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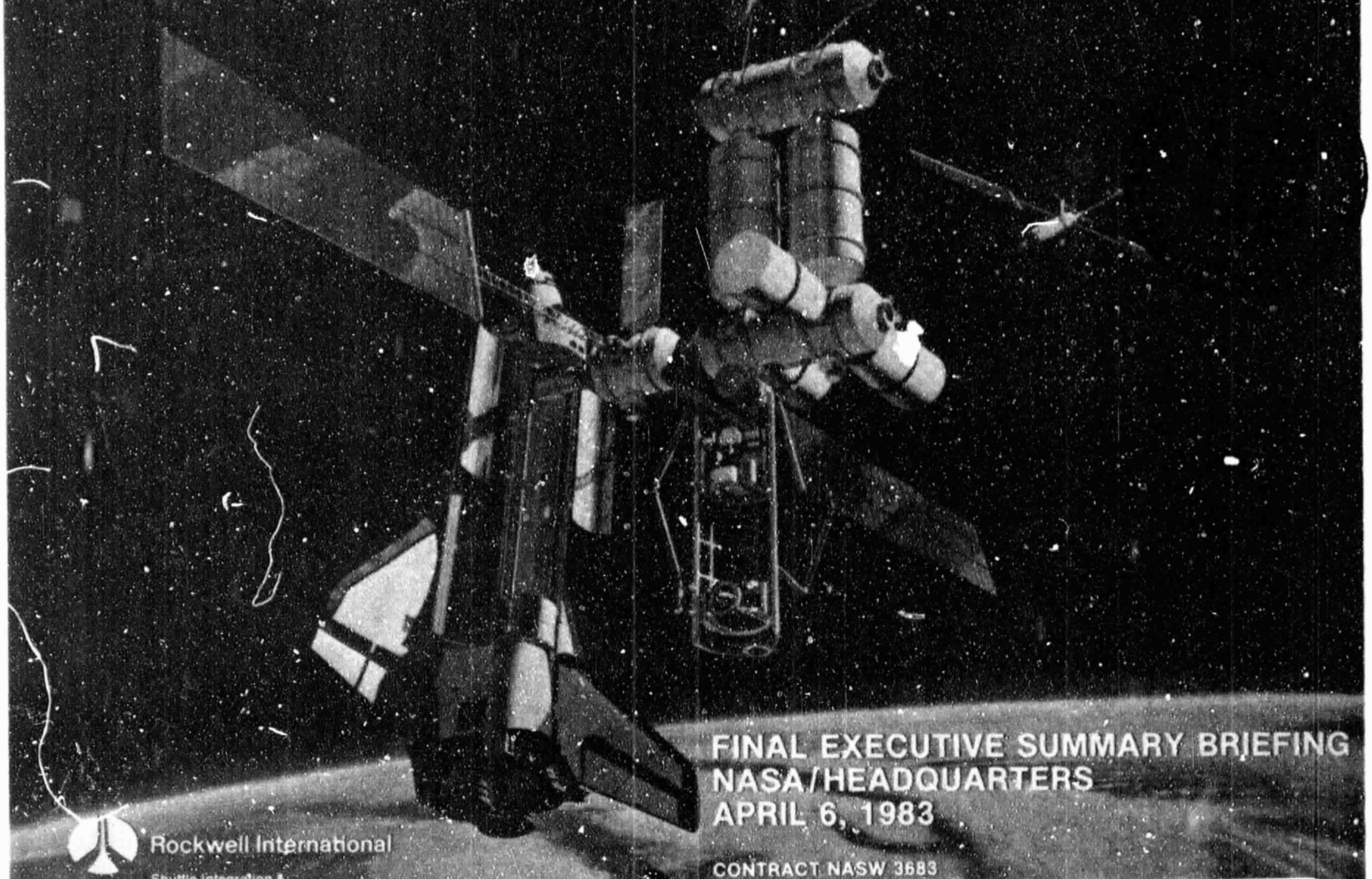
SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY



FINAL EXECUTIVE SUMMARY BRIEFING
NASA/HEADQUARTERS
APRIL 6, 1983

CONTRACT NASW 3683

Rockwell International

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

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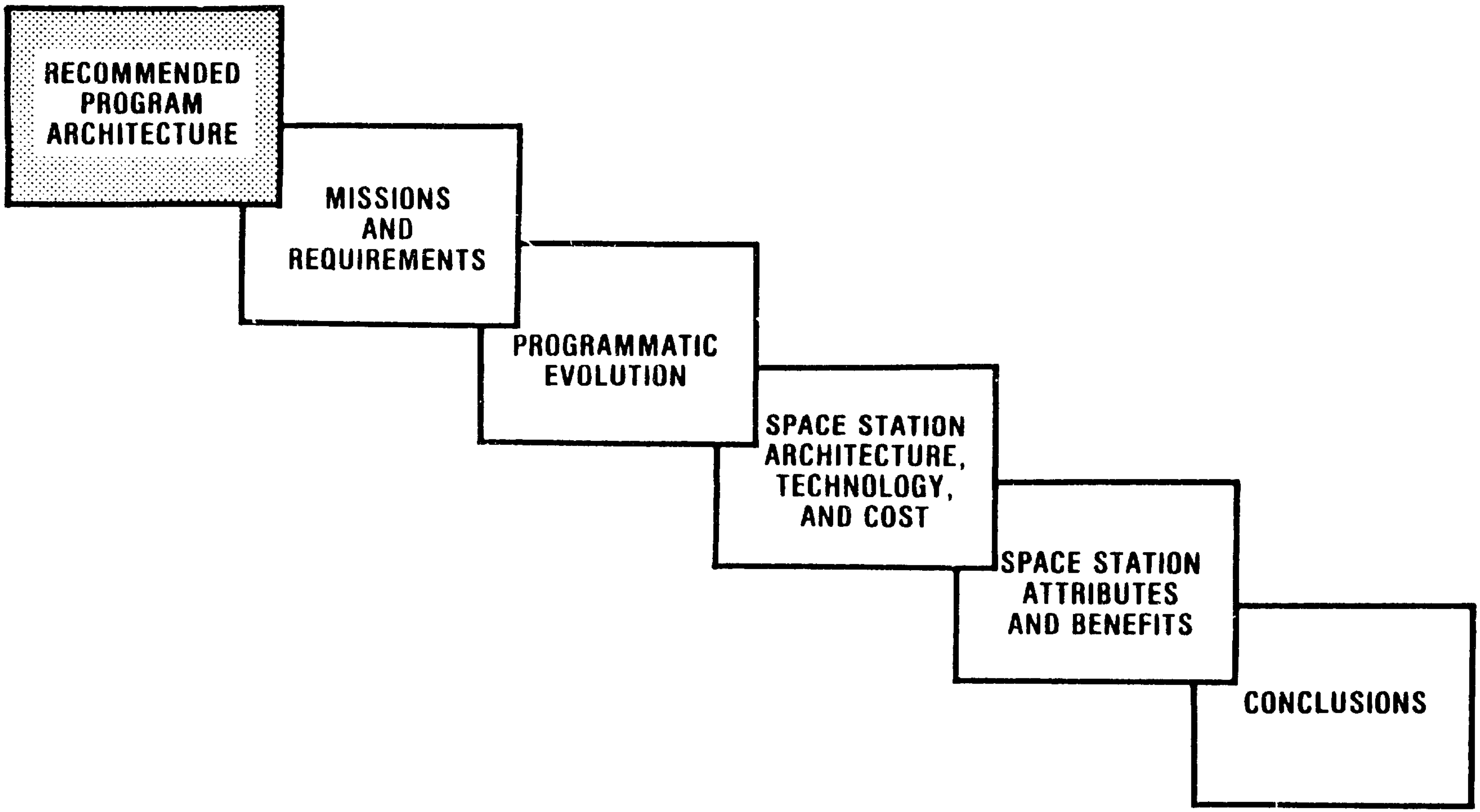
SUMMARY BRIEFING OUTLINE ...



RECOMMENDED SPACE SUPPORT SYSTEM PROGRAM ARCHITECTURE

This chart summarizes the top-level time-phased total space program support system architecture recommended as a result of this study.

The Space Shuttle will play a key role in the early development of orbital operational techniques and OTV and TMS space-basing technology. The Shuttle will also be important in the initial development of commercial space processing and, in this role, will require extended durations. As the station becomes available, the only major change to the Shuttle is the possible capability for propellant scavenging from the ET and/or from the Shuttle main propulsion system.

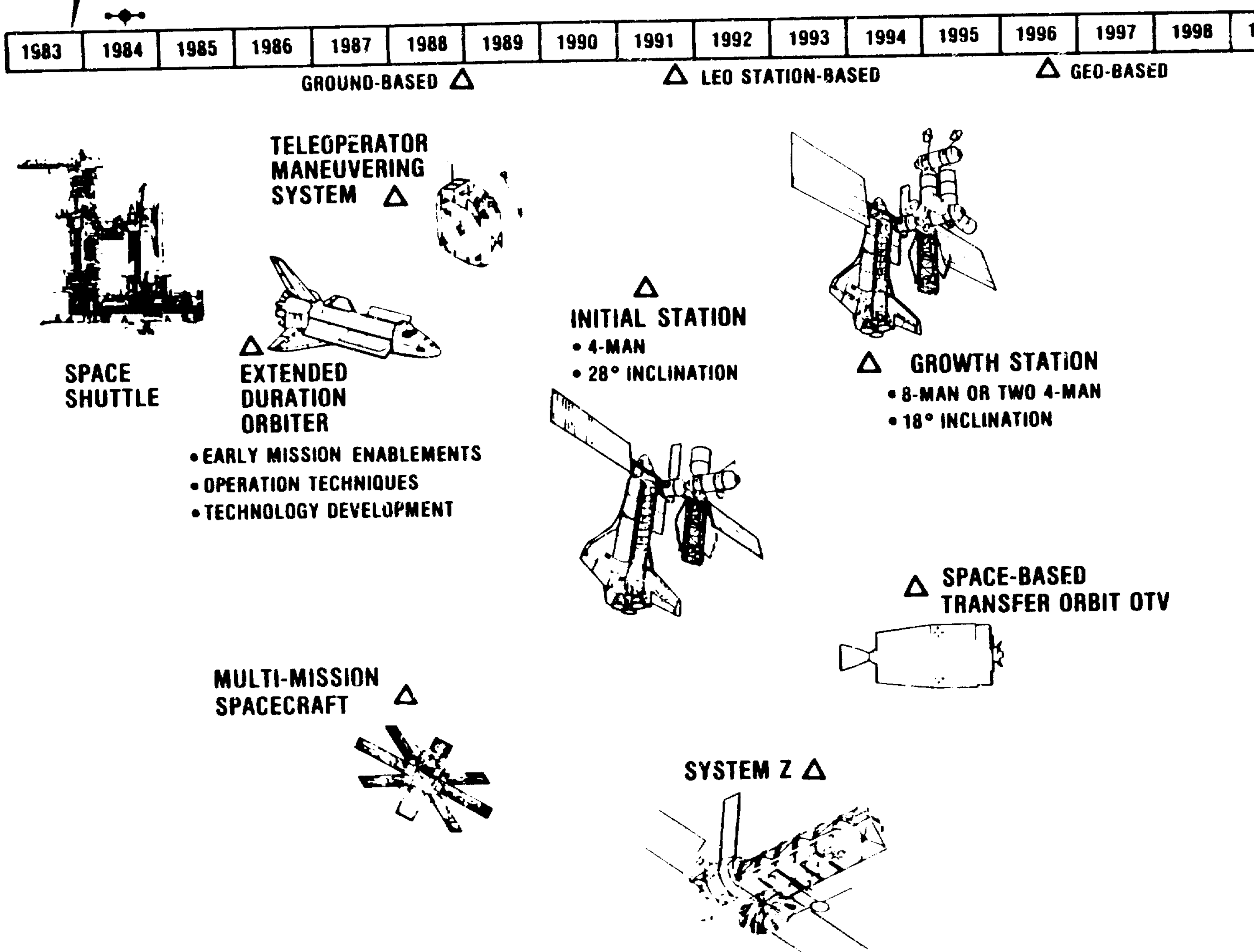
An initial 4-man station along with a space-based TMS will have capabilities for LEO placement and retrieval, station attached and integral mission payloads, storage, and LEO servicing. This station is located at 28° inclination and 200 nmi altitude. Free-flyers and the multi-mission spacecraft (MMS) can support mission payload needs in the vicinity of the station.

An evolutionary Space Station and a space-based OTV are introduced in 1994. The evolutionary Space Station may be the initial Space Station with growth to 8 men and with mission capabilities (in addition to initial capabilities) including OTV high energy orbit payload placement and servicing, assembly, and construction of mission payloads. As an option, two 4-man Space Stations co-orbiting at 28° may be desirable to split potentially incompatible functions of research/development and operations.

System Z, proposed by JPL and Goddard for earth observation missions in high inclination orbit, is accommodated in 1993 using a Space Station derivative platform.

SPACE STATION

RECOMMENDED SPACE SUPPORT SYSTEM PROGRAM ARCHITECTURE ...



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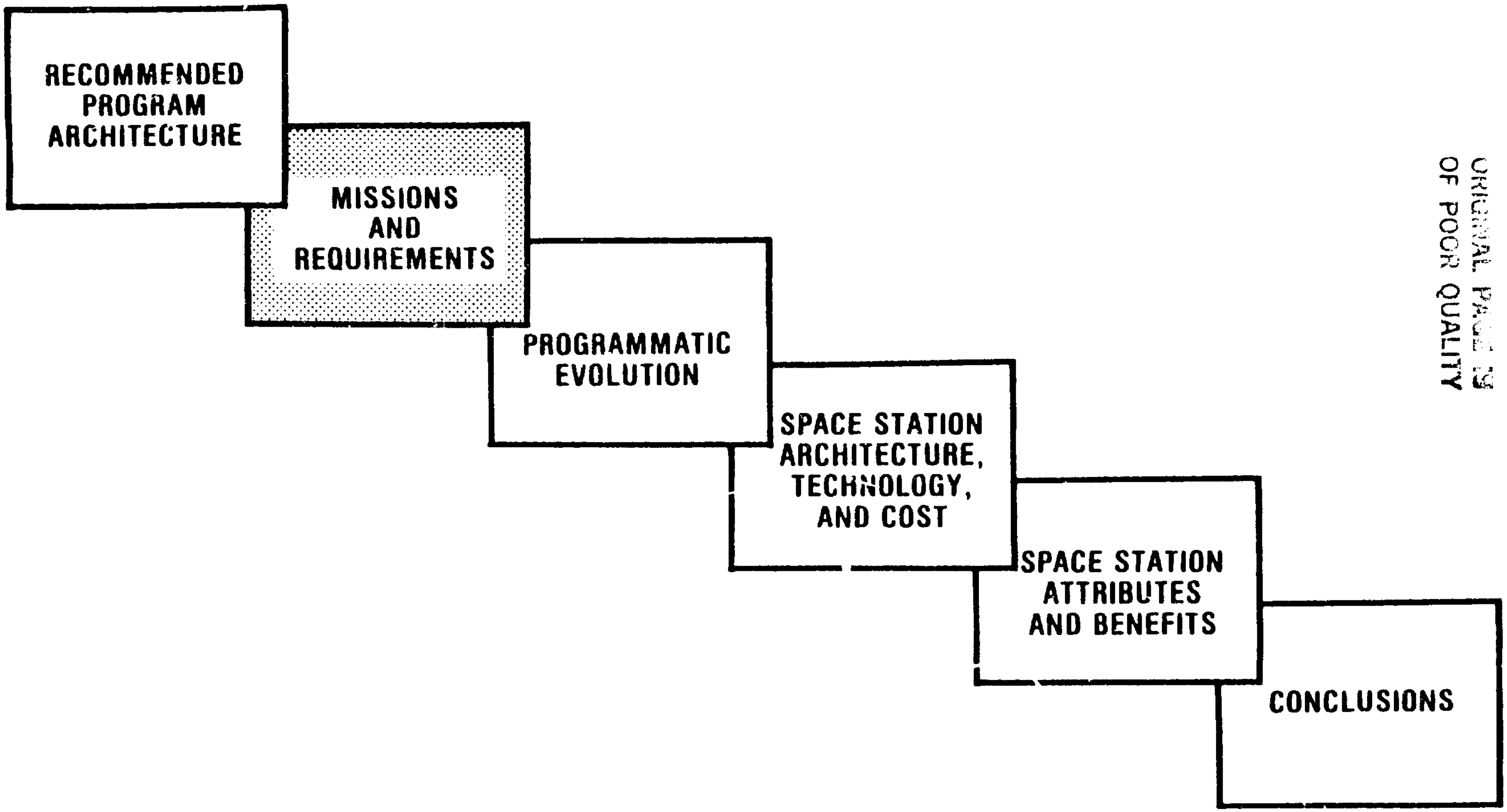
SUMMARY BRIEFING OUTLINE ...



MISSION, SERVICES, AND SUPPORT SYSTEM MATRIX

Space support systems provide the services needed by mission payloads. The approach used to develop the requirements was to determine the services required by the mission payloads. These services are provided by potential alternative support systems dependent upon their availability and the orbital service location. Requirements for a support system are determined by the frequency of the services (derived from the mission model) and the time-phased resource demands of the services. Total requirements are determined by adding the requirement of the support system itself to the mission services requirement. Resources include man-hours, power and heat rejection, data, attitude control, g-level, volume, attachment ports, and length of a linear payload retention facility.

The following series of charts summarize the mission model, the systems providing the support, and the time-phased requirements imposed on the Space Station.

SPACE STATION

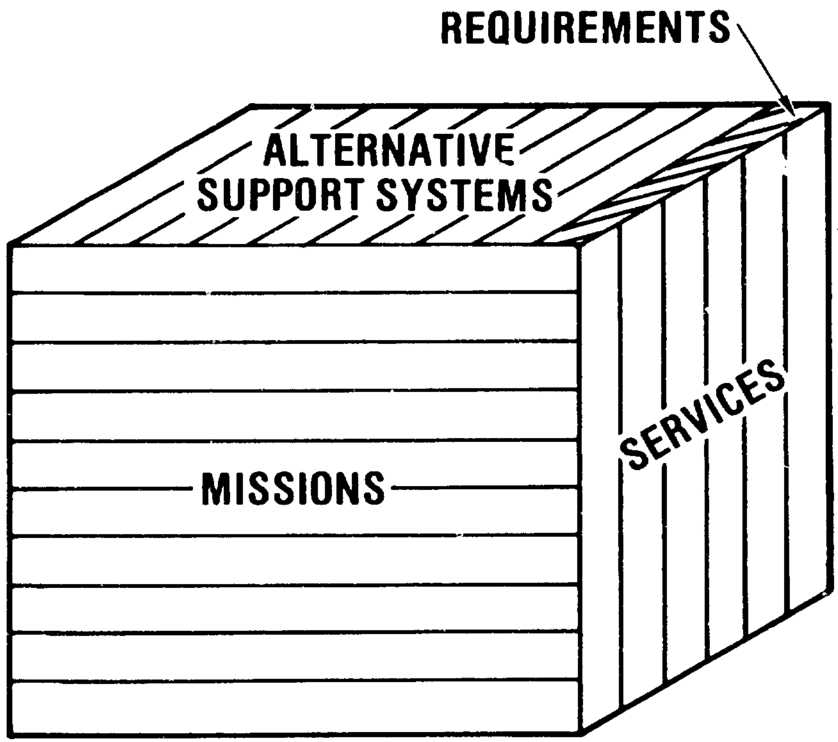
MISSION, SERVICES, AND SUPPORT SYSTEM MATRIX ...

ALTERNATIVE SUPPORT SYSTEMS

- EXPENDABLE LVs
- SHUTTLE
- HLLV
- EXPENDABLE UPPER STAGES
- REUSABLE OTVs
- SPACE STATION
- FREE FLYER S/C
- SPACE PLATFORM
- TMS

MISSION AREAS

- NASA SCI & APPL
- NASA TECHNOLOGY DEV
- GOVERNMENT ENVIRONMENTAL
- DOD
- COMMERCIAL COMM
- COMMERCIAL SPACE PROC
- COMMERCIAL RESOURCES



SERVICES

- LEO PLACEMENT
- LEO SERVICING
- LEO RETRIEVAL
- HEO PLACEMENT
- HEO SERVICING
- ATTACHED P/L
- INTEGRAL P/L
- CHECK-OUT
- DEPLOYMENT
- ASSEMBLY/CONSTR
- STORAGE

MISSION MODEL LEVEL PHILOSOPHY (1991-2000)

This chart summarizes the philosophy that drives the low, medium, and high mission models for each of the mission areas. It also shows the total number of mission payloads and their masses. The masses are only those of the payloads as delivered by the transportation system to their operational orbits. To determine total mass in the Shuttle, other masses need to be added. These include ASE mass, propellant and stage masses, and space support system masses.

