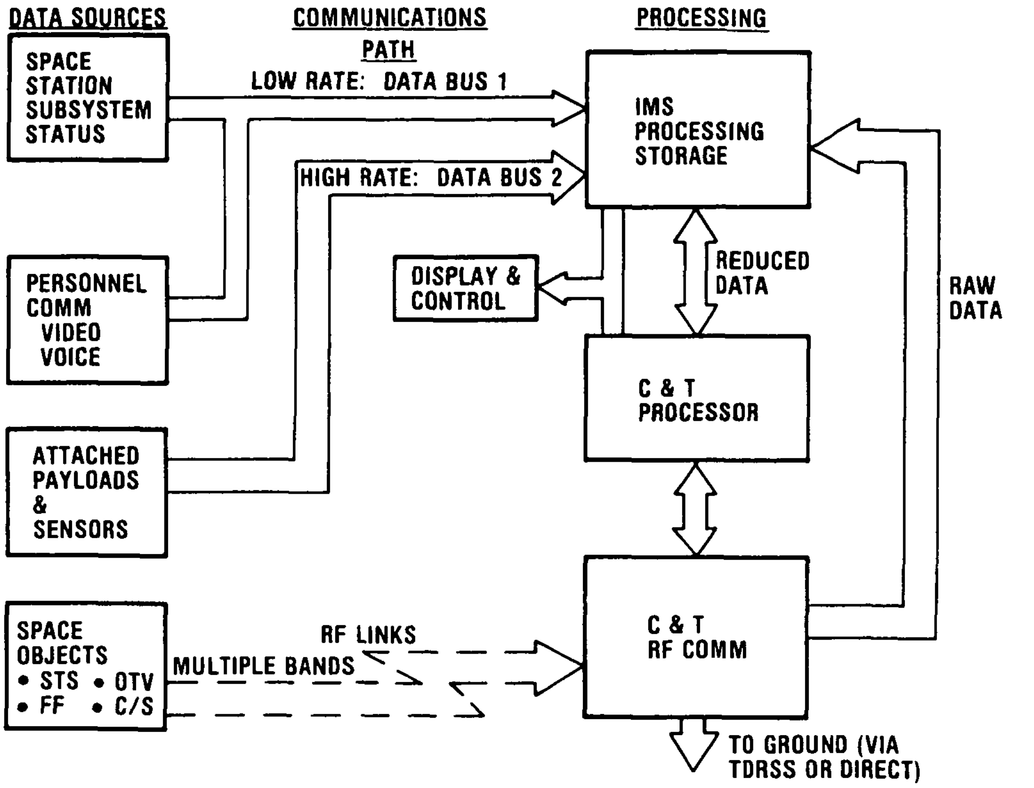
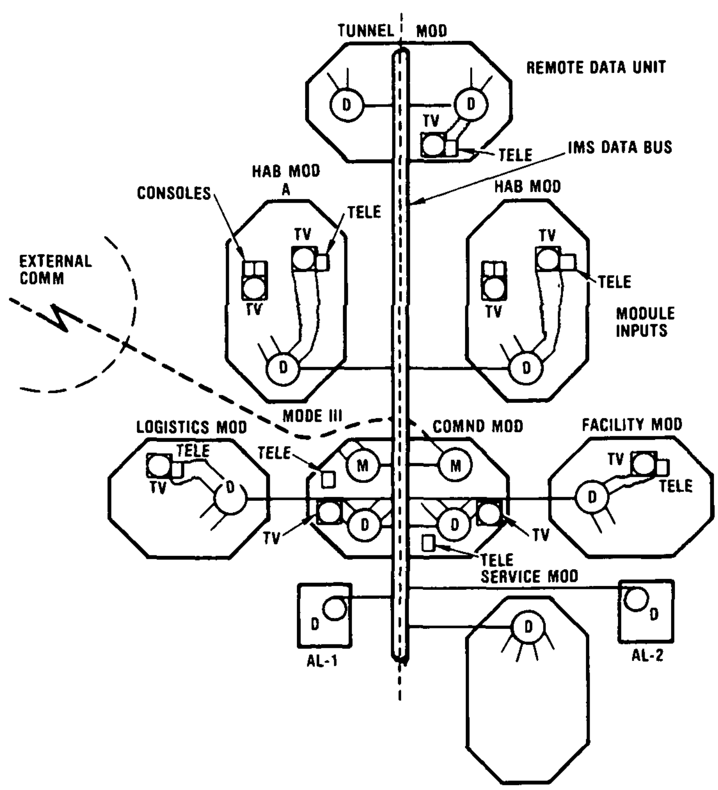


Figure 3-19. Space Station Communications Subsystem Interfaces



- EACH MODULE HAS TV MONITOR AND ORDERWIRE SET
- ENTERTAINMENT VIDEO & SOUND IN SELECTED MODULES
- 1 TELECONFERENCE FACILITY
- ALL COMMUNICATIONS VIA DATA BUS

Figure 3-20. Space Station Internal Communications Subsystem Data Bus Concept position data determined from an advanced processor on the station; likewise, ranging data obtained from TDRSS contact with some of the vehicles may be used for Space Station tracking purposes.

For passive or unknown space objects, a UHF radar subsystem has been baselined for use in the ranging/tracking subsystem. An integrated monopulse antenna subsystem with multiple antennas for spherical coverage will be employed.

The C&T baseline subsystem includes communications transponders for TDRSS S-band (MA) and K-band (SA) links, S-band with STS, and OTV, as well as a UHF radar set, as shown in Figure 3-21. A GPS antenna and receiver is also shown for L-band navigation data sent to the GN&C subsystem. The active components of all subsystems will be spared and there will be no single-point failure modes of any active device.

The KSA equipment will be composed of two modules, one mounted on the antenna and one located in the command module. The antenna subsystem consists of an 11 to 13 foot tracking parabolic reflector and feed subsystem.

As the data requirements increase with station capabilities, the antenna may be increased in size to accommodate higher transmit power (EIRP) and receive noise bandwidth. The parabolic antenna will have both K-band and S-band feeds to communicate in both KSA and MA services. Only one parabolic antenna is baselined. When the higher power requirements cause a larger parabolic antenna to be employed by the Space Station, the smaller dish may be used as a TDRS link backup or for other Ku-band or S-band links (e.g., STS and OTV).

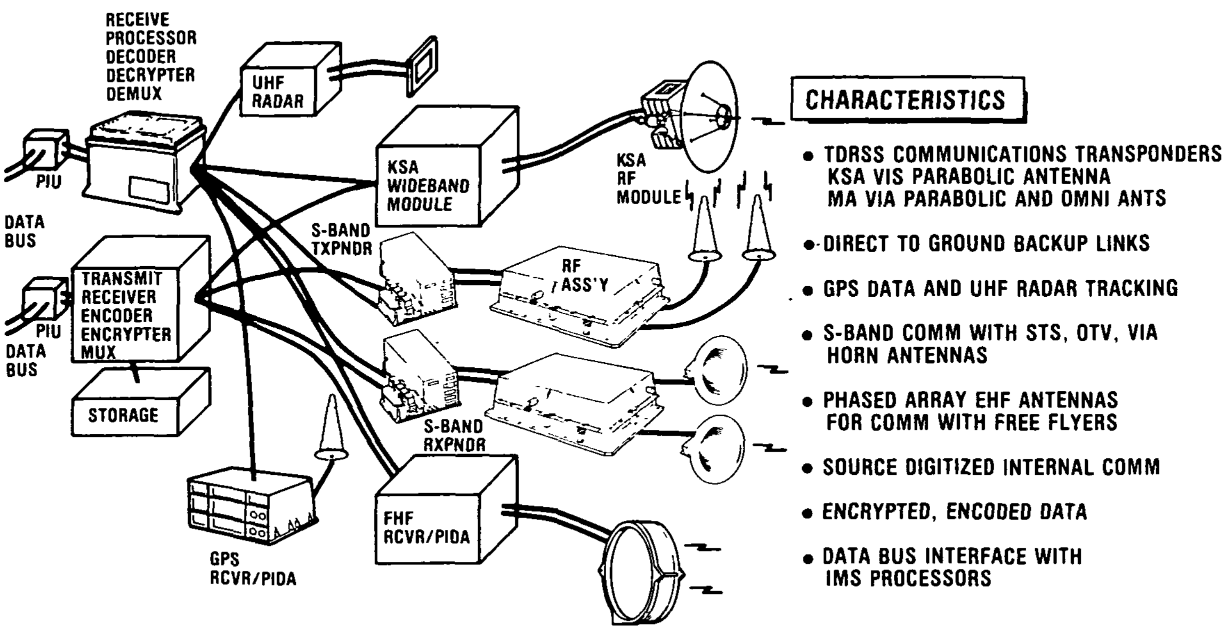


Figure 3-21. Space Station Communications Subsystem Architecture

The parabolic antenna is baselined to be located on the uppermost module on top of a mast of sufficient length to eliminate blockage in communicating with TDRS at any orbital position.

The S-band transponders are standard TDRSS/GSTDN components capable of interfacing with either the relay satellite or the ground subsystem. The antennas are omnicoverage spirals with hemispherical coverage. Two or more will be placed to cover the 360-degree sphere for any possible attitude and shadowing requirements.

The S-band communications links to the STS and OTV will use similar transponders but will employ higher gain horn antennas.

A signal conditioning processor will multiplex and buffer signals between the IMS data bus and the RF components. A communications display and recording device (solid state) will also be located in the command module.

PROPELLANT TRANSFER AND STORAGE ARCHITECTURE

Mission model activities have identified propellant resupply requirements of 300,000 pounds per year. Cryogenic oxygen and hydrogen (6:1 ratio) are required to satisfy full-up operational Space Station requirements.

The resupply propellants are stored in the orbiter bay, as shown on Figure 3-22. After the orbiter is berthed to the station, a fuel transfer arm is automatically attached. The resupply propellants are transferred to the station for distribution. Distribution plumbing is provided to fuel OTV's attached to PSA or to station-attached propellant modules.

Figure 3-23 shows the preliminary schematic of the selected LH_2 (oxygen identical) subsystem installed on Space Station for conveying cryopropellants from the orbiter supply tanks to the station storage tanks or directly to an OTV at the flight servicing facility. Transfer is accomplished by two-phase pumps with little or no pressurization of the supply tank required.

Acquisition of propellants in zero-g in both orbiter resupply and propellant module storage tanks is provided by capillary vane devices. In addition to the two-phase pump, a scavenging compressor is provided to evacuate supply tank residual vapors.

Venting of chilldown vapors can be avoided by compressing and condensing them in the bulk liquid of the storage tank or the resupply tank itself. A total operation time of 9 hours is considered adequate for series transfer of LO_2 and LH_2. The chief hardware development items are zero-g quantity gages and remotely actuated disconnects. Safety provisions include routing of propellant lines around enclosures, and use of leak detectors, and fail-