MISSION MODEL LEVEL PHILOSOPHY... (1991-2000)

MISSION AREA	LOW	MEDIUM	HIGH
SCIENCE AND APPLICATIONS	• SHARED LIFE SCIENCES FACILITIES • AUSTERE PLANETARY PROGRAM • LIMITED OBSERVATION RESEARCH • VIGOROUS ASTROPHYSICS PROGRAM • 143 MISSIONS • 540 KLB MASS	• DEDICATED LIFE SCIENCES MODULE • PLANETARY SAMPLE RETURN • SYSTEM Z • GEO SERVICING • 164 MISSIONS • 640 KLB MASS	• EARLIER LIFE SCIENCE RESEARCH — • 167 MISSIONS • 670 KLB MASS
TECHNOLOGY DEVELOPMENT	• PROGRAMS MADE TO FIT WITHIN AUSTERE LIMITS — SCHEDULES STRETCHED • 15 MISSIONS • 40 KLB MASS	• EMPHASIS ON "MAN-IN-STREET" BENEFITS • OTHER PROGRAMS STRETCHED OUT • 19 MISSIONS • 90 KLB MASS	• FUTURE MAJOR SPACE INITIATIVES SUPPORTED WITH REASONABLE SCHEDULE • 22 MISSIONS • 100 KLB MASS
DOD	• BUSINESS AS USUAL • DOD-SUPPLIED MISSION MODEL + 4 SPECIAL MISSIONS • 153 MISSIONS • 1180 KLB MASS	• MAKE SPACE ASSETS ENDURING (SURVIVABLE) • LEO STORAGE & SELECTIVE SERVICING • 233 MISSIONS • 2490 KLB MASS	• MOVE STRATEGIC & TACTICAL OPERATIONS INTO SPACE • MEDIUM + DEFENSE & ADVANCED RADAR SYSTEMS • 333 MISSIONS • 4890 KLB MASS
COMMERCIAL COMMUNICATIONS	• EXTRAPOLATION OF CURRENT USERS • LOW CAPTURE BY STS AND SP STN • 3 NEW USERS / YR • 106 MISSIONS • 350 KLB MASS	• MOST LIKELY CAPTURE BY STS & SP STN • 4 NEW USERS / YR • MULTI-USER SYSTEMS • 158 MISSIONS • 580 KLB MASS	• STS & SP STN VERY COMPETITIVE vs ELV's • 6 NEW USERS/YR • MORE MULTI-USER SYSTEMS • 239 MISSIONS • 880 KLB MASS
COMMERCIAL SPACE PROCESSING	• PESSIMISTIC MARKET • 9 PRODUCTS • CONSTRAINED RESEARCH • 314 MISSIONS • 440 KLB MASS	• MEETS MOST LIKELY MARKET DEMAND • 16 PRODUCTS • RESEARCH 2 X LOW • 407 MISSIONS • 640 KLB MASS	• MEETS OPTIMISTIC MARKET • 23 PRODUCTS • RESEARCH 3 X LOW • 524 MISSIONS • 860 KLB MASS
TOTAL MISSIONS TOTAL MISSION MASS	731 2550 KLB	981 4440 KLB	1285 7400 KLB

MISSION LOCATIONS AND MASS FLOWS — MEDIUM MISSION MODEL

This chart summarizes where the missions in the medium mission model are located, in terms of inclination and altitude. Three regions (A) low inclination, (B) medium inclination, and (c) high inclination are identified to classify location. Within these regions, low earth orbit (LEO) and high energy orbit (HEO) is used to define their general altitude locations.

The table shows that the most predominant location for missions, total mass to orbit, and crew hours is the low inclination location. This suggests that this may be the best location for a Space Station to provide services to mission payloads either residing in this location or passing through on their way to high energy orbits. Mission analyses have indicated that a Space Station located at a 28° inclination and a 200 nmi altitude can provide a wide variety of services, which are discussed on the next chart. These analyses also show that it is possible and cost-effective to do most of the medium inclination payload placements through the Space Station, thus increasing the capture capability of the Space Station.

SPACE STATION

MISSION LOCATIONS AND MASS FLOWS — MEDIUM MISSION MODEL ...

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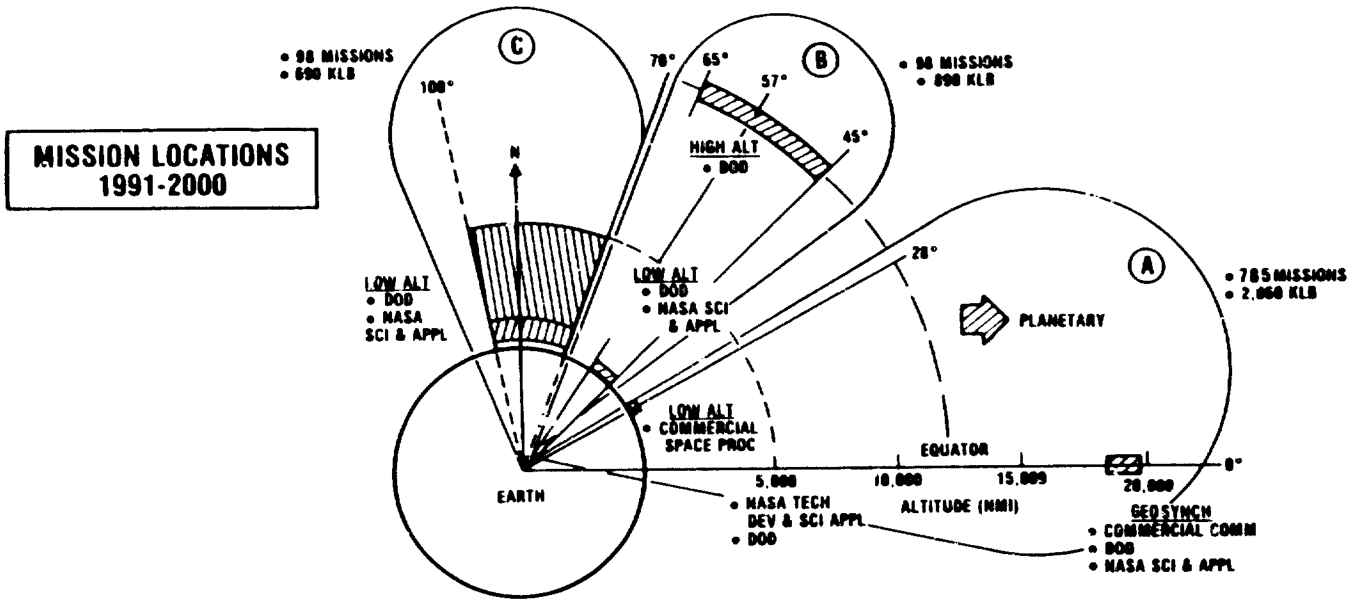


* MASS FLOW THROUGH REGIONS — 1991-2000

LOCATION	NO. OF MISSIONS	MISSION MASS (MILLIONS OF LB)	PROPELLANT MASS (MILLIONS OF LB)	OTHER SYST MASS (MILLIONS OF LB)	TOTAL CARGO MASS (MILLIONS OF LB)	CREW HOURS
A	848	3.0	3.0	5.4	11.4	149,500
B	35	0.8	—	—	0.8	200
C	98	0.7	—	0.6	1.3	3,700
TOTAL	9[illegible]	4.5	3.0	6.0	13.5	153,400

*ASSUMES SPACE STATION AT 28.5° INCLINATION

SELECTED ACCOMMODATION MODES AND SPACE STATION ACCOMMODATION OF MISSIONS

The next two charts summarize the manner in which the mission services desired by the mission payloads are provided for each inclination region. It is assumed that the Space Station is located at a 28° inclination and a 200 nmi altitude. The Space Station would probably not have all of the services listed initially. This accommodation description applies, therefore, to the evolutionary Space Station.

The geometry of mission payloads that are on free-flyers near the station fall into two general categories. One category is those that essentially co-orbit with the Space Station. These payloads include the space processing free-flyers which desire frequent harvesting of products. The other category is NASA Science and Application free-flyers and DOD stored payloads that would need servicing infrequently (one year or greater). These satellites are located at a higher altitude than the station and, although they are also in a 28° inclination, their orbital plane aligns with the station orbital plane about once a year to allow servicing, if desired.

All low inclination placement missions for LEO and HEO go through the Space Station. The LEO payloads are placed in their mission locations by the TMS (which is space-based at the station). HEO payloads are placed in their mission locations using an OTV (also space-based at the Space Station). LEO medium inclination payloads are delivered by the Shuttle directly or by the Shuttle and TMS. HEO medium inclination payloads are delivered to their mission orbits through the Space Station using the OTV. Mission analysis studies have shown this to be the best mode.

No high energy missions exist at high inclination. LEO missions in this region (placement, servicing, and retrieval) are accomplished by the Shuttle or the Shuttle and TMS.

Servicing at LEO and low inclination of the two streams of satellites in the vicinity of the station is accomplished using the TMS in a remote servicing mode. The Shuttle or Shuttle/TMS are used to conduct servicing at LEO in medium inclination orbits. The only HEO servicing currently planned occurs at geosynchronous orbit (certain DOD payloads and communication satellites). These missions are accomplished using a TMS that is based at geosynchronous orbit (GEO). The station-based OTV delivers propellants and other servicing payloads to the TMS. Obviously, the GEO TMS is of a somewhat different design than the LEO TMS.

Some of the Science and Applications missions and all of the pharmaceutical electrophoresis process missions are flown on the multi-mission spacecraft (MMS). Station-attached or integral missions include life sciences, pharmaceutical electro-focusing process and crystal growth production, space processing research (NASA and industry), and sortie pallet missions. System Z (sun synchronous orbit) uses a power platform that is a derivative of the Space Station power module and payload support module.

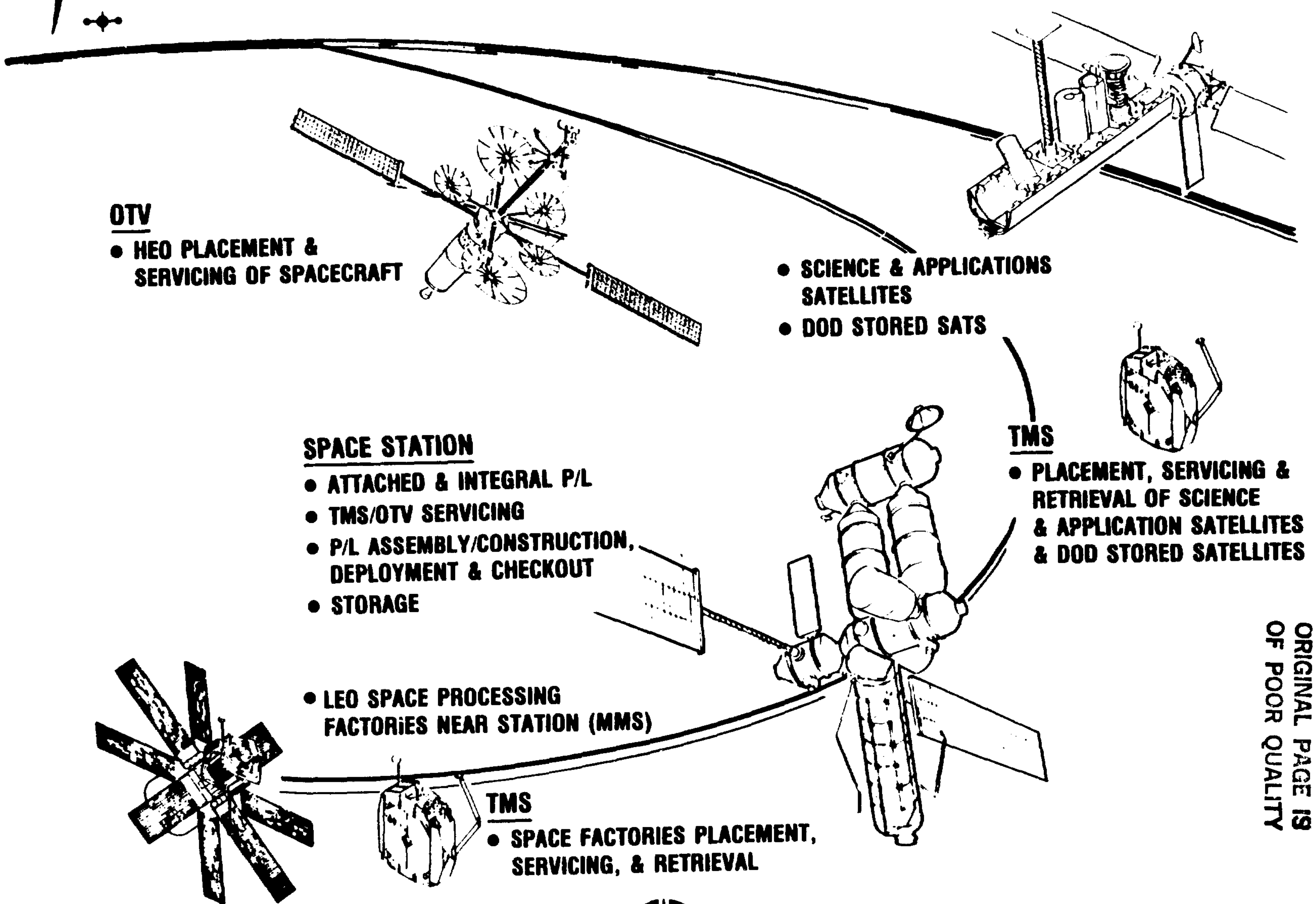
The large 12,000 lb communications satellites are assembled at the station, deployed, and checked out prior to CTV launch to GEO. Deployment and checkout of some smaller communication satellites also occurs prior to launch.

Propellant storage at the station is extremely important in decoupling the mission payloads, upper stages, and propellants in the Shuttle manifest. This allows Shuttle cargo load factors apporaching 1.0 rather than 0.65 which is experienced without this capability.

SELECTED ACCOMMODATION MODES ...

USER SERVICES	SELECTED ACCOMMODATION MODE — INCLINATION REGION: 28°	57°	POLAR
• LEO PLACEMENT	STATION / TMS	SHUTTLE / TMS	SHUTTLE / TMS
• LEO SERVICING	STATION / TMS	SHUTTLE / TMS	SHUTTLE
• LEO RETRIEVAL	STATION / TMS	SHUTTLE / TMS	SHUTTLE / TMS
• HEO PLACEMENT	STATION / OTV	STATION / OTV	—
• HEO SERVICING	STATION / OTV / TMS	—	—
• ATTACHED P/L	STATION / MMS	—	MMS / SYSTEM Z PLATFORM
• INTEGRAL P/L	STATION	—	—
• CHECKOUT	STATION	SHUTTLE	—
• DEPLOYMENT	STATION	SHUTTLE	—
• ASSEMBLY / CONSTR	STATION	—	—
• STORAGE	STATION	—	—

SPACE STATION ACCOMMODATION OF MISSIONS . . .



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TIME-PHASED SPACE STATION REQUIREMENTS

The following series of charts summarize the key Space Station requirements for the crew, power, payload service assembly, mission payload mass, user propellant requirements, and data.

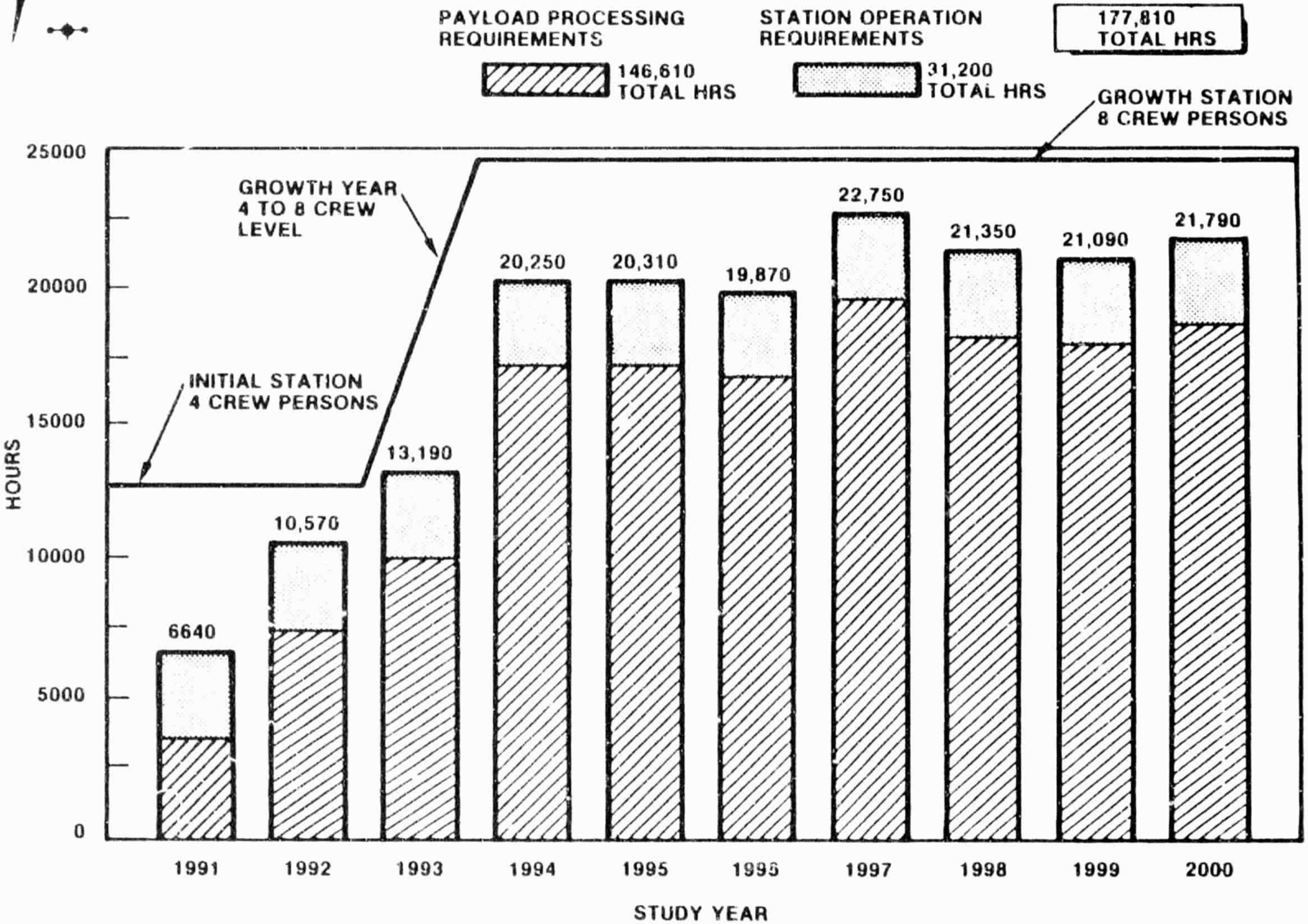
An initial four-man crew provides sufficient capability during the first three years to meet the station and payload processing requirements. Growth to an eight-man capability in 1984 provides ample crew to meet the same requirements. The major requirements for man-hours arises from space processing, which also has the least mass flow through the station.

Power capability of the station is shown as end-of-life power. For this reason, the initial station has sufficient power to meet the integrated requirement. The growth station also has sufficient capability with 50 kW at the bus.

Requirements for the payload service assembly (PSA) indicate a maximum of about 810 feet-days for an entire year. The PSA design is about 43 feet in length and provides 15,600 feet-days in a year.

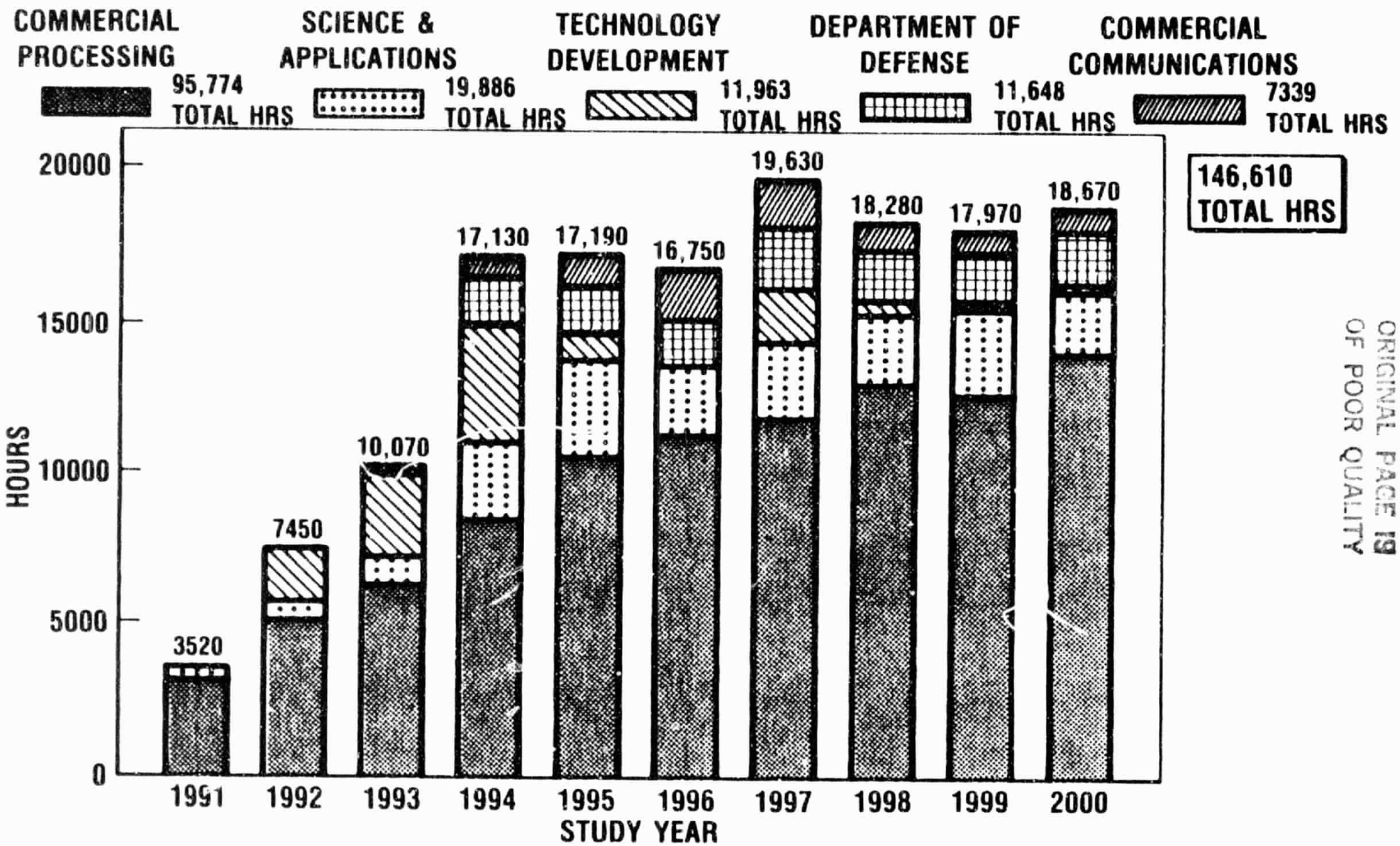
Both the TMS and OTV require propellants at the station in their space-based mode. The bipropellant requirements for the TMS are small compared to the LO_2/LH_2 requirement of the OTV. The OTV requires about 460 pounds of propellant in the peak year.

INTEGRATED CREWHOURS REQUIREMENTS...



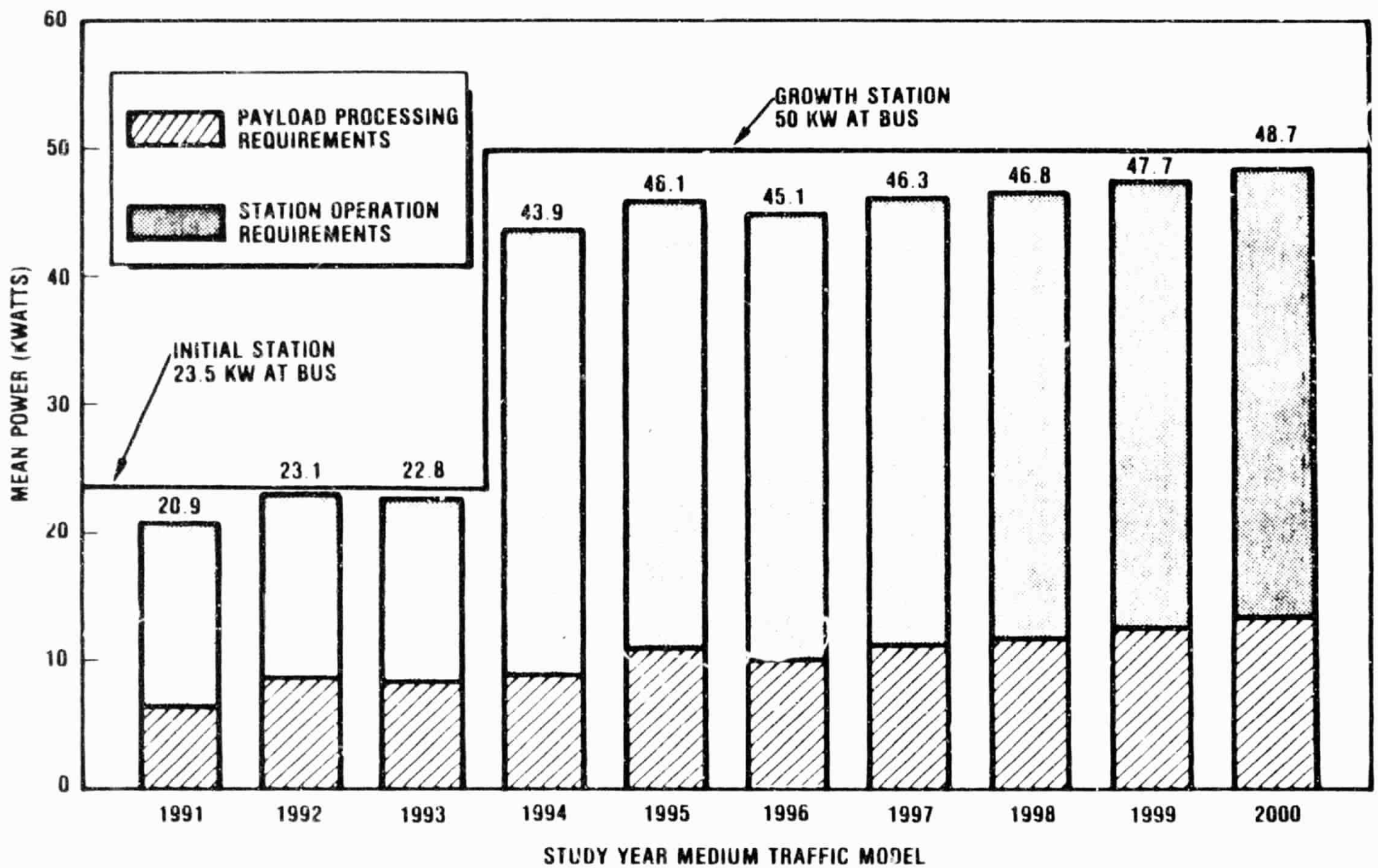
MEDIUM TRAFFIC MODEL

USER MISSION PAYLOAD CREWHOURS . . .



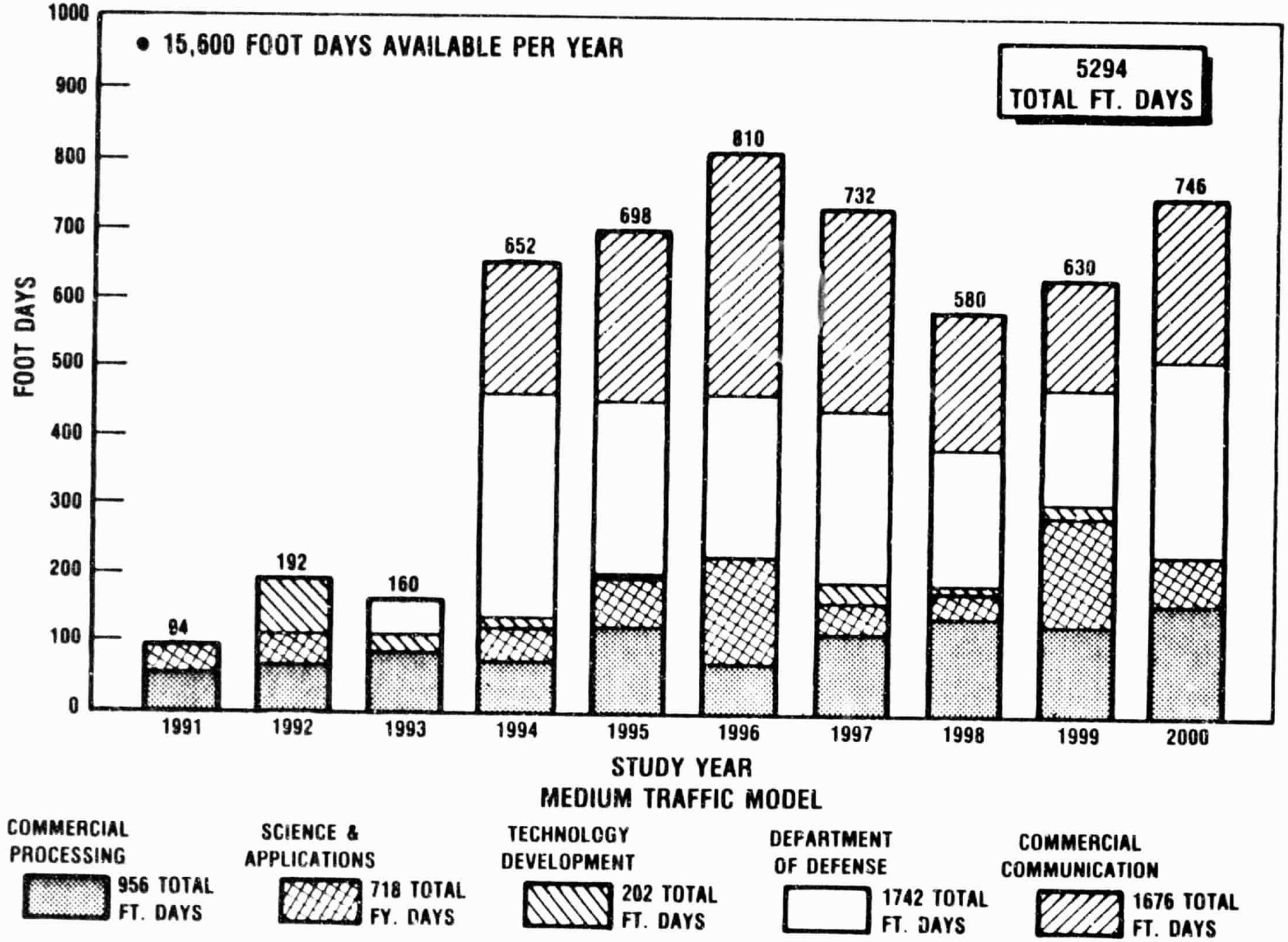
MEDIUM TRAFFIC MODEL

INTEGRATED POWER REQUIREMENTS...



SPACE STATION

PAYLOAD SERVICE ASSEMBLY REQUIREMENTS . . .



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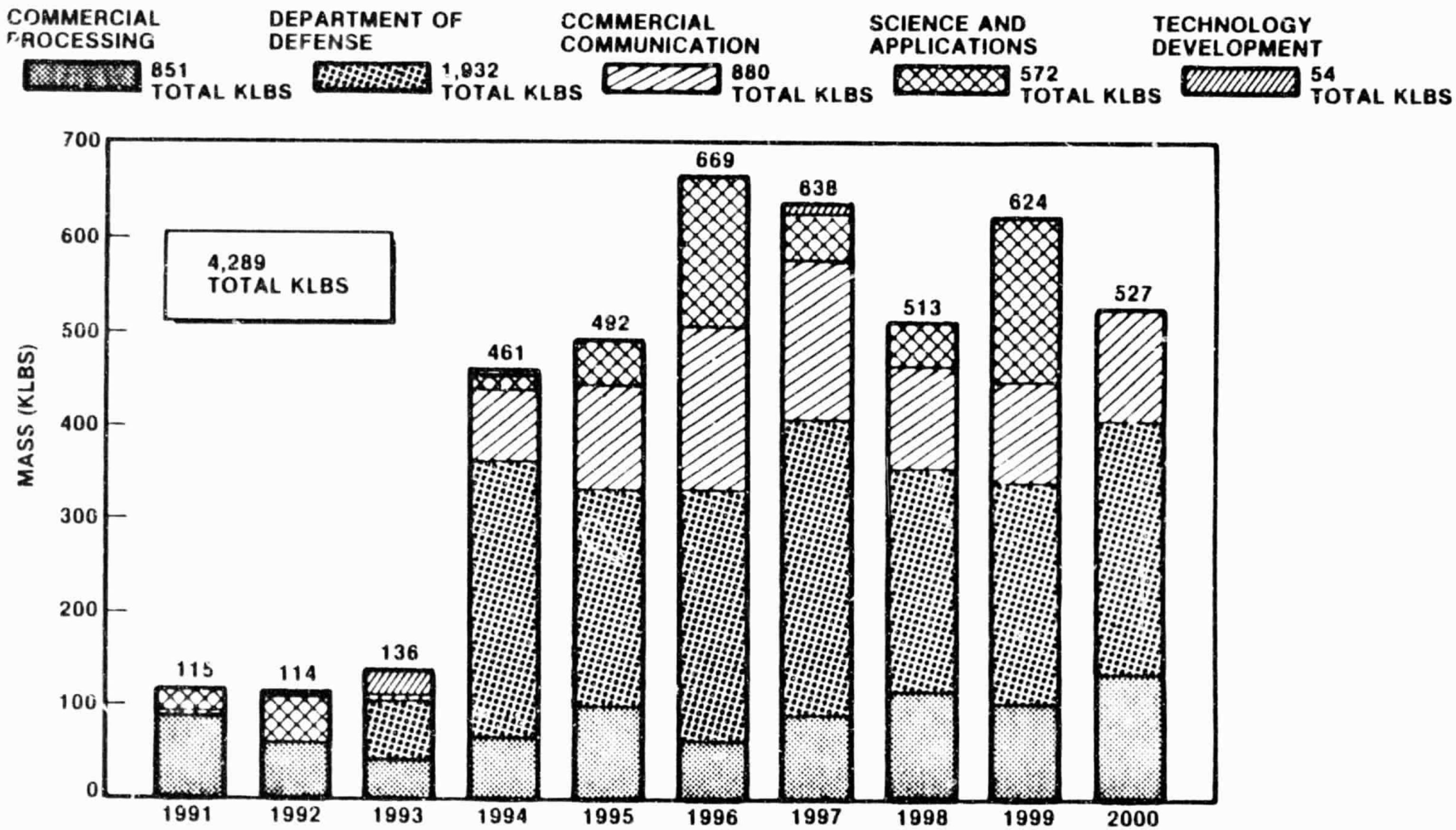
SPACE STATION

USER MISSION PAYLOAD MASS PROCESSED...



MEDIUM TRAFFIC MODEL

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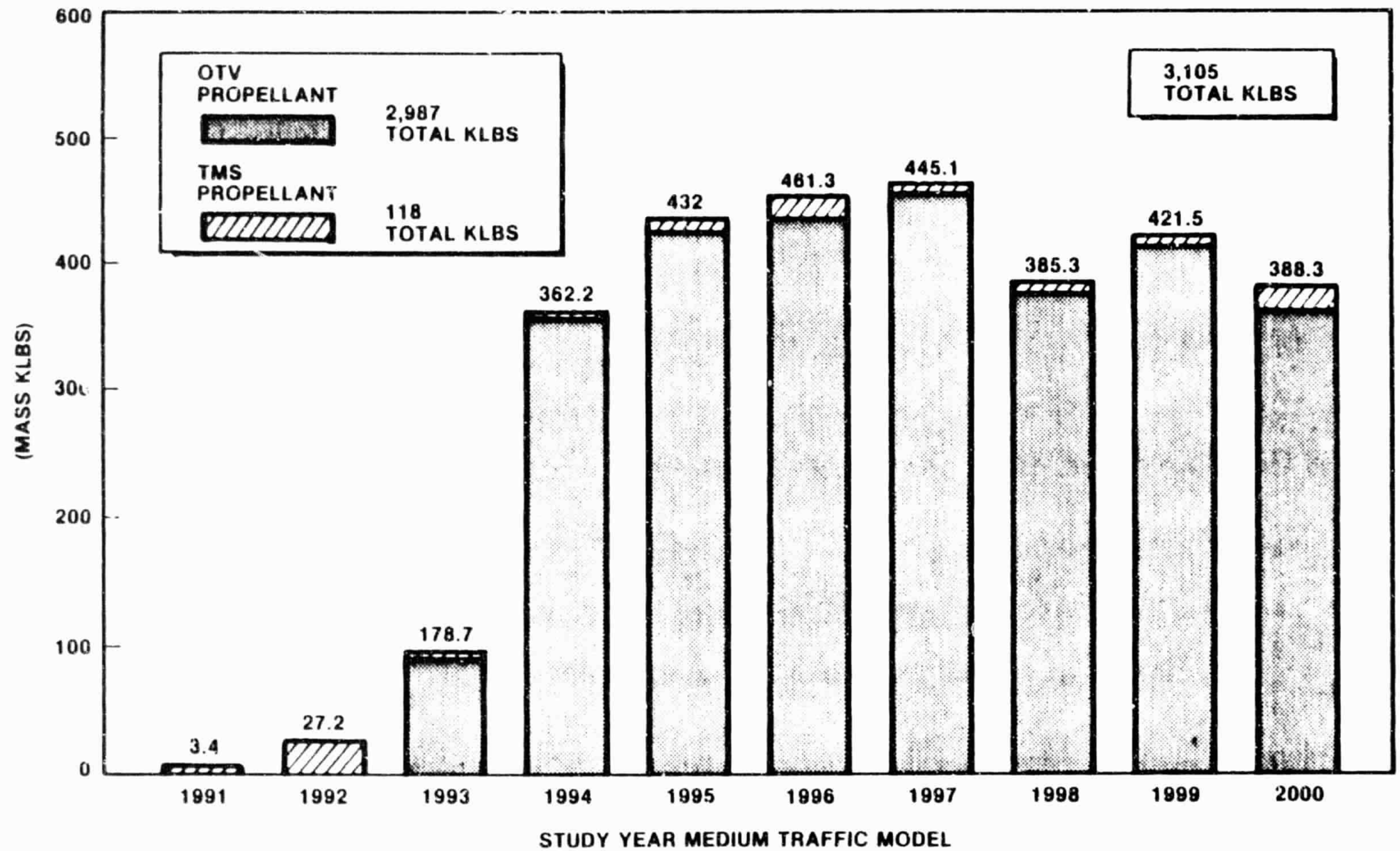
USER MISSION PROPELLANT REQUIREMENTS...



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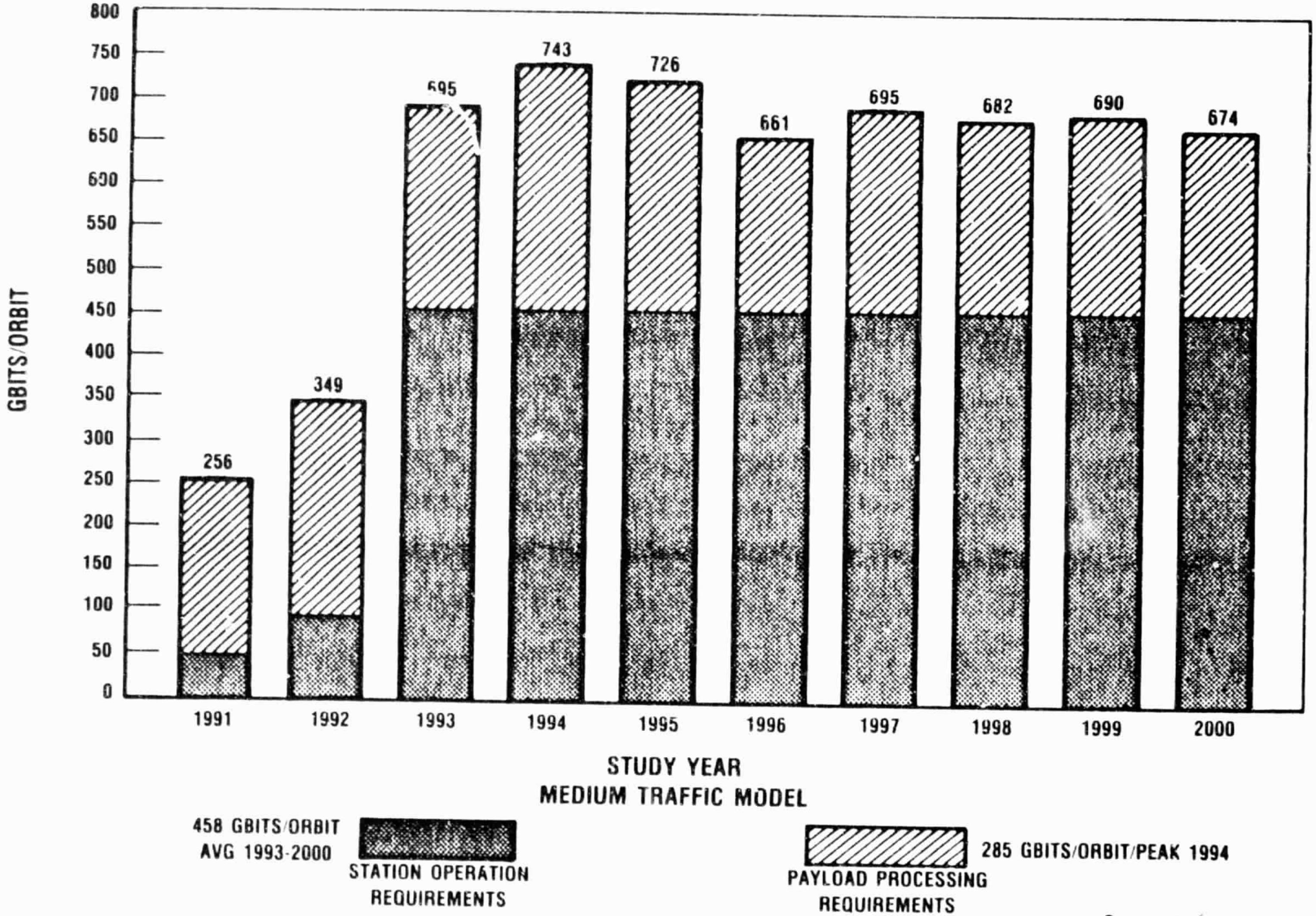
INTEGRATED DATA REQUIREMENTS . . .