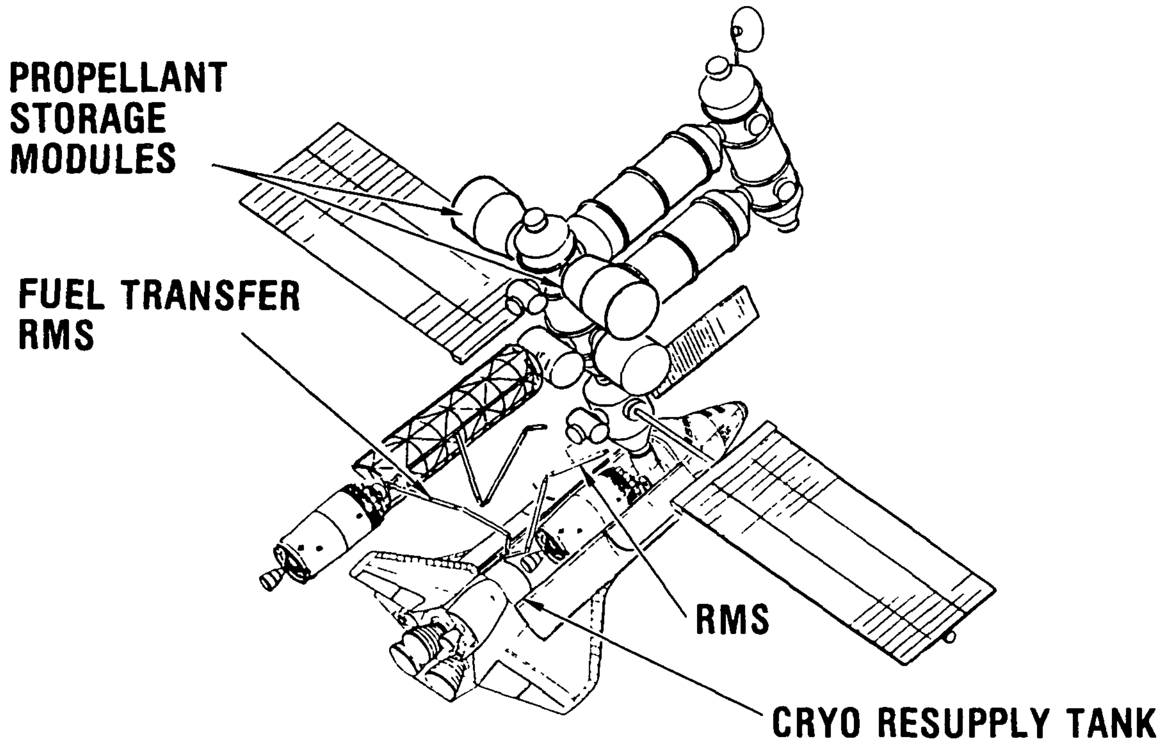


Figure 3-22. Propellant Delivery and Transfer

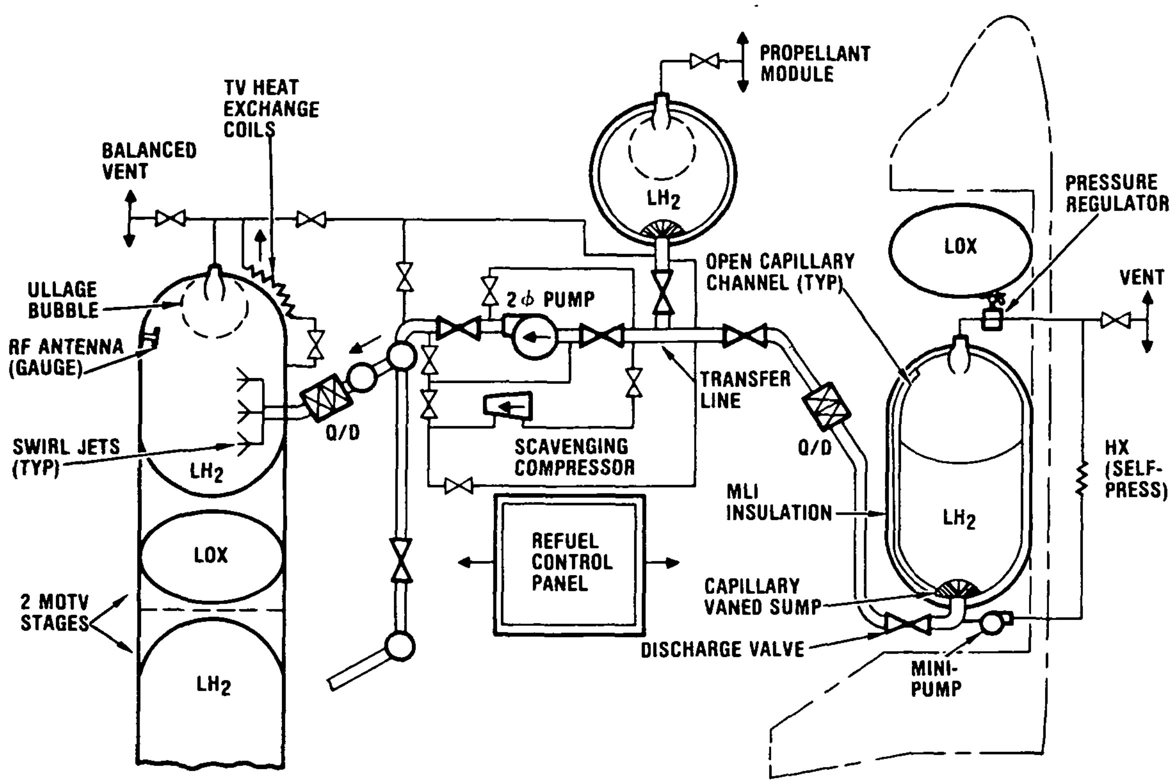


Figure 3-23. Cryo Propellant Handling and Storage Facility

safe subsystem design and control interlocks to preclude hazardous situations. It is anticipated that propellant transfer operations will be automatic; however, manual override by the crew in the event of contingency can be conducted at the refuel control panel.

The propellant module tanks have been sized to contain a total of 108,000 pounds of cryogens at the desired ratio of 6:1.

Meteorite bumpers are provided to reduce the probability of tank puncture to once in approximately 2,700 years. Double wall construction can also be provided to present catastrophic fragmentation of the tanks in the unlikely event of collision with space debris (once in approximately 5,000 years). No electric heaters or other pressurization means are used in the storage tanks since pressurization is not required by the two-phase pumps in the subsystem.

Even with the best available insulation (ML1 and vapor-cooled shields), total bailoff from the two propellant storage modules is expected to be approximately 8,000 lb/yr compared to a projected two-sigma RCS usage of approximately 2,640 lb/yr. Other potential uses for bailoff include fuel cell peak power generation (open cycle) and space processing. Complete reduction of bailoff can be accomplished by active refrigeration or deep subcooling of resupplied propellants prior to Shuttle launch.

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4. TECHNOLOGY

TECHNOLOGY DEVELOPMENT PLAN

NASA is presently pursuing two new space objectives: the next generation of support and mission satellites and increased operational efficiency through a space operations system (SOS).

The following presents Rockwell's recommendations incorporated into a technology development plan for the development of a cost-effective Space Station program.

SPACE STATION GENERAL FEATURES

The Space Station technology plan was developed using the following general guidelines. The Space Station will

1. Assume a Phase C/D start by or before FY 1987 to support a flight as early as 1990
2. Be in LEO and Shuttle compatible for delivery, assembly, and disassembly
3. Be a manned system
4. Support resupply by the Shuttle
5. Provide for nonhazardous, planned disposal at the end of useful life
6. Be designed for indefinite life through on-orbit maintenance, repair, or replacement
7. Have a modular-evolutionary design that permits growth and accepts new technology
8. Have a time-phased capability to accommodate mission needs and requirements
9. Have initial development cost and life-cycle costs as design driver
10. Be user-oriented to the maximum extent possible
11. Have a design goal of commonality for hardware and software of identical or similar functions in terms of systems, subsystems, and interfaces

12. Incorporate on-orbit autonomous operations to minimize crew and/or ground involvement as a design driver

13. Provide for a safe haven and/or escape capability

USER INTERFACE REQUIREMENTS

The subsystems on the Space Station will be designed, integrated, and operated to be user-oriented and compatible to the user to the maximum extent possible. These subsystems will provide simple, standard, and stable interfaces for users. Operations and design will provide for independent user operation and monitoring of payloads. The Space Station subsystems will be compatible with payloads providing their own services.

MAJOR SPACE STATION PROGRAM CONSIDERATIONS AFFECTING DEVELOPMENT OF THE TECHNOLOGY PLAN

Current studies are investigating ways to better utilize STS capabilities and improve space operations systems. The following system definitions and technology development items are under investigation through 1986 in order to define the most efficient Space Station program.

1. Space Station Facility

   - Facility modules
   - Payload support subsystems
   - OTV and servicing subsystems
   - Checkout equipment
   - Satellite servicing subsystems
   - TMS support and servicing subsystem

2. Payload Satellites

   - Large satellites (10,000 lb) assembled in space
   - Deployable structures
   - Scientific experiments
   - Small communication satellites (staging at LEO for launch to GEO)

3. Transition From Development to Fully-Operational Capability: Initially, the Space Station facility development will be the primary program driver. The transition from a development program to fully operational program will require investigations concerning:

- An orderly transition from requirements and proposed technology development to a space hardware program
- Developing unique and efficient space operation capabilities
- Developing direct manned support for LEO
- Developing direct manned support for the OTV at LEO and GEO operations by 1990
- Developing direct manned support for the TMS at LEO (possible GEO) operations by 1990
- Developing potential user area:
  - NASA
  - DOD
  - Commercial (foreign and domestic)
    - Communications
    - Space processing

SCHEDULE

A technology development schedule is provided in Figure 4-1. This schedule shows various engineering phases and milestones that need to be considered. The schedule covers new technology development from the analysis through component development and design to ground tests and flight test verification.

ADVANCED DEVELOPMENT TECHNOLOGIES

The principal role of developing advanced technology is to provide mature technology options for use on the Space Station program. Technology will decide the ultimate operational capability, utilization, and growth potential of the Space Station program. The level of technology used will determine system cost effectiveness. Fortunately, several years of lead time are available at this time to develop and implement advanced technology concepts into the initial design. The following technology issues are designed to provide the opportunity to attain the desired levels of technology for use in the initial design, as well as long-term technology advancement to be used in later applications for improved capabilities and configuration growth. The following

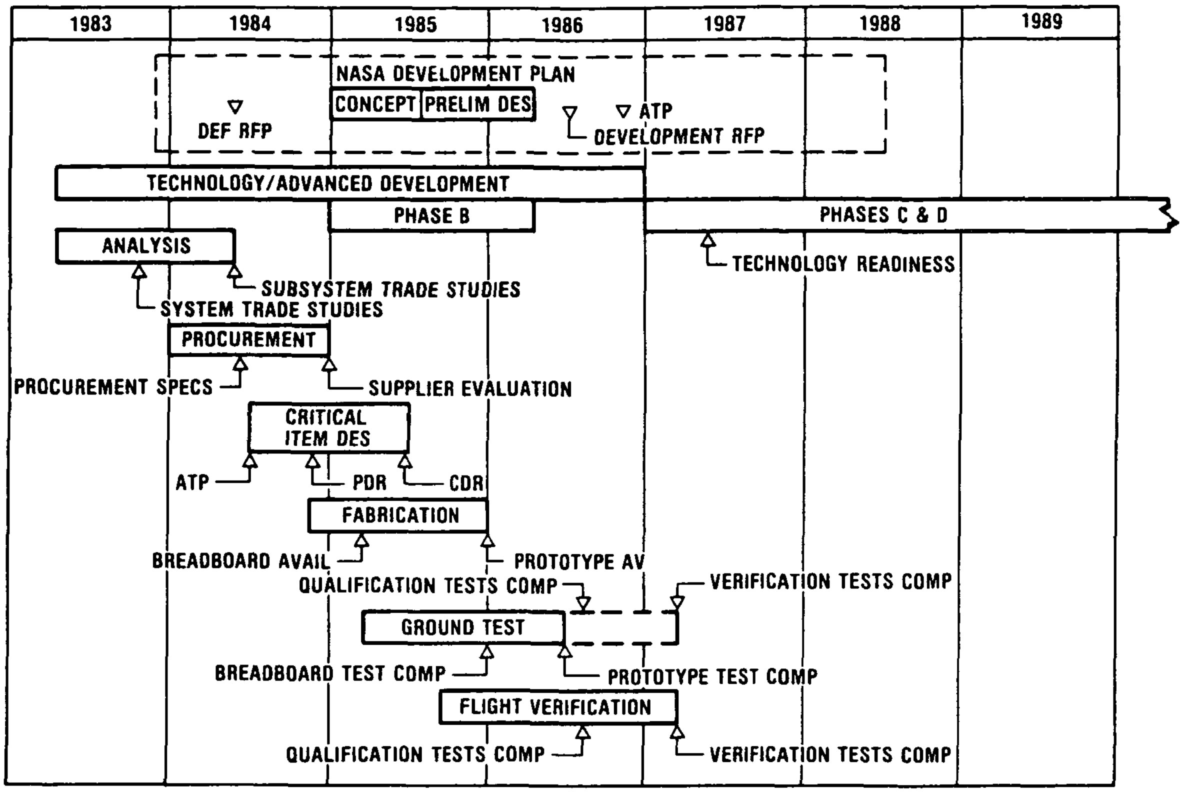


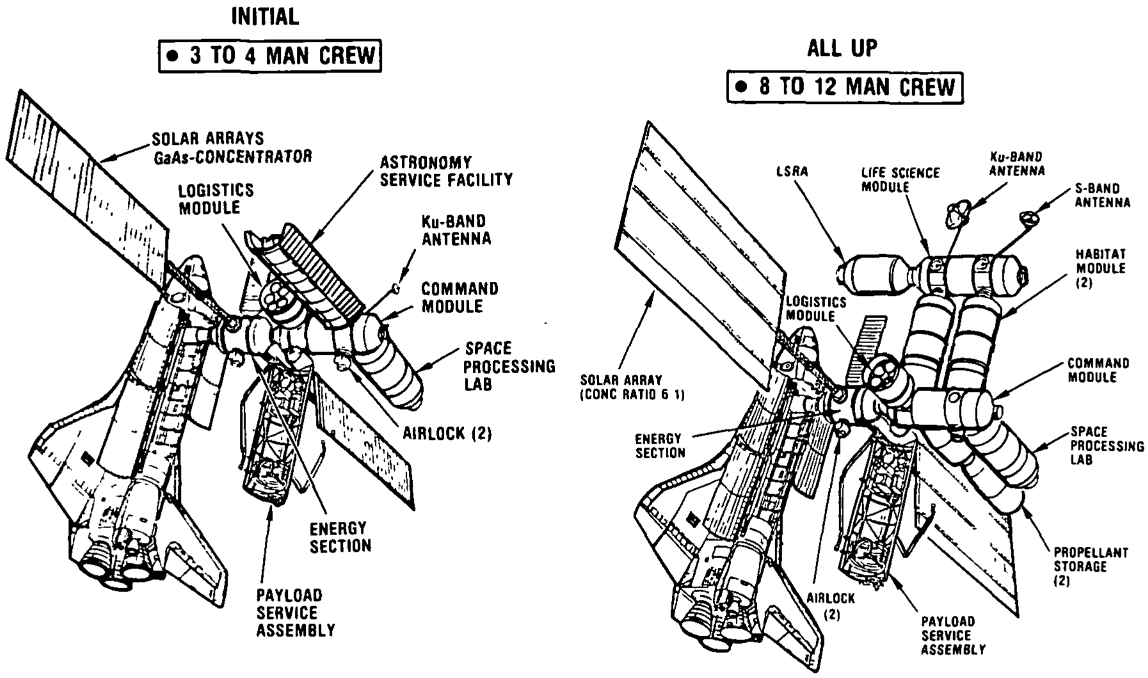
Figure 4-1. Technology Development Schedule

critical to a successful Space Station program. They are derived for application on the Space Station.