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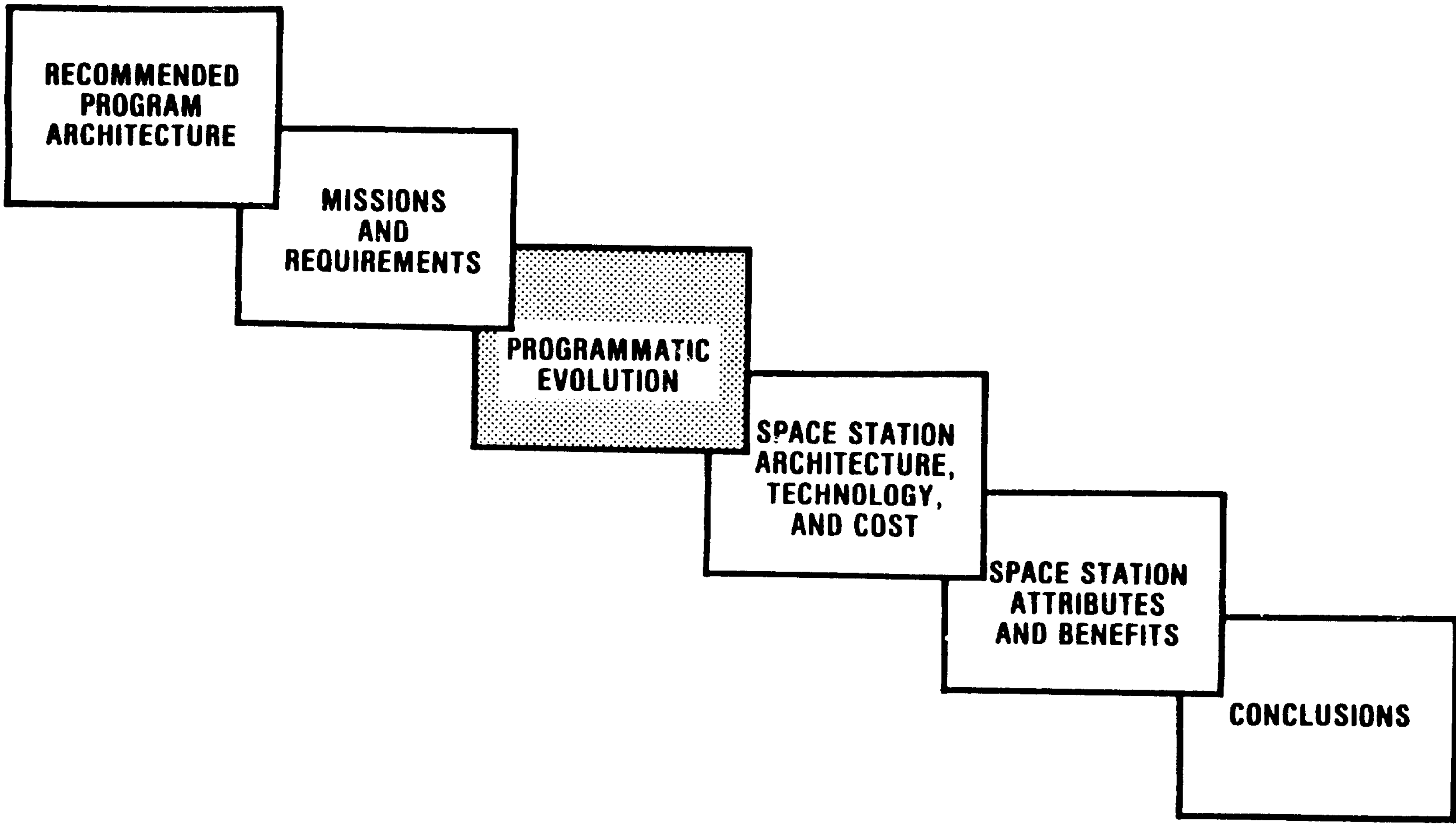
SUMMARY BRIEFING OUTLINE ...



PROGRAMMATIC ISSUES

The most significant programmatic issues that were answered as a result of this study are:

- What is the best orbital location for the Space Station?
- What are the most effective Space Station services and when should they and can they be introduced?

The following series of charts provide the key data that answers these issues.

PROGRAMMATIC ISSUES ...

- WHAT IS THE BEST ORBITAL LOCATION FOR THE SPACE STATION?
- WHAT ARE THE MOST EFFECTIVE SPACE STATION SERVICES & WHEN SHOULD THEY & CAN THEY BE INTRODUCED?

PROGRAM OPTIONS DEFINITION AND JUSTIFICATION

This chart defines the program options that were initially studied to determine the impact of total program and Space Station functions and location on Shuttle launches and program cost.

The first two options are single function Space Station options and are located at a 28° inclination and 200 nmi altitude. Option 1 conducts only high energy mission staging using a space-based reusable OTV. Shuttle scavenging is used to maximize propellant payload. The second option conducts only space processing mission support. High energy missions and other missions are conducted out of the Shuttle. The third option, also located at 28° and 200 nmi provides support to all of the primary mission areas. This option also has space-based OTV's and TMS's. Shuttle propellant scavenging once again is used to maximize propellant mass to orbit. In Option 4, the Space Station is located at a 57° inclination and a 200 nmi altitude. This station supports space processing and a small number of Science and Applications missions that can be conducted in this region. The fifth option assumes no change in current and planned space support systems (no station). This option is used as a comparator to show how the Space Station options benefit compared with no station. A sixth option considered the use of two small stations located at 28° and 57° inclinations. The 28° station accomplished HEO staging (GEO and planetary) and supported local Science and Applications missions. The 57° station supported local Science and Applications and space processing missions and provided HEO staging of missions in the medium inclination region.

PROGRAM OPTIONS DEFINITION AND JUSTIFICATION ...

	SPACE STATION			OTHER ELEMENTS			
OPTION	FUNCTIONS	LOCATION	SIZE	OTV	TMS	SHUTTLE	JUSTIFICATION
1	HIGH-ENERGY MISSION STAGING	28^0 200 nmi	4-MAN	SPACE-BASED REUSABLE SINGLE-STAGE CRYOGENIC	GROUND-BASED & SPACE BASED REUSABLE BI-PROPELLANT	PROPELLANT SCAVENGING	DETERMINE FEASIBILITY SINGLE-PURPOSE SPACE STATION & COMPARE WITH OPTION 5
2	SPACE PROCESSING MISSION SUPPORT	28^0 200 nmi	4-MAN	PAM A&D IUS IUS FIRST STAGE CENTAUR F&G	SAME AS OPTION 1	STANDARD	DETERMINE FEASIBILITY OF SINGLE -PURPOSE SPACE STATION
3	MULTIPLE MISSION SUPPORT	28^0 200 nmi	4-MAN 8-MAN	SAME AS OPTION 1	SAME AS OPTION 1	SAME AS OPTION 1	DETERMINE SYNERGISM OF COMBINED FUNCTIONS
4	SPACE PROCESSING & SCIENCE & APPLICATIONS MISSION SUPPORT	57^0 200 nmi	4-MAN	SAME AS OPTION 2	SAME AS OPTION 1	SAME AS OPTION 2	DETERMINE IMPACT OF ORBITAL INCLINATION
5	NO SPACE STATION			PAM A&D IUS IUS FIRST STAGE CENTAUR F&G	GROUND-BASED REUSEABLE BI-PROPELLANT	STANDARD	BASELINE PROGRAM FOR COMPARISONS
6	TWO SMALL MULTI-FUNCTIONAL STATIONS	28^0 200 nmi 57^0 200 nmi	4-MAN 4-MAN	SAME AS OPTION 1	SAME AS OPTION 1	PROPELLANT SCAVENGING	BALANCED MISSION SUPPORT AT TWO LOCATIONS

COMPARISON OF PROGRAM OPTIONS

This chart compares the six program options. The data show the total number of Shuttle launches, total space support system cost (development, production and operations), and a Shuttle launch summary for OTV options for program Option number 3 (multi-mission support at 28° inclination).

The launch summary shows that Option 3 leads to the lowest number of Shuttle launches. In addition, the cost comparison shows that Option 3 also leads to the lowest total support system cost through the year 2000.

The program cost and launch summaries assumed the use of a single stage reusable OTV that is space-based at the station. The following upper stage options are compared:

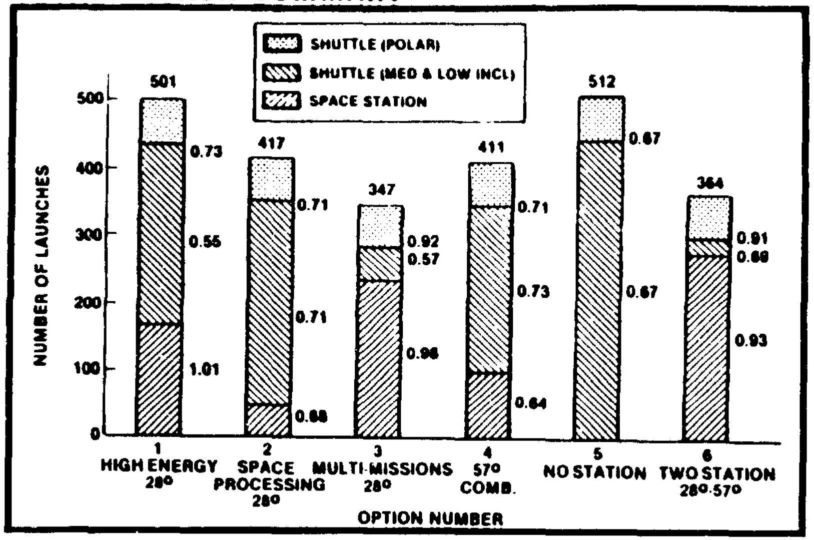
- Option 3 - Single Stage Reusable OTV space-based at station
- Option 5 - No OTV and no Space Station
- Option 7 - Aerobraker Reusable OTV space-based at station
- Option 8 - Perigee Kick Stage Reusable OTV based at station

As shown, the PKS OTV results in the lowest number of Shuttle flights.

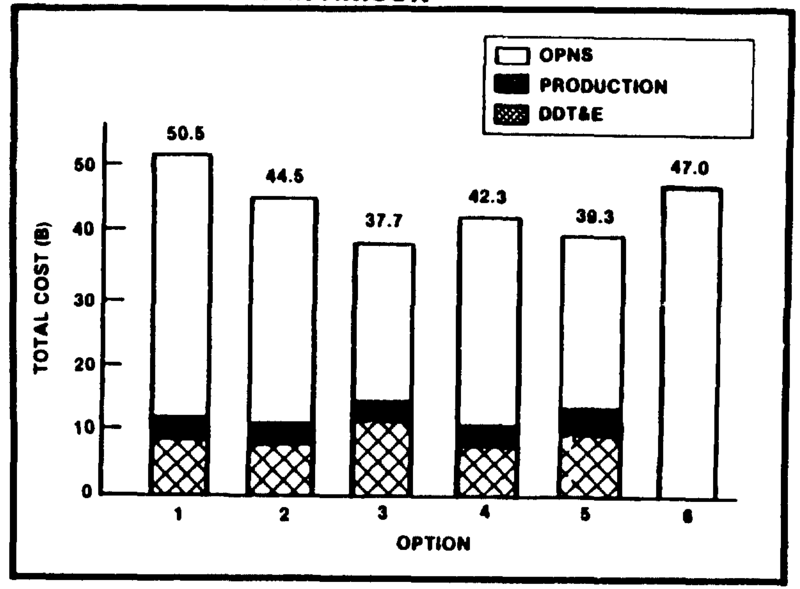
Because of the above comparison, a multi-functional Space Station located at 28° inclination and 200 nmi altitude was selected for the conduct of more detailed subsequent studies. As will be shown, this Space Station benefits significantly all user areas in addition to being the most cost-effective overall. The perigee kick-stage OTV was selected to be space-based at this station. It is expected that the aerobraking OTV will eventually be developed for missions beyond the year 2000 where either large round-trip payloads (such as manned missions) to GEO may exist or where retrieval of payloads may be important.

COMPARISON OF PROGRAM OPTIONS ...

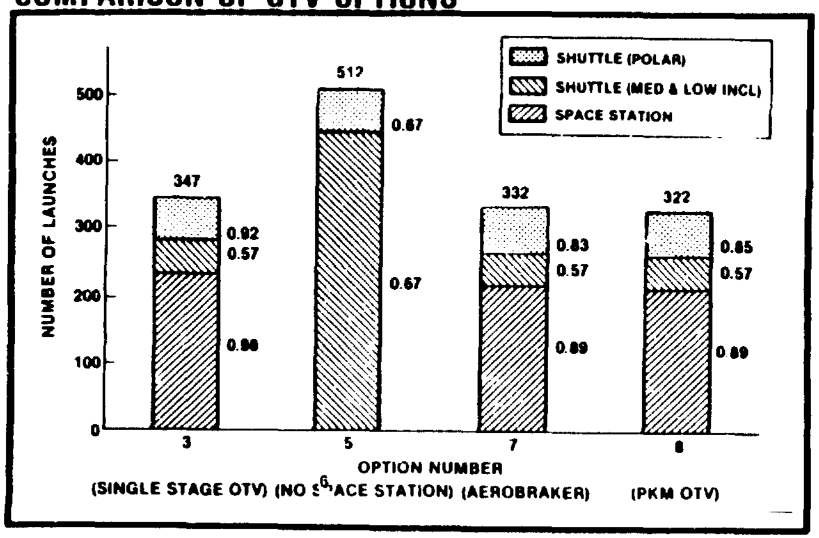
TOTAL LAUNCH SUMMARY



OPTIONS COST COMPARISON



COMPARISON OF OTV OPTIONS



CONCLUSION

- MULTIFUNCTIONAL STATION AT 28°
- REUSABLE LO_2/LH_2 PERIGEE KICK STAGE OTV SPACE-BASED AT STATION

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EVALUATION OF SPACE STATION SERVICES TIMING

Timing of Space Station services depends upon three major considerations: (1) when the user needs it, (2) when technology or demonstration of the service is available, and (3) if it is a government-provided service, when budgetary considerations will allow it to happen. This chart provides an estimate of the date for initial operational capability of each Space Station service.

The user need is virtually immediate at initial station IOC for low orbit placement and retrieval, high orbit placement, low orbit servicing, attached and integral missions, and storage. All of these, except high orbit placement (using an OTV), can be provided at or soon after the Space Station IOC in 1991. For these services, technology development or demonstration is either unnecessary or can be accomplished out of the Shuttle prior to the Space Station IOC. If it is assumed that the TMS will be developed and used in Shuttle prior to the station IOC, budgetary considerations are not important for these services.

High orbit placement with the OTV space-based at the station is more challenging, however, because of the need to store and transfer cryogenic propellants on orbit and the cost of development of this capability and a new OTV. It is believed that most of the technology development and demonstration could be accomplished out of the Shuttle and that two years or less would be required at the station to provide an initial capability. In order to avoid an overlapping development of the Space Station and space-based OTV it is estimated that a delay in OTV IOC to 1994-1995 may be necessary. For this study, the final manifesting analyses assumed a space-based OTV capability in 1994.

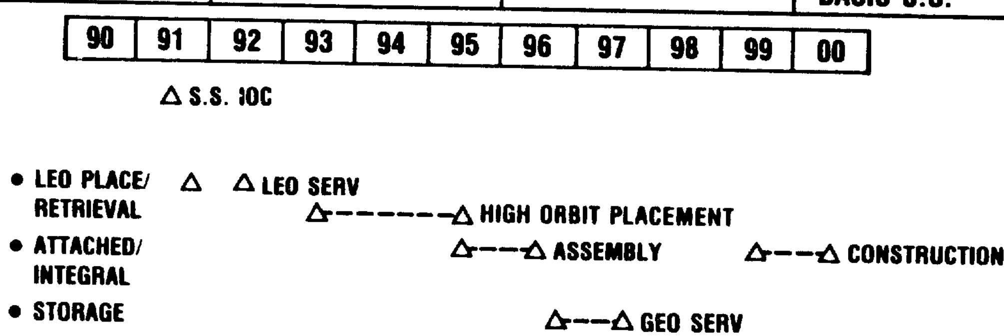
The user need for assembly and construction of mission payloads at the station probably will not occur until 4-5 years after demonstration of this capability at the Space Station by NASA. IOC dates for these capabilities would be 1995-1996 for assembly and 1999-2000 for construction. It does not appear, at this time, that budgetary considerations for these capabilities are important.

The only high energy orbit servicing that appears practical is in geosynchronous orbit, since a number of payloads exist in a single orbital plane and altitude. Users commitment to GEO servicing will probably be contingent upon successful early LEO servicing and OTV availability. Development costs will entail TMS modifications for a long-term stay at geosynchronous orbit with only resupply from the Space Station. An IOC of 1996-1997 is estimated for this capability.

SPACE STATION

EVALUATION OF SPACE STATION SERVICES TIMING . . .

SERVICES	USER NEED	TECH/DEMO	BUDGETARY	IOC
LOW ORBIT PLACEMANT / RETRIEVAL	AT S.S.IOC	OUT OF SHUTTLE WITH TMS	BEFORE S.S. IOC (TMS)	1991
HIGH ORBIT PLACEMENT	AT S.S. IOC	SHUTTLE + S.S. (≈ 2 YRS)	COMMERCIAL? GOVERNMENT (1.1B)	1993-1995
LOW ORBIT SERVICING	AT S.S. IOC	OUT OF SHUTTLE + S.S. (≈ 1 YR)	SMALL $	1992
HIGH ORBIT SERVICING	4-5 YEARS AFTER COMMITMENT	EARLY LEO SERV + OTV AVAIL	TMS MODS (100M̄)	1996-1997
ATTACHED/INTEGRAL MISSIONS	AT S.S. IOC	NOT NECESSARY	AVAILABLE WITH BASIC S.S.	1991
ASSEMBLY	4-5 YRS AFTER COMMITMENT	1991	ASSEMBLY EQUIP (100M̄)	1995-1996
CONSTRUCTION	4-5 YRS AFTER COMMITMENT — WEAK REQUIREMENT	1995	CONSTRUCTION EQUIP (200M̄)	1999-2000
STORAGE	AT S.S. IOC	NOT NECESSARY	AVAILABLE WITH BASIC S.S.	1991



COST IMPACTS OF GROWTH STATION AND OTV TIMING

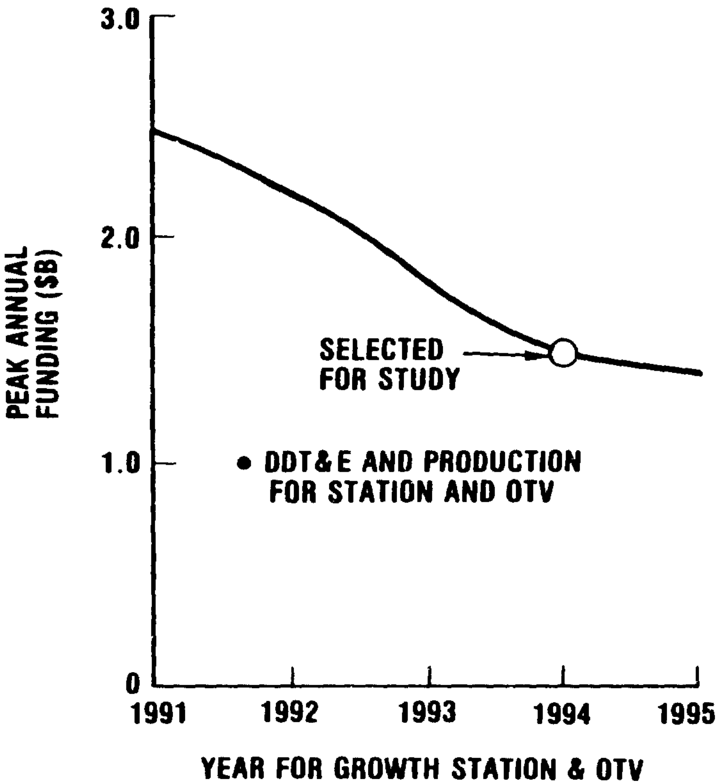
This chart shows the effects of the growth station and OTV introduction year on peak annual funding and high energy users (commercial communications, DOD, and NASA Science and Applications) transportation costs.