TECHNOLOGIES THAT ENABLE A HIGH LEVERAGE ON DEVELOPMENT

A research study was made to leverage out the system impacts of technology alternatives for the initial and the all-up stations, as illustrated in Figure 4-2. The configuration shown was developed to be used as a pathfinder. Our goal is to identify those technologies that enable a high leverage on development. (Enable, as used here refers to an increase in system capability at the same cost and a decrease in facility service requirements resulting in a lower life-cycle cost.) Those parameters of the system that can be related to lower cost fall in the following areas: electrical power, thermal dissipation and cooling, status and monitoring, control and memory, and crew maintenance time and logistic launch costs. In the search for high-technology leverage items, the seven technology readiness levels identified in Figure 4-3 were followed.* Also influencing the selection of candidates were the objectives and technological drivers that were established by the Space Station Technology Steering Committee:

*Carlisle, Richard F. Space Station Technology Readiness. American Society of Mechanical Engineers, Winter Annual Meeting, Phoenix, Arizona, (November 17, 1982).



INITIAL		ALL UP TO 10 YEARS								ADDITIONAL 10 YEARS									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Figure 4-2. Space Station Buildup Phase

LEVEL 1 BASIC PRINCIPALS OBSERVED AND REPORTED

LEVEL 2 CONCEPTUAL DESIGN FORMULATED

LEVEL 3 CONCEPTUAL DESIGN TESTED ANALYTICALLY OR EXPERIMENTALLY

LEVEL 4 CRITICAL FUNCTION/CHARACTERISTIC DEMONSTRATION

LEVEL 5 COMPONENT/BRASSBOARD TESTED IN RELEVANT ENVIRONMENT

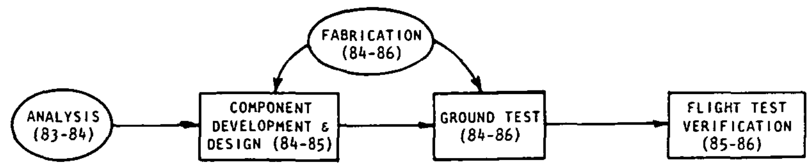
LEVEL 6 PROTOTYPE/ENGINEERING MODEL TESTED IN RELEVANT ENVIRONMENT

LEVEL 7 ENGINEERING MODEL TESTED IN SPACE

(Levels 1–5: TECHNOLOGY DEVELOPMENT; Levels 4–7: ADVANCED DEVELOPMENT)

Figure 4-3. Levels of Technology Development

Table 4-1. Technology Items



SUB-SYS.	TECHNOLOGY AREA	ANALYSIS	COMPONENT DEVELOPMENT & DESIGN	GROUND TEST	SPACE QUALIFICATION & VERIFICATION TEST
EPS	H V DESIGN*	X	CONNECTOR/SWITCH ROTARY POWER TRANSFER	MAINTENANCE/REPLACEMENT DYNAMICS LIFE	H V SPACE PLASMA CHARGING
	GaAs SOLAR CELL*	X	SOLAR ARRAY MODULE*		SOLAR ARRAY PERF VERIF
	RADIATION TEST	X			
	AC POWER DISTRIBUTION*	X	AUTOMATIC POWER MANAGEMENT		
	FUEL CELL, BATTERY, & ELECTROLYSIS DEV	X	REGEN F/C* BATTERY	RELIABILITY, LIFE*	
ECLSS	CO_2 REMOVAL	X	CO_2 REMOVAL	PERFORMANCE	CLOSED ATMOS REVITALIZATION SYSTEM
	CO_2 REDUCTION	X	CO_2 REDUCTION	PERFORMANCE	
	H_2O PROCESSING	X	POTABLE & WASH WATER	RELIABILITY, PURITY	
	WASTE MANAGEMENT* HYGIENE-CLOTHING*	X	REPLACEMENT/CLEANING CYCLE		CLOSED H20 & WASTE MANAGEMENT SYSTEMS
	MAINTENANCE	X	AUTOMATIC, SELF-CHECKOUT & FAULT ISOLATION	INTEGRATION OF SYSTEMS PERFORMANCE	
	LONG-LIFE DYN COMP	X	FLUID COMPONENT REPLACEMENT LONG-LIFE DYN. COMPONENTS	DYNAMICS—LIFE CYCLE	
THERMAL	CAPILLARY PUMP LOOP*	X	CAPILLARY PUMP LOOP (CPL)	PERFORMANCE, CONTROL CAPABILITIES, HEAT LOAD SHARING	PERFORMANCE IN ZERO-G
	WRAPAROUND RADIATOR	X	HEAT PIPE, HEAT EXCHANGER INTERFACES	HEAT PIPE RADIATOR, EXCHANGER	
	DEPLOYABLE RADIATOR	X	FLOW DIRECTIONAL CONTROL, FLEX LINES, NO-LEAK VALVES	DIRECTIONAL FLOW SELECTION VALVE	
	RADIATOR SURFACE PROPERTIES*	X	CLEANING TECHNIQUES, REMOVE & REPLACE TAPES	RELIABILITY & REPLACEMENT	DEGRADATION—SPACE ENVIRONMENT
AUX. PROPULSION AND FLUIDS	LOW-G CAPILLARY PUMPING	X	CAPILLARY DEVICES	PERF /RELIABILITY/MAINT	ZERO-G PERFORMANCE
	NON-VENTED FILL	X	SWIRL NOZZLES	RELIABILITY/MAINTENANCE	ZERO-G PERFORMANCE
	TWO-PHASE FLOW	X	INSTRUMENTATION	PERFORMANCE/RELIABILITY	ZERO-G VERIFICATION
	LOX THRUSTERS*	X			
	LIQUID FILL VENTING	X	THERMODYNAMIC VENT	PERFORMANCE/RELIABILITY	ZERO-G VERIFICATION
	FLUID MIXTURE RATIO	X	NOZZLE MATERIALS	LIFE	
	FLOW RATE	X	TWO-PHASE TRANSFER PUMPS	PERFORMANCE/RELIABILITY	
	NOZZLE EXPANSEOMATIC	X	COMPOSITE NOZZLES	LIFE	
GN&C	MOMENTUM STORAGE AND MGMT CONCEPTS*	X	COMPOSITE CMG's	LIFE, RELIABILITY	GRAVITY-GRADIENT BOOM CONTROL
	AUTO DOCKING SYSTEM*	Y	SOLID-STATE DOCKING SENSORS	DOCKING SYSTEM EVAL	
	DOCKING TRAJECTORIES*	X		CONTROL SIMULATIONS/VERIF	TORQUE EQUILIB ADAPTIVE ATTITUDE CONTROL VERIF
	DYNAMIC ANALYSIS	X			
IMS	IMS SYSTEM REQMTS	X	ADAPTIVE HARDWARE/ SOFTWARE HIERARCHY	LIFE	
	MODULAR ELEMENTS*	X	PARTITIONING & PACKAGING	INTEGRATION, RELIABILITY, PERFORM , MAINTAINABILITY	
	FLEXIBLE CONFIG.	X	ERROR DET & COMPENSATION		
	STATION/USER INTERFACE	X	HIGH-SPEED PROCESSING & DATA TRANSFERS*	TRANSPARENCY TO TECHNICAL CHANGES, FAULT TOLERANCE, AUTONOMY, RECONFIGURATION	
	ALGORITHM SYNTHESIS	X	DATA COMPRESSION,* NETWORKING		
	PROGRAMABLE	X	SYS. & SUBSYS PROGRAMS		
COMMUNICATIONS	EHF COMM.	X	SOLID-STATE DEVICES AND BREADBOARDS	LIFE, EMI/RFI, ANECHOIC CHAMBER	ENVIRONMENT, EMI/RFI; LINK PERFORMANCE
	DATA ENCODING AND ENHANCEMENT	X	VLSI CODECS (VITERBI, CONVOLUTIONAL)	LIFE; MAINT., ENVIRONMENT	LIFE, RADIATION DEGRAD. OF LSI
	LASER COMM.	X	SOLID-STATE LASER SCANNERS & RECEIVERS	LIFE, MAINT , ENVIRONMENT	ENVIRON , LINK PERF.
	LARGE ANT. SYST.	X	STEERING/TRACKING BREADBOARDS	MAINT , ENVIR LIFE	ENVIR , MAINT., LIFE
	MULTIPLE ACCESS TECH.	X	CDMA/TDMA SWITCHING COMPONENTS	EMI/RFI; MAINT., ENVIRON	RADIATION DEGRADATION OF LSI

*HIGH LEVERAGE TECHNOLOGY DEVELOPMENT

Objectives

The objectives were to:

1. Establish the desired level of technology to be used in the initial design and operation of an evolutionary long-life Space Station and the longer term technology to be used for later applications for improved capabilities; initial technology should be available by approximately 1986 to support a Space Station launch as early as 1990

2. Assess the level of technology forecast to be available from that portion of the current research and technology program that will be applicable to a Space Station

3. Plan, recommend, and monitor a program to move the current technology to the level stated

4. Identify, evaluate, and recommend opportunities to utilize the Space Station as a research and technology facility

Technological Drivers

Technological drivers included:

1. Operational costs, which should be reduced to a minimum consistent with the initial resources available

2. Design life and reliability, which must be improved with minimum service and maintenance

3. Automation, which must be implemented to the maximum to reduce direct operational labor costs

4. Performance, which must be improved to the maximum consistent with the above items

Figure 4-4 illustrates Rockwell's Space Station subsystem organization. This subsystem organization was structured to technology development in high leverage areas only and does not show a complete subsystem work breakdown structure (WBS). All subsystem disciplines were reviewed to determine those candidates for technology development, as well as advanced development items. A summary of selected subsystem candidates is presented in Figure 4-5. A more detailed list of technology items for each subsystem is given in Table 4-1. The high leverage items are noted in the figure. Using the technology levels of readiness that were defined and the technological drivers, Rockwell compiled a matrix of subsystem technology developments. A summary of development items that could potentially provide a high leverage on development and a high rate of dollar return over the life of the Space Station is given in Table 4-2. The figures identify areas of current technology, potential advances, performance, and cost impact.