The DDT&E and production costs of both the Space Station and OTV are included in the determination of annual funding. Introduction of the growth station and OTV in 1991 is equivalent to an all-up multi-functional 8-man station capability right away (no evolution from 4-man to 8-man). As shown on the peak funding curve, peak funding drops from 2.5 billion for a 1991 introduction date to about 1.5 billion if the growth 8-man station and OTV are introduced in 1994. There is little advantage to peak funding of introducing the growth Space Station and OTV later than 1994, which is the year selected for the baseline program. In all cases, a 4-man station is introduced in 1991 without the capability to conduct OTV operations.

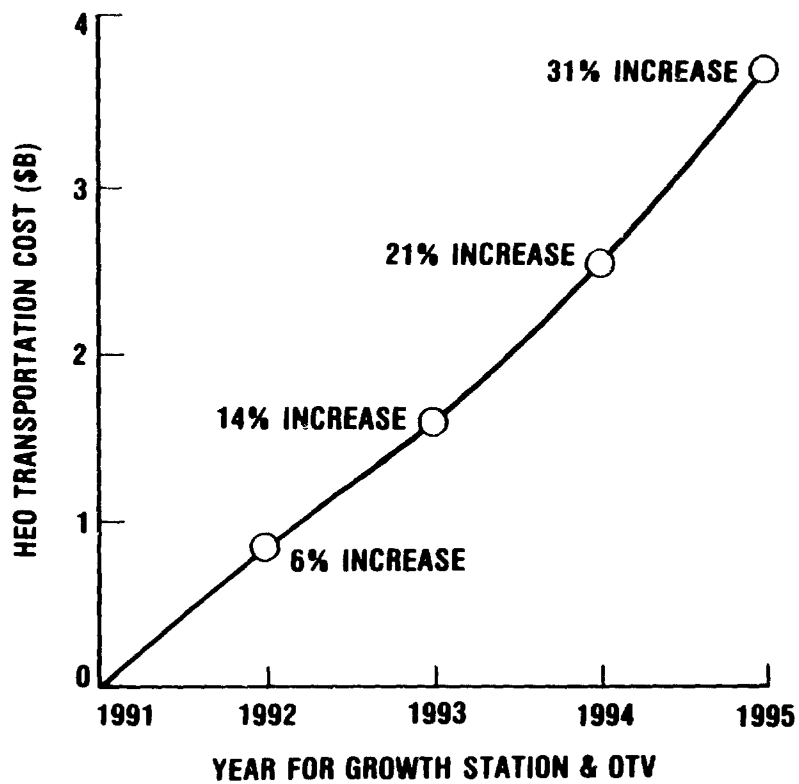
However, the later the growth station and OTV are introduced, the greater the increase in transportation cost to the high energy orbit user. This is caused by higher transportation costs of mass to LEO, and the increased use of expensive expendable upper stages. The baseline year of 1994 results in a 21% increase (2.5 billion) in HEO user transportation costs compared to immediate all-up capability in 1991.

COST IMPACTS OF GROWTH STATION AND OTV TIMING ...

EFFECT ON PROGRAM PEAK ANNUAL FUNDING



EFFECT ON USER HEO TRANSPORTATION COST



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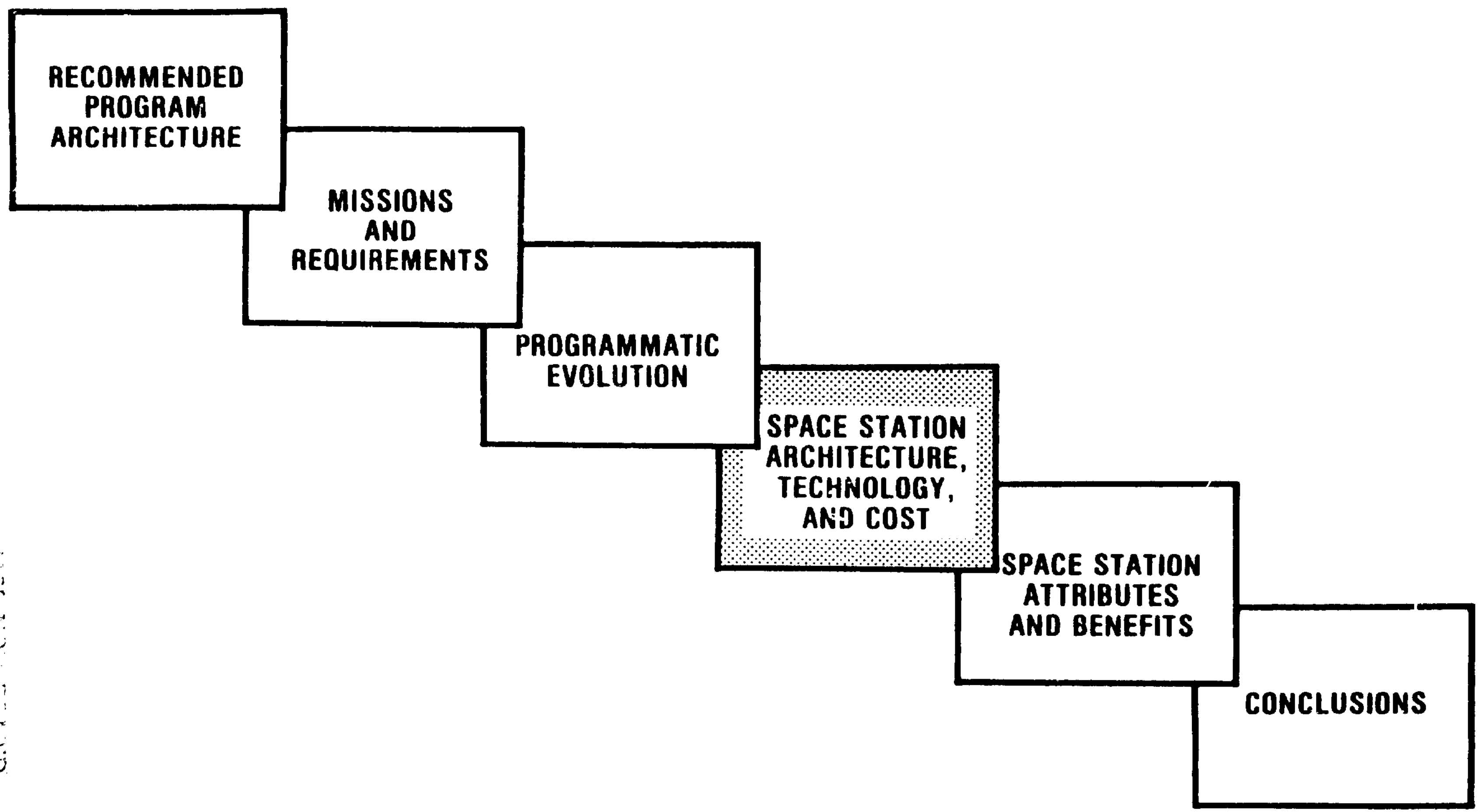
SUMMARY BRIEFING OUTLINE ...



CONSTRAINTS ON SPACE STATION ARCHITECTURE

Four classes of constraints that significantly influence the station architecture are identified in this chart.

(1) The presence of man in space is a significant driver. In addition to providing a comfortable and habitable atmosphere for the crew members, their safety introduces a number of issues such as the dual volumes, redundant subsystems, and space environment protection. Repair and maintenance activities of a crew member required the capability to perform these tasks in the space environment thus requiring EVA facilities and the design of equipment to be compatible with this form of activity. Design conditions are also placed on the equipment and space allocations within the modules which will permit a crew member to perform emergency repairs in an unpressurized module.

(2) Subsystem design issues that are drivers of the architecture include the location and aspect ratio of the solar arrays to minimize the shadowing effects on the arrays from the station elements. Attitude control of the station must consider the extreme changes in station center-of-gravity locations due to the various activities occurring on the station such as OTV/payload assembly and launch and orbiter mating. Proper heat rejection requires available surface areas with clear radiation views.

(3) The Shuttle's cargo bay dimensions and lifting capabilities constrain module sizes. The station configuration is significantly influenced by the orbiters large vertical surface and is also influenced by the cargo unloading clearances required.

(4) Provisions to accept dedicated experiment modules identified by the mission model imposes constraints not only on the provisions for mating ports but also on the interior arrangement that must provide access to these ports for the pressurized experiment modules.

CONSTRAINTS ON SPACE STATION ARCHITECTURE ...

MAN IN SPACE

- CREW SAFETY — DUAL VOLUMES, REDUNDANT SUBSYSTEMS
- EVA ACCOMMODATIONS
- CREW HABITABILITY VOLUME
- SPACE ENVIRONMENT PROTECTION
- SHIRTSLEEVE & IVA MAINTENANCE

SYSTEMS

- SOLAR ARRAY DRAG, SHADOWING
- ATTITUDE CONTROL — C.G. TRAVEL
- HEAT REJECTION

SHUTTLE

- SHUTTLE CAPABILITY
- ORBITER CLEARANCE — FOR UNLOADING & VERTICAL TAIL CLEARANCE

MISSION PAYLOADS

- AVAILABLE PORTS FOR EXPERIMENT MODULES

ALTERNATE SPACE STATION ARCHITECTURE OPTIONS

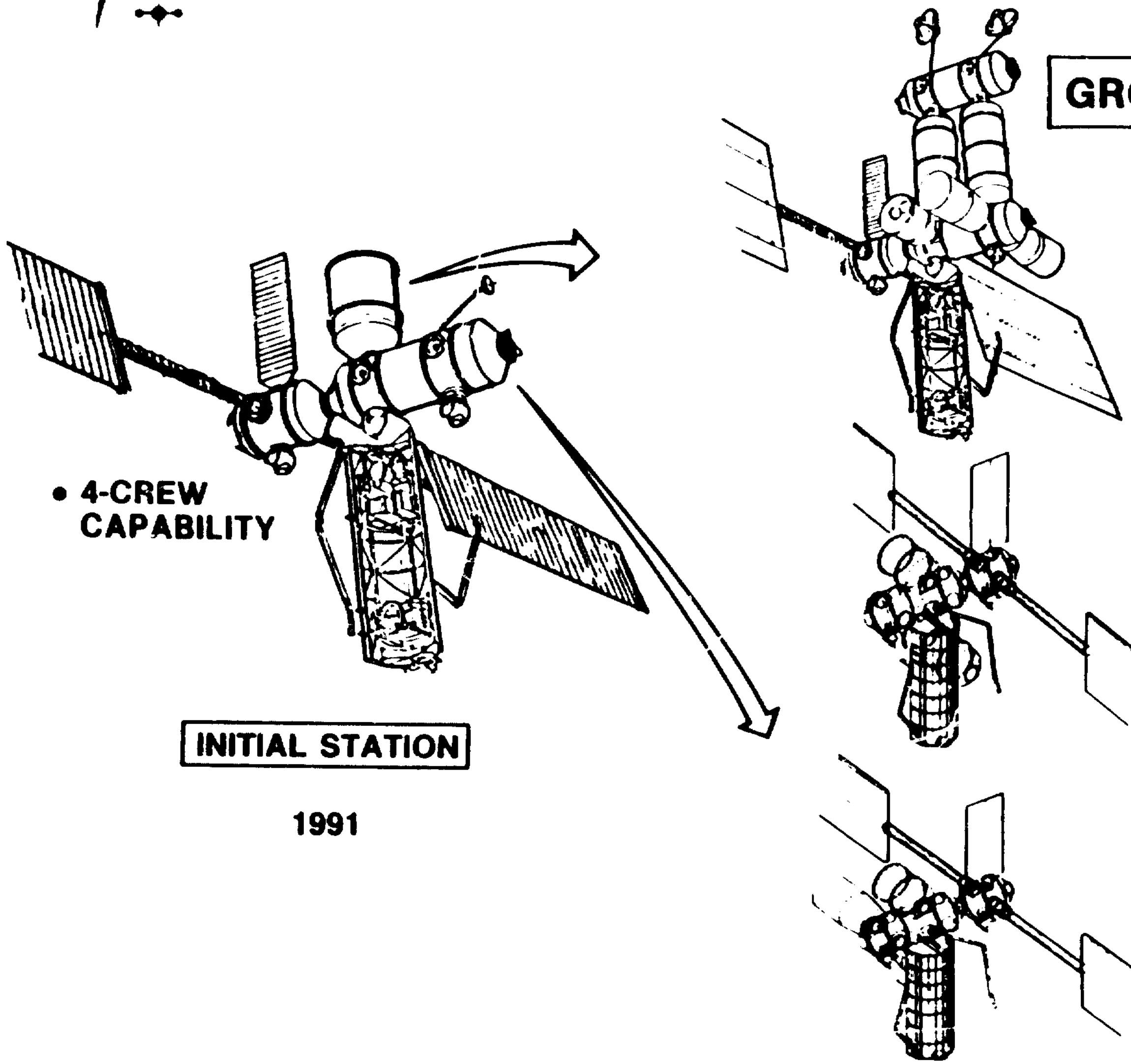
Two growth Space Station architecture options for implementing the mission model are illustrated on this chart. The two options consider a multi-discipline station that accommodates all of the missions and service activities on one Space Station while the other concept considers two small stations.

The multi-discipline station provides the capabilities to perform various functions simultaneously such as satellite assembly, OTV launch and retrieval, remote servicing of satellites via TMS, life sciences experiments, earth observations, astronomy observations, and space processing research and production. The compatibility of these many functions, particularly in the growth configuration, may not be acceptable, or at best constraining to the scheduling of the operations of the various activities.

The various functions, identified in the mission model, are separated into more compatible groups in the two-station concept. Space Station 1 accommodates the science, technology, and space processing activities while Space Station 2 accommodates the space operations activities associated with OTV's and TMS's. Each of the stations has the capability to grow to accommodate more than a crew of four. The two-station concept utilizes the same energy module and command module elements. The payload support assemblies are designed for the most effective use required by the particular disciplines of each station.

SPACE STATION

ALTERNATE SPACE STATION ARCHITECTURE OPTIONS . . .



• 4-CREW CAPABILITY

INITIAL STATION

1991

GROWTH OPTIONS

1994

8-MAN STATION

• MULTI-DISCIPLINE

TWO 4-MAN STATIONS

• SPACE STATION 1
  • RESEARCH & TECHNOLOGY
  • GROWTH CAPABILITY TO ACCOMMODATE 8 CREW

SPACE STATION 2
  • SPACE OPERATIONS

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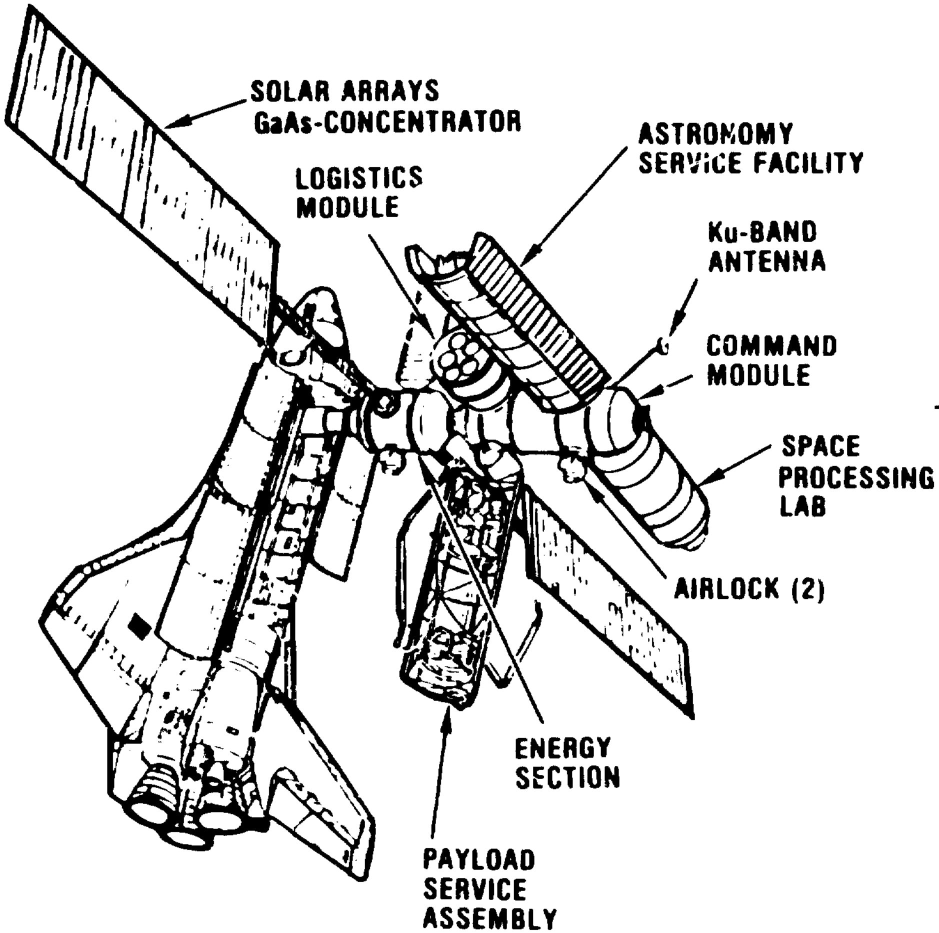
INITIAL SPACE STATION ARCHITECTURE

The initial station illustrated on this chart represents the configuration that would apply for either station architecture concept described on the previous chart. The functions that would be provided are indicated as are the significant characteristics.

INITIAL SPACE STATION ARCHITECTURE...



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:

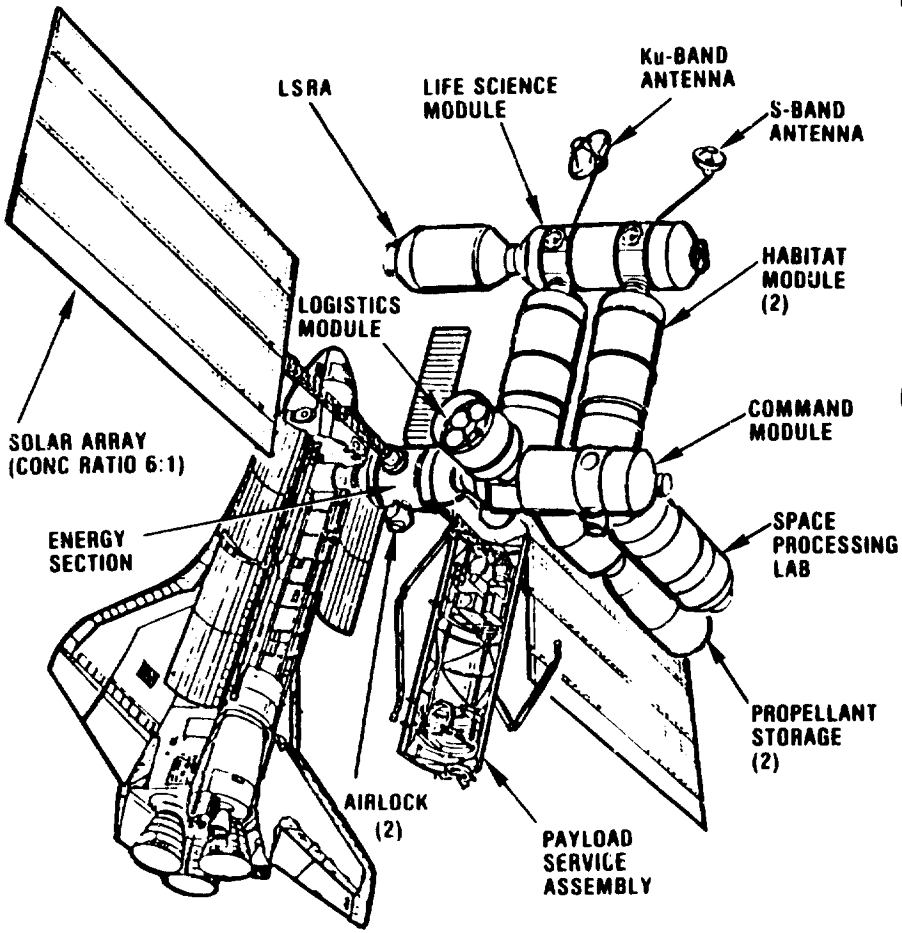
- 4 MATING PORTS TO ACCEPT EXPT MODULES
- PALLET MOUNTING ACCOMMODATIONS ON PSA
- 23.5 kW POWER AT BUS
- ACCOMMODATIONS FOR 4 CREW
- REPLACEABLE SOLAR ARRAYS & RADIATOR
- DUAL VOLUMES FOR CREW SAFETY
- EVA ACCOMMODATIONS

GROWTH 8-MAN SPACE STATION ARCHITECTURE

This station configuration represents the growth station that would provide all of the capabilities required to implement the mission model, spacecraft services, science experiments and crew accommodations. The significant characteristics also are indicated.