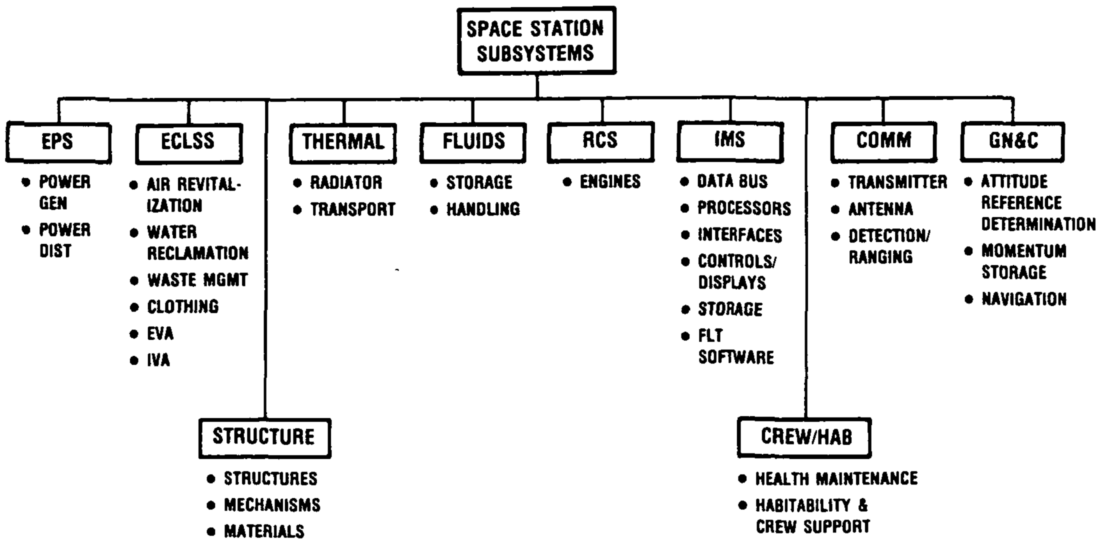


Figure 4-4. Space Station Subsystem Organization

SUBSYSTEM	SELECTED CONCEPT
EPS	
• POWER GENERATION	• SOLAR ARRAY • REGENERATIVE FUEL CELL (220 VDC)
• DISTRIBUTION	• 416 VAC
ECLSS	
• AIR REVITALIZATION	• CO_2 REMOVAL — SOLID AMINE • CO_2 REDUCTION — SABATIER • O_2 SUPPLY — WATER ELECTROLYSIS
• WATER RECLAMATION	• TIMES
• WASTE MANAGEMENT	• ORBITER COMMODE • INCINERATOR
• CLOTHING	• REUSABLE (CLOTHES WASHER)
RCS	
• ENGINES	• LO_2/LH_2 — GASEOUS
THERMAL	
• RADIATOR	• WRAPAROUND — HEAT PIPE • DEPLOYABLE — HEAT PIPE
• TRANSPORT	• CIRCULATING PUMPS (SINGLE PHASE) • CAPILLARY PUMP (TWO PHASE)
IMS	
• DATA BUS	• HARDWIRE • FIBER OPTICS
• PROCESS HIERARCHY	• DISTRIBUTED
• INTERFACES	• BIU
COMMUNICATIONS	
• COMMUNICATION TYPE	• RF
• ANTENNAS	• DEDICATED UTILIZATION • DISPERSED LOCATION • TRACKING/POINTING
• DETECTION/RANGING	• RADAR
GN&C	
• ATT REF DETERMINATION	• STAR SENSING • INERTIAL SENSING
• MOMENTUM STORAGE	• DISTRIBUTED
• NAVIGATION	• GPS

Figure 4-5. Subsystem Technology Candidates

Table 4-2. Evaluation of Technology Improvements (High Leverage Items)

SUBSYSTEM	CURRENT TECHNOLOGY	POTENTIAL ADVANCES	PERFORMANCE/ COST IMPACT
THERMAL CONTROL			
• THERMAL BUS	CIRCULATING PUMP — SINGLE-PHASED FLUID SYST	CAPILLARY PUMP — TWO-PHASE FLUID SYSTEM	• MINIMIZE (OR ELIMINATE) DEPLOYED RADIATOR • 5 kWe PUMP POWER SAVINGS
• THERMAL COATINGS	$\alpha = 0.1 + 0.02 \times$ LIFE	$\alpha = 0.1 + 0.01 \times$ LIFE	• LONGER LIFE SYSTEM • 50% RADIATOR AREA SAVINGS
EPS			
• POWER GENERATION	PLANAR SILICON SOLAR ARRAYS	LOW CONCENTRATION GaAs SOLAR ARRAYS ~ 100 kW	• ONE-FOURTH RECURRING COST (CONC RATIO, 6:1) • GaAs SAVES 1/2 NO. OF CELLS
• ENERGY STORAGE	NiCd BATTERIES	REGEN. FUEL CELLS NiH_2 IPAC	• ONE-HALF (LOWER) WEIGHT • POWER FLEXIBILITY • SIMPLER INTEGRATION
• FUEL CELLS	10,000 kWh LIFE	10,0000-200,000 kWh LIFE	• LOWER REPLACEMENT COSTS
• POWER DISTRIBUTION	28 VDC	HIGH VOLTAGE • 120 VDC • 220 VDC → 50 kWe • 416 VAC	• LIGHTER DISTR WEIGHTS • HIGHER DISTR EFFICIENCY
• INVERTER	75-80% EFFICIENCY	90-93% EFFICIENCY	• LOWER ARRAY AREA
ECLSS			
• WASTE MANAGEMENT	FECAL BAG COLLECTION	INTEGRAL WASTE & TRASH DISPOSAL (INCINERATOR)	• ELIMINATE 384 CHANGEOUTS — 20 YEARS • $45M-$60M SAVINGS
• CLOTHING	DISPOSABLE	REUSABLE — WASHER/DRYER	• 83,000 LB SAVINGS • $60M-80M LESS COST
IMS			
• DATA COMPRESSION	2 1, 4 1 (TOLERATE ERRORS)	8 1 (WITH ACCEPTABLE ERROR RATES)	• INCREASED DATA RATE CAPABILITY GIGA BITS
• COMPUTER PROCESSING HARDWARE — PROCESSING DESIGN & SIGNAL CONDITIONING	LSI	VHSIC	• POWER SAVINGS, SMALLER SIZE ENHANCES REDUNDANCY & FAULT TOLERANCE
• DATA BUS STRUCTURE	WIRE	FIBER OPTICS	• HIGHER DATA RATE CAPACITY >> MBPS
• INTERFACE UNITS	MDM	BIU (WITH VHSIC CHIPS)	• STANDARDIZATION USING "SMART" INTERFACE UNIT — ALLOWS CONTROL DOWN TO LOWEST POSSIBLE LEVEL
COMMUNICATION			
• DATA RELAY	TDRSS	ADVANCED TDRSS	• PERMITS HIGHER TRANSMISSION RATES - 60 MPS (EQUIV)
GN&C			
• DOCKING	MANUAL	AUTOMATIC	• REQUIRED FOR UNMANNED OPS • CREW TIME SAVINGS • HIGHER RELIABILITY & SAFETY
• PROCESSING	CENTRAL	DISTRIBUTED	• LOWER COST, HIGHER RELIABILITY
• CMG	SKYLAB	LARGER SIZE, LOWER WEIGHT	• LOWER LAUNCH COST, SIMPLER SYSTEM
RCS/FLUIDS			
• THRUSTERS	HYDRAZINE	GOX/GH_2	• HIGHER SPECIFIC IMPULSE — 380 SEC
• OTV FUEL FORM (OTV HIGH ENERGY PROPELLANTS)	LOX/LH_2 (GROUND CONVERSION)	LF_2/LH_2 ($NF_3 + LH_2 \rightarrow N_2H_4 + LF_2$) (ON ORBIT CONVERSION)	• LAUNCH SAFETY • HIGHER SP IMPULSE — 490 SEC

TECHNOLOGY HIGH LEVERAGE ITEMS

The section describes a few high leverage candidates from each subsystem area and the resulting potential cost savings or increase in capability. Individual paragraphs identify each subsystem discipline:

1. Electrical power

2. Thermal control

3. Environmental control and life support

4. IMS

5. C&T subsystem

6. Guidance, navigation, and attitude control

7. Fluid systems and reaction control

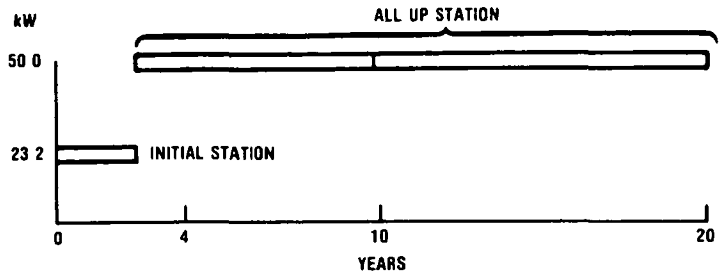
Electrical Power Technology Leverage Candidates

A 20-year Space Station evolution model shows a growth from the 4-year initial station of 4 crewmen and a 23 kW load power, to the 16-year all-up station of 8 crewmen and a 50 kW load power. By using the low recurring cost (Figure 4-6) GaAs low-concentration type solar array, a total of $80 million savings can be achieved comparing the conventional silicon planar solar array in the 20-year operational period. GaAs solar cell has the advantage of high cell efficiency, radiation hardening, and self-annealing capability over the silicon cell. Also, the GaAs solar cell manufacturing technology (MANTEC) development program presently being pursued under Air Force contract will reduce the GaAs cell cost.

The low concentration GaAs solar array configuration, Figure 4-7, illustrates the benefits over the silicon solar array in the following areas: array stiffness, less radiation degradation, more efficient Shuttle stowage, less array area, and low recurring cost. These benefits show that the GaAs solar array is the best of the Space Station power generation candidates.

An attractive alternative to the battery and regenerative fuel cell energy storage subsystems most often considered for this application is the integrated power and attitude control subsystem (IPACS). The IPACS concept stores electrical energy in wheels as kinetic energy. Simultaneous energy and momentum management in these subsystems also permits the subsystem to replace the control moment gyros (CMG's) and to perform the attitude control function. Rockwell trade studies of this concept in the early seventies* have shown it to be an attractive option to the other competing techniques. Technology development work in the IPACS area is recommended in order that it be available by the Space Station technology need date.

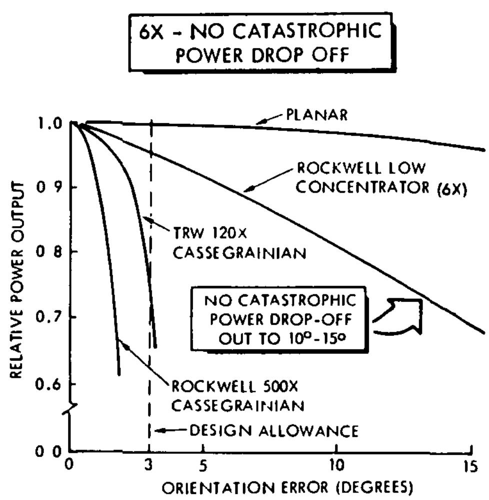
*Integrated Power/Attitude Control System (IPACS) Study. Vol I and II, NASA CR-2383. Prepared by Rockwell International for NASA LaRC (April 1974).

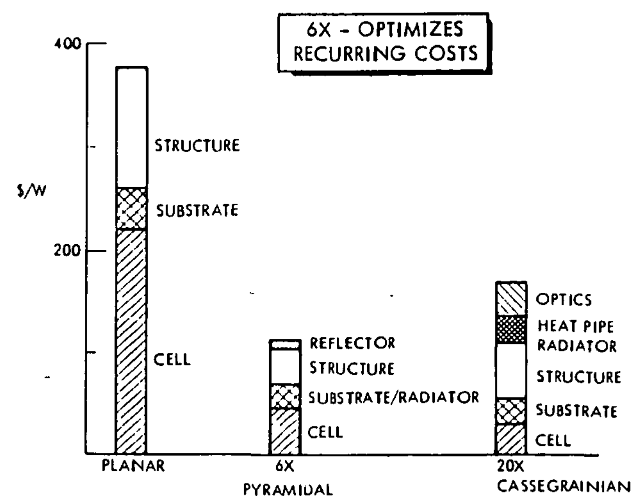


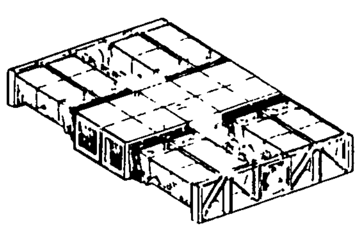
SCENARIO NO		COST ($M) DD&T	RECUR.	REPL.	
1	PLANAR, INITIAL	36 0	23 2		
	PLANAR, ALL-UP	5 0	50 4	—	
	ADDITIONAL 10 YR OPS	—	—	50 4	
		41 0	73 6	50.4	$165M
2	PLANAR, INITIAL	36 0	23 2	—	
	CONC, ALL-UP	43 2	15 6	—	
	ADDITIONAL 10 YR OPS	—	—	15.6	
		79 2	38.8	15.6	$133 6M
3	CONC, INITIAL	43 2	7 2	—	
	CONC, ALL-UP	6 0	15 6	—	
	ADDITIONAL 10 YR OPS	—	—	15 6	
		49 2	22 8	15 6	$87 6M

HOW MANY TECHNOLOGY DOLLARS WOULD YOU INVEST TO GAIN LIFE CYCLE COST SAVINGS?

Figure 4-6. Space Station Evolution Model







6X - BETTER THAN PLANAR

- 5 TIMES STIFFER
- ONE-HALF DEGRADATION
- 50% MORE EFFICIENT SHUTTLE STOWAGE

Figure 4-7. Why Low CR?