SPACE STATION

GROWTH 8-MAN SPACE STATION ARCHITECTURE ...



FUNCTION:

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

CHARACTERISTICS:

- 8 MATING POR:S 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

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GROWTH 4-MAN STATIONS ARCHITECTURE AND GROWTH 4-MAN STATIONS FUNCTIONS AND CHARACTERISTICS

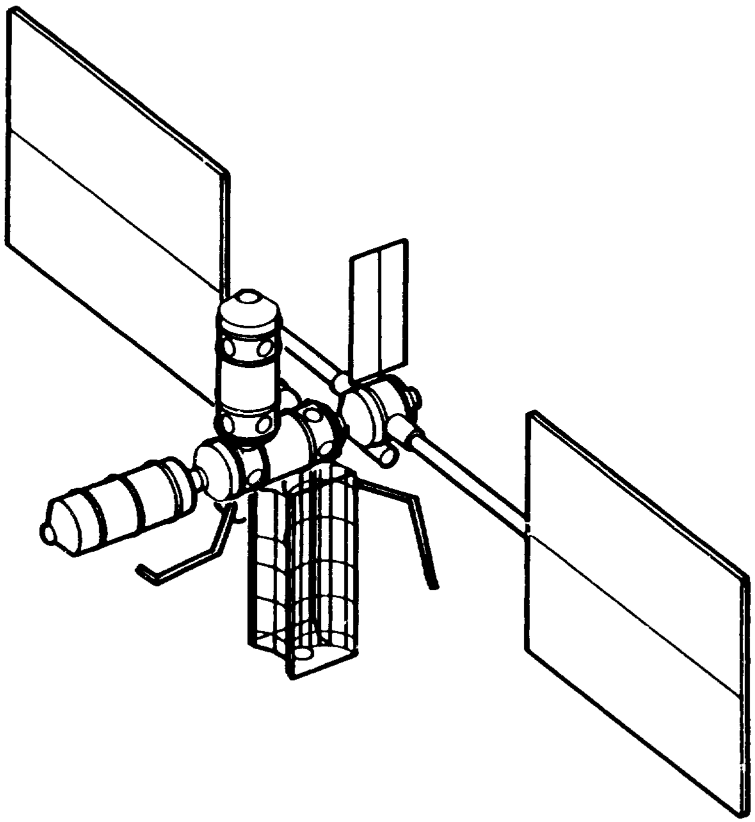
The following two charts illustrate the two 4-man Space Station concept and its functions and characteristics. The principle accommodation differences are in the payload service assembly configurations and in the cryo propellant storage facilities. The science and technology station has a payload service assembly that is configured to accommodate up to eight Shuttle pallet-mounted earth and astronomy observation sensors. The payload service assembly of the Space Operations Station is configured to accept temporary storage of satellites which will be delivered to higher orbits via an OTV. Facilities to service two OTV's also are provided as is the servicing of two TMS spacecraft.

The cryo storage tanks on the Space Operations Station provides the propellant for the OTV spacecraft. Storable propellant storage also is provided on the PSA for the servicing of the TMS.

GROWTH 4-MAN STATIONS ARCHITECTURE...

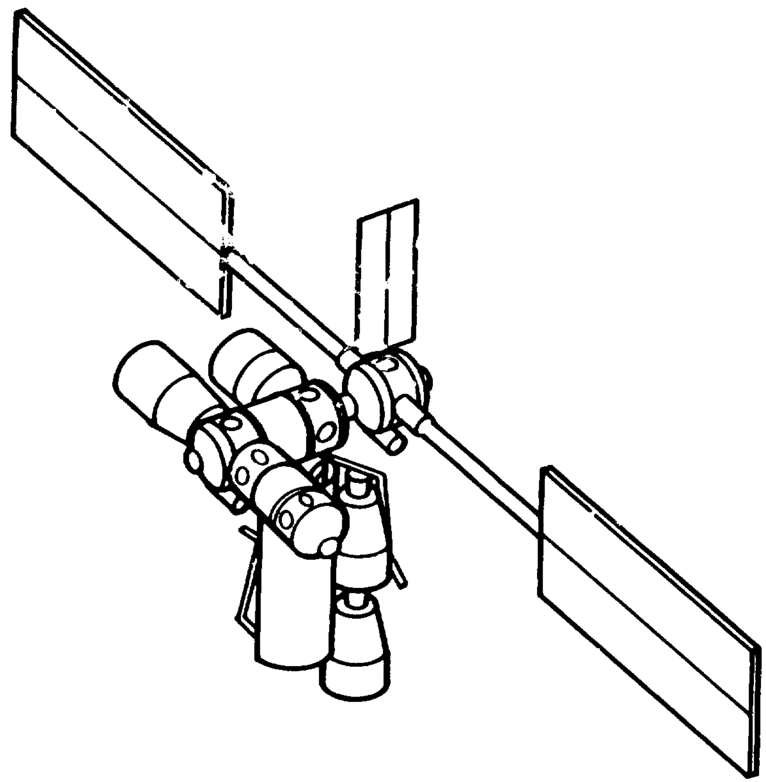
STATION 1

RESEARCH & TECHNOLOGY SPACE STATION



STATION 2

SPACE OPERATIONS SPACE STATION



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GROWTH 4 MAN STATION FUNCTIONS & CHARACTERISTICS ...

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STATION 1
SCIENCE & APPLICATIONS

FUNCTIONS:

- ACCOMMODATE SCIENCE & APPLICATIONS & SPACE PROCESSING RESEARCH & TECHNOLOGY
  - MODULES, PALLETS, INTERNAL
- PROVIDE ELECT. PWR, COMMUNICATIONS, CREW ACCOMMODATIONS FOR 4

CHARACTERISTICS:

- PALLET MOUNTING ACCOMMODATIONS ON PSA
- ELECT PWR GROWTH CAPABILITY
- ACCOMMODATES 4 CREW WITH GROWTH TO 8
- DUAL VOLUMES FOR CREW SAFETY
- EVA ACCOMMODATIONS

STATION 2
GEO STAGING

FUNCTIONS:

- ACCOMMODATE GEO & TMS STAGING MISSIONS
- PROVIDE REUSEABLE OTV & TMS SERVICING
- PROVIDE PAYLOAD ASSEMBLY & SYSTEM VERIFICATION
- PROVIDE ELECT. PWR, COMMUNICATIONS, CREW ACCOMMODATIONS FOR 4
- ACCOMMODATE R&D IF NECESSARY

CHARACTERISTICS:

- CAPABILITY TO ACCOMMODATE MULTIPLE OTV'S & TMS
- CRYO & STORABLE PROPELLANT STORAGE
- PAYLOAD ASSEMBLY & VERIFICATION CAPABILITY
- ELECTRICAL POWER GROWTH CAPABILITY
- ACCOMMODATES 4 CREW WITH GROWTH TO 8
- DUAL VOL FOR CREW SAFETY
- EVA ACCOMMODATIONS

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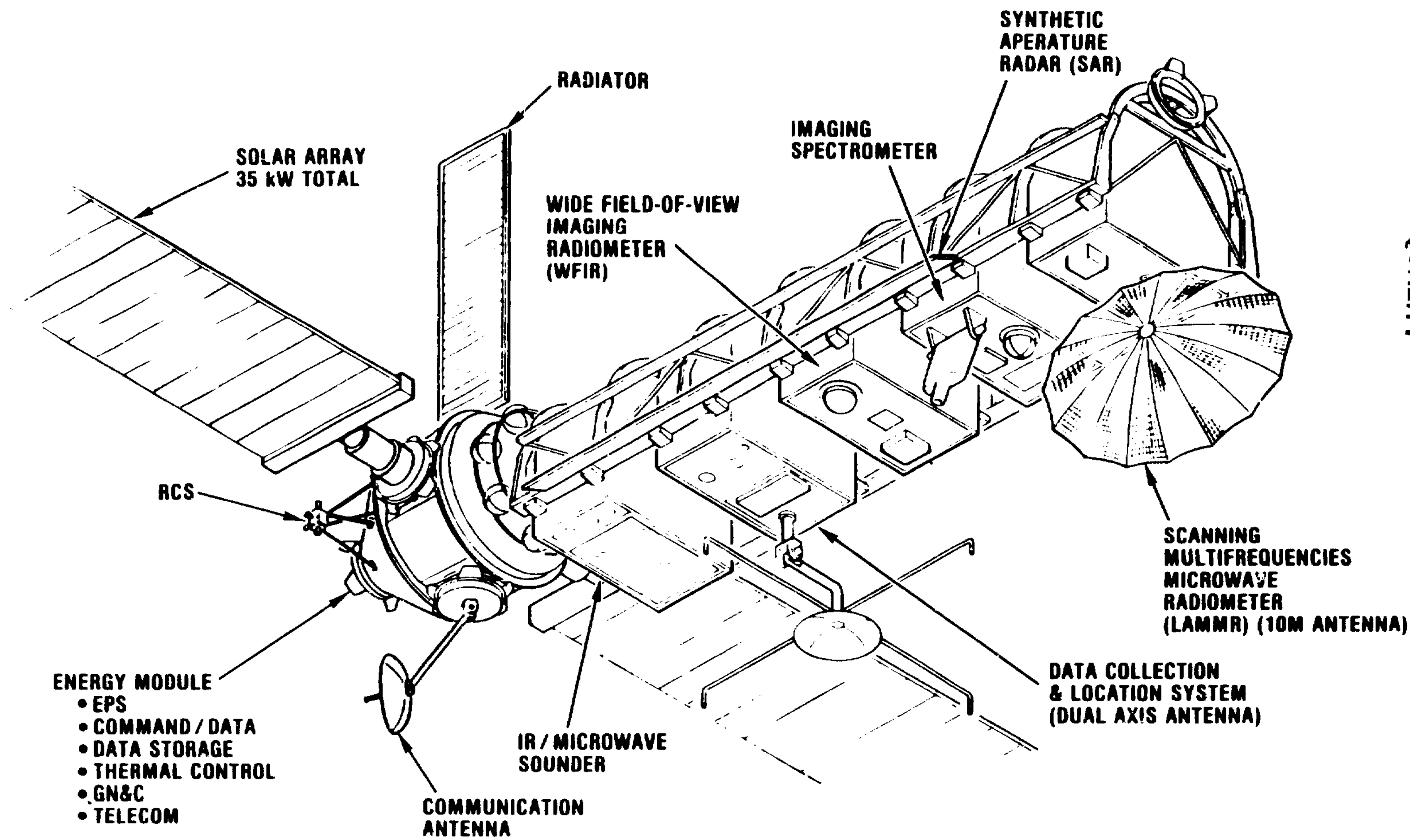
SYSTEM "Z" PLATFORM

System "Z" represents a grouping of earth observation sensors that operate in polar orbit. This figure illustrates a platform concept accommodating a group of these earth observation sensors. This platform concept utilizes two Space Station derived elements: (1) the platform structure and (2) the energy module. The platform structure is similar to the station payload service assembly. This structure simulates the orbiter payload bay and, therefore, can accept the standard Shuttle pallets and their attachments. The energy module of the platform is similar to the station energy module. The solar array and radiator plug-in concept of the station's energy module permits the flexibility of modifying the energy module to the system "Z" platform requirements. The standard mating ports on the platform structure and on the free end of the energy module permit the Shuttle orbiter to mate with the platform for servicing and for the changeout of sensor pallets or individual instruments.

SYSTEM Z PLATFORM...

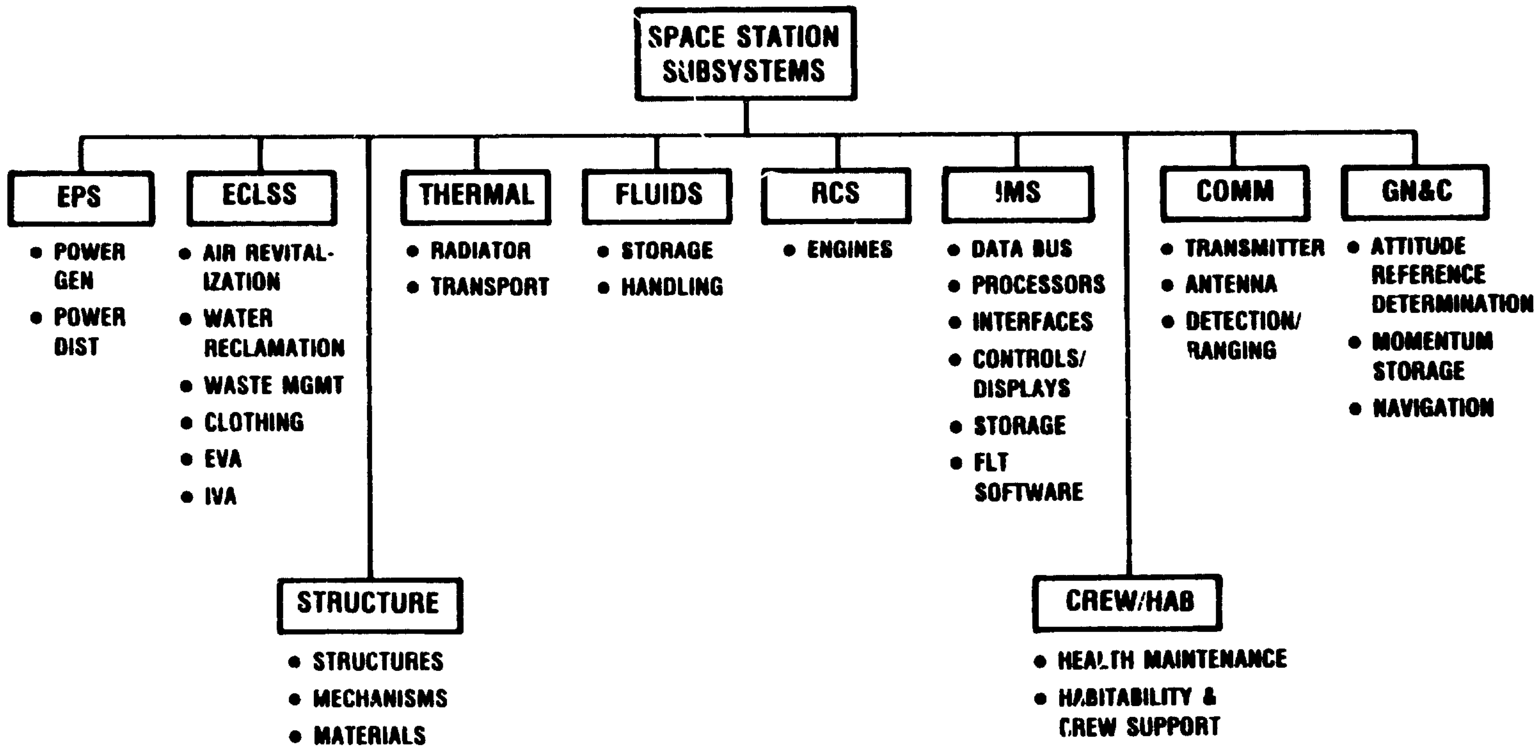


SPACE STATION SUBSYSTEM ORGANIZATION

This chart shows the elements that are included in each of the major subsystem areas.

SPACE STATION

SPACE STATION SUBSYSTEM ORGANIZATION . . .



SUBSYSTEM TECHNOLOGY CANDIDATES

In the EPS (Electrical Power Subsystem), regenerative fuel cells are the Rockwell-preferred technology for power storage and generation during occultation. Evaluation studies shown them to be superior to batteries and/or open-cycle fuel cells in terms of weight and system flexibility. 416 VAC was selected for distribution (versus the various DC voltage levels) because of higher efficiency and lower system weight.

In the ECLSS area, solid amine for CO_2 removal and the Sabatier process for CO_2 reduction were judged preferable to an electrochemical deployed cell and the Bosch process because of inherent system simplicity. Water electrolysis for oxygen supply was found to be more cost effective than logistical methods.

For water reclamation, the TIMES (Thermoelectric Integrated Membrane Evaporation System) was selected over vapor compression distillation for reasons of simplicity and applicability to a wider variety of waste water. The incinerator approach for waste management is preferred over the orbiter commode, due to substantial savings in logistics and handling costs. Similarly, reusable apparel (with a washer/dryer) was found to be more cost effective than disposable clothing.

In the thermal control system, a wraparound heat pipe radiator was devised to handle anticipated thermal loads and eliminate the need for a deployable radiator. This was made possible largely by use of a capillary-pumped, 2-phase fluid, heat transport loop which eliminated the heat load of a mechanical pump and provided the higher coefficients of boiling and condensing heat transfer.

Inasmuch as LO_2/LH_2 will be supplied anyway for OTV usage, GO_2/GH_2 RCS engines were selected over hydrazine due to substantial gains in I_{sp}.

In the IMS subsystem, fiber optics is recommended for the data bus (rather than hardwire) because of its much higher data rate capacity. Instead of a centralized process hierarchy, a distributed configuration was chosen due to inherent advantages in fault detection and compensation. A BIU (bus interface unit) mode is recommended over the conventional MDM (multiplexer/de-multiplexer) hookup because of superior capabilities in controlling and interfacing with the various subsystem levels.

For space communication, RF was chosen over laser on the basis of development risk, cost, and tolerance of atmospheric disturbances. The RF antennas are of three main types: dedicated utilization for discrete frequencies, dispersed location for multi-direction capability, and tracking/pointing for high gain, high rate data links. RADAR is favored for detection/ranging functions, although use of GPS (global positioning satellite system) is still a strong contender for certain satellites which could be outfitted cost-effectively with GPS relay equipment.

SUBSYSTEM TECHNOLOGY CANDIDATES . . .

SUBSYSTEM	TECHNOLOGY CANDIDATES
$\boxed{\text{EPS}}$	
• POWER GENERATION	• SOLAR ARRAY — BATTERY
	— $\boxed{\text{REGENERATIVE FUEL CELL}}$
	— FUEL CELLS (FC)
	— BATTERIES + FC
• DISTRIBUTION	• 28 VDC, 120 VDC, 220 VDC
	$\boxed{\text{• 416 VAC}}$
$\boxed{\text{ECLSS}}$	
• AIR REVITALIZATION	• CO_2 REMOVAL — $\boxed{\text{SOLID AMINE}}$
	— ELECTROCHEMICAL DEPLOYED CELL
	• CO_2 REDUCTION — $\boxed{\text{SABATIER}}$
	— BOSCH
	• O_2 SUPPLY — $\boxed{\text{WATER ELECTROLYSIS}}$
	— LOGISTIC SUPPLY
• WATER RECLAMATION	• VAPOR COMPRESSION DISTILLATION
	$\boxed{\text{• TIMES}}$
• WASTE MANAGEMENT	• ORBITER COMMODE
	$\boxed{\text{• INCINERATOR}}$
• CLOTHING	• DISPOSABLE
	$\boxed{\text{• REUSABLE}}$
$\boxed{\text{THERMAL}}$	
• RADIATOR	$\boxed{\text{• WRAPAROUND — HEAT PIPE}}$
	• DEPLOYABLE — HEAT PIPE
• TRANSPORT	• CIRCULATING PUMPS (SINGLE PHASE)
	$\boxed{\text{• CAPILLARY PUMP (TWO PHASE)}}$

$\boxed{}$ = ROCKWELL PREFERRED CANDIDATE

SPACE STATION

SUBSYSTEM TECHNOLOGY CANDIDATES (CONT) . . .

SUBSYSTEM	TECHNOLOGY CANDIDATES
$\boxed{\text{RCS}}$	
• ENGINES	• HYDRAZINE $\boxed{\text{• } LO_2/LH_2 \text{ — GASEOUS}}$
$\boxed{\text{IMS}}$	
• DATA BUS	$\boxed{\text{• HARDWIRE}}$ $\boxed{\text{• FIBER OPTICS}}$
• PROCESS HIERARCHY	• CENTRAL $\boxed{\text{• DISTRIBUTED}}$
• INTERFACES	• MDM $\boxed{\text{• BIU}}$
$\boxed{\text{COMMUNICATIONS}}$	
• COMMUNICATION TYPE	$\boxed{\text{• RF}}$ • LASER
• ANTENNAS	• DEDICATED UTIL • DISPERSED LOCATION
• DETECTION/RANGING	• TRACKING/POINTING $\boxed{\text{• RADAR}}$
$\boxed{\text{GN\&C}}$	
• ATT REF DETERMINATION	• STAR SENSING • INERTIAL SENSING
• MOMENTUM STORAGE	• CENTRALIZED ACTUATORS $\boxed{\text{• DISTRIBUTED}}$
• NAVIGATION	$\boxed{\text{• GPS}}$

$\boxed{}$ = ROCKWELL PREFERRED CANDIDATE

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EVALUATION OF TECHNOLOGY IMPROVEMENTS (HIGH LEVERAGE ITEMS)

A capillary-pumped, two-phase fluid, heat transport loop represents a major advance over conventional transport loops in terms of simplicity, weight, reliability, performance, and lack of parasitic heat loads which, in the case of Space Station, permits use of a wraparound radiator rather than a deployed radiator. A large reduction in radiator size is also achievable by development of long-life thermal coatings. For instance, a change in the annual rate of degradation from 0.02 to 0.01 permits a 50% savings in radiator size.