TCS

Two-Phase Thermal Control. The capillary pump loop (CPL) technology (Figure 4-8) could be utilized to remove waste heat from the pressurized cabin coldplate directly to the radiator. This concept will not only reduce power penalty, weight, and cost, but will also reduce radiator area requirements drastically, which is greatly needed.

Heat rejection requirements for a full-up station are about 50 kW. The conventional Freon pump power requirements are estimated to be about 4 kW and the CPL pumping power requirements are estimated to be about 0.5 kW. This savings can be translated into a 1,560 ft^2 radiator area, 8.0 kW solar array power generation, and a 670 ft^2 solar array area savings.

The basic subsystem (refer to Figure 4-8) consists of a centralized two-phase thermal bus with heat sources (coldplates and heat exchangers) and sinks (radiators and heat exchangers) connected in parallel. This subsystem can share radiators between modules, heat-load share between modules or individual coldplates to minimize TCS power, and utilize thermal capacitors to damp out peak heat load conditions. This subsystem can also provide considerable

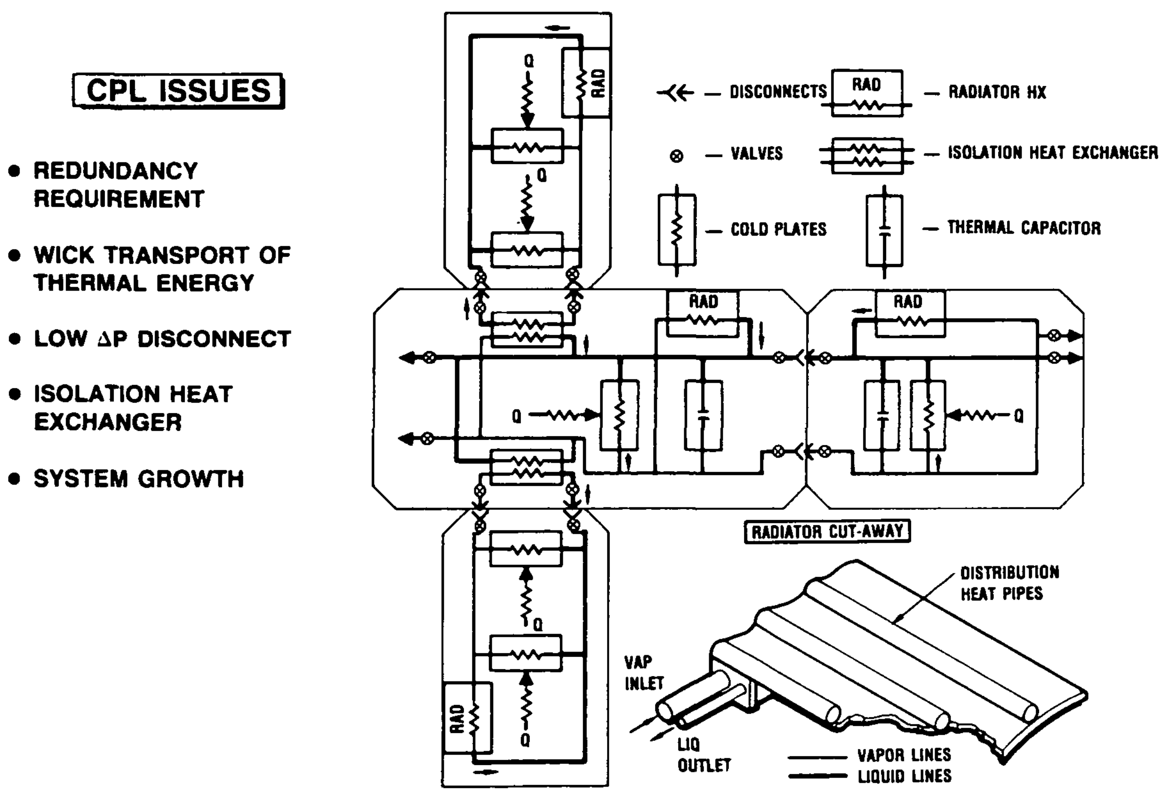


Figure 4-8. Two-Phase TCS Concept

flexibility in growth and mission load profiles. A comparison between CPL and the pumped liquid loop concepts is presented in Figure 4-9. The CPL provides numerous advantages as compared to the pumped liquid loop. For example, the flow rate requirements for the pumped liquid loop is about 35 times higher than the CPL loop for the same heat rejection capability. As a result, the pumped liquid loop requires higher pumping power and radiator sizing as compared to the CPL loop. Also, reliability and growth potential are excellent for the CPL loop.

Thermal Degradation Influence on Radiator Area. The effects of radiator surface properties' degradation rate (solar absorptivity) in Figure 4-10 can strongly influence requirements for radiator area. Presently, the degradation rate of solar absorptivity is assumed to be about 0.02 per year. This value is based on data utilizing FEP/AL coating. An improvement of degradation rate from 0.02 to 0.005 per year, combined with the application of CPL, will further reduce the radiator requirement. One potential impact of this for the initial station is to avoid the requirement for radiators on the PSA modules.

	THERMAL LOOP	
PARAMETERS	LIQUID PHASE	TWO-PHASE
FLOW RATE	$W = \frac{Q}{C_p \Delta T}$ HIGH	$W = \frac{Q}{\lambda}$ LOW
PUMPING POWER	HIGH	LOW
FLOW DISTRIBUTION	REQUIRES CONTROLS	SELF REGULATING
THERMAL DISTRIBUTION	NON-ISOTHERMAL	ISOTHERMAL
RADIATOR SIZING	HIGH	LOW
RELIABILITY	GOOD	EXCELLENT
WEIGHT PENALTY	EQUAL	EQUAL
GROWTH (ADDITIONAL HEAT LOADS)	POOR	EXCELLENT

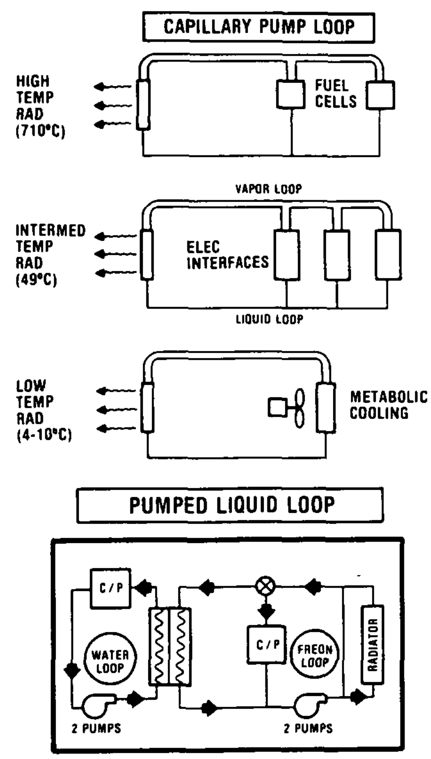


Figure 4-9. Two Phase Thermal Bus Versus Pumped Liquid Loop

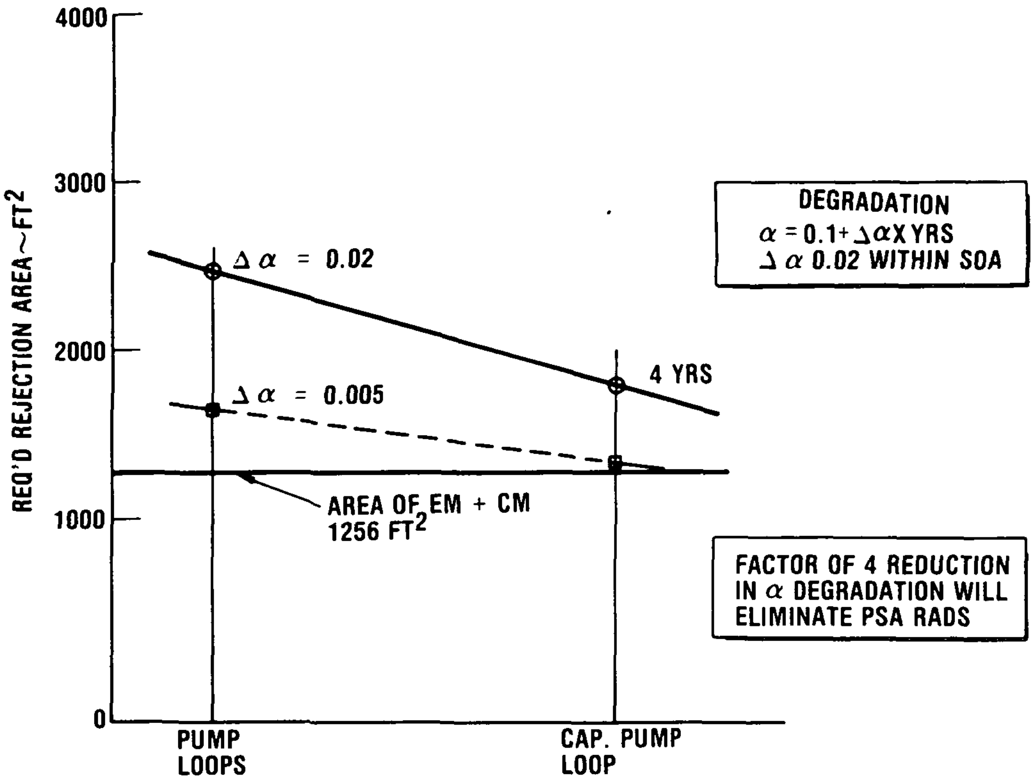


Figure 4-10. Thermal Degradation Influence on Radiator Area

ECLSS

The major ECLSS functions, such as CO_2 removal, CO_2 reduction, water electrolysis, water recovery and management, waste management, and health and hygiene, were reviewed for possible technology candidates that may have a high leverage of dollar return (Figure 4-11).

The two ECLSS areas that require new technology are in the waste management subsystem and the crew hygiene of controlling the cleanliness of clothing.

The present waste management subsystem (Figure 4-12) now being used on the Shuttle orbiter for the STS program is the feces slinger-commode air transport unit built by General Electric Corporation. This unit has a capacity of only 150 man-day uses, and for an 8-man Space Station with two units, it would require removal and replacement every 38 days. This results in 384 changes over the 20-year life of the Space Station. A cost study has indicated that a total of $60 million to $73 million of 1984 dollars are required to cover the DDT&E, recurring, crew maintenance, and launch-ground turnaround costs over the 20-year period. New technology of space disposal is needed to reduce the high cost of present waste management subsystems. The type of technology contemplated is one that would integrate body waste and trash disposal into one process (Figure 4-12). This would reduce the cost of crew maintenance for change of units and eliminate the expensive launch, ground, and turnaround costs.

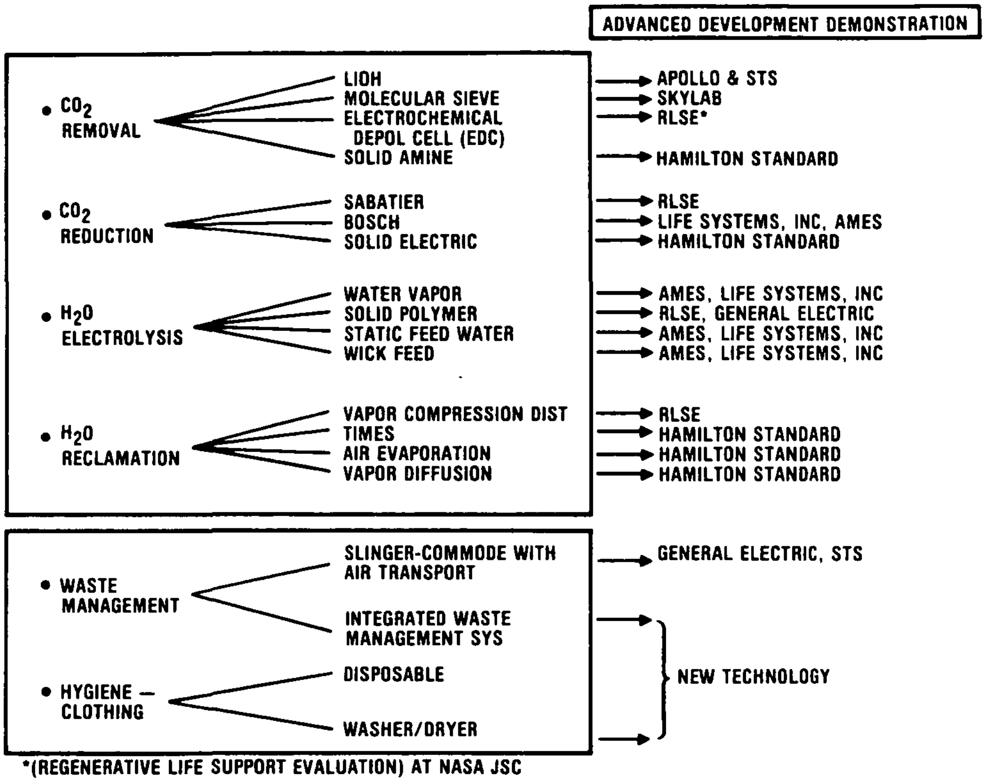


Figure 4-11. ECLSS Technology Development

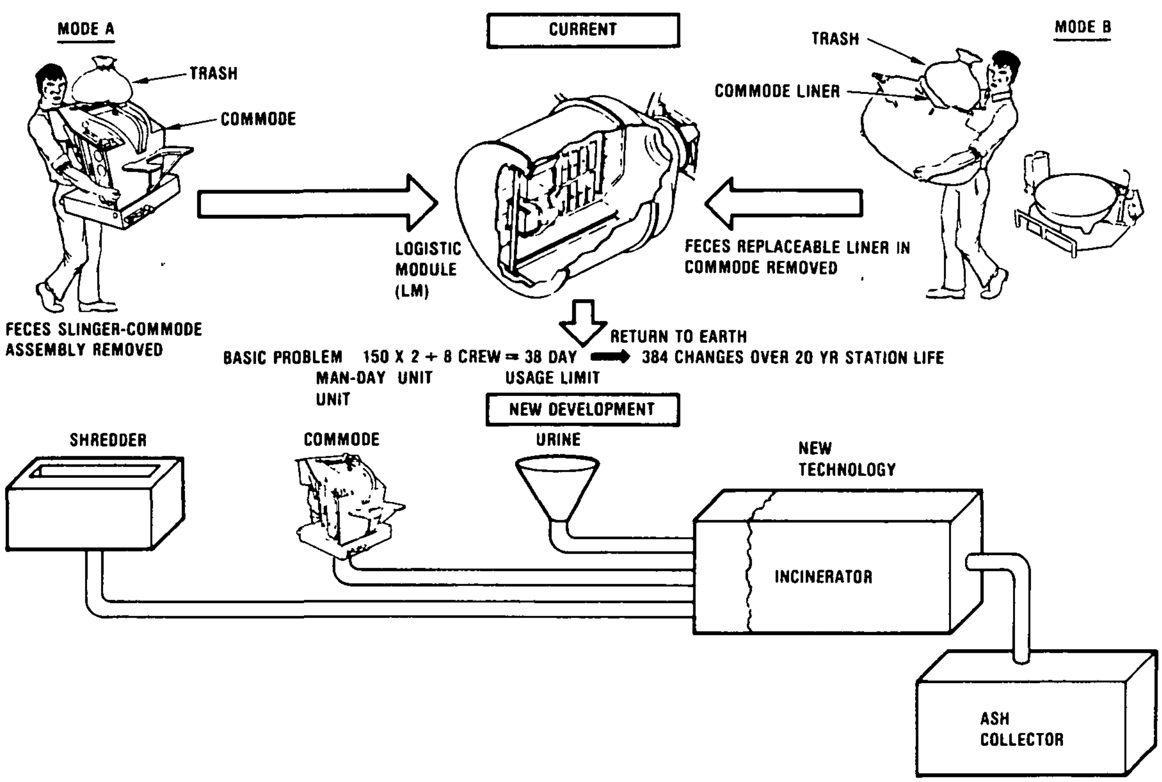


Figure 4-12. Space Station ECLSS Waste Management Technology

It is estimated that a funding of $10 million 1984 dollars for DDT&E would be required over 3 years (1984 through 1986) to develop the concepts, build components, conduct breadboard testing, and fabricate a phototype unit. The recurring costs for the space disposal subsystem is estimated at $5 million. Total estimated cost for the new technology subsystem is $15 million. The potential savings of this new technology program to the present Shuttle orbiter-type waste management subsystem would be between $45 to $58 million over a 20-year period, as illustrated in Figure 4-13.

Space Station crew clothes management and cleaning is another area where new technology may have a high leverage of dollar return. A study of disposable clothes versus a Space Station washer-dryer unit was conducted to determine if there would be a large cost advantage of using a washer-dryer to that of disposable clothes. Including recurring, launch, and ground handling costs over a 20-year period, the cost of disposable clothes is approximately $106.8 million dollars; a washer-dryer unit including DDT&E, recurring, and launch cost over the same time period is $25.3 million.

The potential savings to the program (Figure 4-14) shows that with an investment of $7.2 million for new technology, a zero washer-dryer would save approximately $82 million over the 20-year life span of the Space Station; therefore, on a high-cost leverage return on investment, these new technologies of Space Station waste disposal and the washer-dryer are warranted.

- INTEGRATE BODY WASTE & TRASH DISPOSAL INTO ONE PROCESS
- REDUCE CREW ACTIVITY
- ELIMINATE LAUNCH, GROUND & TURNAROUND COST
- TECHNOLOGY UNKNOWN —
  - REQUIRES RESEARCH, ANALYSIS, IMPLEMENTATION OF IDEAS
  - DEVELOPMENT OF CONCEPTS & COMPONENTS
  - BREAD BOARD TESTING
  - FABRICATION & FLIGHT TESTING OF PROTOTYPE UNIT
- ESTIMATED TECHNOLOGY FUNDING $10M̄ OVER 3 YRS 1984 THRU 1986

PARAMETERS (COST IN M̄)	SHUTTLE TECHNOLOGY MODEL "A"	SHUTTLE TECHNOLOGY MODEL "B"	NEW TECHNOLOGY — WASTE MANGT SYS	
DDT&E	3.2	4.8	10 ESTIMATE *	POTENTIAL SAVINGS
RECURRING	4.0	1.2	5 ESTIMATE	
CREW REPLAC	19.8	38.4	—	
LAUNCH, GROUND TURNAROUND	45.9	15.9	—	
TOTAL COST	72.9	60.3	15	45 TO 58

* MAJOR PORTION OF THIS $10M̄ IS ADVANCED TECHNOLOGY DEVELOPMENT

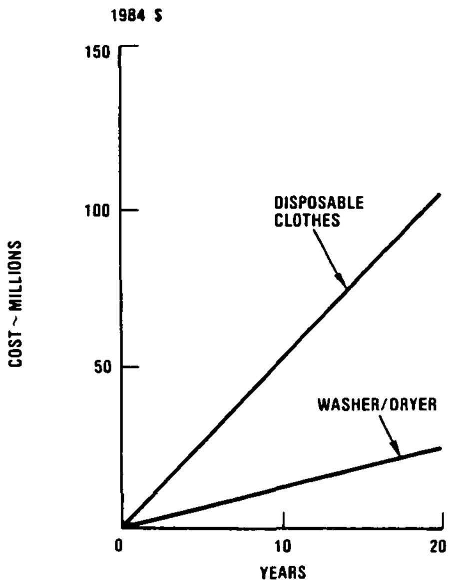
Figure 4-13. Waste Management Process Subsystem--New Technology

DISPOSABLE CLOTHES MODEL

- UNDER CLOTHES — 0 5 LBS/MAN DAY
- FLIGHT SUIT — 1 5 LB/SUIT (3 DAY LIMIT) = 0 5LB/MAN DAY
- WASH TOWELS — 0 5 LB/MAN DAY

CLOTHES WASHER/DRYER MODEL

- EST WEIGHT — 90 LBS
- SOAP — 8(OZ)/DAY (4 LOADS) = 0 5 LB/DAY
- RESUPPLY — 4 SETS/MAN — 90 DAY AT 2 LB/SET = 8 LB/MAN — 90 DAY



PARAMETERS (COST IN $\bar{M}$)	DISPOSABLE CLOTHES	WASHER/ DRYER	SAVINGS 1984
DOT&E	—	7 2	-7 2
RECURRING	1 8	7 2	-5 4
LAUNCH	105	10 9	+ 94 1
TOTAL COST	106 8	25 3	81 5

- INVEST $7 2$\bar{M}$ IN NEW WASHER/DRYER TECHNOLOGY
- SAVE $81 5$\bar{M}$ OVER 20 YEARS

Figure 4-14. ECLSS Hygiene--Disposable Clothes Versus Washer/Dryer Technology

IMS

The prime IMS function (i.e., facility and user subsystem management and control) was reviewed as a technology candidate that would provide the greatest benefit from utilizing advanced technology.

Several areas of new hardware technologies appeared to be viable candidates, e.g., bubble memory, optical disc, fiber optics, and VHSIC; however, when dollar investment and its effect upon advancing the maturity of these technologies was considered, the leverage was miniscule. Investigation of areas not related to particular hardware technology development but rather to their application to the Space Station system control and data management requirements seems to provide the greatest leverage. The choice, therefore, is investment in components or investment in architecture.

Investment in systems engineering at the concept stage will provide the greatest long-term life cycle savings for lowest initial cost. The savings will be reflected throughout the Space Station maturation cycle (i.e., the development integration, verification, operation, and maintenance phases).

The translation of Space Station goals into architecture by means of systems engineering technology should precede component level selection and/or development. This methodology reflects a sound planning and strong management approach to a complex technical problem. (Refer to Figure 4-15).

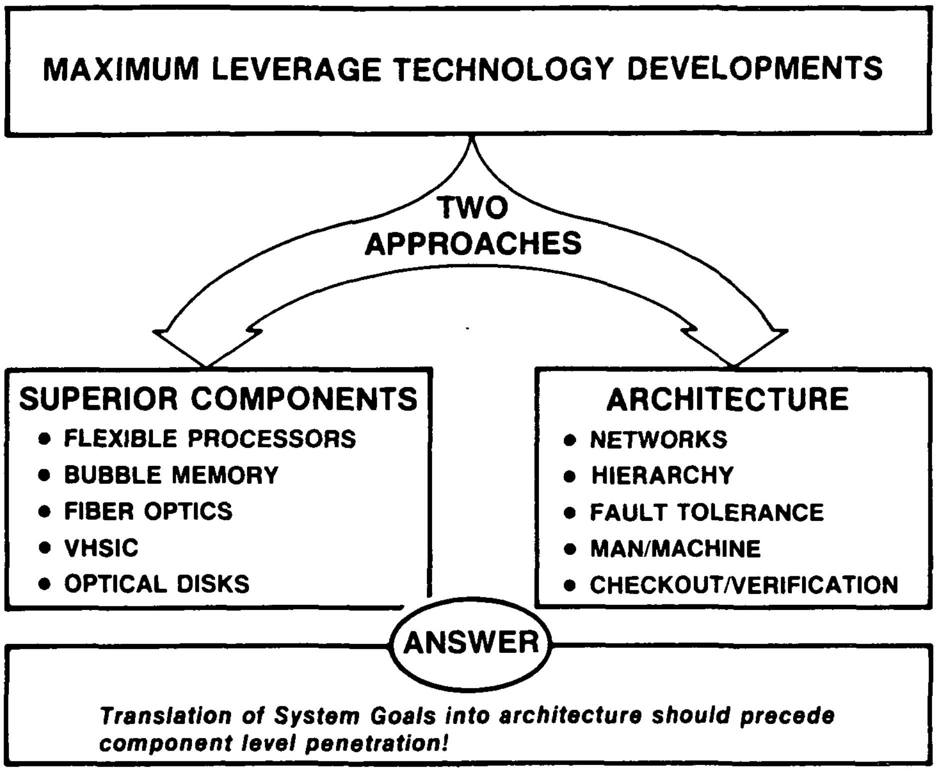
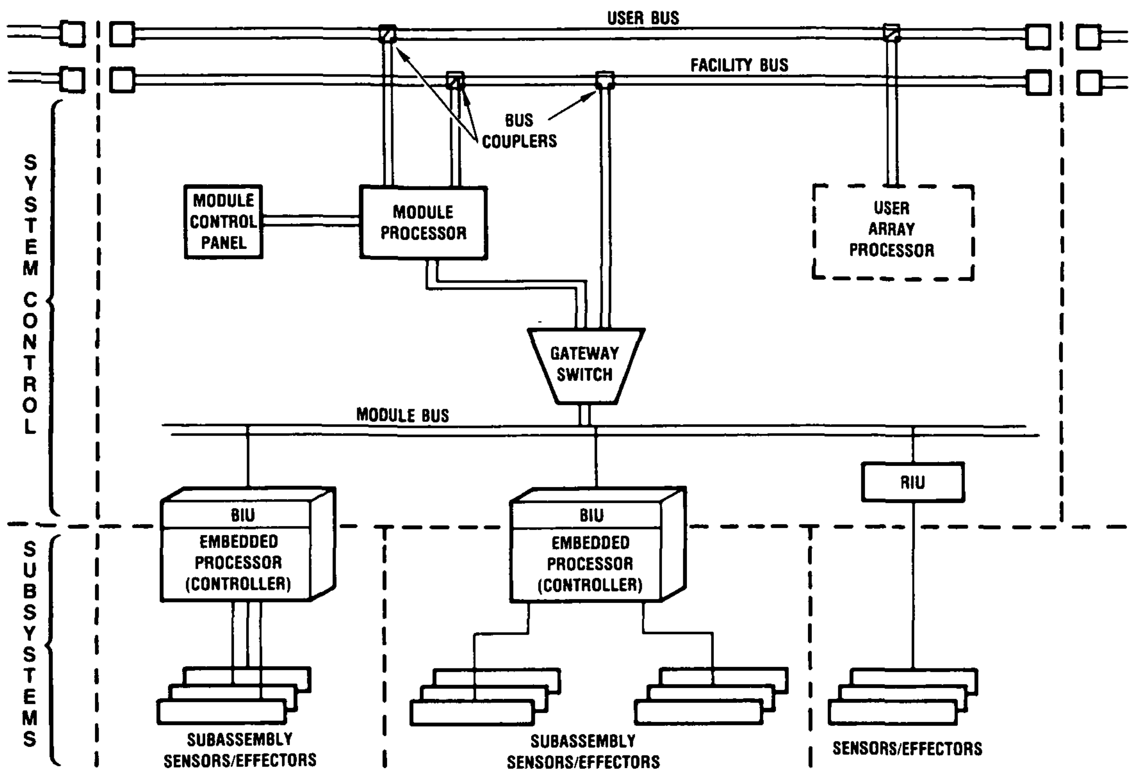