In the EPS, low-concentration ratio (6:1), GaAs solar arrays promise a 4:1 reduction in recurring costs for large (100 kW) units, when compared to conventional planar silicon arrays. The higher efficiency of GaAs cells also reduces collector area and drag. Substantial reductions (2:1) in energy storage weight and improved system flexibility are offered by use of regenerative fuel cells or NiH_2 batteries (versus NiCd batteries). Drastic improvements (10:2 to 20:1) in fuel cell life and replacement costs are believed possible with intensive development. In the distribution system, weight and efficiency gains are obtainable in the 50 kW range by going to higher bus voltages such as 220 VDC or 416 VAC. AC has the advantage of greater flexibility in power processing and interfacing with special loads. This system can benefit from potential new imporvements in inverter efficiency to 90-93% (versus 75-80%, conventional).

In the ECLSS, substantial savings (45\overline{M}$ - 60\overline{M}$) in logistics and handling costs can be realized by processing and disposal of trash and fecal waste in an on-station incinerator. Similarly, a washer/dryer on-station can save 60\overline{M}$ - 80\overline{M}$ in program costs, compared to use of disposable clothing.

In the IMS, potential advances of 8:1 in data compression (with acceptable error rates) is considered possible. Also, VHSIC (very high speed integrated circuits) for computers and microprocessors promises great improvement in avionics compactness, redundancy, and fault detection/compensation. The use of fiber optics for data bus (versus hardwire) can achieve data rates deep into the megabit range. BIU's (bus interface units) with VHSIC chips can provide "smart" interface monitoring and control down to the lowest unit level.

For data communication, the advanced TDAS (Telemetered Data Acquisition System) promises continuous rates of 300 megabits per second (or 60 mps for a 20-minute transmission averaged over a 92-minute orbit).

In the GN&C area, automated docking will be required for unmanned operations, but also offers attractive savings in crew time and higher reliability and safety for manned stations. Distributed processing of GN&C functions versus centralized control offers worthwhile advantages in overall cost and reliability. Larger size CMG designs can provide lower weight and cost and a simpler overall system.

The use of gases O_2/H_2 for RCS thrusters (instead of conventional hydrazine) integrates well with cryopropellant resupply for OTV's and offers worthwhile savings in transport costs, due to higher I_{sp} (380 sec versus 200 sec).

Processing of OTV propellants on orbit provides a means of circumventing the lauch hazard problem which has always been an obstacle to the use of high performance LF_2/LH_2 engines rather than LO_2/LH_2 engines.

The higher mixture ratio of fluorine engines also reduces the required volume of LH_2 by approximately 1/2 and improves the OTV mass fraction. For high ΔV missions (MOTV, DOD, and Planetary), the payload improvement can be large.

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	α = 0.1 + 0.02 × LIFE	α = 0.1 + 0.01 × 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 BATTERY	• ONE-HALF (LOWER) WEIGHT • POWER FLEXIBILITY • SIMPLER INTEGRATION
• FUEL CELLS	10 [illegible] 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

EVALUATION OF TECHNOLOGY IMPROVEMENTS (CONT) (HIGH LEVERAGE ITEMS) . . .

SUBSYSTEM	CURRENT TECHNOLOGY	POTENTIAL ADVANCES	PERFORMANCE/ COST IMPACT
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 → N_2H_4 + LF_2) (ON ORBIT CONVERSION)	• LAUNCH SAFETY • HIGHER SP IMPULSE — 490 SEC

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COST COMPARISON OF SPACE STATION ARCHITECTURE OPTIONS

This chart shows the DDT&E, production and operations and support costs for the initial 4-man station (operational from 1991 to 1993) and two architectural options for the growth station (operational from 1994 to 2000). As shown, the total cost for the initial station is 5.43 billion. If growth is from a 4-man station to an 8-man station, the growth station total cost is 4.17 billion. This is about the same as the 4.26 billion total cost of a growth concept that uses the two 4-man station previously described. Very little DDT&E is required when growing to the two 4-man stations. The production cost is, however, higher for the two 4-man station scheme because of the need to completely replicate the 4-man station. Operations and support costs are higher primarily because of the need to supply two stations (two logistics modules versus one), which is less efficient than logistics to a single station.

COST COMPARISON OF SPACE STATION ARCHITECTURE OPTIONS...

	INITIAL STATION 1991-1993	4 TO 8-MAN SS 1994-2000	4 TO 2 4-MAN SS 1994-2000
DDT&E	3930	1200	170
PRODUCTION	700	470	720
O & S	800	2500	3370
TOTAL	5430	4170	4260

IN MILLIONS OF 1984 $

INCLUDES COSTS FOR SPACE STATION CONTRACTOR HARDWARE, SPACE STATION ASSEMBLY AND LOGISTICS FLIGHT COSTS, SPACE STATION OPERATIONS AND SUPPORT COSTS, AND CONTRACTOR WRAP AROUNDS

COMPARISON OF SPACE STATION ARCHITECTURE OPTIONS

This chart shows additional comparative data for the two growth options.

The cost data on the previous chart has been arranged to determine the total ten year costs for the two architectural options. The differential in cost during this period is trivial.

More man-hours are available for services from the 8-man growth station options since nearly the same amount of crew time (about one man per station) is required for station management whether the station is of 4-man or 8-man size.

Growth capability is better for the two 4-man station option than for the 8-man station option because both of the stations can readily grow to an 8-man capability. Usable volume for the 8-man option is nearly twice that of the two 4-man option. Addition of the two crew modules and the tunnel module for the 8-man station results in a large additional volume. The tunnel module's excess volume is used for a life sciences laboratory. The two 4-man station option would require an additional attached dedicated module for this purpose.

There is no difference in available ports for attached payloads between the two options.

Safety during the initial 4-man station period is the same for both options (21-day wait for a rescue orbiter). The two 4-man option has an advantage in that the second nearby station can provide a haven in an emergency. This would require a means of transporting the crew from one station to another. A possibility would be to use the TMS to transport men in a removable airlock between the two stations.

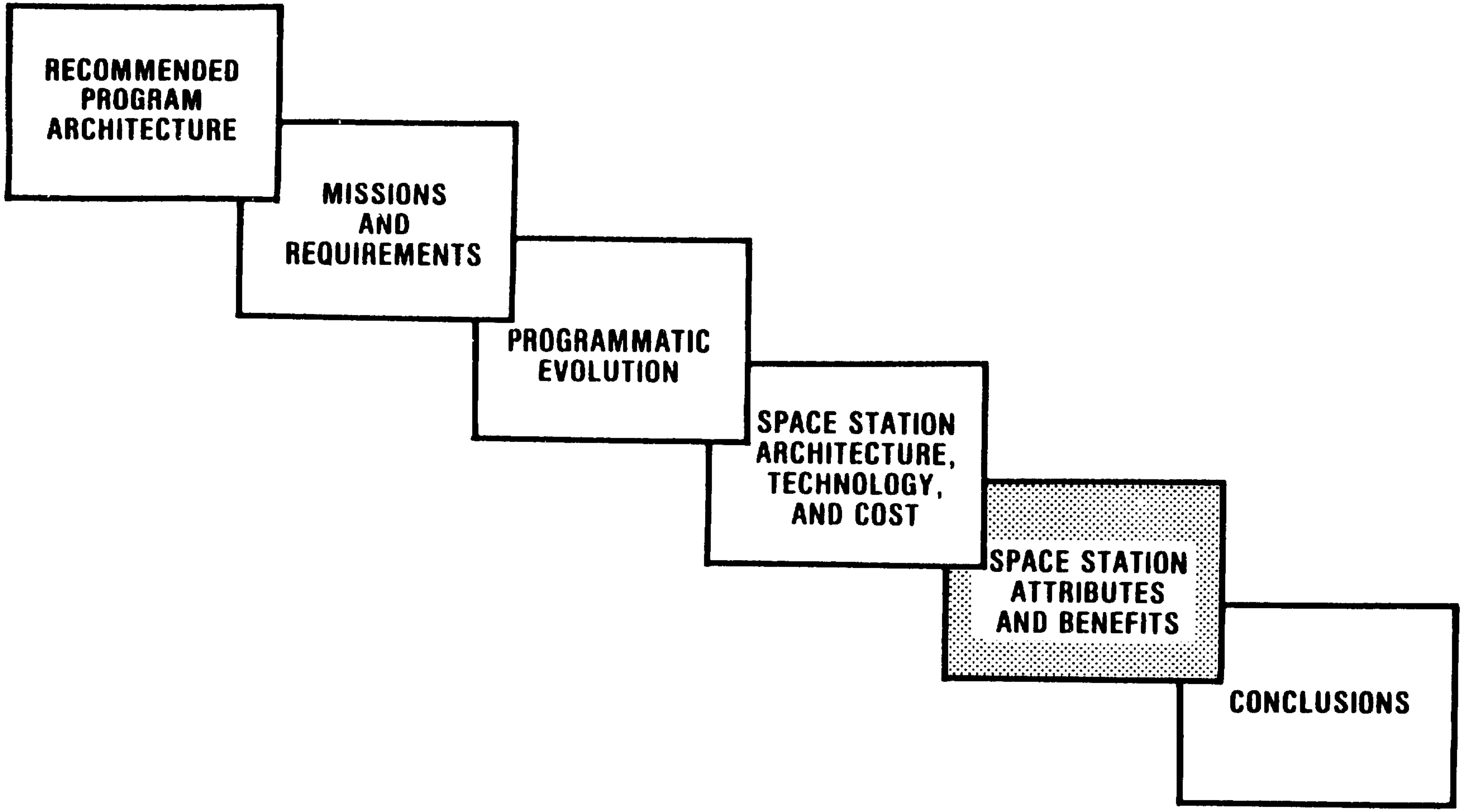
The major advantage, and the most important reason for considering the two 4-man station option is the separation of potentially conflicting functions. R&D and space processing missions usually want low-g and inertial Space Station pointing. When the OTV operations and increased TMS operations are introduced in 1994, a large increase in station disturbance level will exist and the need to orient the station for increased Shuttle, OTV, and TMS docking will interrupt other specialized orientation requirements. For these reasons, it may be desirable to have two stations with non-conflicting requirements.

Considerable additional study is needed to determine which of these approaches is most desirable.

COMPARISON OF SPACE STATION ARCHITECTURE OPTIONS...

	4 MAN → 8 MAN		4 MAN → 2-4 MAN	
STATION COST				
• DDT & E	5,130		4,100	
• PRODUCTION	1,170		1,420	
• OPERATIONS (10 YRS)	3,300		4,170	
• TOTAL	9,600		9,690	
MISSION MAN-HOURS AVAILABLE/YR FOR SERVICES	21,840		18,720	
GROWTH CAPABILITY	PROBABLY NEED TO ADD ANOTHER STATION FOR GROWTH > 8 MAN		CAN GROW BOTH 4-MAN TO 8-MAN	
USEABLE VOLUME (FT3)	3,840	13,700	3,840	7,680
NO. OF PORTS AVAILABLE	4	8	4	8
SAFETY	SHUTTLE RESCUE ONLY MODE — — 21 DAYS WAIT		• SAME FOR INITIAL • TWO STATIONS PROVIDE MUTUAL HAVEN IN EMERGENCY	
OPERATIONAL COMPATABILITY	LOW-G REQUIREMENT CONFLICTS WITH OTV & SERVICING FUNCTIONS		CAN SEPARATE CONFLICTING FUNCTIONS — R & D STATION — OPERATIONAL STATION	

SUMMARY BRIEFING OUTLINE ...



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SPACE STATION ATTRIBUTES AND RESULTING BENEFITS

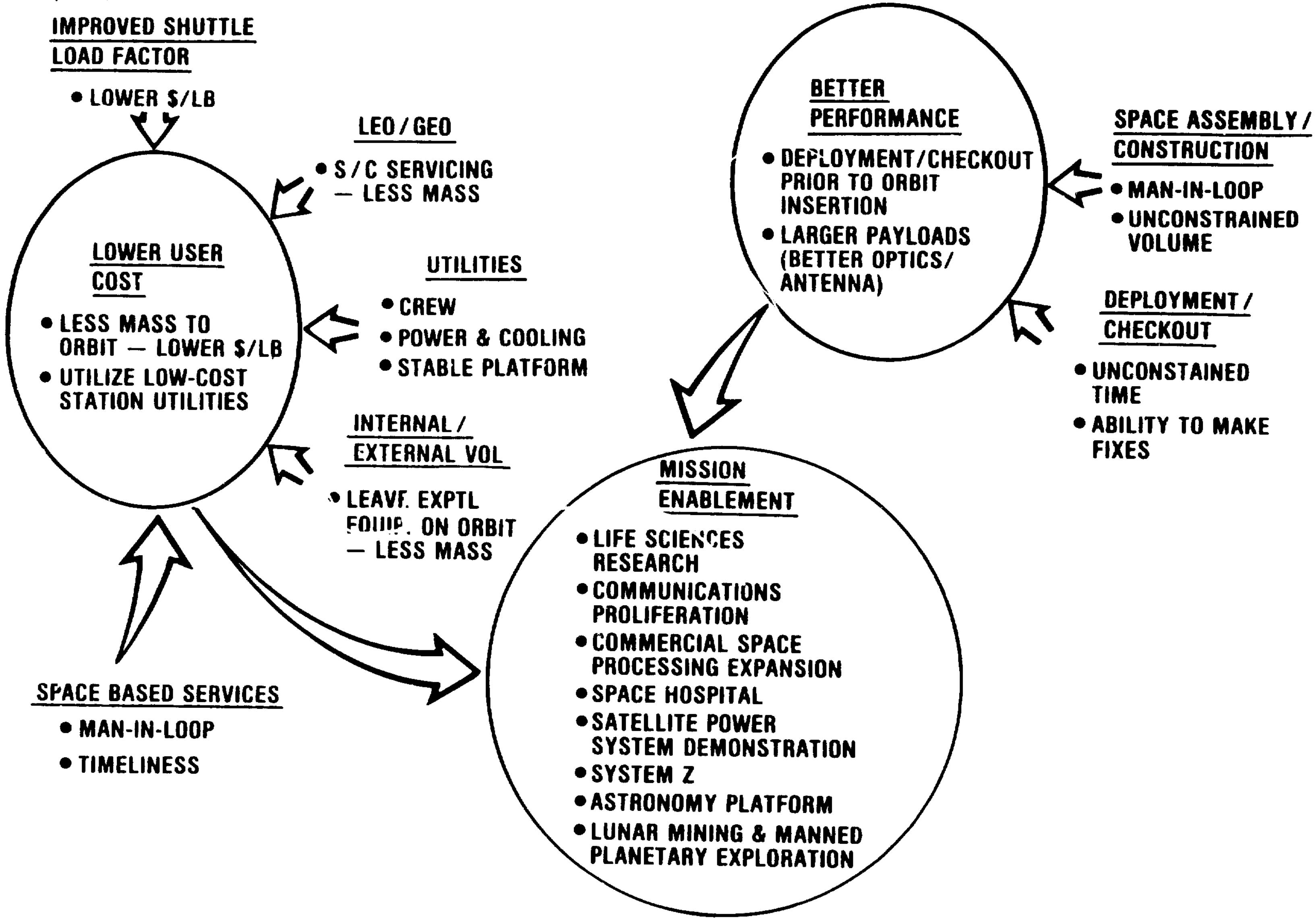
The three major areas of benefits of the station are lower user cost, better performance, and mission enablement. This chart shows how the Space Station attributes relate to these benefit areas.

Better performance can be obtained because of the station capability to deploy and check-out payloads prior to placement in their mission orbit. In addition, if a malfunction occurs, it may be possible to make fixes at the station rather than having to refly the entire payload. The station capability to assemble and construct payloads will lead to larger payloads, including larger optics and larger antennas.

User cost is reduced by a number of factors. Space-basing of mission services for the OTV result in a decoupling of the payload, stages, and propellants. This results in average cargo load factors of about 1.0 for Shuttles going to the station. LEO and GEO servicing from the station also reduces user costs since it allows the spacecraft to have extended life. Additionally, mission equipment can be changed out to take advantage of technology improvements. Since man is on orbit permanently, the services can be provided in a timely manner without the need for manifesting into the orbiter. Utilities provided by the station (crew, power, and stable platform) are obtained at a very low cost compared to other alternatives. The ability to leave equipment on the station is very important to reducing user costs as compared to Shuttle sortie missions, where the experiment equipment needs to be carried up and down. In the space processing research area, the experiment equipment is orders of magnitude greater in mass than the experiment mass.

A combination of lower user cost and better performance, as well as the uniqueness of a permanently manned facility lead to mission enablement. Some of the areas of enablement are shown on this chart. Enablement of system Z and, if needed, an astronomy platform arises from the use of station elements as the basis of a platform (power module and payload support assembly).

SPACE STATION ATTRIBUTES AND RESULTING BENEFITS . . .



USER COST BENEFITS — POST 1994

The next two charts compare the cost of several Space Station services for alternate ways of providing the service.

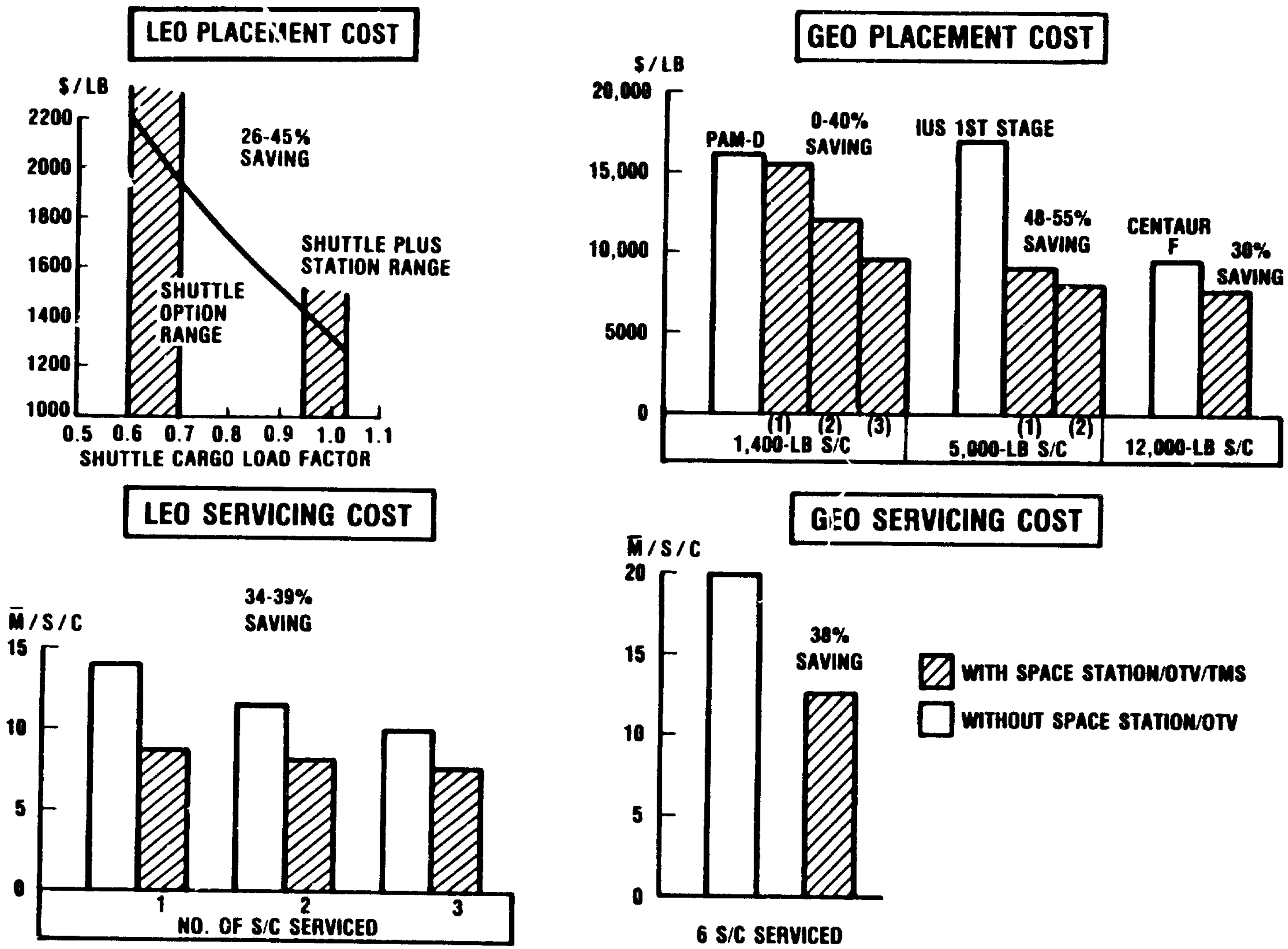
As shown, LEO placement costs through the station are 26-45 percent less than if there were no station. Use of the space-based OTV saves from 0 to 40 percent for the small 1,400-pound GEO communication spacecraft. The 40 percent savings occurs when three are deployed on the OTV at one time. Savings of 48 to 55 percent occur when the OTV is compared to a Shuttle-launched IUS first stage and a 30 percent savings occurs when the OTV is compared to the Centaur F for large 12,000-pound spacecraft.