Figure 4-15. Subsystem Control and Data Management

The architecture initially chosen for the IMS is depicted to Figure 4-16, distributed processor architecture. The salient features of this architecture include a dual data bus structure (a user bus and a facility bus), a gateway switch that enables a remote module processor to access the module bus and, thereby, monitor and control applicable subassemblies, a remote interface unit for direct interface with the module processor for those functions that do not lend themselves to embedded microprocessor organization, and provision for flexible user-demanded configurations (dedicated processors).

C&T Subsystem

The C&T subsystem will require new and sophisticated technological developments in the areas shown in Figure 4-17. In particular, these developments are multiple access and spherical coverage, communications and tracking to space objects, as well as high data rate communications to the ground. It is felt that technology readiness (Level 7) has been reached for the new developments. The initial station requirements, having fewer space objects and on-board payloads, will be designed using existing state-of-the-art hardware. Some minor improvements will be necessary, especially in the area of integrated control. Also, compatibility with existing systems, such as TDRSS for data relay and STS and Cansats for space-to-space communications, constrain new technology requirements.



LEGEND: BIU — BUS INTERFACE UNIT RIU — REMOTE INTERFACE UNIT

Figure 4-16. Distributed Processor Architecture

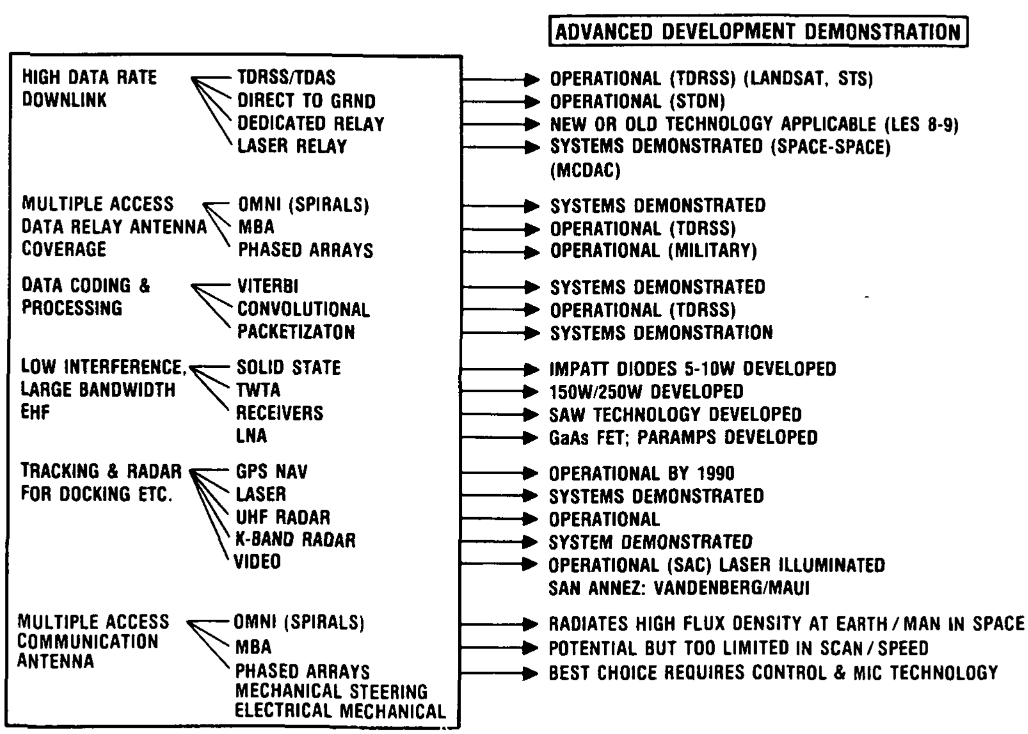


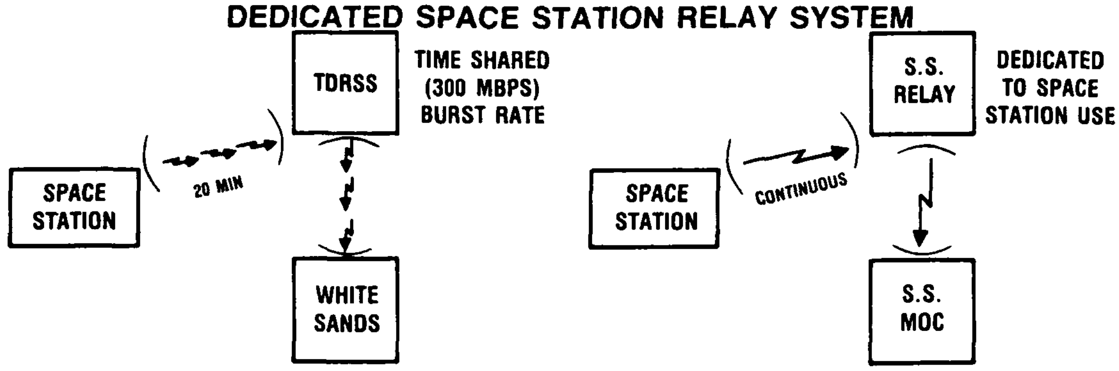
Figure 4-17. C&T Subsystem Technology Leverage Candidates

The many and varied RF communication links that Space Station must provide present problems of coverage, blockage, RFI, and flux-density limits. Major areas to be developed include higher frequency (i.e., EHF) and optical (laser) hardware to alleviate overcrowded frequency spectra. Electronically steered, phased orvax antennas provide directive spherical coverage, and integrated navigation data processing from GPS receivers will provide tracking. Coding techniques for multiple access and reduced bit error rate communications will relieve the RFI multipath and potential blockage problems for space-to-space and space-to-ground limits.

The on-board Space Station communications do not require new technology, but rather improvements in existing systems for greater capacity and distribution, and space-qualified reliability. Miniaturization of wireless video and telephone equipment may be useful to reduce crew maintenance and operations time and costs.

For full Space Station operations, a high data rate real-time communications link requirement at low (i.e., 10^{-5}) bit error rate is anticipated. Since the existing relay systems, TDRSS, operates in a time-shared mode for high data rates, a possible solution, as shown in Figure 4-18, might be a Space Station dedicated relay satellite system that would involve major

TDRSS KSA TIME SHARED RELAY vs DEDICATED SPACE STATION RELAY SYSTEM



TDRSS RELAY SYSTEM

- STORAGE OF ALL DATA
- 20 MIN DATA BURST PER ORBIT
- DELAY IN DATA USE
- AT $5K/HR COST (TDRSS USER COST) $97.5 M FOR 10 YRS
- MAX EQUIVALENT DATA RATE = 60 MBPS (BURST RATE = 30 MBPS)
- CHANGEOVER TO TDAS (1993-1994) SYSTEM ESTIMATE $10-20 M

DEDICATED RELAY SYSTEM

- LITTLE STORAGE REQUIRED
- REAL TIME DATA TO GROUND
- AT $100M/SAT COST OF SYSTEM — $350-400 M (3 SATS, + GRND)
- MAX DATA RATE = 500 MBPS

Figure 4-18. Space Station C&T Technology Development developments in the areas of EHF or laser cross-links and base-band on-board processing. The costs of such a dedicated relay satellite system might be less than the costs of reducing data on the Space Station and the time costs of using TDRSS over ten years.

GN&C Subsystem

Figure 4-19 shows the systematic screening of GN&C high leverage technology development candidates. The top-level function at the left, and the status of each item and reflected. The number on the right is the assessment of the technology readiness level. Items that are known to be under an applicable development program or scheduled for development have been excluded from the candidate list. Those indicated as potential candidates were selected in the preliminary screening and were judged to offer attractive potential for return-on-investment, in terms of enablement, performance, reliability, and/or cost. The selected candidates resulted from the final screening and were selected on the basis of having the highest potential for good return on a minimal investment in technology development dollars.

The three selected candidate items for GN&C are:

1. Advanced momentum storage subsystems

2. Automatic rendezvous docking sensor

3. Distributed processing for GN&C

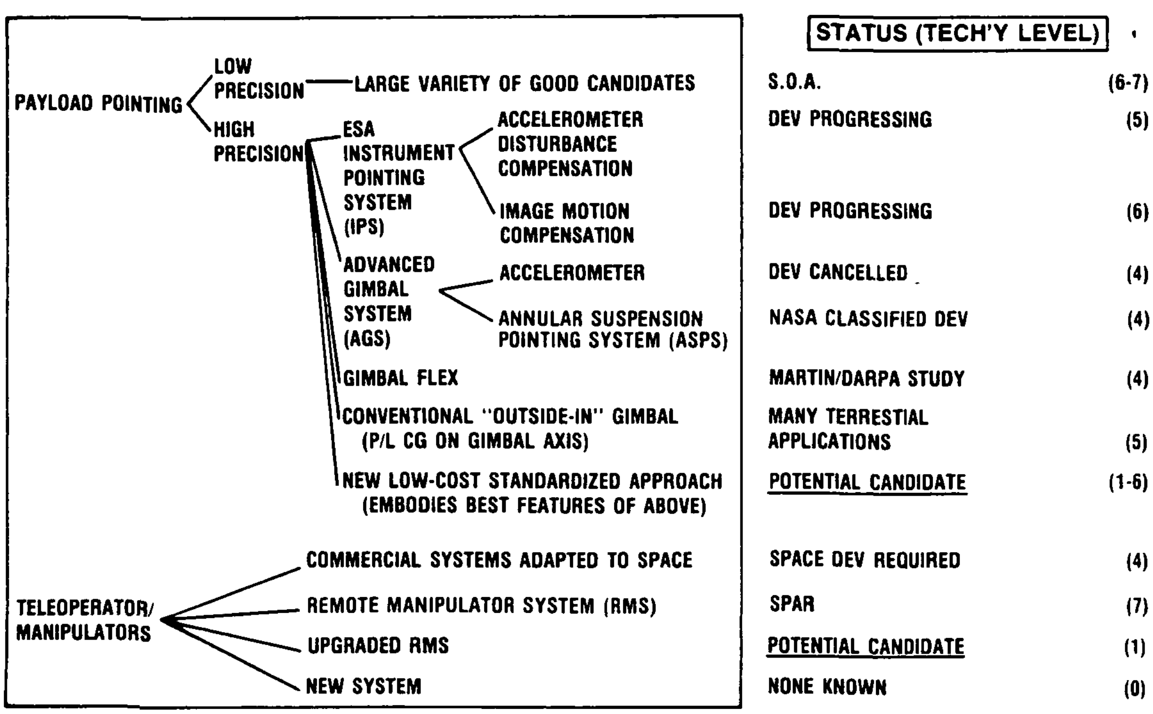


Figure 4-19. GN&C Survey for Technology Leverage Candidates

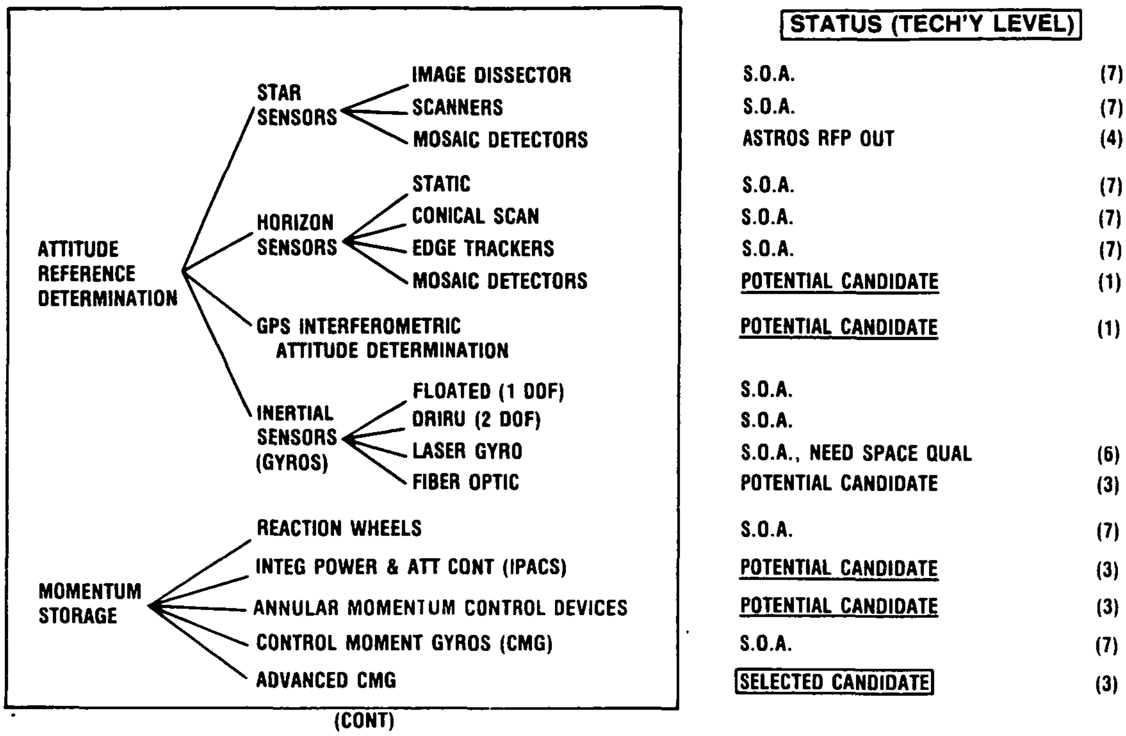


Figure 4-19. GN&C Survey for Technology Leverage Candidates (Cont)

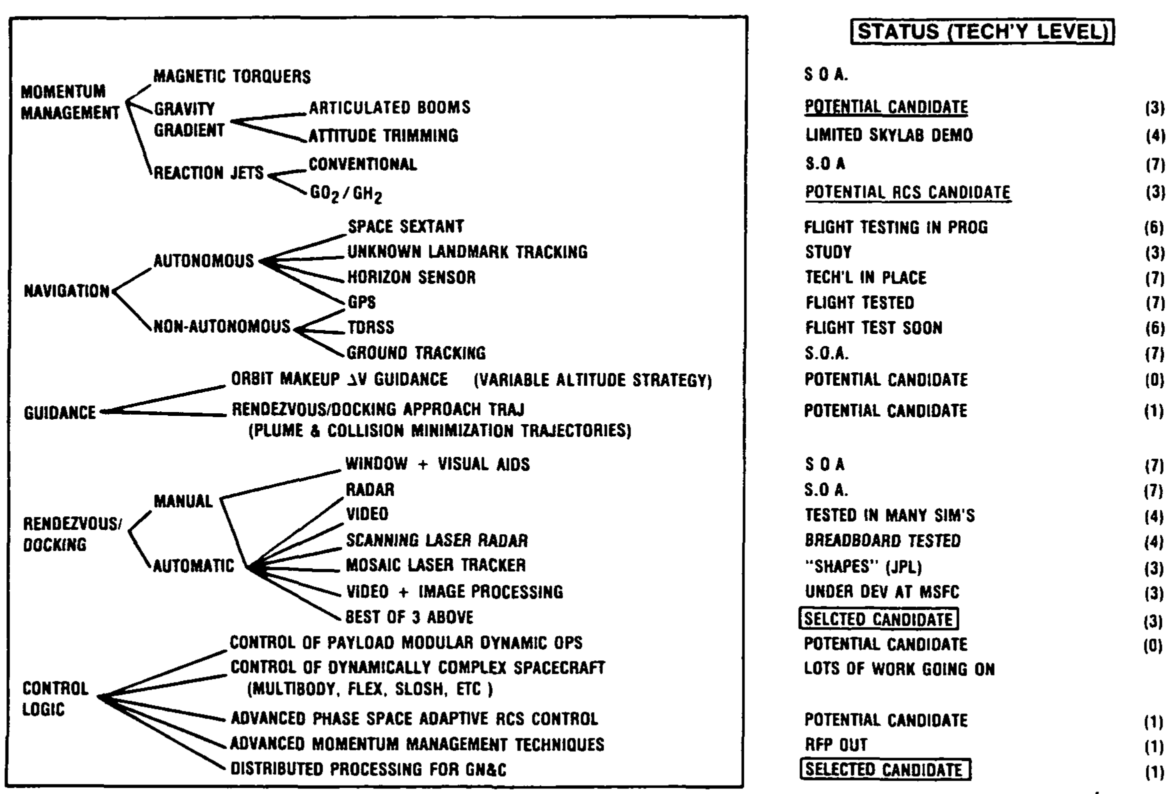


Figure 4-19. GN&C Survey for Technology Leverage Candidates (Cont)

The first item is motivated by the perceived need for larger momentum capacity than the existing Skylab CMG's. The second item is enabling for unmanned rendezvous and docking, and provides advantages for Space Station operations. The third item reflects a perceived need for special attention to the more extensive processing requirements of GN&C and the high cost of software development and software and hardware system testing.

Fluid Systems and Reaction Control

With Space Station, the inherent hazards of launching fluorine propellant can be overcome by coverting safe fluorine compounds such as NF_3 (a cryo-liquid reactant used for space-based lasers) into LF_2 on-orbit (see Figure 4-20).

Use of LF_2/LH_2 propellant for very high ΔV missions has been a goal of mission planners because of its superior I_{sp} and smaller required tankage (compared to LO_2/LH_2). Extensive testing of LF_2/LH_2 engines has shown launch hazards to be the only serious obstacle to their use.

On-orbit, NF_3 can be dissociated to N_2 and F_2 by heat provided from a solar concentrator. N_2 itself can be used for cold gas thrusters, purging, and pneumatic actuation. It can also be reacted with hydrogen to form the storable monopropellant/bipropellant hydrazine, N_2H_4, which can be used in large quantities for space-based propulsive units such as TMS and AKM.

Another potential candidate for in-space processing is the conversion of oxygen (O_2) to ozone (O_3) by electric corona discharge. LO_3/LH_2 propellant is superior to LF_2/LH_2 in I_{sp}, although larger tankage, comparable to LO_2/LH_2 tankage, is required.

Figure 4-21 shows the percent of payload improvement that is possible with fluorine oxidizer (versus oxygen) for a single-stage expendable vehicle launched from a 200 nmi orbit. Initial gross weight (stage, propellant, and payload) was held constant in this comparison. An I_{sp} of 489 (versus 470 for LO_2/LH_2) and a propulsive stage mass fraction of 0.915 (versus 0.906 for LO_2/LH_2) were used.

Significant improvements in payload capability are seen for GEO-manned OTV's, deep space DOD payloads, and planetary missions. If a fixed-size propulsive stage were assumed, the benefits would be even greater at low and medium ΔV requirements (below 30K feet per second).

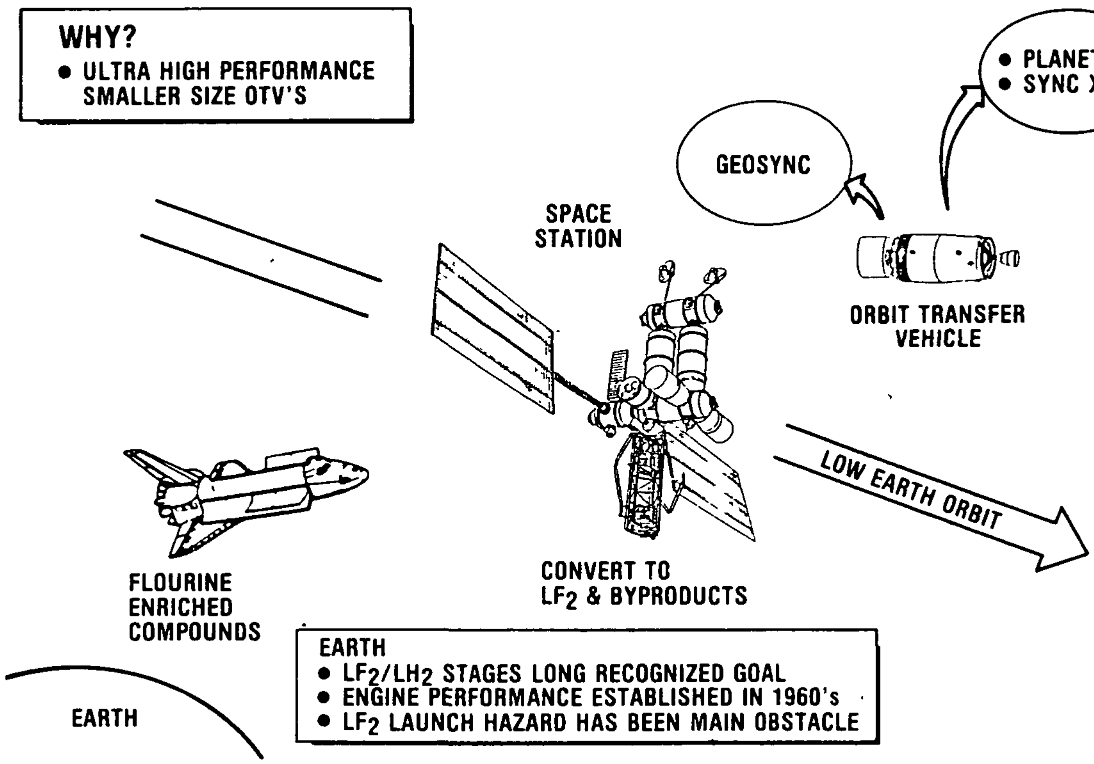


Figure 4-20. Nonhazardous Delivery of Fluorine Propellant

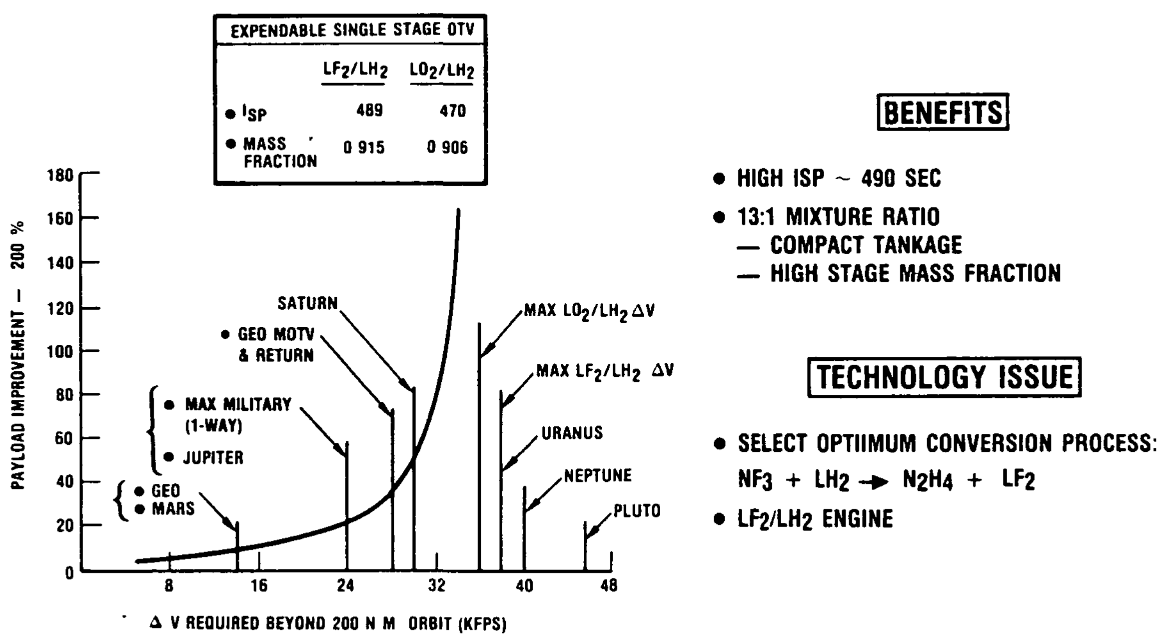


Figure 4-21. Fluorine Propellant Benefits