Cost savings are also shown for LEO and GEO servicing. LEO savings range from 34 to 39 percent dependent upon the number of spacecraft serviced at one time. A 38 percent savings is made for GEO servicing of six spacecraft at one time.

Space processing is the most benefited area. As shown, the processing cost of pharmaceuticals at the station is small compared to the cost of the material that is being processed. A 15-day Shuttle Spacelab sortie results in a processing cost that is greater than the value per pound of the processed material. Enormous cost savings also occur for space processing research on the Space Station.

Finally, attached science is also exposed at a very low cost per day of exposure as compared to an extended duration orbiter.

USER COST BENEFITS — POST 1994 . . .



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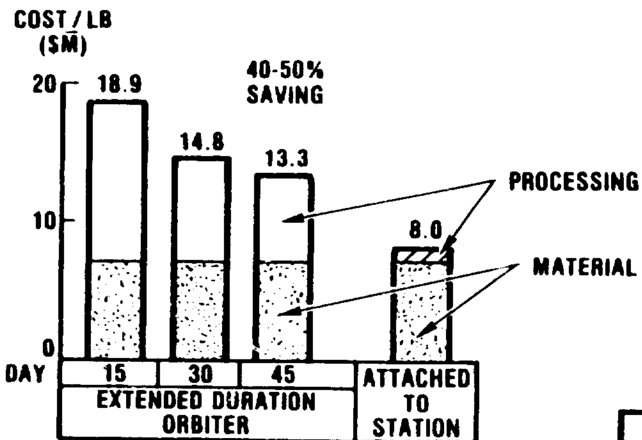
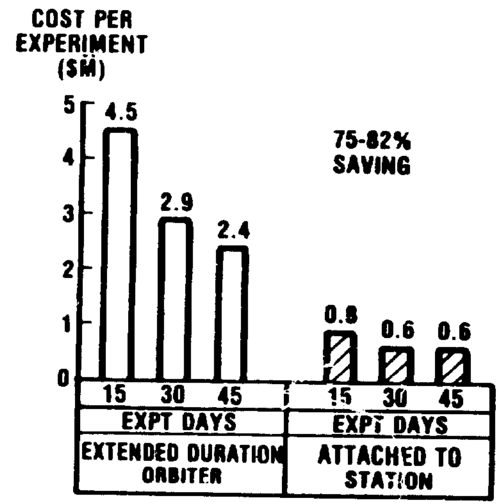
USER COST BENEFITS — POST 1994 ...

SPACE PROCESSING PRODUCTION PHARMACEUTICAL



SPACE PROCESSING RESEARCH



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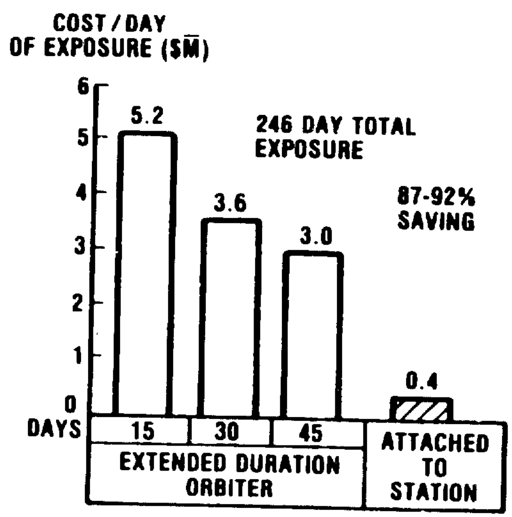
ATTACHED SCIENCE (SIRTF)



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SUMMARY OF MISSION MODEL LEVEL IMPACTS

The following two charts summarize the impact that the mission model level (low, medium, and high) has on (1) the number of missions and mission mass, (2) Space Station crew hours, (3) number of Shuttle flights, and (4) total space support system program cost. All of these data are for operations from the year 1991 to 2000.

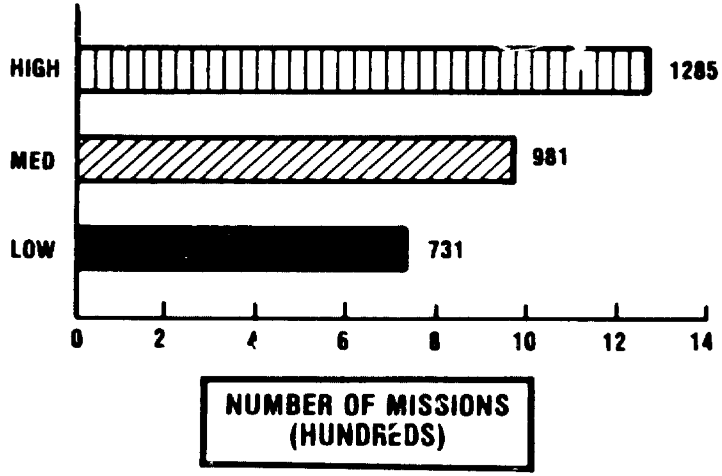
As might be expected, the trend in both number of missions and mission mass is to increase from low to high. The ratio of mass increase going from low to medium and from medium to high is 1.68 and 1.74, respectively, as compared to the ratio of number of missions which is 1.30 and 1.34, respectively. Therefore, the average payload mass increases from low to medium and from medium to high.

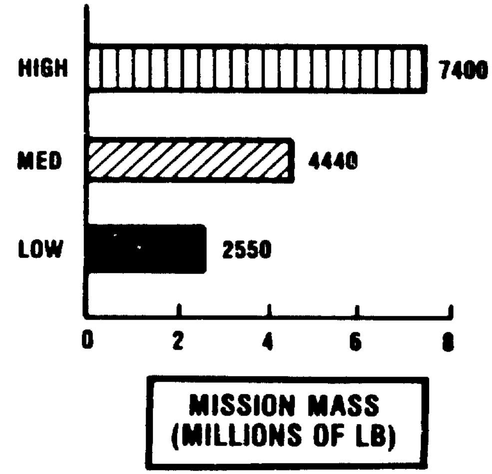
The Space Station crew hours are for the entire ten year period. The low model requires only a 4-man station; whereas, the medium model requires an initial 4-man station that grows to 8 men in 1994. The high model increases the growth requirement to 10 men.

The number of Shuttle flights without the station is nearly double that with the station for all mission model levels. Operations costs also generally follow this trend. Most of the additional flights for the no station case are attributed to the need to accomplish the space processing missions and other inappropriate missions were removed to determine the mission model when there is no Space Station.

SPACE STATION

SUMMARY OF MISSION MODEL LEVEL IMPACTS ...





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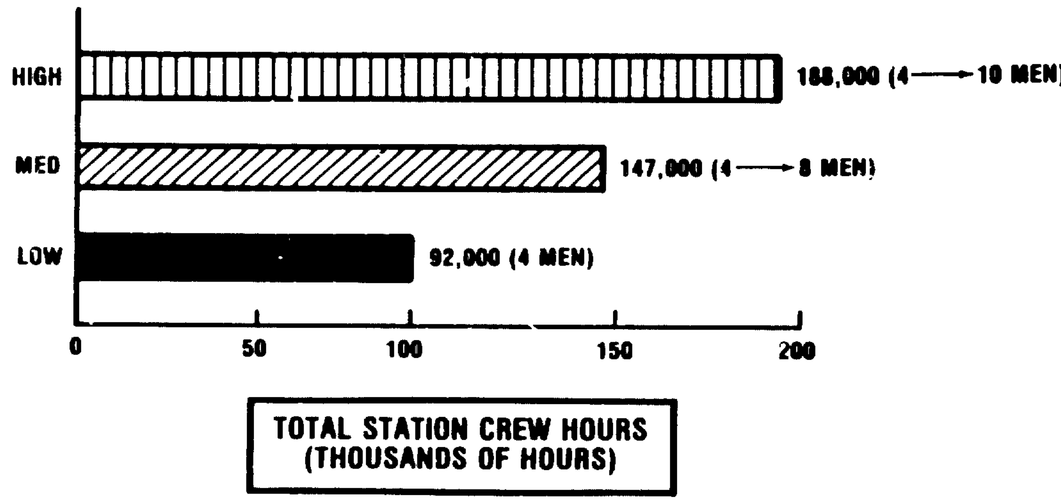

SUMMARY OF MISSION MODEL LEVEL IMPACTS (Cont) ...

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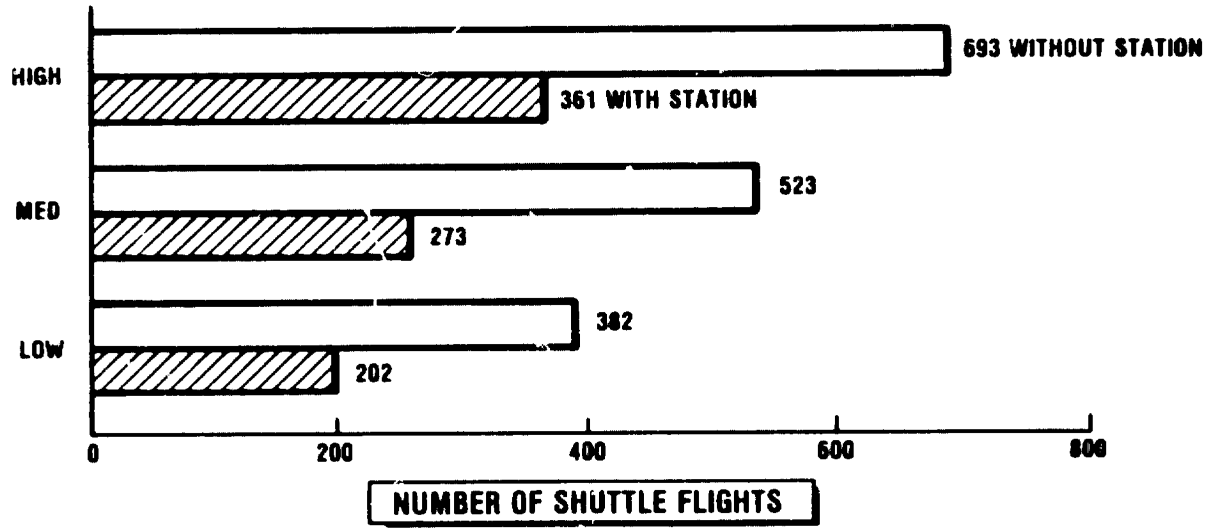

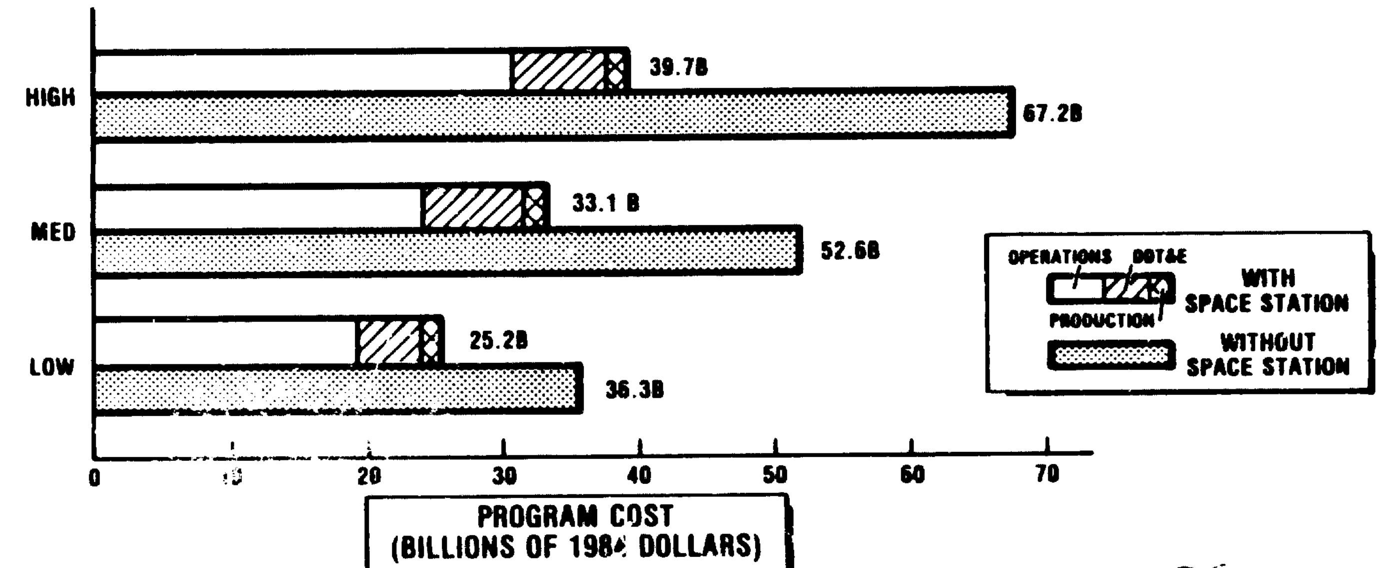

IMPACT OF SPACE STATION ON MISSION MODEL

Two mission models were developed to show the impact on the mission areas due to a Space Station. This chart summarizes some of the major impacts.

IMPACT OF SPACE STATION ON MISSION MODEL...

MISSION AREA	WITH CURRENT SYSTEM & TMS	ADD STATION & OTV
DOD	• SAME PROGRAM THRUST AS WITH STATION • NO GEO SERVICING (151 FLIGHTS)	• ADD GEO SERVICING (130 FLIGHTS)
NASA SCIENCE & APPLICATION	• CONSTRAINED IN ANTENNA & OPTICS SIZES • HIGHLY CONSTRAINED LIFE SCIENCES — SORTIE MISSIONS (71 FLIGHTS)	• ROBUST LIFE SCIENCES PROGRAM • ASTRONOMY & SYSTEM PLATFORMS ARE STATION DERIVATIVES (42 FLIGHTS)
NASA TECHNOLOGY DEVELOPMENT	• CONSTRAINED PROGRAM • LESS AMBITIOUS OBJECTIVES SUPPORTED — SCIENCE & APPL TECH — SPACE STATION TECH (2 FLIGHTS)	• MORE AMBITIOUS OBJECTIVES SUPPORTED — GEOSYNC MULTIFUNC COMM PLATFORM — GLOBAL ENVIRONMENT MONITORING SYSTEM — LUNAR OPERATIONS BASE — MANNED MARS MISSION (4 FLIGHTS)
COMMERCIAL COMMUNICATIONS	• NO MULTI—USER SYSTEMS • NO SERVICING (60 FLIGHTS)	• ADD MULTI-USER SYSTEMS • MORE TRANSPONDERS =) (47 FLIGHTS)
COMMERCIAL SPACE PROCESSING	• CONSTRAINED RESEARCH • ELECTROFOCUSING PRODUCTION ELIMINATED (13 FLIGHTS)	• NO LIMITS TO RESEARCH • ELECTROFOCUSING PRODUCTION ON STATION (11 FLIGHTS)
TOTAL FLIGHTS	297	273 (39 FOR STATION ASSEMBLY & LOGISTICS)

MAJOR USER COMMENTS ON ROCKWELL ARCHITECTURE

Before initiation of the study and during the study, several interactions were accomplished in all potential user areas. This chart summarizes comments obtained from users at the completion of the study. These comments are based on their review of mission models, accommodation modes, requirements and benefits.

MAJOR USER COMMENTS ON ROCKWELL ARCHITECTURE ...

SCIENCE & APPLICATIONS

- MISSION MODEL REASONABLE FORECAST OF S&A ACTIVITY
- ISSUES REMAIN ON SYSTEM Z ORBITAL LOCATIONS
- INCOMPATABILITIES IN ASTRONOMY INSTRUMENT POINTING MAY REQUIRE TWO SMALL PLATFORMS

NATIONAL SECURITY

- CONCURRENCE IN ALL AREAS
  - MISSION MODEL, LINKAGE WITH INFRASTRUCTURE, & FRANGIBLE OPERATIONS CONCEPT

COMMERCIAL COMMUNICATIONS

- SPACE BASED OTV CONCEPT DESIREABLE
  - SINGLE STAGE vs PKS STILL NEEDS STUDY
- MISSION MODEL COMMENTS RANGE FROM TOO LOW TO TOO HIGH
- MASS DISTRIBUTION OF SPACECRAFT ABOUT RIGHT
  - SOME PLATFORMS COULD GROW > 12,000 LB
- STATION ASSEMBLY, DEPLOYMENT, & CHECKOUT DESIREABLE
- GEOSERVICING OF LARGE SATELLITES & PLATFORMS ADVANTAGEOUS

COMMERCIAL SPACE PROCESSING

- MISSION MODEL LEVEL ACCEPTABLE
- ACCOMMODATION OF MISSIONS ACCEPTABLE
  - SOME QUESTION REGARDING CRYSTALS G-LEVEL
- PRODUCT AREAS APPROPRIATE FOR COMMERCIALIZATION
- NEED STATION TO ENABLE COMMERCIALIZATION

SUMMARY BRIEFING OUTLINE ...

RECOMMENDED PROGRAM ARCHITECTURE

MISSIONS AND REQUIREMENTS

PROGRAMMATIC EVOLUTION

SPACE STATION ARCHITECTURE, TECHNOLOGY, AND COST

SPACE STATION ATTRIBUTES AND BENEFITS

CONCLUSIONS

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WHY STATION?

This chart summarizes some of the most important reasons for having a Space Station. These are separated into three main categories: the mission payload, operations, and economic factors.

WHY STATION?...

MISSION PAYLOAD

- REMOVES SIZE CONSTRAINTS
- DECOUPLES PAYLOAD, OTV, & FUEL
- ENABLES CONTINUOUS SERVICING CAPABILITY — LONGER LIFE
- PERMITS DEPLOYMENT & CHECKOUT

OPERATIONS

- UNCONSTRAINED MISSION TIME
- CONTINUOUS CREW/OPERATOR AVAILABILITY
- INCREASED AVAILABILITY FOR DOWN CARGO
- COST EFFECTIVE — PAYLOAD MASS EXPOSURE
- COST EFFECTIVE — PAYLOAD ENERGY

ECONOMIC FACTORS

- MAXIMIZES STS LOAD FACTOR
- PERMITS SPACED-BASED REUSEABLE SYSTEMS
- ENABLES MORE COST-EFFECTIVE SPACE PROCESSING

CONCLUSIONS

This chart summarizes the major conclusions of the study which have been previously explained in greater detail. The conclusions are presented in three major categories: mission definition, system architecture, and benefits.

CONCLUSIONS . . .

MISSION DEFINITION

- LARGE UNCERTAINTY EXISTS IN SPACE PROCESSING MISSION AREA
- USERS SLOW TO RESPOND TO POSSIBLE CHANGES IN THEIR MISSION EQUIPMENT & S/C DUE TO NEW SUPPORT SYSTEMS

SYSTEM ARCHITECTURE

- STATION LOCATED AT 28° INCLINATION PROVIDES SERVICES TO ALL USER AREAS —
  - PROVIDES LOWEST COSTS TO USERS
- INITIAL 4-MAN STATION IN 1991 GROWING TO AN 8 MAN STATION IN 1994
  - TWO 4-MAN STATIONS ATTRACTIVE & NEEDS MORE STUDY

CONCLUSIONS (CONT) . . .

SYSTEM ARCHITECTURE (Cont)

- TMS SPACE BASED WITH INITIAL STATION & PERIGEE KICK STAGE, REUSEABLE CRYOGENIC OTV SPACE-BASED WITH GROWTH STATION
- Z & ASTRONOMY PLATFORM DERIVITIVES OF STATION IN 1993 & 1995 RESPECTIVELY
  - PLATFORM DERIVATIVE NEEDS BETTER DEFINITION

BENEFITS

- SPACE STATION AT 28° INCLINATION PROVIDES SIGNIFICANT BENEFITS TO ALL MISSION AREA
  - INDIRECT BENEFIT TO SYSTEM Z IN HIGH INCLINATION & ASTRONOMY PLATFORM
- THE MOST IMPORTANT SPACE STATION BENEFITS ARISE FROM FUTURE MISSIONS ENABLEMENT
- SIGNIFICANT COST REDUCTIONS OCCUR FOR ALL SERVICES
  - SPACE STATION MAY ENABLE A VIGOROUS COMMERCIAL SPACE PROCESSING PROGRAM